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Comparative analysis of disruption tolerant network routing simulations in the ONE and ns-3

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COMPARATIVE ANALYSIS OF DISRUPTION TOLERANT NETWORK ROUTING SIMULATIONS IN THE ONE AND NS-3

by

Andrew N. Mauldin

December 2017

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COMPARATIVE ANALYSIS OF DISRUPTION TOLERANT NETWORK ROUTING SIMULATIONS IN THE ONE AND NS-3

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Table of Contents

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List of Figures

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List of Tables

List of Acronyms and Abbreviations

AEB	Adaptive Exponential Beacon Protocol
AODV	Ad-hoc On-demand Distance Vector
ASCII	American Standard Code for Information Interchange
BGP	Border Gateway Protocol
CAR	Context Aware Routing Protocol
DECA	Density Aware Reliable Broadcasting Protocol
DOD	Department of Defense
DTN	Disruption Tolerant Network
DTNRG	Delay Tolerant Networking Research Group
DSDV	Destination Sequence Distance Vector
DSR	Dynamic Source Routing
EIGRP	Enhanced Interior Gateway Routing Protocol
FIFO	First In First Out
FTP	File Transfer Protocol
GAPR	Geolocation Aware Routing Protocol
GAPR2	Geolocation Aware Routing Protocol 2
GAPR2a	Geolocation Aware Routing Protocol 2a
GPS	Global Positioning System
GUI	Graphical User Interface

ICMP	Internet Control Message Protocol
IP	Internet Protocol
IRTF	Internet Research Task Force
JiST	Java in Simulation Time
LCAC	Landing Craft Air Cushion
KB	Kilobyte
MAC	Media Access Control
MANET	Mobile Ad-hoc Network
MB	Megabyte
MDR	Message Delivery Ratio
MTU	Maximum Transmission Unit
NPS	Naval Postgraduate School
ns-2	Network Simulator 2
ns-3	Network Simulator 3
OLSR	Optimized Link State Routing
OMNet++	Objective Modular Network Testbed in C++
ONE	Opportunistic Network Environment
OPNET	Optimum Network Performance
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
PCAP	Packet Capture
PDR	Packet Delivery Ratio

PRoPHET	Probabilistic Routing Protocol
RFC	Request For Comments
RIP	Routing Information Protocol
RTT	Round Trip Time
SGBR	Social Group Based Routing Protocol
SUMO	Simulation of Urban Mobility
SWANS	Scalable Wireless Ad Hoc Network Simulator
TCP	Transmission Control Protocol
TraNS	Traffic and Network Simulation Environment
TTL	Time to Live
USN	U.S. Navy
UDP	User Datagram Protocol
UML	Unified Modeling Language
USG	United States government
VANET	Vehicular Ad-Hoc Network
WKT	Well Known Text
XML	Extensible Markup Language

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CHAPTER 1:
Introduction

Disruption Tolerant Network (DTN) promises a more reliable means to share information in networks that experience frequent disconnections or changing topology, unlike traditional Internet Protocol (IP)-based communication. Traditional IP networks and DTNs operate under different networking paradigms. IP networks operate under the assumption that a coherent end-to-end connection always exists between two hosts that are communicating. The Internet uses the IP protocol because an end-to-end connection generally exists between the hosts, and this assumption simplifies the core of the network. In contrast, DTNs do not assume that there is always an end-to-end path between two hosts. DTN protocols must handle frequent and long disconnects. If a path exists between two hosts in a DTN, the connection need not be constant. When an IP-based host moves to a new network, it is assigned a new IP address. If the node was communicating with another host, then the connection between the two nodes must be reestablished. Compared to IP based communication protocols, DTN protocols have a higher level of complexity in order to adapt to changing network conditions and disruptions. As a result, DTN protocols have higher bandwidth overhead compared to IP based communications to forward packets resulting in reduced performance and increased power consumption [1]. This chapter provides the definition of DTNs, discusses the objectives of the research, scope, and structure of the thesis. Chapter 2 discusses DTN strategies, protocols, simulators, and related works.

1.1 Network Evolution

In order to define a DTN, the base definition of a network is required. A network is a graph where the vertices are the nodes and the edges are the links between the nodes. A link is a physical medium such as a cable that connects two nodes together. A node can have zero or more links to other nodes, and a network does not require all of the nodes to be connected. However, more links between nodes yields better connectivity in the network. The number of links in a network can range from zero links to a full-mesh. In a fully-meshed network, every node has a link to every other node, yielding $\frac{n(n-1)}{2}$ links [2].

The purpose of a network is to transfer data from one node to another node. In the case of the Internet, data traverses the network in a hierarchical fashion. The nodes on the edge of the network are hosts, and the nodes on the interior are routers. Typically, edge nodes generate data that must traverse the network to reach other edge nodes. An example is a client retrieving a webpage from a server. In order for the host's data to reach its destination, a path must exist from the source to the destination. Since a host will not be aware of the path, routers are responsible for advertising and determining paths. Routers advertise paths that they can reach. Each router determines the next hop to send the packet using the advertised paths. Example routing protocols include Enhanced Interior Gateway Routing Protocol (EIGRP), Border Gateway Protocol (BGP), Open Shortest Path First (OSPF), and Routing Information Protocol (RIP). Using this routing information, routers determine whether a destination is reachable. These protocols are also known as data forwarding protocols because they only forward packets to the next hop; they do not store packets. The path from the source node to the destination node is the end-to-end path. In the case of the Internet, the end-to-end path must exist in order for packets to be forwarded to the destination [2].

Since traditional IP networks rely on stable end-to-end paths, they are not able to handle intermittent connectivity between nodes. If a break occurs during packet routing, then the network drops the packet because the next hop no longer exists. In the Internet, the router drops the packet and sends the source host an Internet Control Message Protocol (ICMP) destination unreachable error message. The Internet assumes links are stable because they consist of physical cables or stationary wireless links. When a failure does occur, routing protocols in the Internet attempt to find an alternate path. However, routers will drop packets destined to the affected network until the routers discover an alternate path. When an alternate path is discovered, end-to-end protocols require the source host to retransmit the packets. If the packet traversed 12 hops before being dropped, then the network duplicates that work when a node retransmits the packet. In end-to-end networks, retransmissions are end-to-end because there is no store and forward capability [2].

In contrast to traditional hierarchical networking, Mobile Ad-hoc Network (MANET) protocols do not have a hierarchical structure. Similar to the protocols used by the Internet, MANET protocols are data forwarding protocols. However, every node acts as both a router and a host. Each node in a MANET forwards packets to the next hop and generates its own traffic. Wireless networks use MANETs where the nodes have limited mobility or the topology is not well defined. MANET protocols require a node to determine the next hop and handle limited node mobility. MANET protocols determine routes using reactive and/or proactive routing strategies [1].

In proactive MANET routing protocols, nodes calculate routes automatically and independently of traffic. Examples of proactive MANET protocols include Optimized Link State Routing (OLSR) and Destination Sequence Distance Vector (DSDV). Proactive protocols compute routes for nodes that are connected, but they cannot find paths to nodes that are not connected. For reactive MANET protocols, routes are calculated only when traffic needs to be delivered to an unknown host. Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) are examples of reactive MANET protocols. Reactive protocols incur additional delay compared to proactive protocols because paths are determined on-demand. However, reactive protocols reduce overhead because they only find required routes. As a result, MANETs may drop packets when a destination is not reachable. While MANET can handle limited mobility, they fail when the network topology changes frequently causing intermittent connectivity between nodes [1].

DTNs use a different strategy to forward data. In contrast to MANETs and the Internet, DTNs are opportunistic routing protocols. They do not route packets assuming an end-to-end connection. Instead, they use a store-carry-forward strategy to route messages within a network. Store-carry-forward assumes that connectivity is intermittent and an end-to-end path does not exist. Under the store-and-forward paradigm, the source node forwards messages to one or more nodes that the source node encounters. The receiving node stores the message in a buffer and may forward the message to the next node it encounters. This results in multiple copies of the message existing within a network. The store and forward process continues until the message ultimately arrives at the destination [1].

Since DTN nodes store messages, they must determine which messages to send to the next node because buffers are finite. Finite buffers require DTN nodes to decide which messages to evict when the buffer is full. Flooding and predictive flooding are two strategies employed by DTNs to replicate messages. Protocols such as Epidemic [3] send all of the messages held by a node to every node that it encounters. As a result, messages spread throughout the network like an infection. Under ideal conditions of unlimited buffer and transmission speeds, a pure flooding based protocol provides the highest probability of message delivery. However, devices do not have unlimited buffer and transmission speed. Node must manage their resources, and flooding every message requires significant overhead. Some flooding protocols such as Vector [4] try to limit message replication using location information. To reduce the overhead, protocols such as MaxProp and Probabilistic Routing Protocol (PRoPHET) determine the delivery probability to forward messages to other nodes. These protocols use prior knowledge to estimate the probability that a message will be delivered. Messages with the higher probability of reaching the destination are transferred ahead of messages with a lower probability [5].

1.2 Objectives

The field of disruption tolerant networking is of particular interest to the Department of Defense (DOD) because DTN protocols provide a means to ensure that information arrives at its destination despite operating in a challenged environment. The Army and Marine Corps could use DTNs as an alternate means of sending information to soldiers on a battlefield using inexpensive low power devices networked together. The Navy and Air Force can use aircraft to serve as DTN nodes to route messages in challenging environments where satellite communication is denied or limited. The Navy and Marine Corp have independently dedicated resources into developing DTN protocols, but neither have technology that is ready for deployment. For example, the Marine Corps Network-On-The-Move program intends to use to DTN to improve battlefield communication using satellite and mobile platforms [6].

While the military continues to research DTNs, the technology is not ready for deployment. According to *A Delay-Tolerant Network Architecture for Challenged Internets* [7], DTNs experience high latency and low data rate compared to IP networks. A DTN may experience latencies ranging from seconds to hours depending on topology, node capabilities, and mobility. In contrast, IP networks experience latency ranging from milliseconds to seconds. In addition, DTNs have significantly higher overhead. DTN protocols must minimize overhead and latency while maximizing message delivery to be deployed in military applications. The protocols must integrate with existing legacy systems and devices to make deployment feasible. Protocols such as Transmission Control Protocol (TCP) depend on Round Trip Time (RTT) to determine if a packet dropped. Hour long delays do not work with TCP. Security is another issue. DTN nodes must incorporate protection via authentication from unauthorized access because nodes store messages. While integrating security, the protocols require congestion control and reliability. Given these challenges, further research is required to improve DTN performance and integrate the technology with existing devices [7].

Prior simulation-based research into DTN protocols used the Opportunistic Network Environment (ONE) Simulator. The ONE Simulator is a discrete networking simulator. In Ari Keraanen's paper *The ONE Simulator for DTN Protocol Evaluation* [8], the ONE Simulator simulated Direct Delivery, First Contact, Spray-and-Wait, PRoPHET, Max-Prop, and Epidemic DTN protocols under different mobility models. The mobility models used included random movement, map-constrained random movement, and human behavior based movement. Random movement mobility models move nodes within the network in random directions. Map-constrained random movement limits the random movement of network nodes. Human behavior based movement models moves nodes through predetermined routes. The analysis of the DTN protocols under the different mobility models focused on computational and memory requirements. The parameters analyzed included the duration that nodes remained in contact, the time between nodes in communication, the power consumption, message delivery probability, and time to deliver a message [8].

Network Simulator 3 (ns-3) simulates everything from the physical layer to the application layer. In contrast, the ONE simulator abstracts many aspects for the DTN protocols. For example, an abstraction in ONE is control messages. Within the ONE simulator, nodes directly access other node's data structures. Nodes exchange control message information without sending any messages. As a result, the impact of control message overhead is not included in simulation results. Since ns-3 does not use shared data structures like the ONE simulator, ns-3 sends control messages as a packet. The time to synchronize and send these packets affects the amount of data that can be transferred within a given contact time between nodes. In addition, the control messages may increase latency because the node must synchronize prior to sending data packets. Within the ONE Simulator, message transmission does not account for link layer limitations. The link layer's control messages reduce the number of messages transmitted while two nodes are in range. Therefore, ns-3 would provide deeper insight into the performance of DTN protocols.

At the Naval Postgraduate School, the Geolocation Aware Routing Protocol (GAPR) [5] and GAPR2 [9] protocols were developed using the ONE simulator. To reduce overhead, GAPR uses a node's location history and delivery predictability to determine messages to forward to other nodes. The analysis of the GAPR protocol focused on latency, transmission speed, buffer overhead, and packet delivery ratio in scenarios that used geolocation information [5]. Kevin Killeen's thesis [9] explored several DTN protocols and continued development of the GAPR protocol using the ONE simulator. The ONE Simulator simulated several DTN protocols under a variety of mobility models to include a real-world annual military exercise. Geolocation Aware Routing Protocol 2 (GAPR2) combined the original GAPR protocol with the Vector protocol [9]. Vector uses a node's location history to determine the number of messages to send to another node [4]. As a result, GAPR2 uses message delivery probability and limited flooding based on position history to minimize overhead. Analysis revealed that limiting message replication among nodes in the GAPR2 protocol reduced overhead, improved delivery ratio, and reduced latency [9].

While research at Naval Postgraduate School (NPS) demonstrated the benefits of geolocation-based routing protocols, prior research ignored the inaccuracies of Global Positioning System (GPS). Justin Rohrer proposed the Centroid routing protocol in [10]. While GAPR [5], Vector [4], and GAPR2 [9] demonstrated the benefits of including geolocation information, the protocols are not tolerant to GPS errors. Centroid is a DTN protocol designed to handle the errors associated with GPS. Justin Rohrer's paper illustrated the negative effect of GPS errors and the benefits of developing protocols to handle positional errors [10].

My research into DTN protocols will further evaluate performance of DTN protocols and possible optimizations to GAPR. Previous research in GAPR at NPS used the ONE Simulator; implementations using ns-3 will support future research by offering a much higher fidelity simulation, as well as the means to compare previous simulations and ONE simulator implementations. The main objectives of this thesis are to implement DTN protocols in ns-3 and compare performance between simulators and protocols.

1.2.1 Implement DTN Protocols from the ONE in ns-3

The first objective of this thesis is to implement selected DTN protocols from the ONE simulator in ns-3. The selected DTN protocols are Epidemic, Vector, GAPR, GAPR2, and Centroid. Epidemic is the simplest DTN protocol with the least amount of control messages.

GAPR and GAPR2 have the largest control message overhead. Since the ONE does not define control messages, the ns-3 implementation includes control packet declarations and control packet fragmentation. In addition, node data generation in ns-3 uses messages instead of individual packets. In order to accomplish message generation in ns-3, a message is a group of one or more packets.

1.2.2 Compare ns-3 and ONE DTN Protocols

In order to check ns-3 protocols functionality, small scale tests generate log files and perform error checking within the protocol. The tests are small enough to inspect the logs to check protocol operation. Next, the Helsinki scenario generates data to compare ns-3 protocols within larger networks with higher message generation rate to the ONE. The Helsinki scenario is an urban map-based mobility model in Helsinki Finland. The ONE Simulator generates the movements of the nodes. ns-3 uses the movements trace file to position nodes in the simulation. The parameters between the Helsinki scenario in the ONE and ns-3 will be identical. Trace file analysis generates the ns-3 protocol statistics to compare trends in performance between simulators.

1.2.3 Study Performance of DTN Protocols

Not only does the Helsinki scenario compare the ns-3 protocol implementations, but it also provides insight into the impact of control messages and link layer overhead. All scenarios are map-based, and the ONE and ns-3 simulate all selected scenarios. The performance analysis includes simulations across a range of values for selected variables and protocols. Helsinki represents an urban map-based mobility model. Bold Alligator [9] is a military map-based mobility model modeled after an annual amphibious military exercise at Camp Lejeune, North Carolina. The Omaha scenario is an additional map-based military mobility model inspired by the Normandy landings during WWII.

1.3 Scope

This thesis investigates DTN routing protocols and simulates selected protocols in ns-3 and the ONE. Control of specific DTN protocol parameters identifies impacts on performance. The goal is to further previous work conducted at NPS using ns-3 because ns-3 includes network layers that the ONE abstracts away. Specifically, the ONE does not model existing link layer protocols nor does the ONE include the impact of control messages between nodes.

1.4 Limitations

Since the protocols developed in ns-3 are in the ONE, the ONE results are compared against the ns-3 DTN protocol results. Given the differences between the ONE and ns-3, there will be difference between the ns-3 protocol implementations and the ONE protocol implementations. With little DTN development in ns-3, the ns-3 DTN protocol implementations are not independently verified for this thesis.

Second, the military-based scenarios use publicly disseminated data. Data used to develop the scenarios includes participating units, objectives, and the general exercise plan. The data is insufficient to precisely match the movements of the exercises, but the data informs the development of the scenarios to create realistic movements. While exact movement data would be preferred, the period to complete this thesis prevents precisely recreating the military scenarios. Despite the limitations, we believe the military mobility models are realistic and conform to real-world military operations.

Lastly, this thesis required thousands of simulations in both ns-3 and the ONE. Each run produced multiple reports that generated multiple data points for analysis. The large raw data set is too large to include in this thesis. Rather, raw data parsing and organizing generated the data summaries and graphs in the appendices.

1.5 Research Questions

This thesis implements DTN protocols in a simulator not used in previous DTN research at NPS. The thesis analyzes protocol performance between the simulators to study the effects of link layer, control packet, and packet header overhead. The research investigates the following:

1. How does the inclusion of link layer protocols and DTN protocol control messages in simulations affect DTN protocol performance?
2. How does segmentation of large DTN messages affect protocol overhead?

3. How close is the effective bandwidth, when considering segmentation, headers, and link-layer behavior, to the ideal bandwidth for DTN encounters.
4. How does DTN protocol behavior differ when simulated in ns-3 vs The ONE?
5. How does node mobility in urban and military scenarios affect protocol performance?
6. How do GAPR and GAPR2 compare against other protocols when including power consumption?

1.6 Significant Findings

1. From our research, this is the first work to compare DTN routing protocol implementations between the ONE and ns-3. ns-3 does not include DTN protocols in the standard repository. We found one public implementation of a DTN routing protocol (Epidemic), but it was only partially functional.
2. We present an implementation of DTN routing protocols in ns-3. Our ns-3 implementation includes node discovery, routing information sharing, and DTN message segmentation via an IP convergence layer.
3. We found that link layer overhead and control messages yields an effective message throughput between connected nodes that is 40% to 70% lower than the radio bandwidth.
4. The ONE's abstraction of DTN routing ignores the overhead incurred by sending control messages between hosts. Specifically, routing control messages consumed up to 33% of all transmitted data in ns-3 depending on protocol and scenario. Protocols that share more information consumed more transmitted data and consumed more power. DTN message segmentation headers consumed 2-5.5% of all transmitted data.
5. While link layer overhead and control messages overhead are significant factors, message replication overhead is the largest component of a protocol's total overhead.
6. ns-3 results show that mobility models where nodes move in clusters have significantly higher message replication overhead.
7. Overall, the ns-3 protocols returned 31% lower message delivery and 119% higher average latency.
8. We found that GAPR2a provides the best overall performance in the urban scenario, and Vector provides the best overall performance in the military scenarios.
9. We recommend that DTN protocol development should continue in ns-3 instead of

the ONE because the ONE's abstractions may not reflect real-world performance. The abstraction of control information sharing between nodes and link layer protocol overhead affects protocol performance.

1.7 Structure of Thesis

Chapter 2 studies DTN routing strategies, behaviors, and metrics used for comparison. The chapter describes each simulated protocol. The chapter also discusses ns-3 and ONE simulator. The discussion includes the advantages and disadvantages of each simulator. In addition, Chapter 2 covers current interests in DTN technology and advancements. Finally, the chapter includes of relevant literature regarding DTNs.

Chapter 3 details the ns-3 DTN protocol implementations. Chapter 4 covers the methodology employed by this thesis. The chapter includes a discussion of each scenario and the limitations on simulation variables. The data collection methodology for each simulator outlines the settings applied to each set of simulations using tables.

Chapter 5 analyzes and presents the data obtained from the scenarios discussed in Chapter 4. The discussion includes protocol analysis and comparison of the simulations. The analysis provides insight into the conclusions presented in Chapter 6. Chapter 6 discusses recommendations for future work.

CHAPTER 2:
Background

Chapter 2 discusses DTN strategies, simulators, and related works. Section 2.1 covers multiple techniques employed by DTN protocols to forward messages throughout a network, and the section provides an overview of several protocols. Chapter 3 provides the implementation details of protocols. Section 2.2 discusses the simulators, and Section 2.3 provides an overview of the Bundle Protocol that influenced our ns-3 DTN protocols. Finally, Section 2.4 covers related works to the study of DTNs.

2.1 Disruption Tolerant Networking Strategies

Modern DTN protocols use different techniques to route messages. Some protocols use one technique, while other DTN protocols may employ multiple strategies. DTN strategies include flooding, probability, geolocation assistance, social, or a hybrid of the various techniques. Flooding is the simplest strategy, but incurs the most overhead in terms of message replication. The other techniques attempt to reduce message replication while maintaining or improving performance. This section provides an overview of these DTN strategies and examines multiple DTN protocols.

2.1.1 Flooding Based Protocols

The simplest DTN routing strategy is to flood messages. Nodes make multiple copies of a message as they encounter other nodes. Flooding based protocols are also called replica-based protocols. They do not track network topology or use external information to inform routing decisions. Examples of flooding-based protocols include Epidemic and Spray-and-Wait [1], [11].

Epidemic

As the simplest DTN protocol, Vahdat and Becker proposed Epidemic routing [3]. Epidemic provides a baseline for comparing other DTN strategies. A pure Epidemic protocol acts like an infection. A host infects another host with its messages, and that host spreads its messages throughout the network. The process continues until the message infects all hosts.

Messages spread quickly throughout the connected sections of the network. Portions of the network with intermittent activity have a higher probability of receiving the messages because more nodes possess the messages. As a result, messages have a higher probability of delivery because there are more opportunities for messages to reach the intermittently connected nodes [1].

When Epidemic nodes come in contact, they share their list of stored messages using a summary vector. Figure 2.1 shows the Epidemic exchange sequence. The summary vector contains messages held within a node's message buffer. After the summary vector exchange, the nodes transfer messages that the other node does not possess in the order that the node received the messages. The nodes add the new messages to their summary vector. In order for the summary vector to work, every message must have a unique global ID to determine whether a message is contained in the buffer [3]. The Bundle Protocol's global ID is an example.

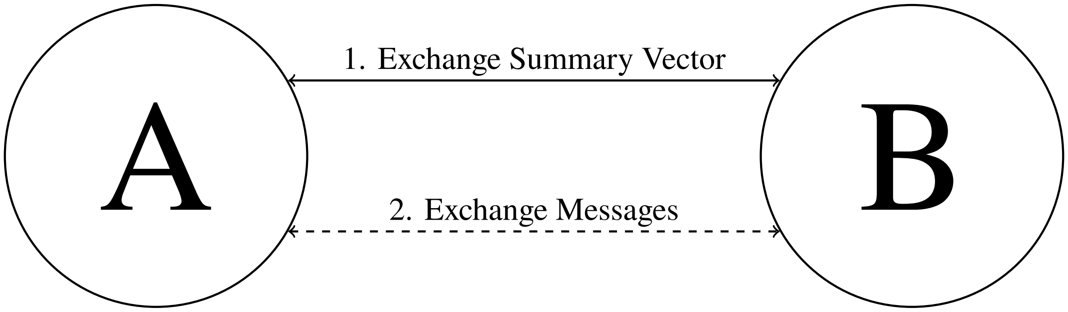


Figure 2.1. Epidemic Logic

Pure Epidemic [1] assumes unlimited resources, so nodes are not limited in buffer size or transmission speed. With unlimited resources, pure Epidemic provides the highest delivery probability. Pure Epidemic trades network resources in message replication for the high delivery probability. However, real systems do not have unlimited resources. Nodes have limited memory and bandwidth, so pure Epidemic is not feasible for a network model. Nodes must manage resources.

Vahdat and Becker's Epidemic [3] algorithm limited network resource consumption using hop counts. The hop count is the maximum number of node exchanges for a message. Nodes decrement a message's hop count during each exchange. When a message's hop count reaches zero, the node stops forwarding the message. Time to Live (TTL) is another method to reduce network resource consumption. Epidemic's TTL is not a counter like the IP version 4 header. Instead, Epidemic's TTL is a timestamp representing a message's expiration time. All messages have a TTL. When a message exceeds its TTL, the node deletes the message to free buffer space and reduces the number of messages to exchange between nodes. The combination of hop count and TTL reduces network resource consumption.

Since nodes have limited message buffer sizes, nodes use a First In First Out (FIFO) policy. FIFO queues are a simple message buffer strategy. When a node receives a new message, the node adds the new message to the end of the queue. When a node transmits a message or removes a message to free buffer space, the node fetches the oldest message in the queue by retrieving the message from the beginning of the queue. FIFO does not provide message priority based on other factors. Instead, nodes determine message priority based on order of message reception [3].

In summary, Vahdat and Becker's Epidemic performs two main steps. First, nodes share summary vectors containing the list of all messages held within a node's buffer. After exchanging summary vectors, nodes determine which messages to transmit based on the summary vector. If the other node is missing a message in its summary vector, then that message is selected for transmission. Nodes transmit the selected messages in FIFO order [3].

Spray-and-Wait

Spyropoulos et al. proposed Spray-and-wait in *Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks* [12]. Spray-and-wait combines the principles of Epidemic [3] and Direct Contact [11] by forwarding messages in two steps. In the spray step, a source node replicates its messages to every node it encounters like Epidemic. The receiving nodes enter the wait step for the received message. In the wait step, the node only forwards the message if the node encounters the destination node like Direct Contact. This limits the number of times that a message is replicated. Compared to Epidemic, Spray-and-Wait reduces message replication overhead by a factor of 1.8–3.3 times lower while maintaining similar latency. Due to reduced message replication, the researchers reported that Spray-and-Wait scales better than Epidemic in larger scenarios [12].

2.1.2 Geolocation Assisted Protocols

Geolocation assisted protocols use node positions to reduce message replication or make forwarding decisions. Geolocation assisted protocols require nodes to measure their position. Nodes use positional information to make routing decisions. Vector and Centroid are examples of geolocation assisted DTN protocols.

Vector

Kang and Kim proposed Vector Routing [4] to reduce the overhead of replica-based DTN protocols. Since Epidemic nodes pass all of their data to nodes they encounter, Epidemic produces many unnecessary replicated messages that waste network resources. Vector attempts to reduce overhead while maintaining delivery ratio.

In order to reduce overhead, nodes use location history to calculate their vector. A vector is a node's direction of motion and velocity, and a vector is not a summary vector. Nodes rely on local information, and nodes do not maintain global information such as network topology. Vector uses node vectors to control message replication. Vector assumes that every node in the network has a reliable means to determine its position such as GPS, but the node does not know the mobility pattern or location history of other nodes [4].

To reduce network overhead, Vector uses hop counts and TTL. Like Epidemic, nodes decrement the hop count every time a node receives a message. When the hop count reaches zero, the node deletes the message. TTL is also the same as Epidemic. When a message exceeds its TTL, nodes delete the message. In addition, Vector uses acknowledgments. Acknowledgments contain the message IDs of messages that that reached their destination. When a message arrives at its destination, multiple copies of that message may exist in the network. Acknowledgments remove the unnecessary replicated messages. When a node receives an acknowledgment, it removes the acknowledged message from its buffer [4].

Vector performs the following steps in Figure 2.2. First, nodes transfer a list of acknowledged messages. Nodes use the acknowledged message list to purge delivered messages from their message buffer. Afterwards, nodes transfer messages destined to the encountered node while transferring summary vectors. These messages are not considered replicated messages because they are message whose final destination is the other node. Like Epidemic, the summary vector contains the list of messages contained in a node's message buffer.

However, the summary vector also contains a node's vector. When a node receives the summary vector, the node uses its vector and the other node's vector to determine a message limit. The message limit is a fraction of the number of messages that the other node does not possess. After determining the message limit, the nodes transfer the allowed number of replicated messages [4].

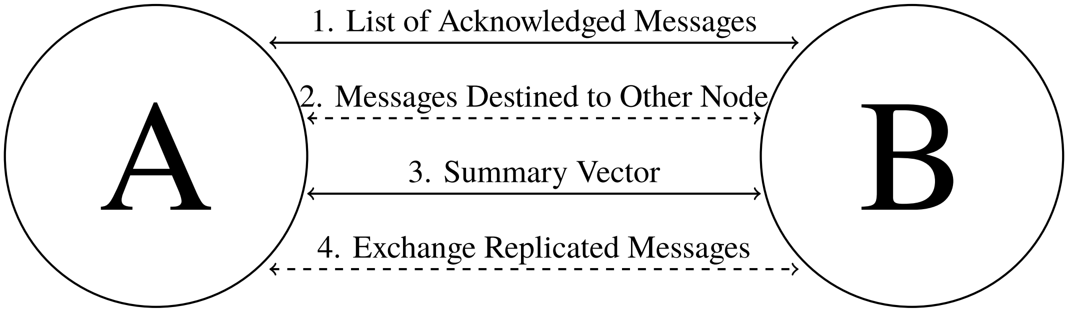


Figure 2.2. Vector Logic

To determine the message limit, each node records its position every Δt seconds. Nodes maintain a list of the N most recent positions. The nodes instantaneous vector, V_{cur}, cannot predict a nodes direction of movement correctly, but a movement history can predict node movement if the node has a regular mobility pattern. Nodes use a weighted average of the node movements from $N\ x\ \Delta t$ positions. The most recent positions weigh more than the oldest positions. In order to determine the number of messages to replicate, Vector uses the angle of incidence, Θ, between the two node vectors u and v:

$$\Theta = \arccos \frac{u \cdot v}{\|u\| \|v\|} \tag{2.1}$$

Nodes traveling in orthogonal directions transfer the most messages because those nodes are more likely to encounter different nodes. Nodes traveling in the parallel or opposite directions are more likely to encounter the same nodes, so they transfer the fewest messages. A linear function determines the message limit based on Θ. When Θ is zero, the node replicates no messages. When Θ is 90 degrees or -90 degrees, the node replicates all messages [4].

Centroid

While previous DTN geolocation assisted protocols assumed no positional errors (perfect GPS data), Rohrer proposed the Centroid [10] routing algorithm that is resilient to errors in positional measurements. Commercial GPS's advertised accuracy is ±20 meters. Dr. Rohrer demonstrated that GPS error does affect protocol performance in some cases, and that Centroid is relatively unaffected by positional errors [10].

Centroid makes routing decisions based on the distance between centroids. A centroid is the geographic center of mass determined by a node's position history. The following equation calculates a node's centroid:

$$C_i(t_p) = \sum_{t=1}^{t_p} \frac{C_i(t_p - 1) \times (t - 1)}{t} + \frac{i_t}{t} \tag{2.2}$$

C is the centroid and i is the X or Y coordinate. t_p is the current time increment in terms of the selected update interval. The change in a nodes centroid at each update is:

$$\Delta C_i(t_p) = \frac{i_t - C_i(t_p - 1)}{t_p} \tag{2.3}$$

The centroid primitive is a running average of a node position. As a result, centroids are resistant to noise introduced by GPS errors [10].

Centroid incorporates Vector's strategy of limiting message replication using geographic information. Vector determined the message limit based on the orthogonality of the node vectors. However, Vector is sensitive to GPS errors because trajectory projection amplifies positional errors. As a result, Centroid determines the message limit based on the distance between the nodes' centroids. Centroid's message limit is the ratio to the two nodes' centroid distances and the longest centroid distance previously encountered by the nodes. The ratio is the fraction of messages in a node's buffer that are transmitted to the connected neighbor. Nodes with centroids that are further apart transfer more messages than nodes with closer centroids. As a result, messages transfer as far as possible while minimizing the number of hops [10].

Centroid's node exchange sequence is similar to Vector in Figure 2.2. Nodes transfer a list of acknowledged messages followed by messages destined to the other node. Afterwards, nodes transfer summary vectors. The summary vector contains the list of messages held by a node, and the node's centroid. Finally, nodes forward messages based on the message limit. Just like Vector, Centroid uses hop counts and message time to live to improve protocol efficiency [10].

2.1.3 Probability Based Protocols

Probability based protocols route messages based on the estimated probability of a node contacting another node in the future. Unlike flooding based protocols, probability based protocol require some knowledge about a network. At a minimum, nodes maintain a database of probabilities to determine message forwarding. Probability based protocols attempt to reduce overhead without affecting the network's message delivery ratio [1]. PRoPHET is an example of a probability-based DTN protocol.

Under PRoPHET [13], nodes maintain a database containing encountered nodes with a delivery predictability value. When a node encounters a new node, the node assigns the encountered node an initial delivery predictability value. When a node encounters a known node, the node increases the corresponding delivery predictability value. Since nodes share their database of known nodes, nodes can estimate node reachability. These delivery predictabilities are transitive, so a node can know that a destination is reachable even if the node is not directly connected to the destination. As a result, nodes maintain some state of the topology of the network. Nodes use the delivery predictability to determine which messages to exchange. If the delivery predictability is above a threshold, then the node replicates the message. Like Epidemic, PRoPHET nodes share summary vectors to prevent nodes from transferring messages that the other node possesses. Probabilistic protocols reduce message replication, but they add complexity to the protocols. They require nodes to share additional information prior to exchanging messages [13].

2.1.4 Hybrid Protocols

Some DTN protocols use a combination of flooding, probability, and geolocation assistance. These protocols do not belong to one particular category, so this thesis refers to them as hybrid protocols. GAPR and GAPR2 are examples of hybrid DTN protocols because they combine probabilistic mechanisms with geolocation assistance.

GAPR

Developed at NPS, Geolocation Assistive Predictive Routing [5] is a hybrid DTN routing protocol that extends MaxProp. GAPR leverages a node's location and encounter history to adapt to heterogeneous and irregular mobility patterns. According to [5], traditional protocols that make forwarding decisions based on geolocation information are susceptible to local maxima conditions. A local maxima condition occurs when GPS information alone does not identify a closer or better neighbor. Predictive routing protocols mitigate local maxima by basing their routing metric on encounter history and delivery probability. The geolocation information forces nodes to forget encounter probabilities that are likely incorrect [5].

GAPR adopts routing strategies from multiple DTN protocols. First, GAPR floods acknowledgments throughout the network for delivered messages like Vector. Second, GAPR uses delivery probability for each message in the node's buffer. Nodes forward messages with higher delivery probabilities ahead of messages with lower probabilities. Finally, nodes delete messages with the lowest delivery probability when the message buffer is full [5]. In order to reduce network overhead, GAPR uses message TTL. When a message exceeds its TTL, nodes delete the message. GAPR does not use hop count limits. Instead, a node increments the hop count when a message is received. Messages with low hop counts are prioritized [5].

GAPR's delivery predictability is based on MaxProp [14]. MaxProp and GAPR use historical encounter information to make routing decisions. The encounter history determines message priority when replicating messages or removing messages from a full buffer. The probability database contains every encountered node i in the network as $f(A,i)$. A is the node performing the probability calculations. N is the size of the network, and $f(A,i)$ is initialized to $1/(N-1)$. When a node encounters a peer, the node sets the corresponding f value to one. Then the node renormalizes the entire probability database so all encounter probabilities sum to one. When nodes encounter a peer, they share their probability databases [5], [14].

GAPR determines message priority using hop count and delivery probability. GAPR does not forward messages already contained in another node's message buffer. First, nodes determine a threshold t. t is set to the minimum hop count of the first p messages in the buffer. Nodes compute p using the following equation:

$$p = \begin{cases} x & \text{if x<}\frac{b}{2} \\ \min(x, b - x) & \text{if } \frac{b}{2} \leq x < b \\ 0 & \text{if b<x} \end{cases} \tag{2.4}$$

b is the size of the transmitting node's message buffer and x is the average number of bytes transferred per node encounter. GAPR assumes there is not sufficient bandwidth to forward the entire buffer at each encounter, so available bandwidth is dedicated to low hop count messages first. After transferring the messages that do not exceed the threshold, node forward the remaining messages by increasing order of cost. The cost of a message is determined by *(1 -f(A,d))*, where d is the message's destination [5], [14].

GAPR uses MaxProp's logic for removing messages when the message buffer is full. Nodes immediately drop acknowledged messages. When the message buffer is full, messages with a hop count greater than the threshold t and lowest delivery probability are dropped first. Messages with the lowest number of hops below the threshold are dropped last [5].

GAPR uses geolocation information to build a map of the network's topology. All nodes maintain a database of historical location information for other encountered or learned nodes. Specifically, nodes maintain two databases. A node maintains its own probability database, and nodes maintain a transitive database. The transitive database contains the locations learned from other nodes. When nodes encounter another node, they exchange their locations with a timestamp. The location history permits nodes to detect changes in the network's topology. When a node receives information from a peer, the node updates its database and transitive database. The node compares the two databases. If a node exists in both databases and the transitive database entry is newer, then the node removes the entry from the location database and resets the delivery probability for that entry to zero. If the new location information shows that a close node suddenly moved far away, then GAPR resets the delivery probability because the old probability is no longer valid. GAPR uses geolocation information to unlearn inaccurate delivery probabilities [5].

In summary, GAPR combines probabilistic modeling, geolocation assistance, and queue management optimizations to attempt to improve performance. When a node encounters another peer, nodes perform five main steps in Figure 2.3. First, nodes exchange a list of acknowledged messages and clear acknowledged messages from their buffers. Then, nodes forward messages destined to the other node. Third, the nodes exchange their probability and location tables. Nodes use the new location information to update nodes that have moved abruptly since the last update. Nodes exchange a Summary Vector containing the list of messages held in a node's buffer. Finally, nodes replicate messages to the peer based on the threshold and delivery probability.

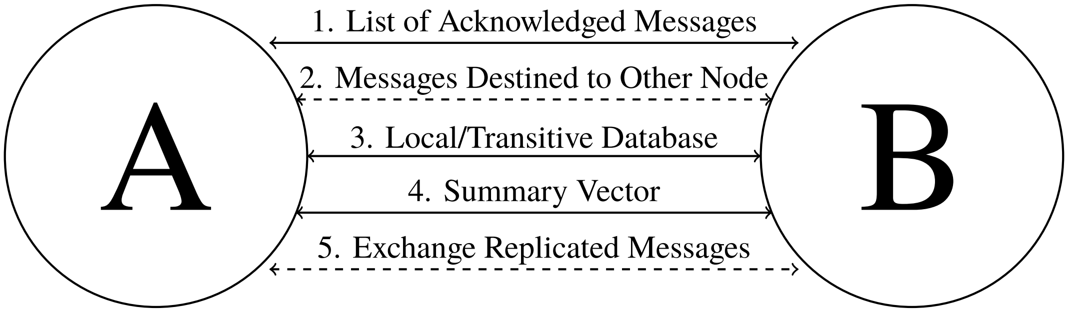


Figure 2.3. GAPR Logic

GAPR2

As an evolution of GAPR, Killeen proposed GAPR2 [9] to improve efficiency of the GAPR protocol by reducing message replication. GAPR2 combines the message limit calculation from Vector with the GAPR protocol. GAPR2 uses the same delivery probability and threshold algorithms discussed in section 2.1.4 to calculate delivery probability and message priority. The operation of GAPR2 is identical to GAPR. Nodes transfer a list of acknowledged messages followed by messages destined to the other node. Then, the nodes transfer their probability and location databases. Afterwards, nodes transfer summary vectors. While GAPR would replicate all messages based on the threshold and delivery probability, GAPR2 limits the number of replicated messages using Vector's message limit calculation. GAPR2 nodes determine the message limit prior to forwarding replicated messages to another node. Killeen reported that GAPR2's message replication overhead was five times lower than GAPR in an urban map-based mobility scenario. However, GAPR2's message delivery ratio was approximately 10% lower than GAPR [9].

2.1.5 Social Based Routing

While this thesis does not implement Social Based Routing protocols, they present an alternate method to route messages and limit message replication. Social based routing protocols capitalize on node behaviors. The platform transporting a node determines node mobility and behavior. For example, nodes of the same social group will tend to cluster and meet more frequently. If the node is associated with a bus, then the node will follow the same route and repeatedly contact certain nodes. Social based routing protocols use human behaviors to improve network performance [1].

Social Group Based Routing Protocol (SGBR) [15] forwards messages based on a node's social group. A social group is a collection of nodes that meet frequently. When a node interacts with a node outside of its social group, that node acts as a representative of its group. That node interacts with other social groups to send messages outside of its social group. Nodes replicate more messages outside of their social group than within their social group. As a result, message replication decreases [1], [15].

Another type of social based protocol is Context Aware Routing Protocol (CAR) [16]. CAR uses information about other nodes to make routing decisions. Nodes use mobility, power, connectivity, and co-location to predict the probability of delivery. While CAR could be a hybrid protocol, the use of other node information, such as power, makes the protocol social based. CAR does not use the current status of another node. Instead, CAR predicts another node's status. An example is battery life because power affects a node's behavior. If a node connects to two other nodes and one node's battery depleted, then the node with more battery would be the better choice to forward the messages. A social based protocol can improve network performance by being power aware [1], [16].

2.2 Network Simulators

This section discusses the two open source network simulators used in this thesis. The ONE is a discrete-time simulator focused on simulating store-carry-forward network protocols. ns-3 is a discrete-event network simulator that can simulate any network protocol. This section covers the basic functions and architecture of the simulators. The section compares the advantages and disadvantages of the two simulators.

2.2.1 The Opportunistic Network Environment Simulator

The ONE is a discrete time simulator for store-carry-forward networks. A set of Java packages defines the simulator. The ONE focuses on modeling the behavior of store-carry-forward networks, so the simulator abstracts away the lower layers of the Open Systems Interconnection (OSI) network model. Instead, the ONE models node movements, inter-node contact, routing, and message handling. Data collection and analysis is handled by the visualization, reports, and post-processing components.

Within the ONE, nodes are the base agents. A node contains a radio interface, storage, movement, energy, and routing capabilities. The modules in Figure 2.4 access node parameters and state. The ONE configures node capabilities such as storage and radio interfaces by directly manipulating node parameters. Complex modules such as routing require separate modules to simulate a specific behavior of a node. All modules in the ONE can directly access any other module. Since the ONE focuses on modeling behavior, the ONE does not model the physical layer or the link layer. As a result, the ONE does not model signal attenuation, link layer overhead, or link layer congestion. Instead, the ONE abstracts the link layer and physical layer as communication range and bit rate. The communication range and bit rate are static throughout a simulation [8].

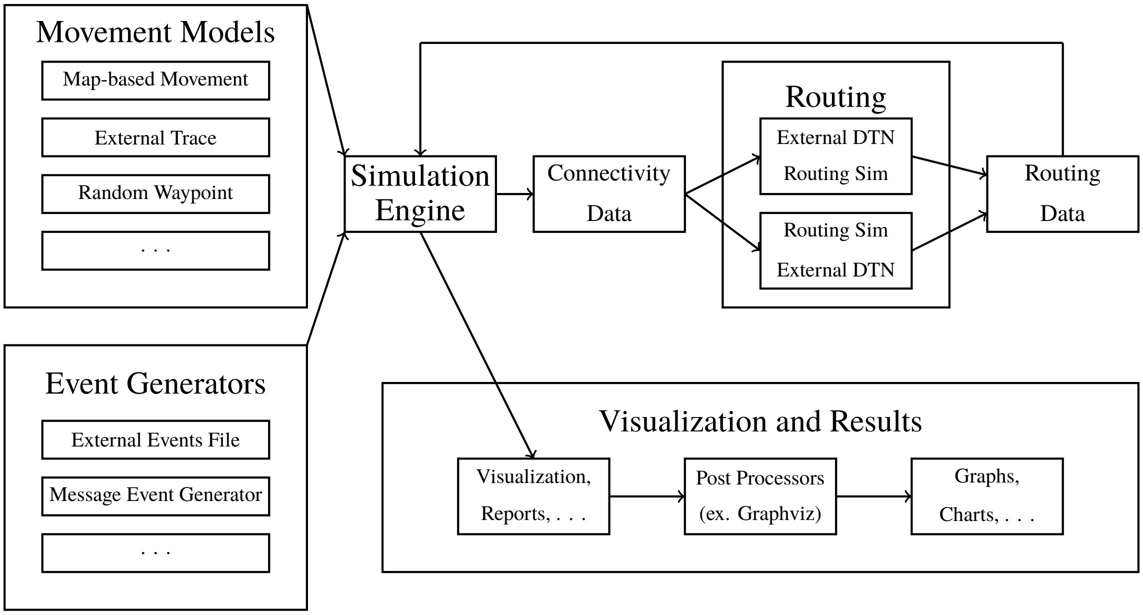


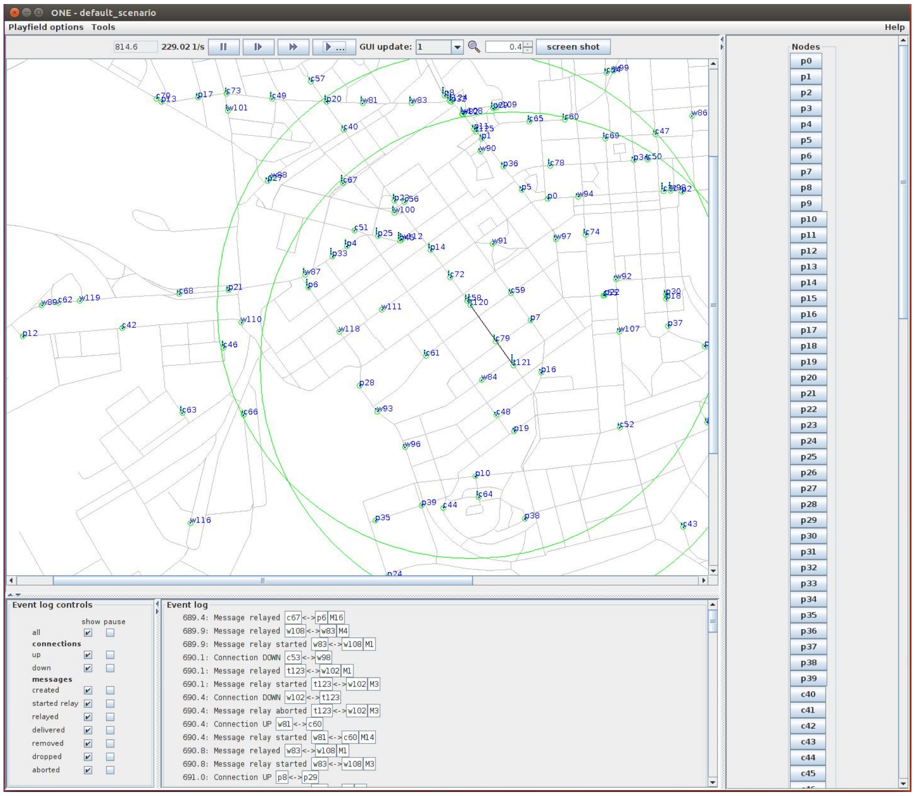
Figure 2.4. ONE Architecture. Adapted from [8]

The ONE includes multiple movement models, and the simulator can load externally generated node movements. Random movement, map-constrained random movement, and human behavior based movement define the ONE's synthetic movement models. Random movement models randomly move nodes, but map-constrained random movement limits nodes to selected predefined paths. Human behavior based models extend the map-based models by modeling human movement patterns [8].

The map-based mobility model contains three map-based models. The Random Map-Based Movement model randomly moves nodes following defined paths. The Shortest Path Map-Based Movement model has nodes randomly choose a random point on the map and routes the node to the point using the predefined paths. The Routed Map-Based Movement model moves nodes along predefined routes. The Well Known Text (WKT) format defines maps. A separate program is required to generate WKT files from real-world map data [8].

The routing module provides the framework to implement DTN protocols. All routing protocols are an extension of the Message Router model. The Message Router contains interfaces required for the simulator to handle events and carry out operations with other modules. As the parent of all ONE routing protocols, the Message Router controls basic routing behavior common to all protocols. The ONE includes Direct Delivery, First Contact, Spray-and-Wait, PRoPHET, MaxProp, and Epidemic [8].

The Reporting and Visualization module provides a Graphical User Interface (GUI) and generates the reports. The GUI displays simulations in real-time showing node location, map overlay, current paths, connections, and number of messages carried by a node. The GUI in Figure 2.5 provides the overall picture of a simulation. The GUI is not required during a simulation, and the ONE supports running batches of simulations. The report module generates the logs and statistics of a simulation. Performance metrics include messages generated, messages delivered, latency, and hop count. In addition, the report module generates Network Simulator 2 (ns-2) movement traces for other simulators [8].



show pause
all ☑ ☐
connections
up ☑ ☐
down ☑ ☐
messages
created ☑ ☐
started relay ☑ ☐
relayed ☑ ☐
delivered ☑ ☐
removed ☑ ☐
dropped ☑ ☐
aborted ☑ ☐

```
689.4: Message relayed c67<->p6 M16
689.9: Message relayed w108<->w83 M4
689.9: Message relay started w83<->w108 M1
690.1: Connection DOWN c53<->w98
690.1: Message relayed t123<->w102 M1
690.1: Message relay started t123<->w102 M3
690.4: Connection DOWN w102<->t123
690.4: Message relay aborted t123<->w102 M3
690.4: Connection UP w81<->c60
690.4: Message relay started w81<->c60 M14
690.8: Message relayed w83<->w108 M1
690.8: Message relay started w83<->w108 M3
691.0: Connection UP p8<->p29
```

Figure 2.5. ONE's GUI Screenshot

The ONE generates traffic using message generators or external event files. The message generator creates messages with a specified or random source, destination, and size. The message can be any size. The ONE does not generate packets. The ONE generates messages at specified or random intervals. The messages are not limited by link layer limitations because the ONE abstracts the link and physical layers [8].

At the heart of the ONE, the simulation engine constructs and manages the simulations. The simulation engine reads command line arguments and configuration files to build the scenario. The simulation engine interacts with the other ONE modules to model node behavior and generate reports. Since the ONE is a discrete time based simulator, the simulation engine updates modules at specific time intervals to generate the required actions and behaviors [8].

2.2.2 Network Simulator 3

ns-3 is a discrete event network simulator implemented in C++. Unlike the ONE, ns-3 does not focus solely on simulating the behavior of DTN protocols. Instead, ns-3 simulates the entire network stack. As a result, ns-3 can simulate traditional network protocols and prototype new protocols. ns-3 supports IP and non-IP based networks. The simulator uses real Linux application and kernel code to provide realistic models. ns-3 supports real-time network emulation that can interconnect with real networks and work with existing protocols [17].

As a discrete-event simulator, ns-3 tracks events scheduled for execution. ns-3 executes the events in sequential order of simulation time. When an event completes, the simulator jumps to the next scheduled event. An ns-3 event is a simulated action. Changing node direction or sending a packet are examples of events [17].

At the base of ns-3's structure in Figure 2.6 is the core. ns-3's core consists of the simulator, scheduler, time, and events. The simulator is the main execution loop. The simulator executes all events from oldest to most recent until there are no events left in the queue. The scheduler manages the queue of events using the simulation time class. In order for multiple classes to interact without specific inter-module dependencies, ns-3 uses callbacks. A callback is a pointer-to-function variable. This permits a function from one class to call a function from another class. On top of ns-3's core is the network layer. The network layer implements the foundation of all networks. Elements such as packets, sockets, queues, addresses, and devices are part of the network layer. The core and network modules make the generic simulator core that builds any type of network [17].

<table>
<tr><td colspan="5">Test</td></tr>
<tr><td colspan="5">Helper (High Level Wrapper)</td></tr>
<tr><td>Protocols</td><td>Applications</td><td>Devices</td><td>Propagation</td><td>. . .</td></tr>
<tr><td colspan="3">Internet</td><td colspan="2">Mobility Models</td></tr>
<tr><td colspan="5">Network (Packets, Sockets, Nodes, Queues, Addresses, NetDevices, ...)</td></tr>
<tr><td colspan="5">Core (Callbacks, Tracing, Scheduling, Events, Time, ...)</td></tr>
</table>

Figure 2.6. ns-3 Software Organization. Adapted from [17]

Above the core and network modules, the upper layers implement specific networks, protocols, mobility models, devices, and physical mediums. These modules inherit and extend the objects in the network layer. The helper modules serve as wrappers for the lower modules to aid in scripting scenarios. The test module assists in debugging scenarios and new module implementations. ns-3's modular design allows users to create new modules without affecting or changing other modules. ns-3 can simulate multiple layers of the network stack. ns-3 simulates multiple types of physical medium, routing protocols, link layer protocols, transport layer protocols, and applications [17].

In addition, ns-3 contains multiple mobility modules. Like the ONE, ns-3 uses a coordinate system to represent node locations. ns-3's MobilityModule does not have map-based mobility like the ONE. Instead, ns-3 contains constant position, constant velocity, constant acceleration, Gauss Markov, random direction, and random waypoint mobility modules. In order to support map-based mobility, ns-3 requires a separate program to generate ns-2 mobility trace files. The ns-2 mobility traces specify node locations, speeds, and direction of movement. ns-3 reads the trace file to determine node position during a simulation [18].

ns-3's tracing system generates a simulation's output for analysis. By default, ns-3 supports generating Packet Capture (PCAP) trace files and ASCII trace files. The trace system supports tracing at the device level or protocol level. The traces permit generating statistics or debugging new module implementations [17].

2.2.3 Differences between the ONE and ns-3

The differences between the ONE and ns-3 are a function of simulator type and goals. As a discrete-event simulator, ns-3 provides a higher fidelity simulation than the ONE. ns-3 executes all events. Since the ONE is discrete-time simulator, the fidelity of the simulation is a function of the selected time interval. A shorter time interval provides a more detailed simulation. However, ns-3 requires more time to complete a simulation than the ONE because ns-3 executes every event. In contrast, the ONE's simulation time is a function of the selected time interval.

Another key difference is the level of abstraction. The ONE abstracts away everything below the routing layer. As a result, new routing protocols are easier to implement and test. However, link layer overhead and congestion affect real-world performance. Since the ONE abstracts away control packets using shared data structures, real-world implementations may not perform the same. In contrast, ns-3 simulates the entire network stack. ns-3 requires control packet definitions, and simulations include link layer overhead. Since the routing protocol must interface with other real-world protocols, the ns-3 implementation provides the opportunity to prototype protocols before deploying physical devices. However, protocols are more difficult to implement in ns-3 because the protocol must interact with other layers of the network stack. The added levels of simulation increase the processing required by a simulation. ns-3's simulation of other layers of the network stack permits researchers to study of the effects of other layers on performance.

2.3 The Bundle Protocol

Request For Comments (RFC) 5050 [19] is the Bundle Protocol Specification that describes an architecture for DTNs. The Bundle Protocol is an end-to-end architecture for networks that experience intermittent connectivity, long delays, and high bit error rates. The Internet Research Task Force (IRTF) Delay Tolerant Networking Research Group (DTNRG) developed the experimental protocol. Kevin Fall's *A Delay-Tolerant Network Architecture for Challenged Internets* [7] provided the basis for the Bundle Protocol's architecture. The Bundle Protocol specification provides a high-level description for exchanging messages within a DTN. While this thesis does not implement the Bundle Protocol, several concepts from the Bundle Protocol are adopted to build the ns-3 DTN routing protocols.

The Bundle Protocol is designed to handle intermittent connectivity by using custody-based retransmission and takes advantage of opportunistic, scheduled, or predicted connectivity. The Bundle Protocol forms a store-and-forward network by providing service at the application layer of several internets. Figure 2.7 illustrates where the Bundle Protocol sits in the network stack [19].

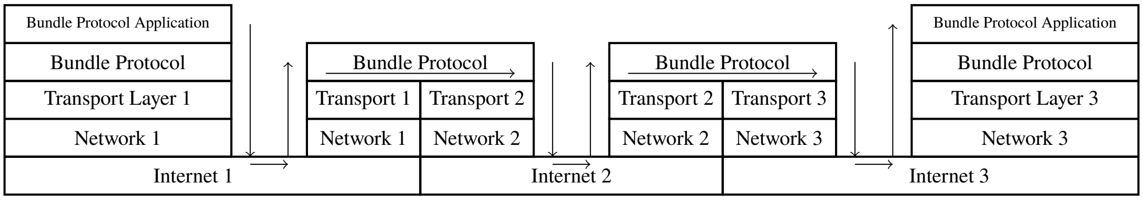


Figure 2.7. Bundle Protocol Network Stack. Adapted from [19]

The Bundle protocol does not define its own network protocols and transport layer protocols.

Instead, the Bundle Protocol uses the network and transport layer protocols employed by the underlying network. The network that a node connects to does not have to be an IP network. The underlying network could be a physical storage device such as a portable hard-drive that is transported between nodes. Figure 2.7 is an example Bundle Protocol network that contains three different internets using different network and transport layer protocols. In order to operate with multiple internets with different underlying protocols, a convergence layer adapter serves as the interface between the bundle protocol and lower level protocols. The Bundle Protocol does not define the routing algorithms, or convergence layer adapters used to transport data through specific internets, and the specification does not detail how routing and forwarding decisions are made [19].

In RFC 5050, bundles are the base unit of DTN data. Bundles are equivalent to messages as the base unit of DTN data. Bundles are identified by a unique global ID derived from the source endpoint ID and time in seconds that the bundle was generated. An endpoint identifies a node using the Bundle Protocol, and endpoint IDs are independent from the underlying network addressing [19].

Bundle Protocol networks send bundles towards nodes with the specified endpoint ID. At each bundle node, the Bundle Protocol determines the next hop based on the endpoint ID. The convergence layer adapter removes network specific information when sending data to the Bundle Protocol layer. When the Bundle Protocol determines the next hop, the convergence layer adapter adds the network specific protocol information and segments the message as needed, in order to send the data to the next hop. When a node passes a bundle to the next hop, the protocol includes an option for acknowledging message reception. The Bundle Protocol also includes options for end-to-end acknowledgements. The underlying routing protocol that determines the next hop or manages the message buffer is not specified in RFC 5050. Instead the Bundle Protocol specifies bundle format, bundle transmission, bundle reception, and endpoint registration [19].

2.4 Related Works

Some DTN research studied protocols using the ONE simulator or built a custom simulator. Other research built DTN prototypes. Since this thesis focuses on comparing protocols using both the ONE and ns-3, a review of prior research studying cross simulator analysis is required. Prior research into GAPR and GAPR2 did not analyze power consumption, so this section includes of discussion of power consumption and improving protocol energy efficiency. The discussion includes the metrics and methodology employed.

2.4.1 Cross Simulator Evaluation

As network simulators evolve, protocol implementations in the older version of a simulator may not work in the new version of the simulator. As a result, the developer must implement protocols in the new version of the simulator. *From ns-2 to ns-3 – Implementation and Evaluation* [20] details the implementation and evaluation structure for transferring the Density Aware Reliable Broadcasting Protocol (DECA) [21] from ns-2 to ns-3. DECA is a Vehicular Ad-Hoc Network (VANET) protocol that operates under the store and forward paradigm. ns-3 superseded ns-2 to support simulation and emulation of networks. ns-3 implementations transfer to real systems with less work compared to ns-2.

In order to meet the design goals of ns-3, the entire code structure changed to a modular design. As a result, ns-2 code is not compatible with ns-3. First, the researchers implemented DECA in ns-3. Then, they compared the protocol using the same traffic scenario in ns-2 and ns-3. Simulation of Urban Mobility (SUMO) generated node movements. Traffic and Network Simulation Environment (TraNS) converted SUMO's output in ns-2 mobility trace files. The scenario used the ns-2 mobility trace in both ns-2 and ns-3, so the node movements are identical, accurate, and repeatable. Their mobility scenario consisted of straight two-lane 4-kilometer road. Nodes used an 802.11 radio with a 250-meter transmission range. Message generation consisted of a source node transmitting five messages at 10-second intervals. The scenario varied the speed of the vehicles and the number of vehicles per kilometer [20].

The metrics compared between ns-2 and ns-3 included overhead and reliability. They defined reliability as the fraction of nodes that received the message to the total number of nodes. Overhead is the cost of message retransmission for every node. The authors compared the metrics between ns-3 and ns-2 implementations. Since the results between simulators were similar, the researchers concluded that DECA in ns-3 performs the same as DECA in ns-2 [20].

In *A Performance Comparison of Recent Network Simulators* [22], researchers conducted a performance comparison study of five network simulators in an identical scenario. The study examined run-time performance and memory consumption of ns-2 [23], ns-3 [24], Objective Modular Network Testbed in C++ (OMNet++) [25], SimPy [26], and Java in Simulation Time (JiST)/Scalable Wireless Ad Hoc Network Simulator (SWANS) [27]. In order to compare the simulators, the benchmarking simulation did not rely on an existing simulation model. Instead, the model consisted of a basic network of nodes arranged in a square topology. The model did not simulate a realistic network, but the scenario used traditional IP protocols. They implemented the same scenario in each simulator, and they checked that each implementation returned similar results. After verifying the implementations, the researchers varied the network size from 4 to 3025 nodes. The authors measured the simulation run-time and memory consumed by each simulator. The results showed that ns-3, OMNet++, and JiST are the most efficient at simulating large networks. JiST was the fastest, but consumed the most memory. However, the authors concluded that ns-3 provided the best overall performance [22].

OPNET Modeler and Ns-2: Comparing the Accuracy Of Network Simulators for Packet-Level Analysis using a Network Testbed [28] is another study that compared network simulators. The study compared the accuracy of packet level simulations in ns-2 and Optimum Network Performance (OPNET) Modeler by comparing the results to a network testbed. The network testbed consisted of a server, client, router, hub, and two traffic generators. The same network was constructed in ns-2 and OPNET. The researcher ran two sets of experiments. One scenario generated traffic at a constant rate, and the other scenario used File Transfer Protocol (FTP) to share information between two computers. Packet captures from the network testbed and simulators provided the data. The network testbed provided the baseline to compare the two simulators. The authors reported that both simulators provided accurate modeling of constant bitrate data traffic, but both simulators did not accurately model FTP under the default settings. OPNET provided a more accurate model of FTP traffic when parameter adjustment was performed [28].

While these simulator comparison studies do not model DTNs, they do show common trends in comparing network simulators. The scenarios comparing the simulators must be the same. Simulations involving node movement must be identical, and traffic generation must be similar. Despite modeling the same scenarios and protocols, simulator results may vary.

2.4.2 Study of Power Consumption

While mobile devices are good candidates for building DTNs, power consumption is an important parameter in evaluating a protocol. Most of the works discussed so far focused on the performance of a protocol without accounting for power consumption. In *Energy Impact Analysis on DTN Routing Protocols* [29], Rodrigues-Silva developed the Energy Module for the One Simulator. The Energy Module tracks the energy spent by a node during message transmission, message reception, and search for new nodes. The module simulates a battery, assigns the power consumed performing a task, and enables recharging a battery. A node can be off, inactive, scanning, transmitting, or receiving. In the scan mode, a node spends energy to detect the presence of another node. The inactive mode has a node listen for other nodes and exchanges messages with nodes that it detects. The Epidemic and PRoPHET protocols integrated the energy module and simulated in the Helsinki scenario. The Helsinki scenario used the Shorted Path Map Based Movement model. Nodes are restricted to the path they can take (roads, sidewalks, or railroads), but the destination of the node is chosen randomly. The scenario executed under different values for battery capacity, time required to recharge a battery, transmission energy, and scan intervals. The research revealed that the energy consumed for node discovery is greater than the energy consumed for sending and receiving messages. When accounting for energy consumption, protocols optimizing message exchange have little impact on performance depending on the scenario [29].

In contrast to the movement model used by [29], *Evaluating the Impact of Energy Consumption on Routing Performance in Delay Tolerant Networks* [30] used the Working Day Movement model in the Helsinki Map. The Working Day Movement model simulates the movement of people through a typical working day. People tend to revisit the same locations at certain times throughout the day, and people do not tend to move randomly. For example, people commute to work at the same time and eat lunch at the same time. As a result, the contact time between nodes in the Working Day Movement model closely resembles real-world data. The protocols analyzed included Epidemic, Spray and Wait, PRoPHET, MaxProp, and Bubble Rap. Performance evaluation focused on overhead, delivery ratio, average latency, hop count, average energy consumption, and average residual energy. Bubble Rap performed the best, but used the most amount of energy. MaxProp used the least amount of power, but MaxProp had the lowest delivery ratio. Spray and Wait, Epidemic, and Prophet had similar power consumption with a shorter latency compared to Bubble Rap [30]. The results from [29] and [30] demonstrate that the impact on performance compared to energy consumption of DTN protocols depends on the scenario.

Furthermore, implementing node power states to conserve energy when discovering nodes is not the only method to reduce power consumption. *Performance Evaluation of a Multi-Radio Energy Conservation Scheme for Disruption Tolerant Networks* [31] suggested using a low power radio for node discovery and a high-power radio for exchanging messages. Within a specified duty cycle, a node transmits a beacon using the low power radio. When a node detects the beacon, it determines the messages to deliver and transmits the messages using the high-power radio. To assess performance and power consumption, the simulation executed the PRoPHET protocol using a random waypoint mobility model using fixed grid points that nodes selected to travel to in a straight line. Metrics analyzed included energy consumption, delivery ratio, and average end-to-end delay in relation to packet generation rate and node density. The research concluded that using two tiers of radio power reduces power consumption while maintaining similar performance to single radio nodes. In addition, the low power radio's range must be equal to or less than the high-power radio range to prevent node discovery when the node is not in range to send a message [31]. Banerjee's paper *An Energy-Efficient Architecture for DTN Throwboxes* [32] prototyped a DTN module using the two-radio scheme to conserve power. The DTN throwbox used a low power XTend radio for node discovery and a high power Wi-Fi radio to exchange messages. DTN throwboxes are stationary network nodes intended to improve the number of contacts between nodes. The research confirmed that node discovery consumes a significant portion of a throwboxes battery, and the two-radio method reduces power consumption. Throwbox power consumption reduced from 2500 mW to 80 mW [32].

In Choi's *Adaptive Exponential Beacon Period Protocol for Power Saving in Delay Tolerant Networks* [33], Choi presented the Adaptive Exponential Beacon Protocol (AEB) to reduce DTN node power consumption. The nodes running the protocol used a single radio, and the nodes broadcasted beacons to discover other nodes. AEB dynamically adapted the beacon broadcast frequency and the amount of time that the node's radio was turned on based on the contact availability. When a node transmits a beacon, the node listens for a response or a beacon from another node. When the nodes meet another node, it determines if there are messages to send or receive. If there are messages to exchange, the beacon interval is set to the minimum value and the node's radio remains turned on. If a node does not receive a response or does not have messages to exchange, the node doubles the beacon interval and turns off its radio until the next beacon. The beacon interval doubles until reaching a maximum value. Analysis of AEB used the Spay-and-Wait DTN protocol simulated in ns-2 using a random waypoint mobility model. Performance measures included power consumption, average packet delivery ratio, and average packet delay. The controlled parameters consisted of topology size, node speed, number of nodes, and traffic generation rate. As the node density goes down, AEB reduces power consumption while maintaining similar performance. As node speed increases or the number of nodes increases, the AEB marginally reduces power consumption because nodes initiate connections with other nodes more frequently. AEB reduced node power consumption by exploiting the intermittent connectivity associated with DTN networks [33].

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CHAPTER 3:
Implementation

In order to understand our methodology in Chapter 4, a basic understanding of our ns-3 protocols is required. Certain parameters in the scenarios are ns-3 specific, and ns-3 data collection references the code structure. Chapter 3 defines our ns-3 protocol control packets and messages used to generate the metrics discussed in our methodology. This chapter discusses the six DTN routing protocols implemented in ns-3. The discussion includes the overall code structure, node discovery, message handling, and message generation. Since all ns-3 DTN protocols originated from Alenazi's Epidemic [34], this chapter includes a discussion of the changes we made to the original ns-3 Epidemic code. The chapter includes an in-depth discussion of the Epidemic, Vector, Centroid, GAPR, GAPR2, and Geolocation Aware Routing Protocol 2a (GAPR2a) routing protocols. The implementation discussion includes control packets, buffer management, and algorithms related to the functionality of the protocol.

3.1 Code Structure

The ns-3 DTN protocols build upon the Alenazi's Epidemic [34] code, so all ns-3 DTN routing protocols are broken into four main classes. Unlike Alenazi's Epidemic, the DTN protocols transmit groups of data packets called messages instead of individual packets. Section 3.2 describes how the protocols handle messages instead of individual packets. This section provides an overview of the code structure. Some routing protocols contain additional classes to define additional data structures, but all DTN routing protocols contain a group of packet classes, packet queue class, queue entry class, and routing protocol class. The Unified Modeling Language (UML) diagram in Figure 3.1 shows common functions and attributes used by all ns-3 DTN protocols to implement the DTN logic.

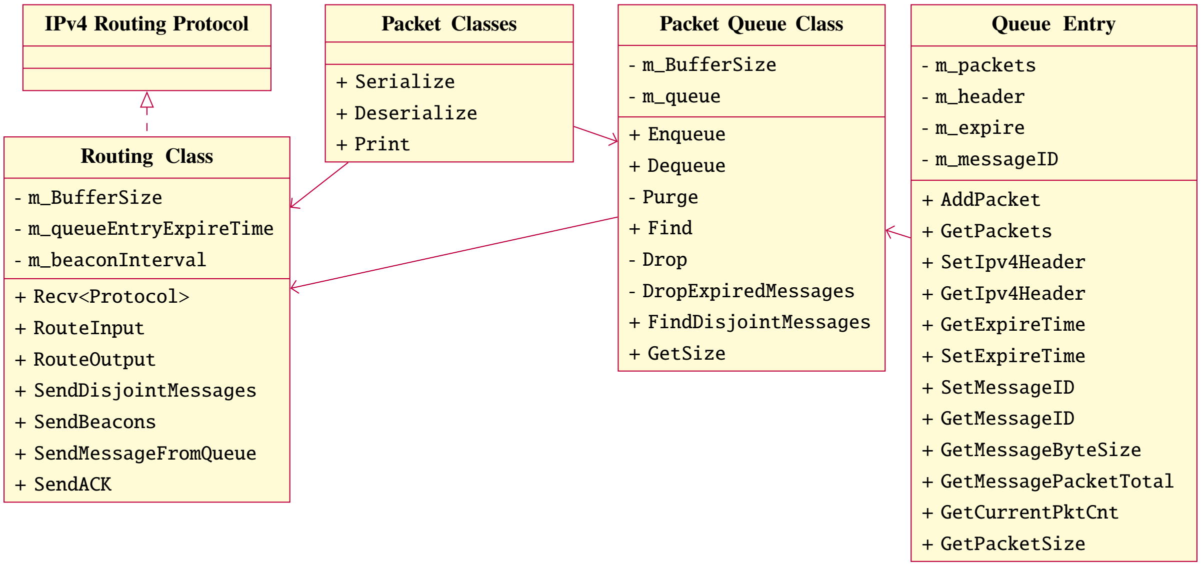


Figure 3.1. DTN UML Diagram

3.1.1 Packet Classes

The packet classes are the packet header declarations used by the DTN protocols. Each packet header is its own class because the packet header is a data structure that defines a packet. The packet classes inherit ns-3's `Header` class. The `Header` class defines a packet and provides the interface for other classes to interact with the packets. The routing class and packet queue class interact with the packet class to read and write packet headers. Since packet headers have various types of information, they have their own accessors and mutators. However, all packet header declarations require a `Serialize` and `Deserialize` function because of the `Header` class. The `Serialize` function writes the header information to a packet buffer, and the `Deserialize` function reads from a packet buffer. These functions are required because ns-3 passes packets between nodes as byte arrays [24]. When a node receives a packet, it uses the `Serialize` and `Deserialize` function to obtain the header information. The `Print` function permits another class to print the header to the screen or log file.

3.1.2 Packet Queue and Queue Entry Classes

The Packet Queue Class manages a node's message buffer. The Routing Protocol class interacts with the Packet Queue class to manage messages and generate control packets. The Packet Queue class implements a protocol's buffer management scheme. The `m_BufferSize` attribute defines the maximum size of the message buffer in bytes. `Enqueue` adds messages to the buffer, and `Dequeue` removes messages from the buffer. After a node adds a message to the message buffer, `DropExpiredMessages` removes expired messages. If the message buffer is full, `Purge` removes messages according to the protocol's queue management scheme. `FindDisjointMessages` generates the list of messages to replicate according to a protocol's message priority. The `Drop` function removes a selected message from the buffer. The `GetSize` function returns the number of messages in the buffer.

Since messages are groups of packets, the message buffer requires a data structure to group packets. The `m_queue` is a map matching a message ID to a queue entry defined by the Queue Entry class. A queue entry is a data structure that stores the packets belonging to a message, the IP header, expiration time, and message ID. The `GetMessageByteSize` returns the number of packets contained in message. The `GetMessagePacketTotal` returns the total number of packets belonging to a message. The `GetCurrentPktCnt` returns the number of packets currently contained in the queue entry. The `GetPacketSize` returns the size a data packet in a message. `AddPacket` adds a packet to the queue entry. `GetPackets` returns all of the packets contained in a message. The Packet Queue uses the Queue Entry functions to generate control packets, manage the message buffer, and retrieve messages for the Routing Protocol class.

3.1.3 Routing Protocol Class

The Routing Protocol class inherits from ns-3's `Ipv4RoutingProtocol`. The Routing Protocol class implements the control logic of the DTN protocols. The `Recv<Protocol>` function executes the control packet exchange based on the packet headers defined in the packet class. The Routing Class initializes the packet queue. The routing class interacts with the packet queue class to generate control packets, and the routing protocol class interacts with the packet queue class to store and retrieve messages. The `SendBeacons` function transmits beacon packets at the specific interval. The `SendDisjointMessages` calls the `FindDisjointMessages` from the Packet Queue class to generate the list of message to transmit to another node. Then `SendDisjointMessages` calls `SendMessageFromQueue` to transmit the messages from the generated message list. When a node receives a packet, `RouteInput` determines the interface, buffer, or function to execute. `RouteInput` handles the logic for buffering incomplete messages and acknowledging messages described in Section 3.2. `RouteOutput` handles packets leaving a node.

3.2 Message Generation and Handling

As discussed in Chapter 2, the ONE and ns-3 handle node data differently. This section discusses how ns-3 and the ONE implement message handling and generation. The discussion includes the changes made to the original ns-3 Epidemic implementation to handle messages, and ns-3 message-traffic generation.

3.2.1 ONE Behavior

In the ONE, traffic generation uses messages. The ONE does not have packets like IP networks, so the ONE does not have packet header definitions. Messages are similar to bundles from RFC 5050 because messages are the base unit of DTN data. Unlike IP packets, messages can be any size. The ONE handles messages as a single object. The ONE does not fragment messages, and the ONE does not permit partial messages to propagate throughout the network. If a node does not completely receive a message, then the node drops the message. Messages do not carry control instruction, and nodes share control information by directly accessing another node's data structures. The ONE does not include the cost of control instructions in its simulation results.

3.2.2 ns-3 Behavior

Since ns-3 implements the entire network stack, our ns-3 protocols define groups of packets generated by one source node destined to another node as a message. A message is equivalent to RFC 5050's bundles as the base unit of DTN data. The User Datagram Protocol (UDP) packets used to share routing information between nodes are control packets. Control packets are not messages because they are routing protocol specific, so they are not the base unit of DTN data. Our protocols assume an IP-based convergence layer. Unlike the ONE, ns-3 cannot generate a message as a single object of any size. In our DTN implementation, we chose to create messages out of groups of individual packets. Each packet is assigned a header with a custom identifier. The identifier associates a packet with a DTN message. Defining messages as groups of packets integrates with the existing code base, and does not require the modification of protocols below the routing layer. Since messages are groups of packets, then ns-3 could support partial messages to propagate throughout the network. To compare the ns-3 implementations to the ONE implementations, ns-3 does not propagate partial messages throughout the network. The following subsections discuss how ns-3 defines and handles messages. The discussion includes the changes made to the original ns-3 Epidemic implementation to handle messages, and ns-3 message-traffic generation.

3.2.3 Message Definition

Our ns-3 DTN data packet header is the custom header that identifies a packet belonging to a message. The Bundling Protocol (RFC 5050) [19] influenced our ns-3 DTN data packet header, but our ns-3 DTN protocols do not implement the Bundling Protocol. The original ns-3 Epidemic implementation does not have the DTN data packet header. Instead, the original Epidemic only uses UDP packets as the base unit of data with the IP address identifying source and destination nodes.

In our ns-3 DTN protocols, the DTN data packet header in Figure 3.3 identifies a packet belonging to a message. Each DTN data packet header contains a Message Identification Number, last hop, packet count, and packet index. The Message Identification Number in Figure 3.2 is a 64-bit unsigned integer derived from the source Node Identification Number and timestamp. The first 16-bits of the Message Identification Number are the source Node Identification Number. The last 48-bits are the message's generation timestamp in microseconds. The source Node Identification Number used by the DTN packet header is the node number from ns-3. ns-3 assigns a unique integer to every node in the simulation.

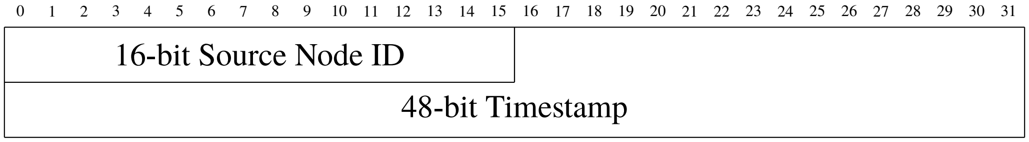


Figure 3.2. Message Identification Number

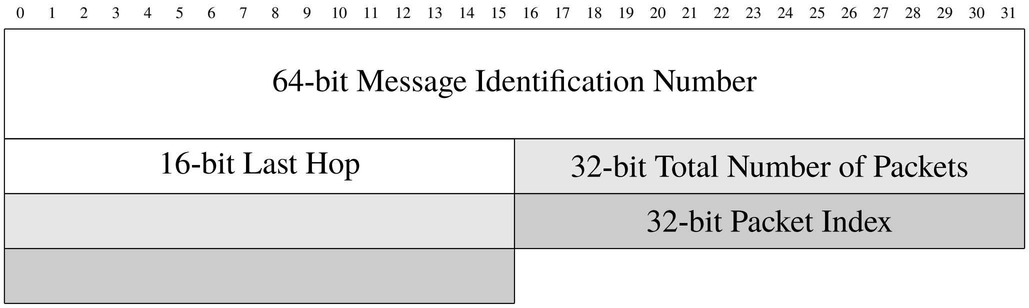


Figure 3.3. DTN Data Packet Header

The scenarios require a node to generate several messages in a millisecond, but nodes do not generate more than one message in a microsecond. The timestamp is in microseconds to ensure that every Message Identification Number is unique. While a per-node sequential message counter would also create a unique identifier, our ns-3 protocols require message generation time and source node identification for routing decisions. Eliminating the counter reduces the size of the header. The scenarios studied in this thesis would exceed the largest time in microseconds represented by a 32-bit timestamp. Therefore, the timestamp is 48-bits. The last hop is the 16-bit Node Identification Number of the last node that forwarded the message. Nodes use the last hop to buffer incomplete messages for message reconstruction. The 32-bit total number of packets and the 32-bit packet index guide message reassembly.

3.2.4 Original ns-3 Epidemic Message Handling

Alenazi's ns-3 Epidemic [34] provided the starting point to implement the DTN protocols. Alenazi's ns-3 Epidemic managed packets instead of messages. In Alenazi's Epidemic, nodes pushed all packets selected for transmission to the link layer immediately after completing the control packet exchange. ns-3's link layer contains a packet queue that has a limited size. The packet queue is FIFO and cannot be manipulated by higher layers in the network stack. The upper layers can only add packets to the queue [17]. When a node's message buffer equals or exceeds the size of the packet queue, then the node will fill the packet queue. Any new packets sent to the full queue are dropped. The link layer will attempt to transmit the packets in FIFO order regardless if the destination node is connected. If the first node moves out of range, then the link layer will still transmit the packets. As a result, the node wastes available bandwidth and meeting opportunities. The wasted bandwidth is not a limitation of the Epidemic protocol, but it is a limitation of Alenazi's implementation of Epidemic in ns-3.

3.2.5 Message Handling

All new ns-3 DTN protocol implementations use the DTN data packet header, and all of the DTN protocols use the same logic for sending and receiving messages between two directly connected nodes. However, the determination of message transmission order differs between protocols. The routing protocol class handles the transmission and reception of messages.

In order to improve link utilization, `ACK` packets in Figure 3.4 control the message exchange sequence. `ACK` packets do not acknowledge messages reaching their final destination. Rather, `ACK`s acknowledge messages transmitted between two connected nodes. When a node receives a complete message from another node, it sends an acknowledgement packet. The acknowledgments consist of the 64-bit Message Identification Number, 16-bit Node Identification Number, and 16-bit Message Status. The Message Identification Number is the received message's message ID. The Node Identification Number is the node that received the message. The Message Status block permits adding reliability in future work. The Message Status indicates if a node received a message successfully. If the message transfer is unsuccessful, then Message Status is zero. Currently, DTNs send the next message regardless of the value of the Message Status block.

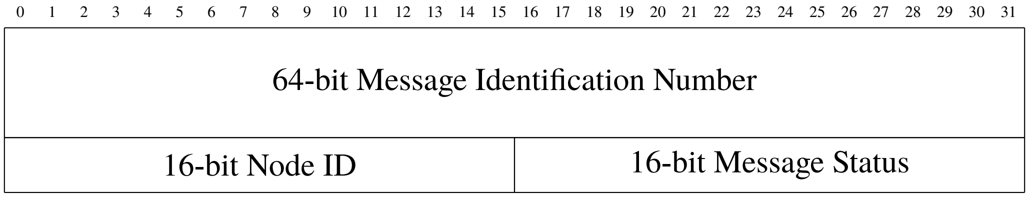


Figure 3.4. DTN Acknowledgement Header

After the transmitting node determines message priority, the node fetches the first message. A node transmits the complete message and waits for an `ACK` before sending the next message. The receiving node queues the message's packets in a message reception buffer. The receiving node possesses a message reception buffer for each node that is connected. Each connection's receiving buffer can buffer only one message. When a message is complete, the receiving node transmits an `ACK`. `RouteInput` handles message reconstruction and `ACK` generation. Upon receiving the `ACK`, the transmitting node transmits the next message. The `Recv<Protocol>` function handles `ACK` reception. If the connection breaks, then the node resets the message reception buffer for that connection. A node considers a connection broken when the node does not receive any packets from that neighbor for two beacon intervals. When a node does not receive a complete message, it deletes the partial message. As a result, nodes do not forward partial messages.

Deleting partial messages may seem wasteful, but dropped messages due to a lost packet occurs less than 0.1% of the time in the Helsinki scenario. The time required to implement dropped packet recovery outweighs the cost of deleting partial messages due to dropped packets. When a connection between nodes is broken due to node moving out of range, the next interaction between the nodes restarts the control packet exchange sequence because it is considered a new connection. The messages held in the prior connection may have been delivered or replaced, so a node may not be able to complete the partial message. To simplify the implementation, the node deletes the partial message when the connection is reestablished.

While `ACK`s improve link efficiency, `ACK`s have limitations. First, a node requires a large link layer buffer because the buffer must store all of the packets contained in a message. When the link layer's packet buffer exceeds the packet limit, the node removes the newest packets from the queue. As a result, those packets fail to transfer causing messages to drop. ns-3's link layer limits the number of packets that can be stored in the buffer, so the scenario configuration file must increase the link layer's buffer to accommodate the expected message sizes. Second, the link layer buffer deletes packets based on a time-limit. When a packet exceeds the time-limit, the link layer buffer deletes the packet. For the purposes of this thesis, the scenarios set the link layer buffer to the size of the node's message buffer. The scenarios set the packet queue time-limit to two beacon intervals because two beacon intervals correspond to a dropped connection.

3.2.6 Message Generation

By default, ns-3 does not have a traffic generator using the DTN Packet Header. The DTN Application generates message traffic using the DTN Packet Header. ns-3's On-Off Application provided the base code. The DTN Application generates UDP packets with the DTN Packet Header. The application generates the UDP packets according to the specified size in bytes and packet generation rate in bytes per second. The message size parameter in bytes and packet size determines the number of generated packets. The DTN Application generates one message according to the entered parameters. The Message Identification Number uses the source Node Identification Number and message generation time. If a scenario requires more than one message, then the scenario must include multiple DTN Application message generators.

Since future work may use packets instead of messages for data traffic, all ns-3 DTN protocols are backwards compatible with UDP packets. When a node generates a UDP packet that does not have the DTN Packet Header, the node creates a DTN Packet Header for that data packet. `RouteInput` handles DTN Packet Header generation for standard UDP packets. The Message Identification Number uses the packet's generation time in microseconds and the packet's source Node Identification Number to generate the Message Identification Number. As a result, a node treats each packet as an individual message. This permits ns-3's default UDP packet generators to work with the DTN protocols.

3.3 Node Discovery

DTNs do not have constant connectivity, so nodes must discover other nodes to initiate a connection. Unlike ns-3, the ONE handles node discovery. As a result, the ns-3 protocols must include a node discovery mechanism. This section discusses how the ns-3 DTN protocols handle node discovery.

3.3.1 Original ns-3 Epidemic

In Alenazi's Epidemic [34], nodes transmitted `BEACON` control packets at a specific time interval for node discovery. The `BeaconInterval` defines the frequency of beacon transmission. To ensure that all nearby nodes can receive the beacon, the node broadcasts a beacon using the network's broadcast address. Since nodes broadcast beacons, nodes are likely to synchronize in sending broadcasts. This synchronization will result in lost beacons due to collisions. In order to prevent synchronization among nodes, a uniform random variable staggers the beacons. The `BeaconRandomness` variable defines the upper bound of the uniform random distribution to add to the base beacon interval. Since a beacon starts the exchange process between nodes, nodes may already be exchanging packets when the next beacon interval occurs. The `HostRecentPeriod` prevents hosts from re-exchanging redundant control packets [34].

3.3.2 Modifications to Original ns-3 Epidemic Code

DTNs use beacons for node discovery. A node broadcasts beacons at a set interval plus a random delay to minimize beacon collisions. However, the DTN protocols in this thesis do not use the `HostRecentPeriod` to prevent hosts from re-exchanging redundant control packets. Nodes with large buffers will exceed the `HostRecentPeriod` used by Alenazi's Epidemic [34], and the nodes will exchange control packets and messages while already transferring messages. This may cause a message to be sent multiple times and waste bandwidth. Instead, a node remembers the neighbors with which it is currently in contact. Every time a node receives a control packet or data packet from another node; it updates its record of connected nodes. A node considers a connection broken when the node does not receive anything from the neighbor for two beacon intervals.

A node can have more than one radio interface and IP address, so IP address is not sufficient to prevent two nodes from restarting a connection when they detect the second radio interface. When the nodes detect the second interface, they see the different IP address as another node. Then, the nodes will start a new connection. This wastes bandwidth because the nodes already have a connection and are already transferring messages.

The `BEACON` control packet is a `MessageType` header with the field set to `BEACON`. The `MessageType` header field indicates the type of control packet. Since a node does not know whether another node has more than one IP address, the beacon must include the Node Identification Number. Therefore, the `MessageType` header includes the 16-bit Node Identification Number. Figure 3.5 illustrates the `MessageType` Header. ns-3 provides a unique number to every node in a simulation. A node uses the Node Identification Number to determine whether a node is considered connected. If a node is not connected, then the node adds the Node Identification Number with a timestamp to its list of connected nodes. Then, the node continues the control packet exchange. If the Node Identification Number is in the list of connected nodes and the connected timestamp does not exceed two beacon intervals, then the node ignores the `BEACON`. However, every data packet and control packets other than `BEACON`s update the connection timestamp. A `BEACON` changes the timestamp only when the timestamp exceeds two beacon intervals because it is considered as a new connection.

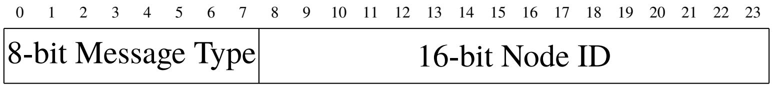


Figure 3.5. DTN `MessageType` Header

3.4 Epidemic

ns-3's Epidemic implements the Epidemic logic discussed in Chapter 2. Mohammed Alenazi implemented Epidemic [34] in ns-3, but Alenazi's Epidemic possessed many limitations. As previously discussed in Section 3.2, Alenazi's Epidemic handled individual packets instead of messages. As discussed in Section 3.3, Alenazi's node discovery mechanism results in wasted bandwidth for nodes with large buffers. Alenazi's Epidemic implemented the control logic using control packets. Control packets are not messages because they only share required routing information between two connected nodes. Control packets do not carry data from source to destination. Instead, control packets implement summary vectors, beacons, and other protocol specific routing data structures.

The original ns-3 Epidemic did not support control packet fragmentation, and they were limited to the size of one UDP packet. Large message buffers can generate summary vectors that exceed the size of a UDP packet. The original ns-3 Epidemic does not divide the summary vectors into multiple UDP packets. When the control packet exceeded the size of a UDP packet, the simulation crashed. The lack of control packet fragmentation restricted the number of messages that a node could handle. Our ns-3 Epidemic implementation addresses Alenazi's Epidemic lack of control packet fragmentation. As a result, the code structure and control packet exchange is similar. However, the control packet headers, node discovery, and data handling is different.

3.4.1 Overview

The ns-3 Epidemic control logic performs four main steps as shown in Figure 3.6. After receiving a `BEACON`, nodes exchange `REPLY` and `REPLY_BACK` control packets. `REPLY` and `REPLY_BACK` control packets are the summary vectors discussed in Section 2.1.1. The goal of sending message summaries is to avoid sending messages that the other node already contains in its buffer. Since both nodes are likely to send a response to a beacon at the same time, an anti-entropy session prevents node responses from colliding. The node with the lower IP address sends its message summary first as a `REPLY` packet. When the node with the higher IP address receives the `REPLY` packet, it sends a response using the `REPLY_BACK` packet. After a node receives the list of messages that the other node contains, the node sends messages that the other node does not have in its buffer [34].

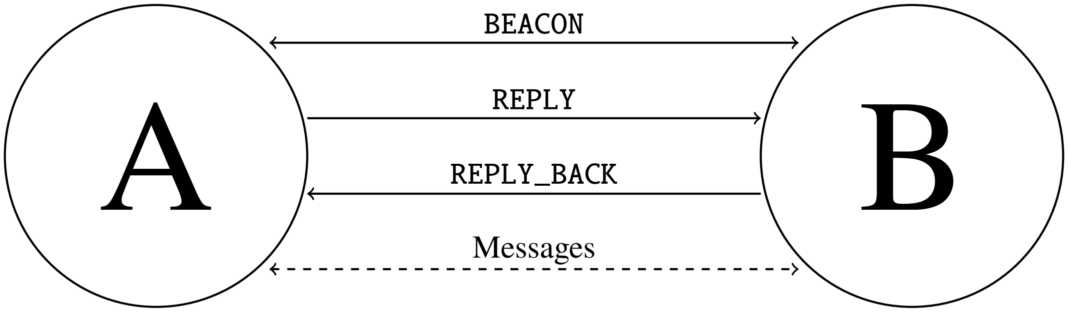


Figure 3.6. Epidemic Control Packet Exchange Sequence

3.4.2 Message Identification and Limits

Since DTNs manage messages instead of packets, we changed the `EpidemicHeader` from Alenazi's Epidemic [34]. Figure 3.7 illustrates the `EpidemicHeader`. First, the 64-bit Message Identification Number from Section 3.2 replaced the 32-bit packet identification number. Since the Message Identification Number includes the source node and timestamp of message generation, our Epidemic removed the original Epidemic 64-bit timestamp.

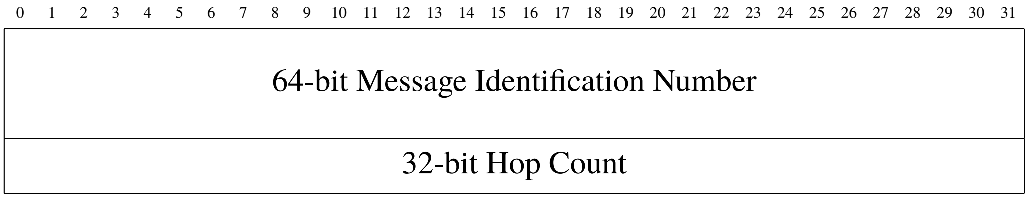


Figure 3.7. `EpidemicHeader`

The ONE uses hop limits and message TTL to reduce network resource consumption. The lower 48-bit portion of the Message Identification Number permits the routing protocol to remove expired messages from a node's buffer. When a node receives a message, the node checks the timestamp against the maximum age of a message. If the timestamp exceeds the amount of time a message can live, then the node discards the message. The `EpidemicHeader` retained the 32-bit hop count from Alenazi's Epidemic to limit the number of hops that a message can traverse. When nodes generate a message, they initialize the hop count to the maximum number of hops a message can traverse. At each hop, the node decrements the hop count. When the hop count reaches zero, the node discards the message.

3.4.3 Control Packet Identification

The `MessageType` Header in Figure 3.5 identifies control packets. Only the ns-3 protocols contain control packets because the ONE used shared data structures share routing information. Control packets are not messages. Control packets share routing specific information between two connected nodes. The 8-bit Message Type field indicates the type of control packet. For Epidemic, control packets are `BEACON`, `ACK`, `REPLY`, and `REPLY_BACK`. The `MessageType` Header encapsulates the control packets in order to identify the control packet. When a node receives a packet, it checks the Message Type field for the packet type to call the appropriate packet header class.

3.4.4 Summary Vector

While Epidemic uses the same control packet sequence as Alenazi's Epidemic [34], the `SummaryVectorHeader` in Figure 3.8 is different from Alenazi's Epidemic. The `SummaryVectorHeader` defines `REPLY` and `REPLY_BACK` control packets. The original

Epidemic's 32-bit packet identification number changed to the 64-bit Message Identification Number. The original Epidemic's 32-bit Summary Vector Length counted all of the packets held by a node's buffer. In this version of Epidemic, the 16-bit Summary Vector Length counts the number of Message Identification Numbers in the `SummaryVectorHeader`. A 16-bit unsigned integer is large enough cover a `SummaryVectorHeader`. Since the `MessageType` Header encapsulates the `SummaryVectorHeader`, a node identifies the other node using the Node Identification Number instead of the IP address because nodes can have more than one IP address.

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td colspan="16">16-bit Fragmentation Block</td><td colspan="16">16-bit Summary Vector Length</td></tr>
<tr><td colspan="32">64-bit Message Identification Number #1</td></tr>
<tr><td colspan="32">. . .</td></tr>
<tr><td colspan="32">64-bit Message Identification Number #N</td></tr>
</table>

Figure 3.8. Epidemic `SummaryVectorHeader`

The original Epidemic did not support control packet fragmentation. In order to support fragmentation, the Fragmentation Block identifies whether there are more `SummaryVectorHeader` packets. When the Fragmentation Block is one, then more `SummaryVectorHeader` packets remain. When the Fragmentation Block is zero, then that packet is the last `SummaryVectorHeader`. Once a node receives a `SummaryVectorHeader` with the Fragmentation Block set to zero, the node continues the message exchange sequence. The control packet fragmentation can tolerate packet loss if the lost packet had the fragmentation block set to one, but the fragmentation protocol does not support retransmission of control packets. If the lost control packet had the fragmentation block set to zero, then the control packet sequence would stop until a beacon restarts the exchange sequence.

3.5 Vector

Kang and Kim implemented Vector in ns-2 [4], but the original code is not available and not compatible with ns-3. Despite missing the original code, Killeen implemented a version of Vector in the ONE for GAPR2 [9] based on Kang and Kim's paper [4]. Since Killeen demonstrated his Vector implementation in [9], the Vector exchange sequence and algorithms for the ns-3 implementation is based on [4] and [9]. The algorithms discussed in this section are identical in the ONE and ns-3.

3.5.1 Overview

As shown in Figure 3.9, Vector nodes interact in four main steps. First, nodes transmit a small beacon packet at a set interval. Second, a node sends the list of acknowledged message IDs to the beacon's source node. After receiving a list of acknowledged messages, a node sends its vector and the list of messages in its message buffer. At the same time, the node sends all of the messages destined to the other node. Finally, a node sends replicated messages based on the message limit after receiving the other node's message list. The node's geographic trajectories determine the message limit.

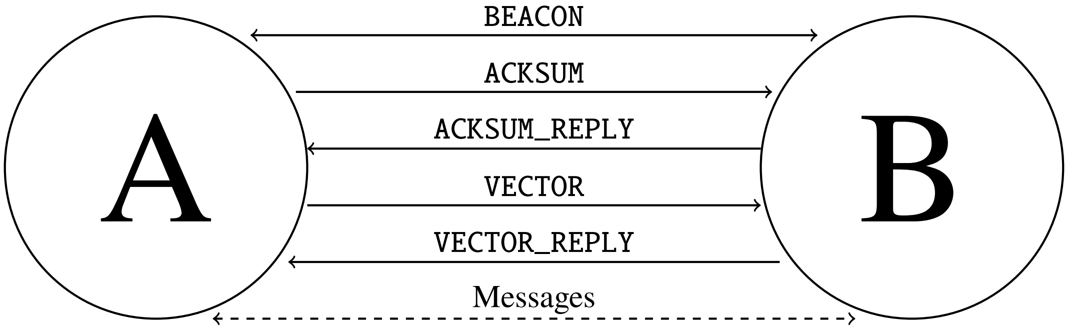


Figure 3.9. Vector Control Packet Exchange Sequence

As discussed in Section 3.3, nodes use beacons to discover other nodes. Unlike Epidemic DTN, Vector generates a list of acknowledged messages when a node receives a `BEACON`. The node with the smaller IP address sends the list of acknowledged message IDs as an `ACKSUM` packet. When the other node receives the `ACKSUM` packet, the receiving node sends its known acknowledged messages as an `ACKSUM_REPLY`. When a node receives an `ACKSUM` or `ACKSUM_REPLY`, the node transmits messages destined to the other node. When a node receives an `ACKSUM_REPLY`, the receiving node generates a list of messages held in its buffer as a `VECTOR` packet. When a node receives a `VECTOR` packet, it responds with a list of its messages in a `VECTOR_REPLY`. After a node receives a `VECTOR` or `VECTOR_REPLY` message, the node determines the number of messages to send based on node direction to limit the number of replicated messages. The node then transmits the replicated messages. Figure 3.9 illustrates the Vector control packet exchange. The `MessageType` Header in Figure 3.5 defines the type of Vector packet by using an 8-bit Message Type field and 16-bit Node Identification Number. The Message Types used by Vector are `BEACON`, `ACKSUM`, `ACKSUM_REPLY`, `ACK`, `VECTOR`, and `VECTOR_REPLY`.

3.5.2 Message Identification and Limits

The `VectordtnHeader` in Figure 3.10 identifies messages and stores information used to reduce network resource consumption. A `VectordtnHeader` contains the 64-bit Message Identification Number and 32-bit hop count. Vector uses the same DTN Packet Header as Epidemic, so the Message Identification Number is the same as Figure 3.3. The hop count and timestamp in the Message Identification Number are flood control mechanisms. The hop count limits the number of hops that a message can traverse before dropping the message. When a node generates a message, the timestamp is the message generation time. When a node receives a message, the node checks the timestamp. When the timestamp plus timelimit exceeds the current time, the node drops the message.

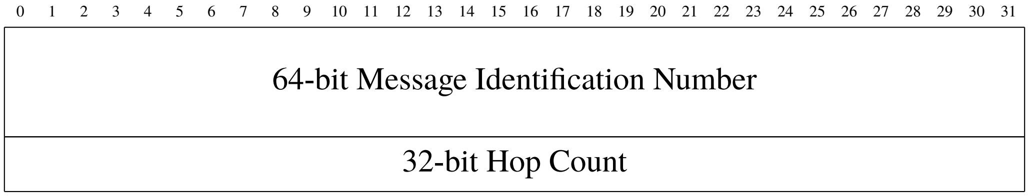


Figure 3.10. `VectorDTNHeader`

3.5.3 Acknowledged Message Lists

As discussed in Section 2.1.2, Vector requires nodes to spread lists of acknowledged messages throughout the network. The `ACKSumVectorHeader` defines the `ACKSUM` and `ACKSUM_REPLY` packets. The `ACKSumVectorHeader` in Figure 3.11 contains a list of acknowledged message IDs with a timestamp. The acknowledged message ID is the message that arrived to its final destination. Since DTNs replicate messages, multiple copies of a message can exist in the network. The `ACKSUM` packets allow nodes to remove delivered message from their buffer. The timestamp is required to expire old acknowledgements. The timestamp is set to the original message's expiration time. This prevents acknowledgements for already expired messages from spreading throughout the network. Since nodes transfer the complete list of acknowledged messages, expiring old acknowledged messages reduces overhead.

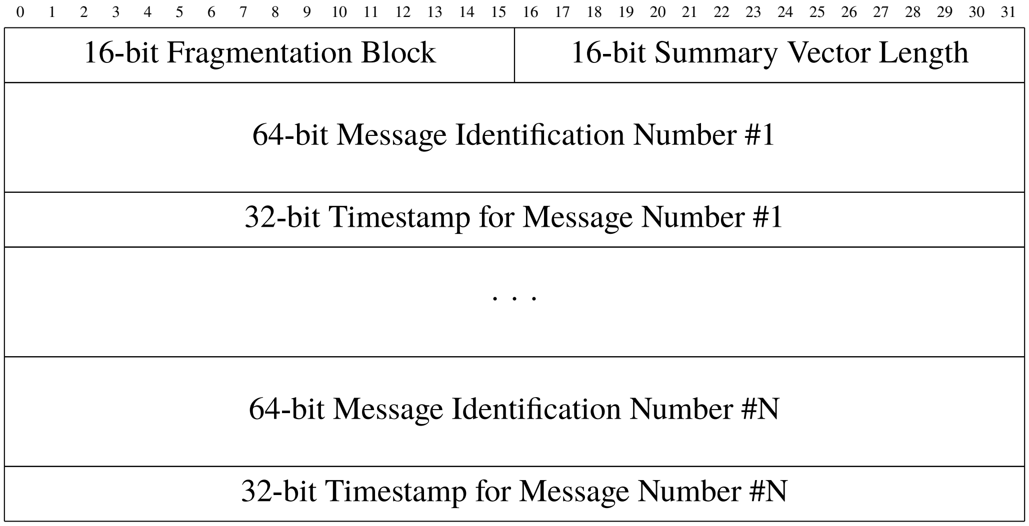


Figure 3.11. Vector `ACKSumVectorHeader`

The Packet Queue class stores and generates the list of acknowledged messages. The 32-bit timestamp is the time in seconds that the node can delete the acknowledgement. The 16-bit Summary Vector Length field identifies the delivered number of message IDs in the `ACKSumVectorHeader`. The 16-bit Fragmentation Block permits control packet fragmentation. `ACKSumVectorHeader` fragmentation is the same as Epidemic's `SummaryVectorHeader` fragmentation in Figure 3.8. The `VectorRouting` class sends the `ACKSUM` packet using the `SendACKSum` function. The PacketQueue class generated the `ACKSUM` packets via `GetACKSum` function.

3.5.4 Summary Vector

The `VectorVectorHeader` defines the `VECTOR` and `VECTOR_REPLY` packet used for the Summary Vector discussed in Section 2.1.2. A `VectorVectorHeader` in Figure 3.12 contains the list of messages held within a node's message buffer and the node's vector. The Fragmentation Block, Summary Vector Length, and Message Identification Number are the same as Epidemic DTN in Figure 3.8. However, the `VectorVectorHeader` includes the node's vector. The vector represents the direction of a node's movements. A node's vector contains the X and Y components. A 32-bit float represents the components of the node's vector. To avoid conversion errors, nodes handle the vector components of the `VectorVectorHeader` as byte arrays. The `VectorRouting` class sends `VECTOR` packets via the SendVector function. The Packet Queue's `GetSummaryVector` generate the `VECTOR` packets for the `VectorRouting` class.

<table>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th><th>29</th><th>30</th><th>31</th></tr>
<tr><td colspan="16">16-bit Fragmentation Block</td><td colspan="16">16-bit Summary Vector Length</td></tr>
<tr><td colspan="32">32-bit Node‘s Vector X Component</td></tr>
<tr><td colspan="32">32-bit Node‘s Vector Y Component</td></tr>
<tr><td colspan="32">64-bit Message Identification Number #1</td></tr>
<tr><td colspan="32">. . .</td></tr>
<tr><td colspan="32">64-bit Message Identification Number #N</td></tr>
</table>

Figure 3.12. Vector `VectorVectorHeader`

3.5.5 Vector Calculation

Kang and Kim's Vector [4] determined a node's vector using a location history. Their algorithm averaged the node's movements to determine a node's vector. In Kevin Killeen's Vector [9] implementation in the ONE, nodes used their current vector. As discussed in Section 2.1.2, a current vector cannot predict a node's direction of movement correctly. As a result, the vector calculation in the ONE changed to the algorithm used in ns-3.

A node determines its vector using a location history. Nodes remember the last ten locations, and nodes record their position every second. ns-3 does not have a GPS module, but ns-3's mobility model allows a node to access its location. Since this thesis does not focus on errors associated with GPS, accurate node position from the mobility module is sufficient. A node calculates its vector using a weighted average of the distance traveled in the X and Y directions using the last ten node locations. `UpdateVector` in the `VectorRouting` class calculates a node's vector. The most recent position has the highest weight, and the oldest position has the lowest weight. The weighted average helps to smooth the vector over time because a node might make frequent large changes while the overall direction remains unchanged. The pseudocode in Algorithm 1 calculates a node's vector using the weighted average of a nodes movement history.

Algorithm 1 Vector Calculation Pseudocode

```
if history.size() >= 2 then
    x = 0
    y = 0
    weight = 0
    for 1 to N do
        weight += N-i
        x += (N-i)*history[i].x
        y += (N-i)*history[i].y
    end for
    nodeVector_x = x/weight
    nodeVector_y = y/weight
else
    nodeVector_x = 0
    nodeVector_y = 0
end if
```

3.5.6 Message Limit Determination

After a node receives the final `VECTOR` or `VECTOR_REPLY` packet, the node calculates a message limit. Vector determines the message limit based on the angle of incidence between the two node's vectors. Section 2.1.2 covers the calculation of the angle of incidence. The `getAngleofIncidence` function from the `VectorRouting` class calculates the angle of incidence. Once a node determines the angle of incidence, the node determines the message limit. The `getMsgLimit` in the `VectorRouting` determines the message limit using Algorithm 2. ns-3's message limit algorithm is the same as the ONE's Vector implementation [9]. Our ns-3 Vector implementation includes the option to disable the message limit. If the message limit is disabled, then the message limit is the number of messages held in a node's buffer. This permits Vector to behave like Epidemic with acknowledgement summaries to reduce message replication and overhead. By default, Vector enables the message limit.

Algorithm 2 Vector Message Limit Algorithm

```
if $\Theta < \pi/12$ or $\Theta > 11*\pi/12$ then
    return 0
else if $\Theta < \pi/6$ or $\Theta > 5*\pi/6$ then
    return numMsgInCollection/4
else if $\Theta < \pi/4$ or $\Theta > 3*\pi/4$ then
    return numMsgInCollection/3
else if $\Theta < \pi/3$ or $\Theta > 2*\pi/3$ then
    return numMsgInCollection/2
else
    return numMsgInCollection
end if
```

3.5.7 Message Buffer

Vector's packet queue class stores and retrieves messages, and the class maintains the list of messages that reached their destination. Vector tracks the order at which messages arrive. The packet queue class uses a FIFO queue to manage the messages. Kang and Kim did not specify the message buffer management algorithm in [4]. Since the research did not focus on buffer management schemes and Epidemic provides the baseline, the Vector protocol uses FIFO. Kevin Killeen's Vector implementation in the ONE used FIFO [9], so the ns-3 Vector implementation uses FIFO. When a new message arrives and the message buffer is full, the node removes the oldest message to make room for the new message. When a node fetches a message to transmit, nodes transmit the oldest message first. FIFO does not provide message priority based on other factors. Instead, nodes determine message priority based on message reception order. `FindDisjointMessages` generates the list of messages to replicate. The `FindDestinationMessages` generates the list of messages that are destined to the other node. The `GetVectorVector` function generates a packet containing the list of messages within its buffer. The `GetACKSumVector` function generates the packet containing a list of all known messages that reached their final destination.

3.6 Centroid

Chapter 2 presented the Centroid routing protocol. Centroid is similar to Vector because Centroid limits message replication based on location history. While Vector determines the message limit based on the direction of node movements, Centroid determines the message limit based on the distance between nodes' centroids.

3.6.1 Overview

Vector provided the base code to implement Centroid because Centroid's control packet exchange is similar to Vector as shown in Figure 3.13. The `RecvCentroid` function handles control packets. After a node receives a beacon, the node transfers a list of messages that already reached their final destination in an `ACKSUM` or `ACKSUM_REPLY`. When a node receives an `ACKSUM` or `ACKSUM_REPLY`, the node transfers the list of messages held in their buffer using a `MSG_SUM` or `MSG_SUM_REPLY`. In addition to sending a `MSG_SUM` or `MSG_SUM_REPLY`, the node transmits messages destined to the other node. Finally, the nodes transfer the replicated messages after receiving a `MSG_SUM` or `MSG_SUM_REPLY`.

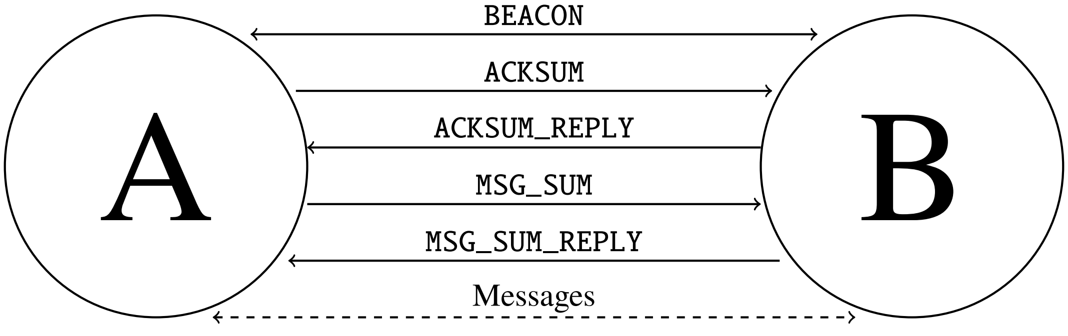


Figure 3.13. Centroid Control Packet Exchange Sequence

Centroid's packet classes define Centroid's control packets. To implement the control logic, control packets consist of beacons, acknowledgement summaries, and message summaries. Centroid uses the `MessageType` Header in Figure 3.5 to identify control packets with the 8-bit Message Type field and 16-bit Node Identification Number. The Message Type field values are `BEACON`, `ACKSUM`, `ACKSUM_REPLY`, `ACK`, `MSG_SUM`, and `MSG_SUM_REPLY`. The `CentroidHeader` in Figure 3.14 performs the same function as the `VectorDTNHeader`. The 64-bit Message Identification Number is the same a Figure 3.2. The timestamp in the Message Identification Number and the 32-bit hop count help to reduce overhead by removing expired messages. The hop limit and timelimit actions are the same as Vector and Epidemic.

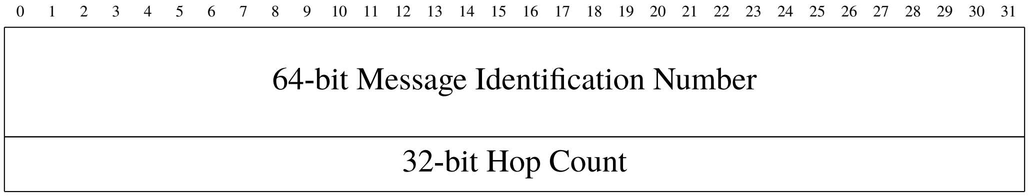


Figure 3.14. `CentroidHeader`

3.6.2 Acknowledged Message Lists

Centroid's `ACKSumHeader` creates the `ACKSUM` and `ACKSUM_REPLY` packets. `ACKSUM` and `ACKSUM_REPLY` control packets contain the list of delivered messages. The use of the Fragmentation block, Summary Vector Length block, Message Identification Number, and timestamp are the same as Vector's `ACKSUMVectorHeader`. Figure 3.15 shows the construction of the `ACKSumHeader`. When a node receives a `BEACON` from another node, the node with the lower Node Identification Number transmits an `ACKSUM` control packet. When a node receives an `ACKSUM` packet, the node responds with an `ACKSUM_REPLY`. After a node receives the final `ACKSUM` or `ACKSUM_REPLY` packet, the node transmits all of the messages that are destined to the other node.

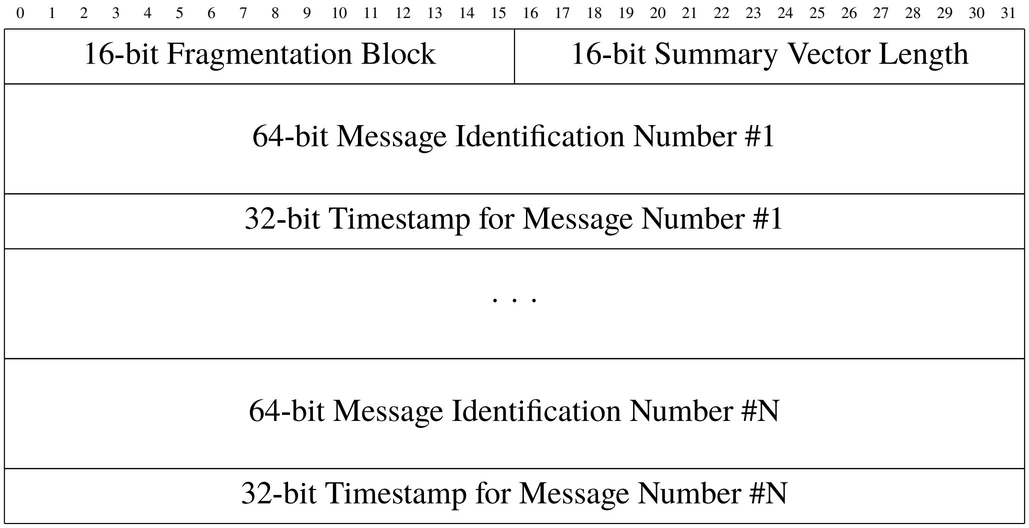


Figure 3.15. Centroid `ACKSumHeader`

3.6.3 Summary Vector

The `MsgSumHeader` defines `MSG_SUM` and `MSG_SUM_REPLY` control packets. The `MSG_SUM` and `MSG_SUM_REPLY` control packets contain a list of messages held in a node's buffer. The control packets implement the message summary vectors discussed in Section 2.1.2. The `MsgSumHeader` in Figure 3.16 performs the same functions as Vector's `VectorVectorHeader`. The functions of the Fragmentation Block, Summary Vector Length Block, and Message Identification Number are identical. However, Centroid uses the X and Y coordinates instead of X and Y vector components. The `MSG_SUM` packets are the response to the final `ACKSUM_REPLY`. When a node receives the final `MSG_SUM` control packet, the node sends the `MSG_SUM_REPLY` packets and the replicated messages.

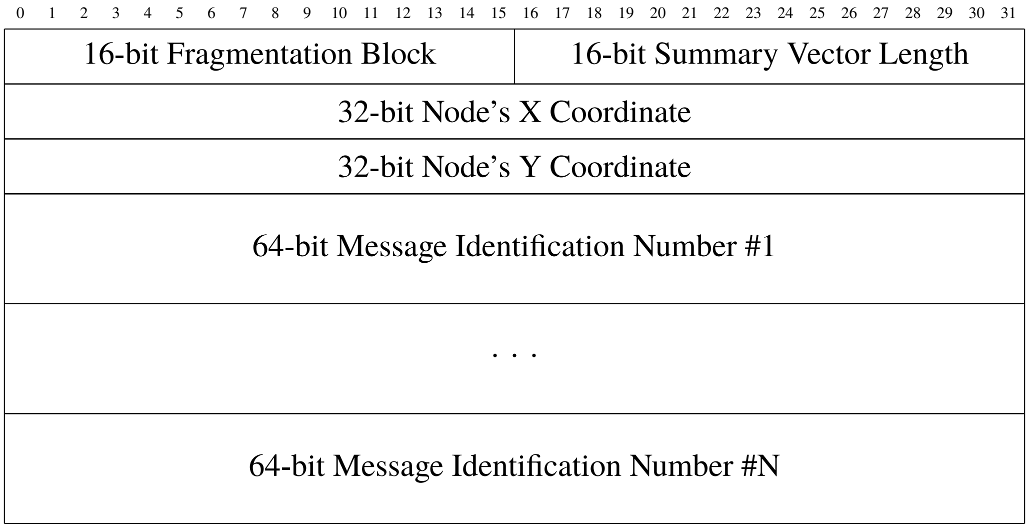


Figure 3.16. Centroid `MsgSumHeader`

3.6.4 Message Limit Determination

A node determines its centroid using a location history. Centroid uses a running average of its location, and a node updates its position every second. The `getCentroid` function in the `CentroidRouting` class calculates a node's centroid. Like Vector, Centroid implements the message limit determination using the `getMsgLimit` function. However, Centroid does not use the angle of incidence between the two nodes vectors to determine the message limit. Instead, Centroid uses the distance between the two nodes to determine the messages. Section 2.1.2 covers how a node determines its centroid and message limit.

3.6.5 Message Buffer

The packet queue class manages the stored messages and maintains the list of acknowledged message IDs. Centroid uses FIFO like Vector and Epidemic to manage the message buffer. When a new message arrives and the message buffer is full, the node removes the oldest message to make room for the new message. When a node fetches a message to transmit, nodes transmit the oldest message first. FIFO does not provide message priority based on other factors, and message priority is based on message reception order.

3.7 GAPR, GAPR2, and GAPR2a

Based on the discussion from Chapter 2, GAPR2 builds on GAPR by incorporating the message limit calculation from Vector. Therefore, the ns-3 Vector implementation provided the basis for the GAPR and GAPR2 implementation. GAPR2a builds on GAPR2. Instead of using Vector's logic to calculate a message limit, GAPR2a uses Centroid's logic to calculate the message limit. The original ONE simulator code for GAPR [5] and GAPR2 [9] provided the logic and algorithms.

3.7.1 Overview

Nodes interact in six main steps as illustrated in Figure 3.17. First, nodes transmit beacon packets at a set interval. Second, nodes send a list of acknowledged message IDs to the beacon's source node. After receiving a list of acknowledged messages, nodes send their database of probabilities as well as the messages destined to the other node. Since every node in GAPR maintains a database of other node's probability databases called transitive probabilities, nodes send the transitive probabilities after receiving the other node's probabilities. After sharing transitive probabilities, nodes transfer a summary of all messages held in a node's buffer. Finally, a node sends replicated messages based on the message limit. Like Vector, the nodes' geographic trajectories determine the message limit for GAPR2. GAPR2a uses Centroid's algorithm to determine the message limit.

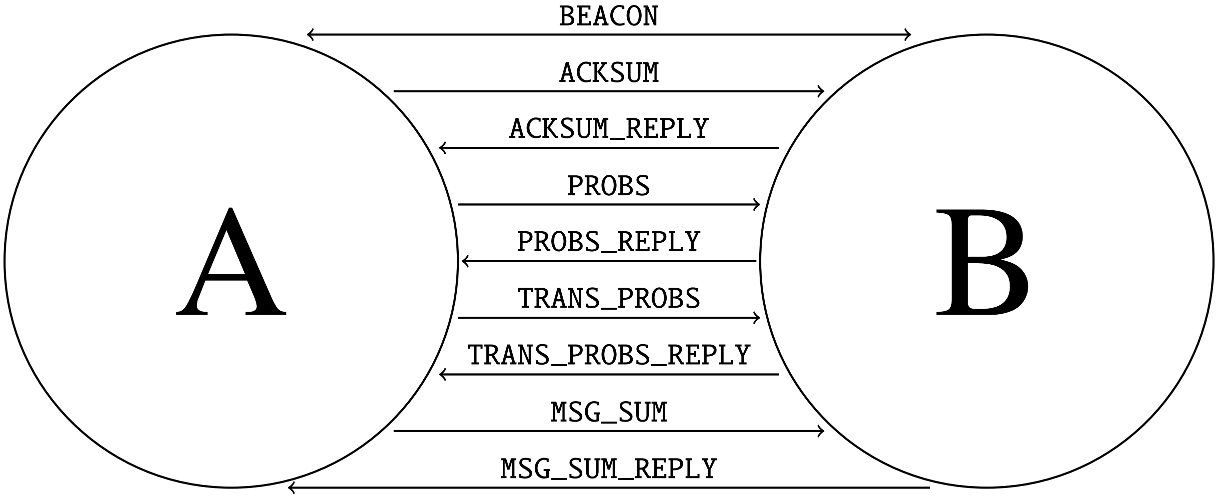


Figure 3.17. GAPR and GAPR2 Control Packet Exchange Sequence

3.7.2 Packet Identification and Limits

To implement the control logic, GAPR's control packets consist of beacons, acknowledgement summaries, probability summaries, transitive probability summaries, and message summaries. The `MessageType` Header encapsulates all packets. The `MessageType` Header in Figure 3.5 defines the packet type using an 8-bit Message Type field and 16-bit Node Identification Number. Message Types include `BEACON`, `ACKSUM`, `ACKSUM_REPLY`, `ACK`, `PROBS`, `PROBS_REPLY`, `TRANS_PROBS`, `TRANS_PROBS_REPLY`, `MSG_SUM`, and `MSG_SUM_REPLY`.

The `GAPRHeader` in Figure 3.18 performs similar functions as Epidemic's `EpidemicHeader`. The 64-bit Message Identification Number is the same a Figure 3.2. The header includes the timestamp in the Message Identification Number and the 32-bit hop count help to reduce overhead by removing expired messages. Just like Epidemic, nodes remove messages that exceeded their maximum age limit based on the timestamp. However, GAPR's hop count field is different from Epidemic. When nodes generate a message, they initialize the hop count to zero. At each hop, nodes increment the hop count. GAPR does not have a hop count limit, so nodes will not immediately remove messages with high hop counts. Instead, GAPR's buffer management algorithm removes messages based on hop count and delivery probability.

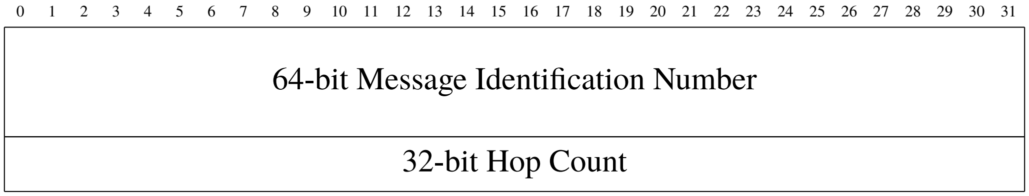


Figure 3.18. `GAPRHeader`

3.7.3 Acknowledged Message Lists

GAPR's `ACKSumHeader` creates the `ACKSUM` and `ACKSUM_REPLY` packets. An `ACKSUM` and `ACKSUM_REPLY` control packet contains the list of messages that reached their final destination. The use of the Fragmentation block, Summary Vector Length block, Message Identification Number, and timestamp are the same as Vector's `ACKSUMVectorHeader`. Figure 3.19 shows the construction of the `ACKSumHeader`. When a node receives a `BEACON` from other nodes, the node with the lower IP address transmits an `ACKSUM` control packet.

When a node receives an `ACKSUM` packet, the node responds with an `ACKSUM_REPLY`. After a node receives the final `ACKSUM` or `ACKSUM_REPLY` packet, the node transmits all of the messages that are destined to the other node.

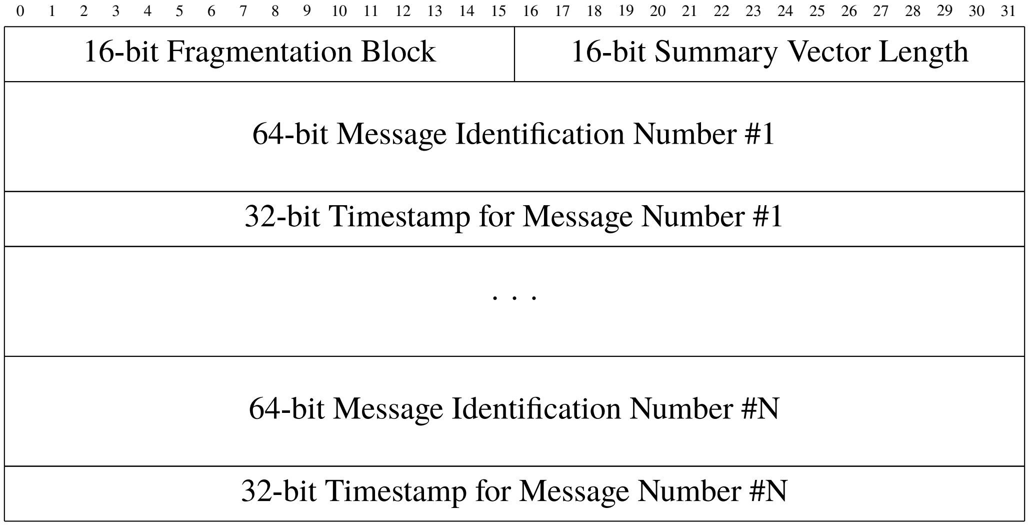
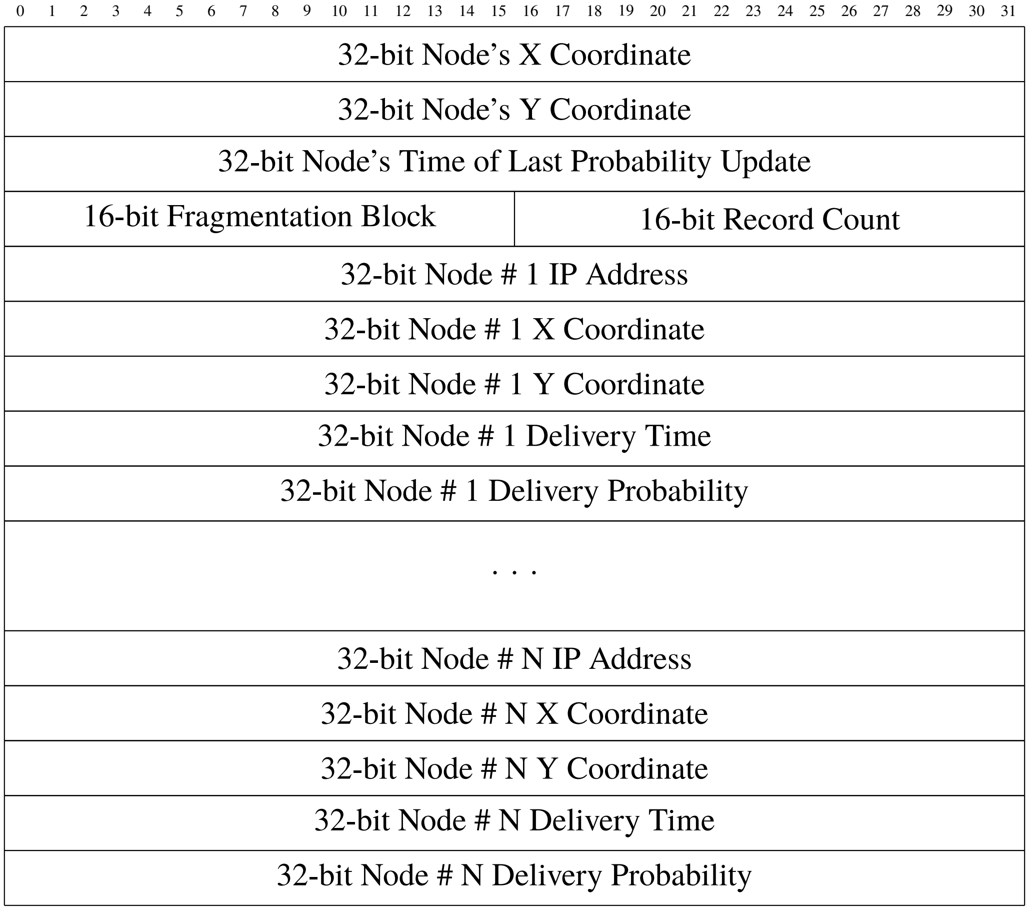


Figure 3.19. GAPR, GAPR2, & GAPR2a `ACKSumHeader`

3.7.4 Probability and Location Database Sharing

All versions of GAPR use location history and probability to determine the order of message replication. When nodes interact, they share their probability and location databases. The `GAPRProbsHeader` contains a node's database of delivery probabilities, encounter location, encounter time, and the node's own location. The `GAPRProbsHeader` defines the `PROBS` and `PROBS_REPLY` control packets in Figure 3.20. The 16-bit Fragmentation Block performs the same functions as the Fragmentation Blocks discussed for other control packets. The 16-bit Record Count is the number of records contained in the control packet. A record in the `GAPRProbsHeader` is the encountered node's IP address, x coordinate, y coordinate, delivery time, and delivery probability. The coordinates and probabilities are 32-bit floats. The delivery time and time of last probability update are a 32-bit unsigned integers representing time in seconds. The delivery time is the time at which the node encountered the other node. The time of last probability update is the time at which the node last updated its database. When a node receives the final `PROBS` or `PROBS_REPLY` packet, the node updates its probability and location databases store in the Packet Queue class before continuing the control packet exchange.



<table>
<tr><td colspan="2">32-bit Node’s X Coordinate</td></tr>
<tr><td colspan="2">32-bit Node’s Y Coordinate</td></tr>
<tr><td colspan="2">32-bit Node’s Time of Last Probability Update</td></tr>
<tr><td>16-bit Fragmentation Block</td><td>16-bit Record Count</td></tr>
<tr><td colspan="2">32-bit Node # 1 IP Address</td></tr>
<tr><td colspan="2">32-bit Node # 1 X Coordinate</td></tr>
<tr><td colspan="2">32-bit Node # 1 Y Coordinate</td></tr>
<tr><td colspan="2">32-bit Node # 1 Delivery Time</td></tr>
<tr><td colspan="2">32-bit Node # 1 Delivery Probability</td></tr>
<tr><td colspan="2">. . .</td></tr>
<tr><td colspan="2">32-bit Node # N IP Address</td></tr>
<tr><td colspan="2">32-bit Node # N X Coordinate</td></tr>
<tr><td colspan="2">32-bit Node # N Y Coordinate</td></tr>
<tr><td colspan="2">32-bit Node # N Delivery Time</td></tr>
<tr><td colspan="2">32-bit Node # N Delivery Probability</td></tr>
</table>

Figure 3.20. `GAPRProbsHeader`

3.7.5 Transitive Probability Database Sharing

After nodes exchange `PROBS` and `PROBS_REPLY` control packets, nodes transfer `TRANS_PROBS` and `TRANS_PROBS_REPLY` control packets. The `GAPRTransProbsHeader` in Figure 3.21 defines the `TRANS_PROBS` and `TRANS_PROBS_REPLY` control packets. As discussed in Section 2.1.4, nodes store the probability databases learned from other nodes as transitive probabilities. After nodes share their own probabilities, they then share the probabilities they learned from other nodes. The `GAPRTransProbsHeader` represents a record in a node’s transitive probability database. The 32-bit Record Node IP Address identifies the node that generated the record. The Record’s Time of Last Probability Update is the time at which the record's node updated its probability database. A record contains the IP address and associated delivery probability of every node that the record's node encountered or learned.

<table>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th><th>29</th><th>30</th><th>31</th></tr>
<tr><td colspan="32">32-bit Record's Node IP Address</td></tr>
<tr><td colspan="32">32-bit Record's Time of Last Probability Update</td></tr>
<tr><td colspan="8">More Records Flag</td><td colspan="8">Fragmentation Flag</td><td colspan="16">16-bit Number of Probabilities</td></tr>
<tr><td colspan="32">32-bit Node # 1 IP Address</td></tr>
<tr><td colspan="32">32-bit Node # 1 Delivery Probability</td></tr>
<tr><td colspan="32">. . .</td></tr>
<tr><td colspan="32">32-bit Node # N IP Address</td></tr>
<tr><td colspan="32">32-bit Node # N Delivery Probability</td></tr>
</table>

Figure 3.21. `GAPRTransProbsHeader`

The number of records in the database can be large, so the control packet fragmentation in the `GAPRTransProbsHeader` is different from the previously discussed control packets. First, the database is broken into records. A record is another node's probability database. The record contains the IP address and delivery probability of every node that the other node encountered or learned. The 8-bit More Records Flag identifies if more records remain. A More Records Flag of zero means that there are no more records. Any other value means that there are more records. Since a record can exceed the size of a packet, the Fragmentation Flag indicates that the record is fragmented. A Fragmentation Flag of zero means that it is the last packet in the record. Any other value of the Fragmentation Flag means that there are more fragments in the record.

3.7.6 Summary Vector

The `MsgSumHeader` creates GAPR's `MSG_SUM` and `MSG_SUM_REPLY` packets. The `MSG_SUM` and `MSG_SUM_REPLY` control packets contain a list of messages held in a node's buffer. The`MsgSumHeader` implements the message summary vector discussed in Section 2.1.4. The `MsgSumHeader` in Figure 3.22 performs the same functions as Vector's `VectorVectorHeader`. The functions of the Fragmentation Block, Summary Vector Length Block, Vector X Component, Vector Y Component, and Message Identification Number are identical. However, GAPR2a replaces a node's vector with the nodes centroid because GAPR2a uses the distance between nodes' centroids to determine the message limit. The `MSG_SUM` packets are the response to the final `TRANS_PROBS_REPLY`. When a node receives the final `MSG_SUM` control packet, the node sends the `MSG_SUM_REPLY` packets and the messages to replicate. GAPR nodes transmit all messages within a node's buffer, but GAPR2 limits the number of replicated messages.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
16-bit Fragmentation Block	16-bit Summary Vector Length
32-bit Node's Vector/Centroid X Component	
32-bit Node's Vector/Centroid Y Component	
64-bit Message Identification Number #1	
. . .	
64-bit Message Identification Number #N	

Figure 3.22. GAPR, GAPR2, & GAPR2a `MsgSumHeader`

3.7.7 Message Limit Determination

GAPR2's control packet exchange is identical to GAPR, but GAPR2 uses a message limit to reduce message replication. GAPR2 uses the same logic as Vector to determine the message limit. The `UpdateVector`, `getMsgLimit`, and `getAngleofIncidence` are the same as Vector. Killeen's GAPR2 [9] ONE implementation used a node's current vector. GAPR2 proposed integrating Vector's message limit to GAPR. The ONE's GAPR2 uses a nodes average vector instead of the current vector. Since GAPR, GAPR2, and GAPR2a share the same code, the routing class includes the option to select the GAPR version using an attribute. GAPR version one is the default. GAPR version one disables `getMsgLimit`'s message limit calculation by returning the number of messages in the message buffer. GAPR2 uses Vector's message limit calculation.

Like GAPR2, GAPR2a reduces GAPR's message replication with a message limit. However, GAPR2a does not use the difference between node vectors to determine the message limit. Instead, GAPR2a uses the distance between two node's centroids to determine the message limit. As a result, GAPR2a is a combination of GAPR and Centroid. The control logic is the same as GAPR in Section 2.1.4, but GAPR2a uses Centroid's message limit algorithms in Section 2.1.2. Instead of sharing vectors, nodes share centroids. As a result, GAPR2a's message limit calculation is tolerant of GPS errors. The GAPR Routing Class includes the `getCentroid` function to calculate a node's centroid from the Centroid Routing Class. The `getMsgLimit` function contains the Centroid code to determine the message limit. The Centroid code is enabled by the version attribute within the GAPR Routing Class. The version attribute also determines whether the `MSG_SUM` packets contain a node's centroid or vector. When GAPR2a, the `MSG_SUM` packets contain centroids. Any other version sends vectors.

3.7.8 Message Buffer

GAPR's packet queue class manages the stored messages and maintains the list of acknowledged message IDs. GAPR does not use FIFO. Instead, GAPR uses a custom comparator for sorting messages according to their delivery probability and hop count. Section 2.1.4 covers how message priority is determined. Nodes transmit messages that are below a calculation threshold first. Messages above the threshold are transmitted in order of delivery probability. `FindDisjointMessages` generates the list of messages to replicate to another node. Nodes delete messages that exceed the threshold with the lowest delivery probability first when making room in the message buffer.

3.8 ONE DTN Routing Protocol Bugs

Cross simulator protocol evaluation identified a bug in several ONE protocols. As previously discussed in Section 2.1, Vector and Centroid use FIFO for queue management. However, the ONE versions did not use FIFO. Centroid [10] and Vector [9] use the ONE's `getMessageCollection` to retrieve the list of messages held by a node. Both protocols determine which messages to send from that list, but `getMessageCollection` does not sort the list. Instead, the function returns a reference to the message buffer [35]. As a result, the protocols did not send replication messages in FIFO order. To fix the issue, the ONE's Vector and Centroid now sort the messages according to arrival time prior to removing messages for the message limit. The results included in this thesis are from the corrected Vector and Centroid versions.

GAPR2 [9] in the ONE also contained a bug. GAPR2 sorts the messages according to a custom sorting algorithm. However, the ONE's GAPR2 sorted the list of messages after removing messages according to the message limit. As a result, GAPR2 would not send messages that should have higher priority. To fix the protocol, the ONE's GAPR2 now sorts the list of messages prior to removing messages for the message limit. As a result, GAPR2 does not skip higher priority messages.

CHAPTER 4:
Methodology

Chapter 4 discusses the scenarios and methodology. Section 4.1 covers data collection, and Section 4.2 discusses node mobility generation. Section 4.3 discusses the metrics, and Section 4.4 discusses protocol evaluation. Finally, Section 4.5 discusses the Helsinki, Bold Alligator, and Omaha scenarios.

4.1 Data Collection

In order to analyze the performance of the ns-3 DTN protocols, multiple trace files are required. ns-3 provides the ability to generate American Standard Code for Information Interchange (ASCII) trace files at the Media Access Control (MAC) layer and IP layer, but ns-3 does not have a built-in trace file generator for the routing layer. ns-3 does not have a trace file for power consumption. Our ns-3 routing protocols include a routing trace file generator, and the scenarios generate the power trace file. Data analysis uses the IP layer trace files, routing layer trace files, and power trace files.

ns-3's IP ASCII trace file generator provides insight into protocol overhead. Every transmitted and received packet is included in the trace file, so the trace file includes control packets and data packets. The IP trace accounts for partial messages. Control packet overhead affects protocol performance and scalability. Since the ONE does not account for control packet overhead, the IP trace file provides insight into the additional cost. Analysis of IP ASCII trace file returns the number transmitted and received beacons, control packets, and packets belonging to messages. Analysis also yields control packet specific metrics such as the average number of message IDs contained in `MSG_SUM` packets during a scenario.

While the IP layer trace file provides insight into protocol overhead, the metrics generated by the IP trace is not comparable to the ONE. The IP layer does not handle messages, so all of the ns-3 DTN protocols include a custom trace file generator. The `LogToFile` function records every received, transmitted, and dropped message. A dropped message in the message log occurs when a node fails to receive a complete message due to a dropped packet. The dropped message record does not record which packet was dropped. The dropped message log does not record when messages are dropped due to nodes moving out of range. The difference between the number of transmitted and received messages minus the number of dropped messages due to lost packets provides insight into dropped message due to node mobility. The trace does not indicate which packets were lost or which packets were delivered. The trace file focuses on message level events, so the same metrics from the ONE apply to ns-3.

The ns-3 energy module provides the framework to measure power consumption of individual nodes. However, ns-3's energy module does not include a logging function. At the end of every scenario, the scenario script generates a log containing the power consumed by each node in the network. The log also includes the total power consumed by all nodes, and the log contains the power consumed by selected groups of nodes.

While the trace files provide a log of events, trace file analysis generates the metrics to study protocol performance. The ONE provides these reports as options, but ns-3 does not. A separate Python script performs the trace file analysis to generate the metrics. Multiple runs with different seeds for each set of selected parameters generate statistical significance. Given the large data set, a Python program generates the metric summary tables and graphs from the raw data.

4.2 Node Mobility Generation

As previously discussed in Chapter 2, ns-3 requires an external program to support map-based mobility models. ns-3 generates random node movements, but ns-3 does not support path following and tailored node behavior like the ONE. As a result, ns-3 requires a separate module to generate node movements for map-based scenarios. The separate ns-3 module must generate an ns-2 movement trace file. ns-3 uses the ns-2 movement trace file to position nodes throughout the simulation. Since the ONE generates ns-2 movement trace files, the ns-3 scenarios use the ONE generated node movements. The ONE simulator mobility movement random number generator seeds create multiple movement maps for ns-3. The movements in the ONE are identical ns-3.

The ONE generated movements allow the same scenarios to be comparable between the two simulators. The modeling of the start and end of each contact opportunity is the same because ns-3 uses the mobility traces generated by the ONE. ns-3's range propagation loss model is used in all ns-3 scenarios. Under the range propagation loss model, nodes within the specified range receive transmissions at the transmission power level [17]. Nodes outside the specified range receive nothing. The simple range model does not introduce bit error or signal to noise ratio degradation when nodes are in range. As a result, link layer overhead head is isolated to the link layer protocol. Like the ONE, only nodes within the specified range communicate in the ns-3 scenarios.

The ONE's random number generator creates the random variation in node movements. Multiple seeds generate the multiple movement maps read by ns-3. To ensure that node mobility is the only random variable, ns-3's message generator's random number generator seed is the same for all simulations. This ensures that the nodes generate the same messages at the same time for the set of mobility maps. The ONE's random number generator creates random variation in ns-3 by generating the set of movement maps read by ns-3.

4.3 Metrics

Multiple metrics collected within the scenarios compare protocol performance across the simulators. Previous DTN research focused on average latency, average hop count, overhead, and message/packet delivery ratio. This thesis extends the work in GAPR [5] and GAPR2 [9] by including power consumption. Since the ONE's overhead does not include control packets, this thesis uses two overhead metrics.

For the metrics to be statistically significant, multiple runs per set of parameters generate the raw data. Python analysis scripts calculate the average and ninety-five percent confidence interval for each metric. The ONE requires more runs to generate statistically significant data, and ns-3's longer simulation time limits the number of runs. While the same number runs between simulators is preferable, the reduced number of runs in ns-3 generates statistically significant data using the ninety-five percent confidence interval.

4.3.1 Message Delivery Ratio

The primary measure of DTN performance is the fraction of messages that reach their destination in the scenario. Message Delivery Ratio (MDR) is the ratio of the total number of unique messages delivered over the total number of message generated in the scenario. MDR is not per node, but it is over all nodes in the scenario. The ONE refers to the MDR as the delivery probability within its reports [8]. ns-3 does not generate the MDR metric, so a Python script analyzes the routing layer trace files generated by the protocol's routing class to calculate MDR.

$$\text{MDR} = \frac{\text{Messages Delivered}}{\text{Messages Generated}} \tag{4.1}$$

4.3.2 Average Hop Count

The average hop count is the average number of times that messages transfer between nodes before reaching the destination. Average hop count only accounts for delivered messages and is an average of all messages in the scenario. Protocol forwarding decisions and buffer management affect hop count. The ONE generates the average hop count metric within its reports. ns-3 generates the metric using the Python script analyzing the trace files generated by the protocol's routing class.

4.3.3 Average Latency

Latency is the difference between the time of message generation and the time that a message reached its destination. Average latency is the average of the latency of all messages that reached its destination in the scenario. Average latency does not include messages that do not reach its destination. Latency provides insight into the applicability of DTN protocols. Some applications are tolerant to high latency while other applications require low latency. For example, file transfers tolerate high latency and video surveillance requires lower latency. The ONE generates the average latency metric within its own reports model, but ns-3 does not generate the metric. A Python script analyzes the routing layer's trace files to determine the average latency.

4.3.4 Message Replication Overhead Ratio

Message replication overhead focuses on overhead with respect to messages. Message replication overhead is the ratio of messages successfully relayed between nodes minus the number of messages delivered divided by the number of messages delivered [8]. The metric does not include control packet overhead, and message replication overhead does not include partially transmitted messages. Instead, Message replication overhead focuses on the cost of message replication throughout the network. The ONE generates the metric using the reports module. A Python script analyzes the routing class's trace file to determine the metric.

$$\text{Message Replication Overhead} = \frac{\text{Messages Relayed - Messages Delivered}}{\text{Message Delivered}} \tag{4.2}$$

4.3.5 Network Overhead Ratio

Network overhead applies only to ns-3. Network overhead is the total amount of data transmitted between nodes in bytes divided the total number of messages generated in bytes. A Python script analyzes the IP layer trace files to generate the metric. Since the IP layer trace file includes every transmitted or received packet, network overhead metric includes control packets and partially transmitted messages. The ONE does not generate this metric. Network overhead represents the total cost of a protocol.

$$\text{Network Overhead} = \frac{\text{Data Transmitted Between Nodes in Bytes}}{\text{Sum of Messages Generated in Bytes}} \tag{4.3}$$

4.3.6 Average Power Consumed Per Node

The ns-3 scenarios record the power consumed by battery powered nodes. As a result, the power consumption metric excludes vehicles. The ns-3 scenario scripts calculate the total power consumed by all battery powered devices in Joules. The number of Joules divided by the length of the simulation calculates the power consumed in Watts. Dividing the number of Watts consumed by the number of nodes measured returns the average power consumed per node.

4.3.7 Protocol Efficacy Ratio

Protocol efficacy is a single metric that captures the goal of high delivery ratio and low overhead. We would use efficiency, but efficiency is approximately the inverse of overhead. Efficiency would not serve as a separate metric. As a ratio of message delivery ratio over network overhead, an efficacy of 1 is the ideal case. An efficacy of 1 means that an MDR of 1 required a network overhead of 1. An efficacy of 0 is the worst case because no messages were delivered. High network overhead penalizes efficacy. Protocol Efficacy includes control packets, message copies, and partially transmitted messages.

$$\text{Protocol Efficacy} = \frac{\text{MDR}}{\text{Network Overhead Ratio}} \tag{4.4}$$

4.4 Protocol Evaluation

The evaluation methodology discussed in Section 2.4.1 compared simulators in the same scenario. Protocol evaluation adopts techniques from Section 2.4.1 to evaluate protocol performance. First, test scenarios check ns-3 protocol functionality. After testing protocol operation, larger scenarios compare protocol performance trends between ns-3 and the ONE.

4.4.1 Test ns-3 Protocol Operation

Three small scale test scenarios test ns-3 DTN protocol operation. First, a small-scale scenario tests the protocol using two stationary nodes generating message traffic. Analysis of the simulation's trace files checks the control packet exchange sequence and message replication. Afterwards, another small scenario adds random mobility and additional nodes. The second test simulation script consists of ten nodes where one node generates a message. The script tests message replication and control packet functionality in larger networks. Console line output in the source code checks key functions in the protocols. ns-3 assertions throw errors when logic errors occur. The small-scale tests using console line output and trace file analysis checks the basic functionally, but they do not verify the buffer management given the small amount of traffic generated. To test buffer management, a larger 50-node test script has every node generate messages to every node in the network. The test script employs random mobility. The large amount of message traffic forces control packet fragmentation and message buffer management. Analyzing the trace files by hand is not feasible, so assertions check for logic errors and a trace file analyzer checks performance. These test scripts and test cases check the ns-3 code's functionality.

4.4.2 Cross Simulator Evaluation

After testing ns-3 protocol operation, the ns-3 protocols compare against the ONE protocols in the same scenarios. The ONE generates the movements for ns-3, so node movements are identical between the two simulators. Transmission speed, transmission range, warmup time, and simulation duration are the same in ns-3 and the ONE. The number of messages and message generation rate are equivalent. The transmission speed and buffer size are varied to study how the protocols behave for the given resource. A Python analysis script analyzes the ns-3 trace files to generate the statistics. While the results between the two simulators will not be identical, the overall trends in protocol performance should be similar. In order to compare the trends, graphs are the most efficient method to compare the ONE and ns-3 results given the large data set. For example, the Helsinki scenario contains 175 data points in ns-3 and 150 data points in the ONE collected over 2900 simulation runs. A table showing the performance difference between the ONE and ns-3 implementation is included. The performance difference between simulators is generated used the following equation:

$$\%\ \text{Difference} = \frac{\text{ns-3 Metric - ONE Metric}}{\text{ONE Metric}} \cdot 100\% \tag{4.5}$$

In addition to the table summarizing the percent difference, the appendices contain summaries of the raw data generated in both simulators.

4.5 Scenarios

Three map-based mobility scenarios test the DTN protocols in the ONE and ns-3. The Helsinki scenario is an urban environment, and Bold Alligator simulates a real-world military exercise. The Normandy Landings during WWII inspired the Omaha scenario. This section describes the scenarios and parameters.

4.5.1 Helsinki

The Helsinki scenario is a map-based simulation that is included in the ONE. Helsinki is widely used in the area of DTN research because the simulation models real-world mobility. The scenario models urban movements in Helsinki Finland in Figure 4.1. The urban simulation models the movements of pedestrians, cars, and trams.

Figure 4.1. Helsinki Scenario Map. Adapted from [8]

As discussed in Section 2.2.1, the ONE's map-based mobility defines maps using WKT files. A WKT file defines the base map as well as the predefined paths. A WKT file defines the movements for a specific type of node. Nodes only traverse the paths defined in their WKT. In Helsinki, the scenario contains three types of nodes. Cars only travel on roads, and pedestrians travel on walkways. Trams only traverse tracks.

Pedestrians and automobiles use the shortest path map-based mobility generator. Nodes select a random point in its WKT file. Then, the node determines the shortest path to that point. Once a node reaches its destination, the node pauses for a set amount of time before selecting the next destination. Trams use the ONE's route-map movement mobility module. Trams start at a randomly selected position within its WKT file. Then, the trams follow the route defined in their WKT file. At each stop, the trams pause for a set amount of time before continuing to follow the route [8].

The Helsinki scenario approximates node behavior in an urban environment, so the realism does not exactly match real life. However, Helsinki's approximation of node movement in a restricted city environment does generate data to compare the performance of protocols. The movements are repeatable and varied to generate significant data for comparison between protocols or other works. As a result, the Helsinki scenario is a common simulation used to study DTN protocol performance.

Movement Parameters

In order to execute the ns-3 Helsinki scenario, the ONE generates the movement maps. Table 4.1 shows the parameters used to generate node movements. Ten movement model seeds create the ns-2 movement trace files for ns-3. The movement model seed number each ns-2 movement trace file. The movement parameters are not changed for collecting the ONE data, so the movements between the two simulators are identical for a given movement model seed.

Parameter	**Values**
Simulation Duration	12 hrs
Number of Pedestrians	80
Number of Cars	40
Number of Trams	6
Pedestrian Speed	0.5 - 1.5 m/s
Car Speed	2.7 - 13.9 m/s
Tram Speed	7 - 19 m/s
Pedestrian Pause Time	0 - 120 s
Car Pause Time	0 - 120 s
Tram Pause Time	10 - 30 s
Movement Model Seed	1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Table 4.1. Helsinki Movement Parameters

Scenario Parameters

Table 4.2 contains the simulation parameters. The Helsinki scenario is twelve hours. Since some protocols require position history or delivery probability, a warmup period is required. A 1000-second warmup period prevents node initialization from affecting the results. During the warmup period, nodes do not generate message traffic. However, nodes exchange control packets during the warmup period. Analysis excludes the control packets exchanged during the warmup period. The 0.1-second timestamp resolution only applies the ONE because the ONE is discrete time simulator.

Parameter	**Values**				
Simulation Duration	12 hrs				
Simulator Seed	719				
Warmup Time	1000 s				
Timestamp Resolution	0.1 s				
Beacon Interval	5 s				
Base Radio Bandwidth (Mbps)	6	12	24	36	54
Tram Radio Bandwidth (Mbps)	58.5	117	234	351	526.5
Base Radio Transmit Range	10 m				
Tram Radio Transmit Range	1000 m				
Base Buffer Size (MB)	5	10	25	50	100
Tram Buffer Size (MB)	50	100	250	500	1000
Message Rate	1 / 25 - 35 s				
Message Size	0.5 - 1.0 MB				
Message TTL	5 hrs				
Hop Limit	50				
Protocols	Epidemic, Centroid, GAPR, GAPR2, GAPR2a, Vector				

Table 4.2. Helsinki Scenario Parameters

Radio Parameters

The Helsinki scenario employs two radios. All nodes have the base radio, and two trams have a high-speed long-range radio. The remaining trams only use the base radio. The high-speed radio is approximately ten times faster than the base radio. For ns-3, the base radio uses the 802.11g protocol and the high-speed radio uses 802.11ac. The 802.11g radio operates at 2.4 GHz with the default channel width, and the 802.11ac radio operates at 5 GHz with a 160 MHz channel width. The 802.11ac radio uses one spatial stream with an 800-nanosecond guard interval. The modulation and coding scheme determines 802.11g transmission speeds. For 802.11g, the available modulation and coding schemes permit bandwidths of 6, 12, 24, 36, 48, and 54 Mbps [36]. The modulation and coding schemes set the 802.11ac radio transmission speeds. While 802.11ac does have transmission rates that are exactly ten times the values permitted by 802.11g, 802.11ac requires varying more parameters [36]. Varying all of the 802.11ac parameters introduces more variables. To ensure consistency between radios, the scenario fixed all 802.11ac parameters with exception of modulation and coding scheme.

With respect to transmission range, the high-speed radio's range is 100 times farther than the base radio. Since the base radio is supposed to be low power, the base radio range is 10 meters. The high-speed radio effectively has unlimited power because they are powered by the trams. Therefore, the trams have a 1000-meter transmission range. Since ns-3 emulates the physical layer, Helsinki uses the Range Propagation Loss Model. The Range Propagation Loss Model simulates propagation loss based on the distance between the transmitter and receiver. If the radios are in range with sufficient signal strength, the nodes communicate. If the nodes are out of range, the nodes will not communicate regardless of signal strength. The transmission gain and receive gains were selected to ensure that nodes in range would have ample signal strength under the Range Propagation Loss Model. The selected gains do not affect the power consumption in ns-3 because the ns-3 Energy Module determines power consumption based on radio mode and current consumed by the radio's mode. The current consumed by a radio is a separate parameter in the Energy Model. Helsinki uses the default currents [24].

Node Buffer Sizes

In addition to varying transmission speed, Helsinki varies buffer size. Message buffer size affects DTN performance because of the store-carry-forward paradigm. In Helsinki, pedestrians and cars use the base buffer size. All tram buffers are ten times that size of the base buffer. The base message buffer sizes are 5, 10, 25, 50, and 50 Megabyte (MB). As a result, the corresponding tram buffer sizes are 50, 100, 250, 500, and 1000 MB.

Message Generation Parameters

The Helsinki scenario does not focus on the effects of congestion on network performance, so message generation must not introduce congestion. If congestion occurs, then congestion should be due to message replication. To prevent artificially congesting the network, a random node generates a message to another random node every 25 to 35 seconds. Since the message generator uses a random number generator, all runs use the same random number generator seed. Each message is 0.5 to 1.0 MB. Messages expire after five hours.

Protocols such as Epidemic, Vector, and Centroid use hop limits, so their hop limit is set to 50 hops. The ONE's Helsinki uses 50 hops as the default, and 50 hops is sufficient to reach the destination. GAPR, GAPR2, and GAPR2a do not use hop limits, so they do not have a hop limit.

4.5.2 Bold Alligator

Kevin Killeen developed the Bold Alligator scenario in [9] to simulate node movements in military operations for DTN protocol evaluation. Bold Alligator is an annual amphibious military exercise conducted at Camp Lejeune, North Carolina. Bold Alligator consists of U.S. forces conducting an amphibious assault to evacuate civilians from a country invaded by a rogue nation. Killeen used the planning materials for Bold Alligator to develop the scenario, but the scenario is not an exact recreation of the exercise. Instead, the scenario realistically models a portion of the exercise where military forces evacuate civilians. The exercise consists of soldiers, Humvees, Landing Craft Air Cushion (LCAC)s, helicopters, and ships [9].

Figure 4.2 illustrates the patrol areas and movements of the nodes. The ships patrol 5 nautical miles from shore. The LCACs follow the yellow dotted line to move Marines to and from the ships. Helicopters follow the dotted red lines to transport Marines and evacuees to and from the ships. Humvees patrol along the solid green lines to transport Marines and evacuees. The four Marine squads follow in the orange, pink, light green, and purple lines. The drones patrol within the dotted green box [9].

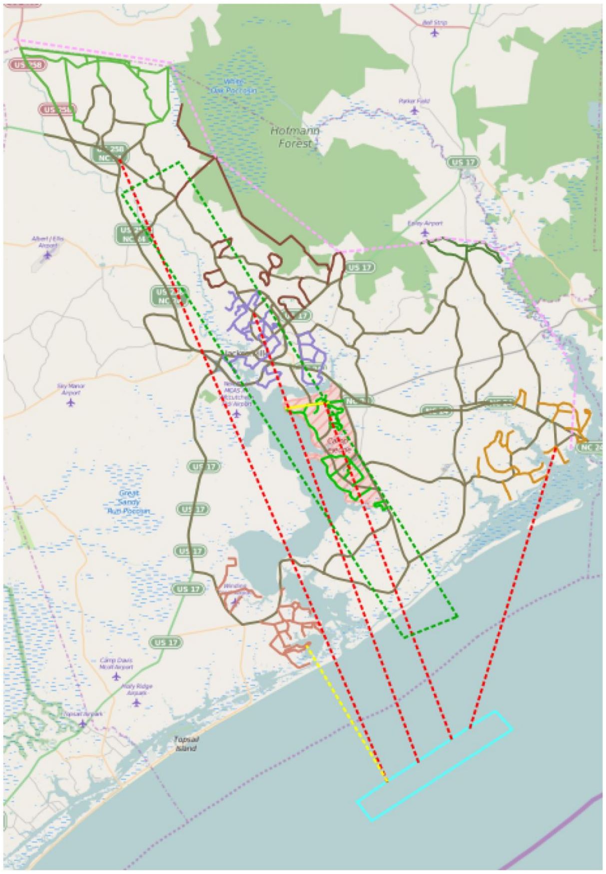


Figure 4.2. Bold Alligator Scenario Map. Source: Killeen (2015) [9]

Movement Parameters

First, the ONE generates the ns-2 movement trace files for ns-3. Table 4.3 lists the movement model parameters. Ten movement model seeds create the ns-2 movement trace files. Each movement trace file is numbered according the movement model seeds. The movement parameters are not changed when collecting the ONE data, so the movements used in both simulators are identical for the given movement model seed. The scenario consists of 105 nodes with varying amounts of mobility over a 24-hour period.

Parameter	**Values**
Simulation Duration	24 hrs
Number of Marines	70
Number of Humvees	20
Number of Drones	2
Number of Helicopters	8
Number of LCACs	2
Number of Ships	3
Marine Speed	0.5 - 1.5 m/s
Humvee Speed	13 - 22 m/s
Drone	11 - 19 m/s
LCAC Speed	11 - 19 m/s
Helicopter Speed	125 - 167 m/s
Ship Speed	1 - 4 m/s
Marine Pause Time	0 - 60 s
Humvee Pause Time	0 - 60 s
Helicopter Pause Time	0 - 1800 s
LCAC Pause Time	0 - 1800 s
Ship Pause Time	0 s
Movement Model Seed	1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Table 4.3. Bold Alligator Movement Parameters

Scenario Parameters

After generating the movement trace files, data collection starts in ns-3 and the ONE. Table 4.4 lists the simulation parameters. Like Helsinki, Bold Alligator requires a warmup period. Carrying over the parameters from [9], Bold Alligator uses a 10800-second warm up period. Nodes exchange control packets during this period, but nodes do not generate message traffic. Performance analysis excludes control packets generated during the warmup period. The ONE's timestamp resolution is set to 0.1 seconds.

Parameter	**Values**			
Simulation Duration	24 hrs			
Simulator Seed	719			
Warmup Time	10800 s			
Timestamp Resolution	0.1 s			
Beacon Interval	5 s			
Base Radio Bandwidth	12, 24, 36, 54 Mbps			
Humvee Radio Bandwidth	54 Mbps			
Drone Radio Bandwidth	6 Mbps			
Ship Radio Bandwidth	54 Mbps			
Base Radio Transmit Range	100 m			
Humvee Radio Transmit Range	3000 m			
Drone Radio Transmit Range	3000 m			
Ship Radio Transmit Range	10000 m			
Marine Node Buffer Size (MB)	5	10	25	50
Drone Node Buffer Size (MB)	5	10	25	50
Humvee Buffer Size (MB)	50	100	250	500
LCAC Buffer Size (MB)	50	100	250	500
Helo Buffer Size (MB)	50	100	250	500
Ship Buffer Size (MB)	500	1000	2500	5000
Marine Message Size	250 - 500 KB			
Humvee Message Size	0.5 - 1.0 MB			
Ship Message Size	0.5 - 1.0 MB			
Marine Message Rate	1 / 5 - 10 s			
Humvee Message Rate	1 / 10 - 20 s			
Ship Message Rate	1 / 25 - 35 s			
Message TTL	5 hrs			
Protocols	Epidemic, Centroid, GAPR, GAPR2, GAPR2a, Vector			

Table 4.4. Bold Alligator Scenario Parameters

Radio Parameters

Bold Alligator contains four types of radios. All radios use the 802.11g protocol operating on their own channel. Nodes with multiple radio interfaces relay messages between the different radio networks. The 802.11g radios operate at 2.4 GHz with the standard channel width. All nodes have the base radio. Drones have the drone radio interface and base radio interface. Humvees, LCACs, and helicopters have the Humvee radio and base radio. The ships have the Ship radio, Humvee radio, and base radios. The Ship radios and Humvee radios have the highest transmission speed of 54 Mbps because they effectively have unlimited power. In the original Bold Alligator scenario from [9], the drones had the slowest link speed. Therefore, the drone radio interface is 6 Mbps. The base radios use a range of transmission speeds to study how network performance scales with link speed. The base radio transmission speeds are 12, 24, 36, and 54 Mbps. All other radio interfaces are fixed for all runs.

The radio interfaces have different transmission ranges. Power is a major consideration because batteries limit radio performance. Ships, Humvees, LCACs, helicopters, and drones effectively have unlimited power because the vehicle powers the radio. Marines must use a battery to power the radio, so the base radio limits transmission range. The base radio can transmit up to 100 m. The drone radio and Humvee radios can transmit up to 3000 meters. The ship radio range is 10000 meters. Bold Alligator uses ns-3's Range Propagation Loss Model. As previously discussed in Section 4.5.1, the Range Propagation Loss Model determines whether two nodes can communication based on the distance between the two nodes. The transmission and reception gains are set to ensure that nodes within range would communicate. The ns-3 Energy Model does not use the gains to determine power consumption. Instead, ns-3 uses the radio's mode and current consumed in that mode. Bold Alligator uses the default Energy Model currents.

Buffer Sizes

In addition to varying link speed and transmission range, nodes also employ different message buffer sizes. Marines tend to stay clustered, and they have the least amount of mobility. Marines rely on vehicles to relay messages to other portions of the network. Therefore, Marines have the smallest buffers. Drones also tend to stay in a specific area and do not require a large buffer. Humvee, LCACs, and helicopters have larger buffers because of their mobility. Humvee, LCAC, and helicopter buffers are ten times the size of the message buffer used by Marines and drones. Ships represent the command and control center of an operation, and ships effectively have unlimited resources because they are not limited on space or power. As a result, the ship buffers are 100 times bigger than a Marine's message buffer. The base buffer sizes used in Bold Alligator are 5, 10, 25, and 50 MB. The other node types use the appropriate multiplier.

Message Generation Parameters

Bold Alligator uses three message generators to generate message traffic based on the classification of the node. Marines generate the most message traffic because there are more Marines than vehicles. While their message generation is higher, their messages are smaller because they are typically status reports. Humvees, LCACs, and helicopters have the second highest message generation rate, but the messages are larger than the Marine's messages. The ships have the lowest messages generation rate, and the ships have the same message sizes of the Humvees. The Vector, Centroid, and Epidemic message hop limit is set to 50 hops because 50 hops is the default value. The message TTL for all messages is set to 5 hours.

4.5.3 Omaha

The Omaha beach landing was a small part of a larger military operation in Normandy, France on June 6th, 1944, famously known as D-Day. The Omaha landing is reported to have 43,250 infantry, 2 battleships, 2 cruisers, 13 destroyers, and 1,010 vessels [37]. Creating the simulation scenario involved Open Street Maps, Open Jump, and a tool authored by Christoph P. Mayer [38] to generate the scenario. Open Street Maps captures a screenshot of Omaha Beach in France and exports the data into an Extensible Markup Language (XML) formatted file with extension .osm. Then, Dr. Mayer's java program, osm2wkt, converts the .osm file into a WKT file. The WKT file is a compatible format for map-based movement scenarios in the ONE simulator. Finally, Open Jump adjusts the map by adding and removing paths. Figure 4.3 presents the Omaha scenario's map.

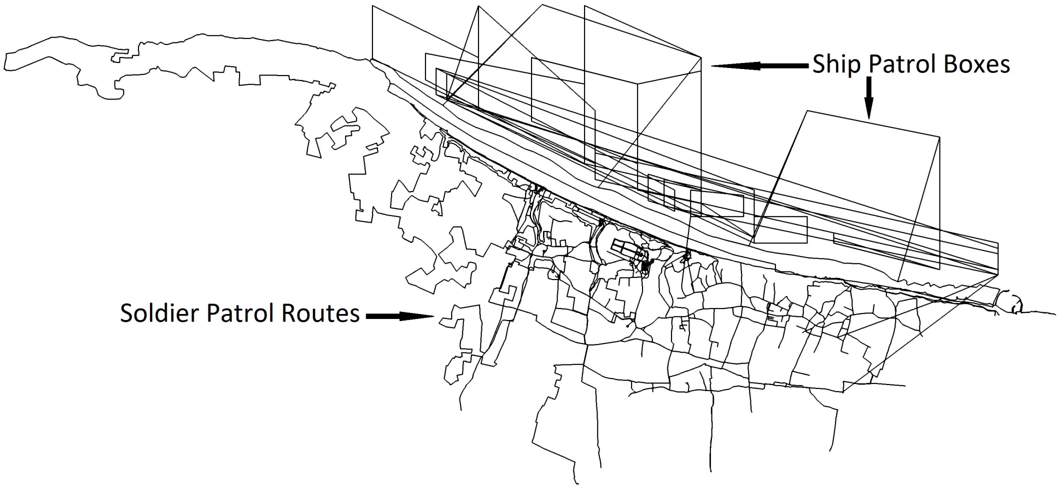


Figure 4.3. Omaha Scenario Map

Movement Parameters

First, the ONE generates the ns-2 movement trace files using the parameters listed in Table 4.5. Ten movement model seeds create the ns-2 movement trace files, and the movement model seeds number the movement trace files. The movement parameters are constant when collecting the ONE data, so the movements used in both simulators are identical for the given movement model seed. The scenario consists of 61 nodes with varying amounts of mobility over a 12-hour period.

The exact path of the ships, vessels, and infantrymen are unknown and thus adjustments are made to abstract the movements. For instance, the exact paths that ships traveled is unknown, but they patrol near the shore. Each ship is assigned a path, and no two ships have the same route. However, routes do overlap, allowing an opportunity for the ships to communicate as they pass one another. Ships travel up to 16 m/s, but they will not travel at top speed all the time. For this reason, ships have a random speed between 8-16 m/s. The Normandy invasion contained approximately 44,000 infantry and 1,000 vessels. If treated individually, it would create 45,000 nodes. To save simulation time, the scenario assumes that infantry travel in groups, and utilize the vessels as a group. For every vessel, 1,000 infantry traveling together. The infantry groups will find themselves in the ocean for a brief period to simulate the act of the landing craft making its way to the shore. Then, they will randomly travel along the paths provided on the Omaha Beach map. All nodes communicate with a common, single radio interface.

Parameter	**Values**
Simulation Duration	12 hrs
Warmup Time	1000 s
Timestamp Resolution	0.1 s
Number of Soldiers	44
Number of Ships	17
Soldier Speed	0.5 - 1.5 m/s
Ship Speed	8 - 16 m/s
Soldier Pause Time	0 - 60 s
Ship Pause Time	0 - 300 s
Movement Model Seed	1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Table 4.5. Omaha Scenario Movement Parameters

Radio Parameters

The Omaha scenario uses one radio interface. Table 4.6 lists the Omaha scenario parameters. The 802.11g radios operate at 2.4 GHz with the standard channel width. The radios use a range of transmission speeds to study how network performance scales with link speed. The radio transmission speeds are 6, 12, 24, 36, and 54 Mbps. The radios transmit up to 550 m. Omaha uses ns-3's Range Propagation Loss Model. As previously discussed in Section 4.5.1, the Range Propagation Loss Model determines whether two nodes can communicate based on the distance between the two nodes. The transmission and reception gains are set to ensure that nodes within range can communicate. The ns-3 Energy Model does not use the gains to determine power consumption. Instead, ns-3 uses the radio's mode and current consumed in that mode. Omaha uses the default Energy Model currents.

Parameter	**Values**				
Simulation Duration	12 hrs				
Simulator Seed	719				
Warmup Time	1000 s				
Timestamp Resolution	0.1 s				
Beacon Interval	5 s				
Radio Bandwidth	6, 12, 24, 36, 54 Mbps				
Radio Transmit Range	550 m				
Soldier Node Buffer Size (MB)	5	10	25	50	100
Ship Node Buffer Size (MB)	50	100	250	500	1000
Message Rate	1 / 25 - 35 s				
Message Size	0.5 - 1.0 MB				
Message TTL	5 hrs				
Protocols	Epidemic, Centroid, GAPR, GAPR2, GAPR2a, Vector				

Table 4.6. Omaha Scenario Parameters

Buffer Sizes

Omaha also varies message buffer size. DTN nodes must be small and inexpensive for soldiers. As a result, the soldier nodes have less memory than the ships. Ships represent the command and control center of an operation, and ships effectively have unlimited resources because they are not limited on space or power. As a result, the ship buffers are ten times a soldier's message buffer. The base buffer sizes are 5, 10, 25, 50, and 100 MB.

Message Generation Parameters

Message generation is similar to Helsinki. Message generation must not create congestion. If congestion does occur, the congestion is due to message replication. A random node generates a message to another random node every 25 to 35 seconds. Since the message generator uses a random number generator, the same random number generator uses the same seed for all runs. Each message is 0.5 to 1.0 MB. Message TTL is five hours. Protocols such as Epidemic, Vector, and Centroid use hop limits, so their hop limit is set to 50 hops. GAPR, GAPR2, GAPR2a do not use hop limits, so they do not have a hop limit.

CHAPTER 5:
Analysis

Since ns-3 is a discrete-event simulator, the ns-3 versions of the scenarios generated terabytes' worth of data that took three months to collect. In contrast, the ONE versions of the scenarios generated megabytes' worth of data that took three weeks to collect. ns-3 takes 25 to 50 times longer than the ONE in real time to complete the same amount of simulated time. The time to complete the ns-3 simulations and the large ns-3 trace files limited the number of runs and data points. This chapter presents the summarized data because the data set is too large to present in its raw form. ns-3 generates the raw data as multiple trace files that are analyzed to generate the metrics. The raw trace files are not comparable to the ONE's reports without trace file analysis. Chapter 6 discusses the general conclusions of the protocols and scenarios. The focus of this chapter is to present the results and compare the ns-3 and ONE DTN protocols.

Due to the size of the data set, data visualization is the most efficient method to summarize the data sets. Line graphs identify trends in protocol performance, and they are the easiest method to illustrate changes in performance across the range of variables. A table for each protocol summaries the percent difference between protocol implementations for a given scenario to quantitatively compare simulators. Bar graphs compare overall ns-3 protocol performance in the three scenarios. While we do not include the raw data set, the appendices contain the aggregated data tables. The appendices of aggregate data tables and graphs allow for future analysis, recreation, and evaluation.

This chapter contains individual sections covering the Helsinki, Bold Alligator, and Omaha scenarios. Each scenario section qualitatively reviews the scenarios and presents the data. Finally, each section analyzes the performance observed in the scenarios in both the ONE and ns-3. Section 5.3 also discusses the effective throughput of the IP convergence layer adapter that defines groups of packets as messages in ns-3. Section 5.4 compares overall protocol performance across the three scenarios, as simulated in ns-3. Section 5.5 quantitatively compares overall results between the ONE and ns-3 simulators.

5.1 Helsinki Scenario

The Helsinki scenario studies DTN performance in urban environments. A randomly selected node generates a 500 Kilobyte (KB) to 1 MB message using a uniform random number generator every 25 to 35 seconds. The average message size is 750 KB with a message generated every 30 seconds. On average, a node stores 6 messages for every 5 MB of buffer space.

The Helsinki scenario constrains the base nodes buffer sizes to 5, 10, 25, 50, and 100 MB. Tram buffers are ten times the size of the base node buffers. Helsinki constrains the base node transmission speeds to 6, 12, 24, 36, and 54 Mbps. Tram transmission speeds are approximately ten times the base transmission speed. Varying the transmission and buffer speeds provides insight into how resources affect protocol performance. Transmission speed affects the number of messages transferred between two connected nodes for a given amount of contact time. As a result, message priority affects protocol performance. Message buffers greater than 50 MB have effectively unlimited space for Helsinki's message generation rate, so transmission speed becomes the dominant factor. Message buffers less than 50 MB tests the effects of protocol buffer management and message priority.

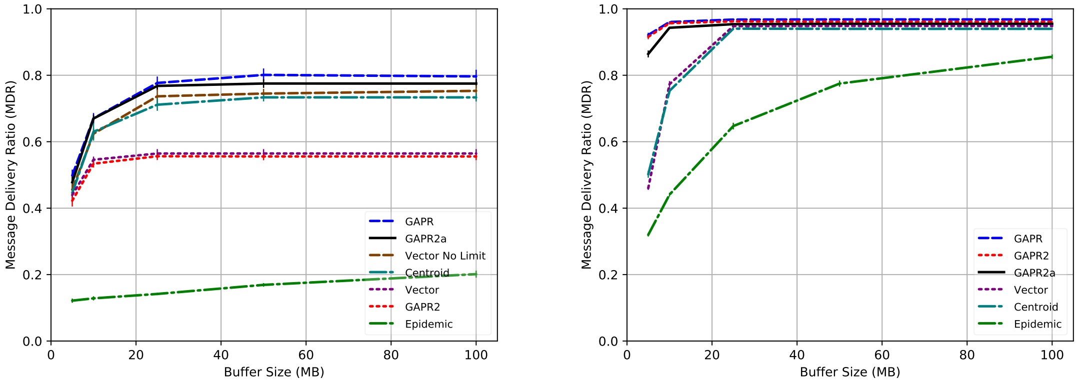
5.1.1 Data Presentation

The Helsinki scenario graphs are from both the ONE and ns-3. 1500 simulation runs in the ONE generated the data, and each data point in the ONE graphs is the mean of 10 runs. 1400 ns-3 simulation runs generated the ns-3 graphs, and each graph data point is the mean of 8 runs. A ninety-five percent confidence interval calculates the error bars for each data point. Most data points return a confidence interval less than 5% of the data point's value, and the error bars are small on the graphs. Increasing the number of runs returned minimal changes in the confidence interval. ns-3's runtime per simulation prevented executing ten runs per data point in the allotted time, but the error per data point is acceptable because both simulators return confidence intervals less than 5% of the data point's value. Within each set of figures, the graphs illustrate the effects of buffer size for the given metric. Since node type dictates buffer size in Helsinki, all graphs use the base node buffer sizes for the x axis. The section presents graphs from the ONE and ns-3 side-by-side to demonstrate the similarities and differences between the two simulators.

5.1.2 Analysis of Message Delivery Ratio

Figure 5.1 illustrates the effect of buffer size on the message delivery ratio in ns-3 and the ONE with the 6 Mbps base radio. Both simulators show message delivery increases asymptotically with buffer size. At buffer sizes greater than 50 MB, the improvement in MDR is negligible for the given amount of message traffic. No protocol delivers all messages because the scenario continues to generate messages until the simulation ends. The messages generated near the end of the simulation have insufficient time to reach their destination.

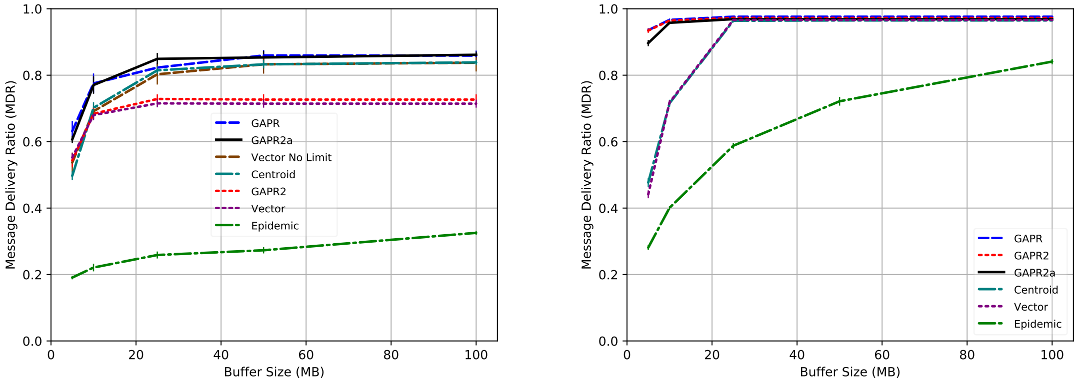
All DTN protocols implemented in ns-3 return lower MDR than the ONE DTN protocols, but they both have similar trends. At buffer sizes less than 25 MB, GAPR performs the best. After 25 MB, all protocols except for Epidemic show negligible gains in performance. Vector without the message limit enabled represents Epidemic with acknowledgement summaries to free resources in the network. Since GAPR performs better than Vector without the message limit, GAPR's message priority strategy improves performance. In ns-3, GAPR2a maintains similar MDR to GAPR and performs better than GAPR2.



(a) ns-3 (b) ONE

Figure 5.1. Helsinki MDR vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

When base radio transmission speed increases to 12 Mbps, all ns-3 protocols increase MDR while most ONE protocols remain the same in Figure 5.2. The ONE's Epidemic MDR decreases slightly for small buffers. GAPR and GAPR2a continue to provide higher message delivery ratio with Epidemic performing the worst. Vector and GAPR2 have equivalent performance in ns-3. GAPR2a's MDR continues to match GAPR in ns-3. GAPR, GAPR2a, and Vector without the message limit have similar MDRs when the message buffer is greater than 25 MB. ns-3's Epidemic continues to improve with increasing buffer size. By comparing the 12 Mbps graphs to the 6 Mbps graphs, the ns-3 protocols show sensitivity to transmission speed. In contrast, the ONE shows minimal change in MDR.

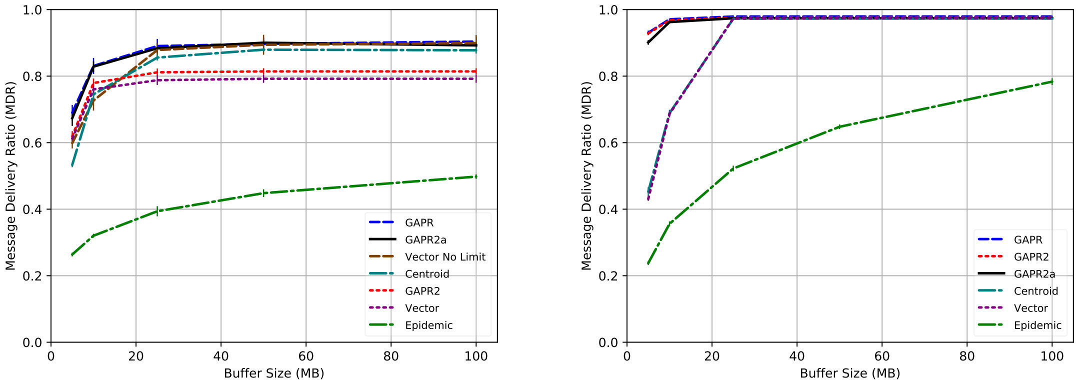


(a) ns-3

(b) ONE

Figure 5.2. Helsinki MDR vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

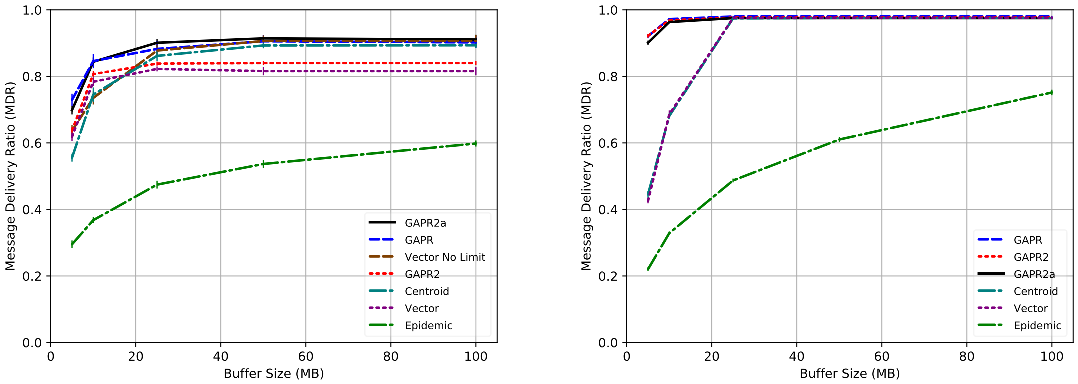
In Figure 5.3, base radio transmission speed increases to 24 Mbps. Like the 12 Mbps link, all ns-3 protocols improve MDR. The ONE protocols remain consistent, with exception of Epidemic. The ONE's Epidemic MDR lowers when transmission speed increases. The cluster of protocols when buffer size is less than 25 MB is like the 12 Mbps link, but the MDR is higher. ns-3's GAPR2a continues to match GAPR's MDR for all buffer sizes, and the ONE shares this trend.



(a) ns-3 (b) ONE

Figure 5.3. Helsinki MDR vs. Buffer Size for 24 Mbps Base Radio in ONE and ns-3

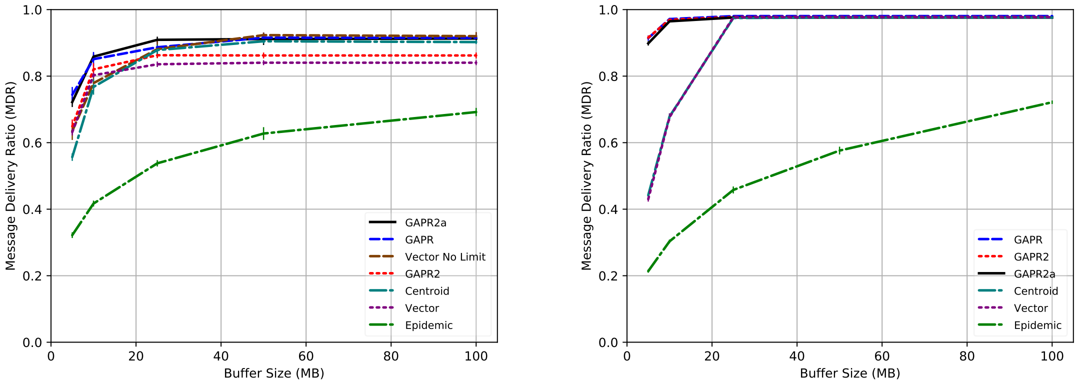
For the 36 Mbps radio, the gains in ns-3 protocol MDR compared to the 24 Mbps link reduces in Figure 5.4. Most ONE protocols remain the same, but the ONE's Epidemic MDR decreases as link speed increases. ns-3's Epidemic MDR increases.



(a) ns-3 (b) ONE

Figure 5.4. Helsinki MDR vs. Buffer Size for 36 Mbps Base Radio in ONE and ns-3

At the maximum base radio of 54 Mbps in Figure 5.5, ns-3 protocol performance is like the 36 Mbps link. The ONE's Epidemic MDR decreases, but ns-3's Epidemic MDR increases.



(a) ns-3

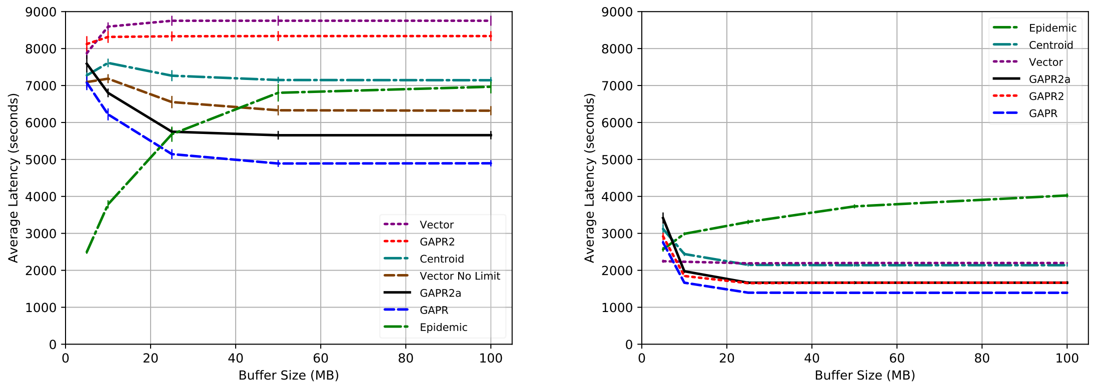
(b) ONE

Figure 5.5. Helsinki MDR vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

In summary, the ONE shows less sensitivity to transmission speed compared to ns-3. After 36 Mbps, the ns-3 protocols show diminishing gains in MDR as transmission speed increases. When the message buffer is greater than 25 MB, transmission speed dominates protocol performance for the given message traffic. When the message buffer is less than 25 MB, buffer size significantly affects protocol performance. While the ONE and ns-3 protocols do not precisely match, they both show asymptotic gains in MDR with buffer size.

5.1.3 Analysis of Average Latency

Figure 5.6 illustrates the effect of buffer size on average latency for the 6 Mbps base radio. ns-3 protocols return higher average latencies than the equivalent ONE versions. Epidemic demonstrates an asymptotic increase in average latency with increasing buffer size. All protocols except for Epidemic show minimal changes in average latency when the message buffer is greater than 25 MB in both simulators. GAPR's message priority algorithm reduces latency when compared to Vector without the message limit. ns-3's GAPR2 has lower latency than Vector, but the two protocols cluster together. ns-3's GAPR2 increases latency over GAPR, which is consistent with the ONE. GAPR2a returns a lower average latency compared to GAPR2, but GAPR2a's latency is higher than GAPR.

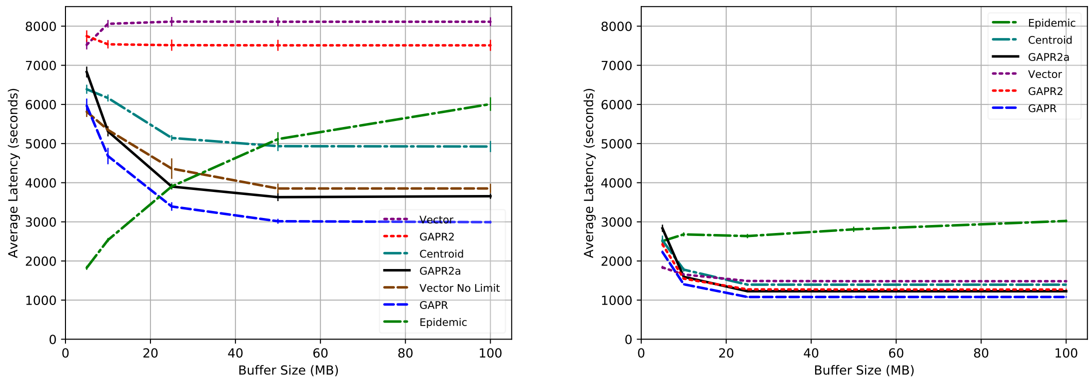


(a) ns-3

(b) ONE

Figure 5.6. Helsinki Average Latency vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

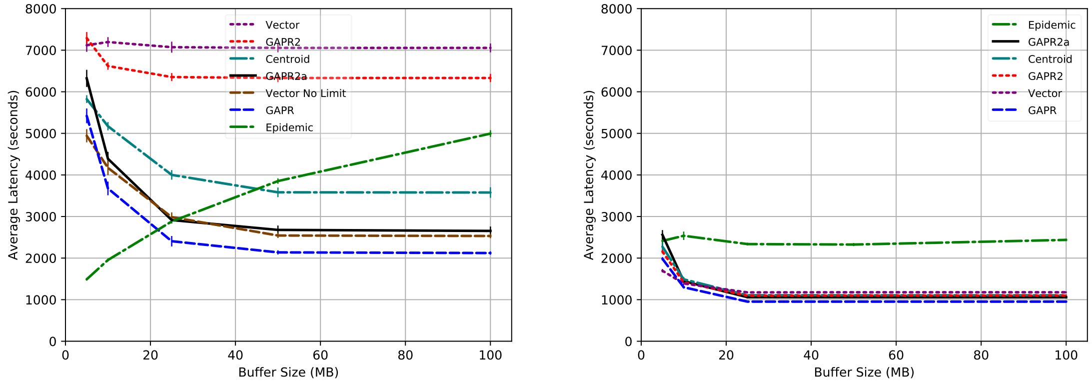
When link speed increases to 12 Mbps, average latency for all protocols decreases in Figure 5.7. Most ns-3 protocol average latencies decrease by approximately 1000 seconds, but most ONE protocols lower by approximately 500 seconds. ns-3's Epidemic maintains an asymptotic curve, but the ONE's Epidemic starts to flatten. ns-3's GAPR2, Vector without the message limit, GAPR, GAPR2a, and Centroid show latency decreases with increasing buffer size until 50 MB. At 25 MB, the change in average latency is less than the change for buffer sizes less than 25 MB for all protocol implementations.



(a) ns-3 (b) ONE

Figure 5.7. Helsinki Average Latency vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

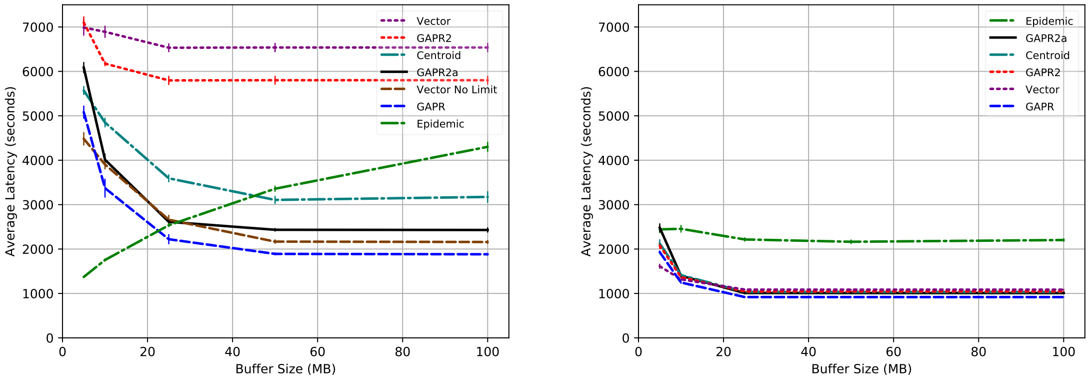
For the 24 Mbps base radio, ns-3's protocols decrease average latency by approximately 1000 seconds in Figure 5.8. The ONE's protocol average latencies lower by a few hundred seconds. The ONE's Epidemic no longer shows an asymptotic increase in latency, but ns-3's Epidemic maintains the asymptotic trend. All other ns-3 protocols show average latency lowers with increases in buffer size.



(a) ns-3 (b) ONE

Figure 5.8. Helsinki Average Latency vs. Buffer Size for 24 Mbps Base Radio in ONE and ns-3

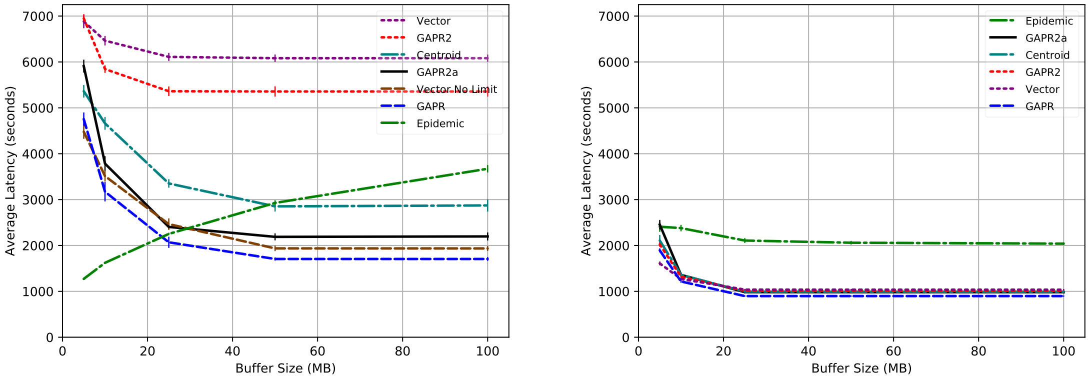
At 36 Mbps in Figure 5.9, the ns-3 protocols return lower average latency. Most ns-3 protocols lower latency by a few hundred seconds. ns-3's Epidemic maintains the same shape from previous link speeds. ns-3's Vector, GAPR, GAPR2, and Centroid show a steeper change in latency from 5 MB to 25 MB. In contrast, the ONE protocols remain consistent between transmission speeds. However, both simulators show that buffer size affects latency for buffers less than 25 MB.



(a) ns-3 (b) ONE

Figure 5.9. Helsinki Average Latency vs. Buffer Size for 36 Mbps Base Radio in ONE and ns-3

Figure 5.10 shows the average latency for the 54 Mbps base radio. ns-3's average latency decreases for all protocols while the ONE lowers slightly compared to the 36 Mbps link. All protocols maintain the same trends from the 36 Mbps link. Average latency decreases with increases in buffer size when the message buffer is less than 25 MB.



(a) ns-3

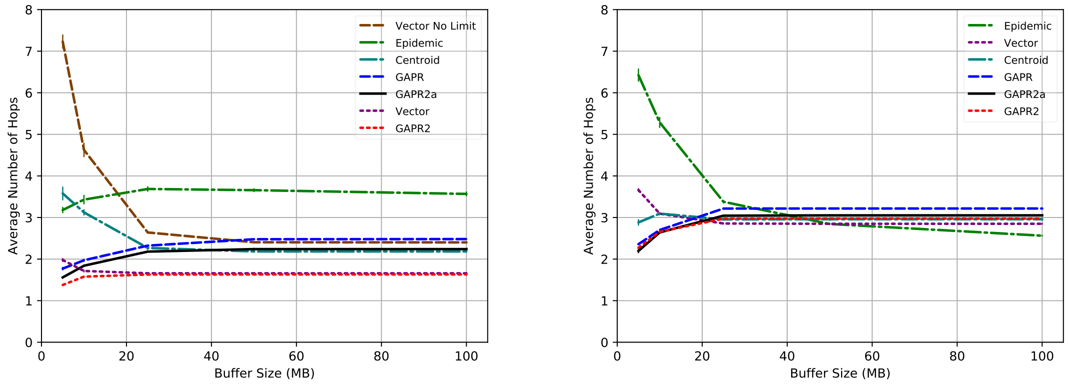
(b) ONE

Figure 5.10. Helsinki Average Latency vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

Based on the observed trends, transmission speed affects latency for all buffer sizes. The impact of transmission speed is significantly greater in ns-3 than in the ONE. For the given message traffic, message buffers less than 25 MB affects average latency in both the ONE and ns-3. The ONE's Vector and GAPR2 implementations perform better than the ns-3 versions, but both implementations show that GAPR2 performs better than Vector. GAPR maintains better latency than GAPR2 in both simulators. GAPR2a provides average latencies close to GAPR and performs better than GAPR2 in both simulators.

5.1.4 Analysis of Average Hop Count

Figure 5.11 compares average hop count versus buffer size for the 6 Mbps base radio. ns-3's Vector with the message limit disabled and the ONE's Epidemic both show an exponential decrease in hop count as buffer size increases, but ns-3's Epidemic does not follow the same trend as the ONE's Epidemic. GARP2, GAPR2a, and GAPR for both simulators show a slight asymptotic increase in average hop count as buffer size increases. Vector and Centroid show a decrease in hop count as buffer size goes up. All protocols show little change in average hop count when the buffer size exceeds 25 MB.

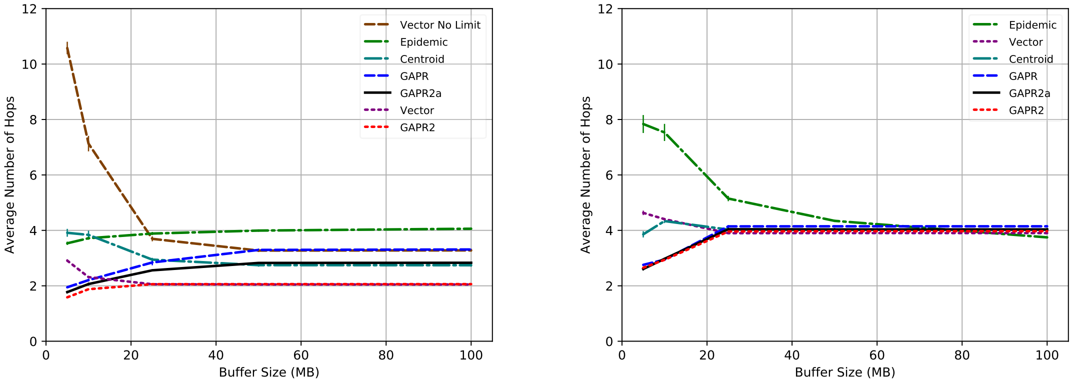


(a) ns-3

(b) ONE

Figure 5.11. Helsinki Average Hop Count vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

At the 24 Mbps base radio in Figure 5.12, ns-3's protocols show a small increase in average hop count. The ONE's Epidemic hop count decreases while the other protocols remained nearly the same. Once again, message buffers less than 25 MB show the greatest change in average hop count in both simulators. The 12 Mbps base radio also showed similar changes, and the 12 Mbps radio graph is located in the Helsinki graph appendix.

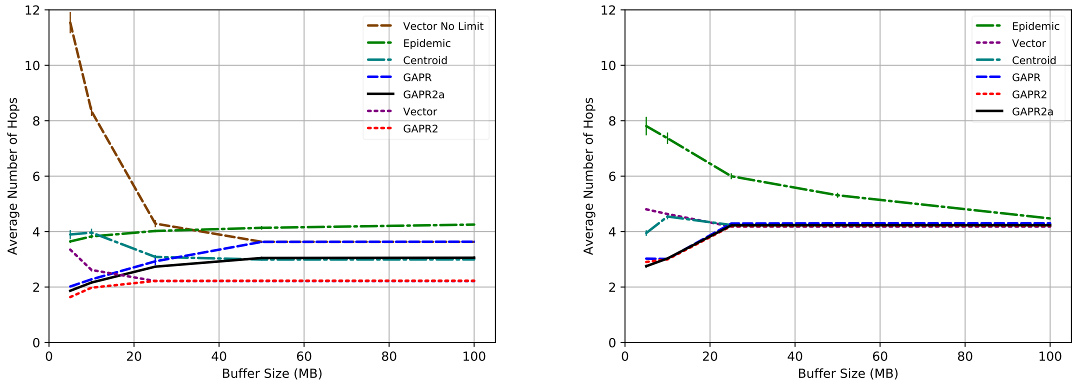


(a) ns-3

(b) ONE

Figure 5.12. Helsinki Average Hop Count vs. Buffer Size for 24 Mbps Base Radio in ONE and ns-3

At 54 Mbps in Figure 5.13, both simulators show a small increase in average hop count. The 36 Mbps link also showed this change, and the 36 Mbps graph is located in the Helsinki graph appendix.



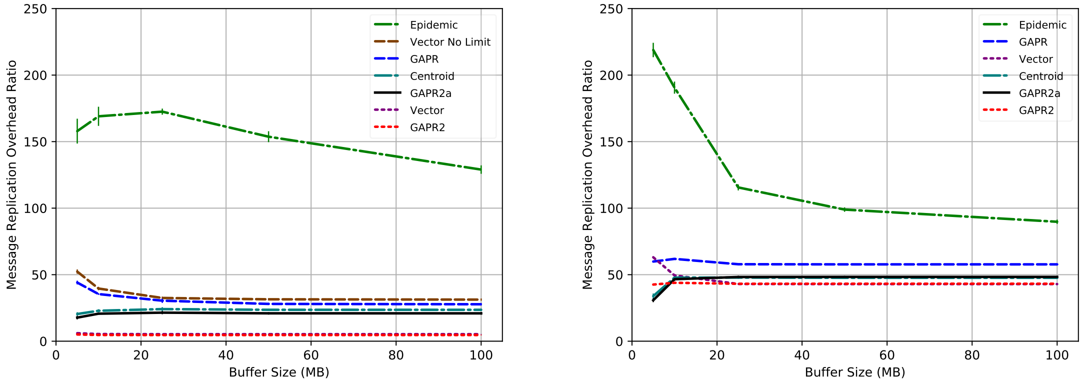
(a) ns-3 (b) ONE

Figure 5.13. Helsinki Average Hop Count vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

Based on the average hop count graphs, message buffer size affects average hop count. Both simulators show slight sensitivity to link speed when studying the average hop count. As transmission speed increases, average hop count increases slightly. Higher transmission speeds permit more message transfers per interaction, so more messages can be delivered. As a result, average hop count increases. The ns-3 DTN protocols return lower average hop counts due to the additional overhead reducing the number of messages transferred per node interaction. For the scenario's message generation rate, message buffers less than 25 MB influences average hop count. Message buffers greater than 25 MB show minimal changes. When constrained by buffer size, average hop count trends are determined by the protocol.

5.1.5 Analysis of Message Replication Overhead Ratio

DTN protocols that do not limit message replication have the highest message replication overhead for the 6 Mbps base radio in Figure 5.14. Epidemic in ns-3 and the ONE has the highest overhead with GAPR returning the next highest overhead. Vector without the message limit enabled illustrates that acknowledgements significantly reduce message replication. Epidemic and GAPR demonstrate that message buffers less than 25 MB increase message replication overhead. GAPR2, GAPR2a, Vector, and Centroid maintain consistent message replication overhead for all buffer sizes greater than 10 MB in both simulators. Most ns-3 protocols return lower message replication overhead compared to the ONE. The 12 Mbps link shows the same trends as the 6 Mbps link, but the 12 Mbps radio shows an increase in message replication overhead. The 12 Mbps radio graph is located in the Helsinki graphs appendix.

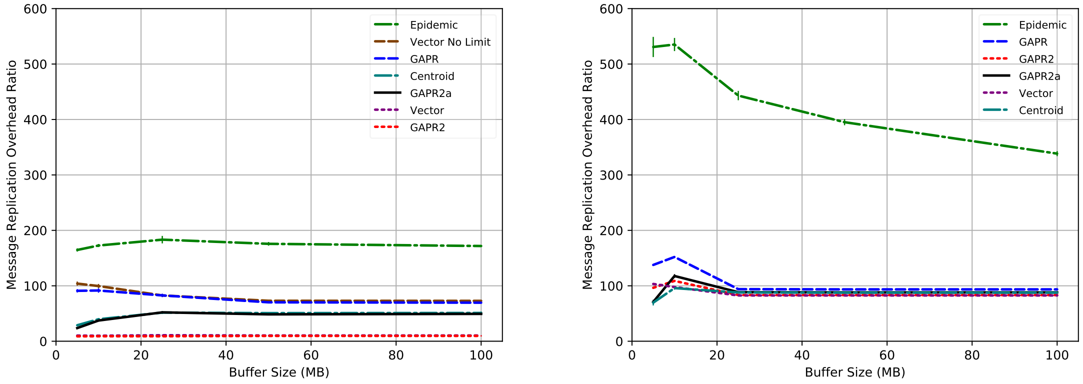


(a) ns-3

(b) ONE

Figure 5.14. Helsinki Message Replication Overhead Ratio vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

At the 24 Mbps base radio in Figure 5.15, message replication overhead increases. Protocols that do not limit message replication continue to show that smaller buffers result in higher message replication overhead. ns-3's GAPR2a and Centroid show that message replication overhead increases with buffer size when the message buffer is less than 25 MB. GAPR2 and Vector continue to show that message replication overhead remains consistent for all buffer sizes. The 36 Mbps base radio continues the same trend, but message replication overhead is higher. The 36 Mbps base radio message replication overhead graphs are located in the Helsinki graphs appendix.

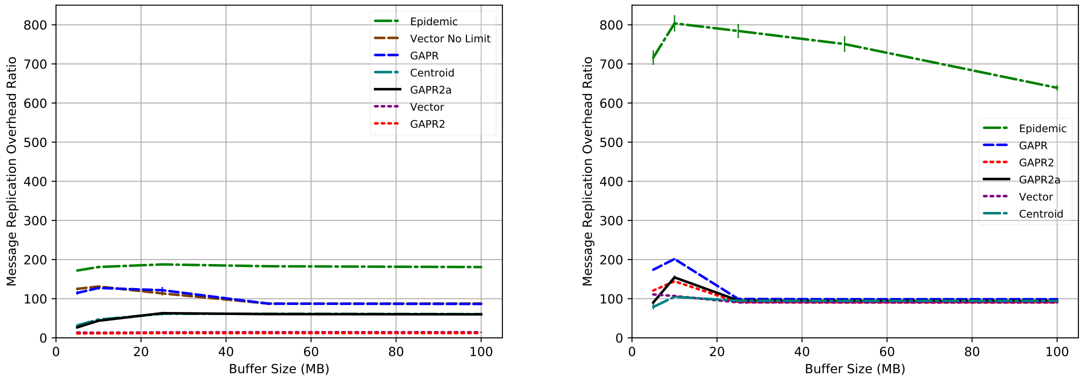


(a) ns-3

(b) ONE

Figure 5.15. Helsinki Message Replication Overhead Ratio vs. Buffer Size for 24 Mbps Base Radio in ONE and ns-3

Figure 5.16 illustrates message replication overhead for the 54 Mbps base radio. All protocols maintain similar trends in performance from the slower link speeds.



(a) ns-3

(b) ONE

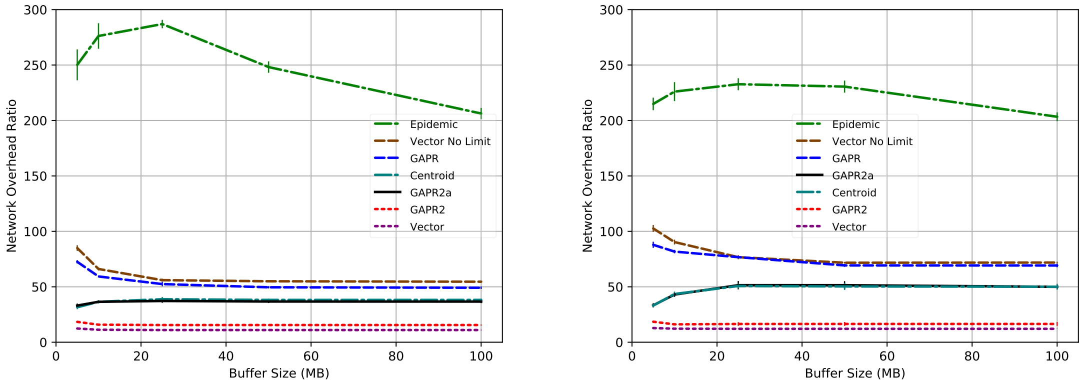
Figure 5.16. Helsinki Message Replication Overhead Ratio vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

In summary, buffer size and transmission speed affects message replication overhead. Protocols that limit message replication have lower message replication overhead. For the given message generation rate, message buffers less than 50 MB return the greatest change in overhead. Both simulators show that higher link speeds increase message replication overhead. Higher transmission speeds permits nodes to transfer more messages per interaction, so message replication increases. When constrained by buffer size, message replication overhead trends depend on the routing protocol.

5.1.6 Analysis of Network Overhead Ratio

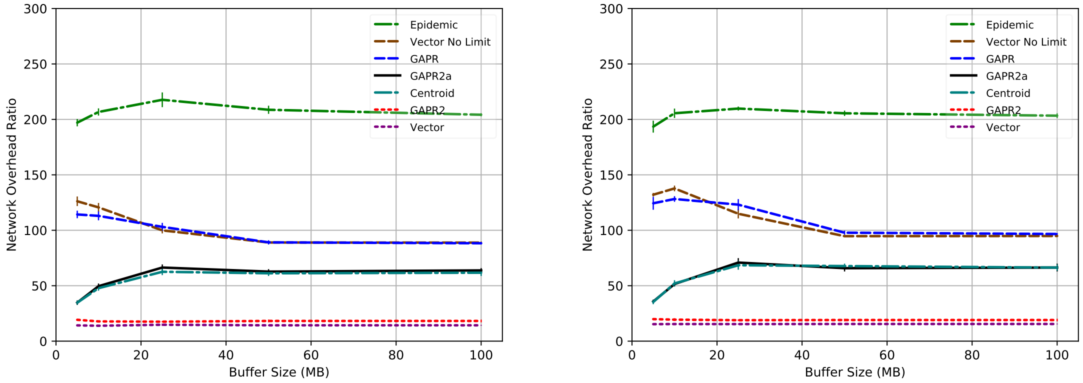
Network overhead includes message replication and control packets. The ONE does not generate network overhead, so all network overhead graphs are from ns-3. Figure 5.17 plots the network overhead for each base radio used in the Helsinki scenario. The trends in network overhead mirror the trends in message replication overhead. Since network overhead is a ratio of bytes transmitted divided by bytes of delivered messages, protocols with lower MDR tend to have higher network overhead. As a result, the network overhead graphs share similar trends as the MDR graphs. While control packets increase the overall overhead of a protocol, messages contain more data than control packets. Message replication contributes more to network overhead than control packets.

Like message replication overhead, higher transmission speeds result in higher network overhead. At message buffers less than 50 MB, protocols that do not limit message replication tend to have higher network overhead. Centroid's and GAPR2a's network overhead increases with buffer size until 25 MB. Vector and GAPR2 have similar overhead. GAPR and Vector without the message limit enables have similar overhead. However, GAPR2's network overhead is always slightly higher than Vector because of GAPR2's larger controls packets. GAPR2 uses the same message limit as Vector, but GAPR2 shares more information to make routing decisions. GAPR's network overhead is slightly higher than Vector without the message limit enabled for transmission speeds greater than 36 Mbps. GAPR2a's network overhead is lower than GAPR, but GAPR2's overhead is lower than GAPR2a.



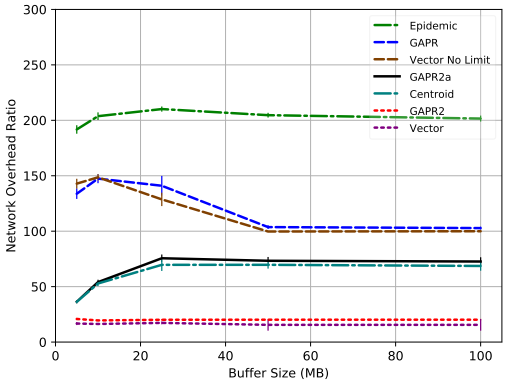
(a) 6-Mbps Base Radio

(b) 12-Mbps Base Radio



(c) 24-Mbps Base Radio

(d) 36-Mbps Base Radio



(e) 54-Mbps Base Radio

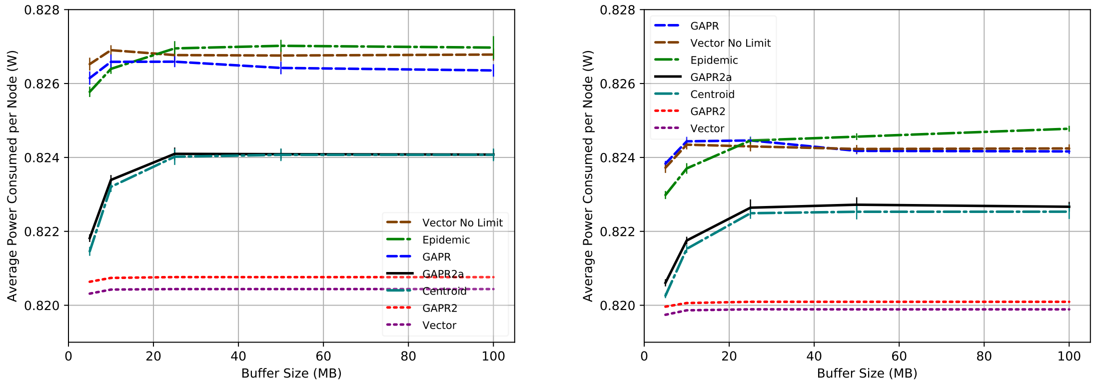
Figure 5.17. Helsinki Network Overhead Ratio vs. Buffer Size

5.1.7 Analysis of Average Power Consumption

ns-3's energy module collected the power consumed by selected nodes using the Wi-Fi radio energy model. Power consumption is a function of the radio's mode and corresponding current consumed in that mode. Figure 5.18 graphs the average power consumed per-node in watts for the Helsinki scenario. Since the radios use the same current for all transmission speeds, no conclusions about changes in power consumption between transmission speeds is possible. However, power consumption between protocols for a given transmission speed are comparable.

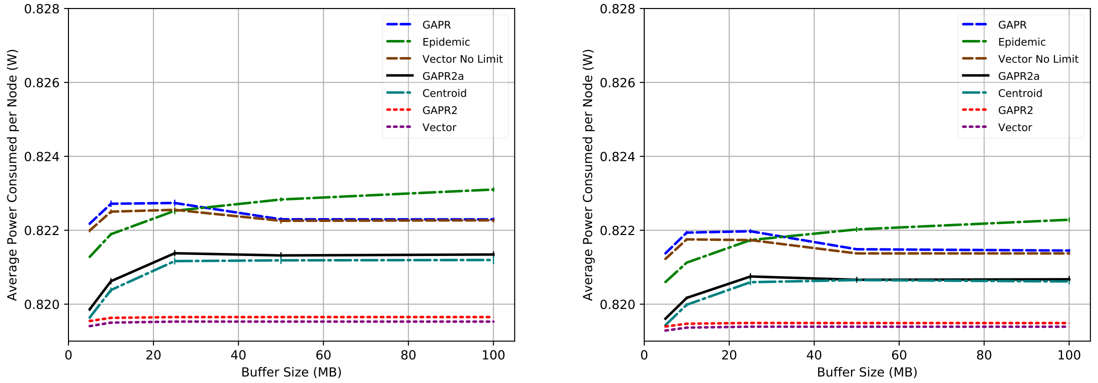
Message replication is a significant factor in energy consumption. Based on the observed trends, message replication influences power consumption. Protocols that transmit more messages consume more power. For protocols that limit message replication using the same message limit, the protocol that uses more control packets consumes more power. GAPR2a consumes more power than Centroid, and GAPR2 consumes more power than Vector. Node density and node mobility also affects power consumption. Denser network and higher node mobility can increase the number of node interactions. More frequent interactions increases the amount of shared routing information between nodes in a scenario. As a result, the radio remains in a transmit state longer with more frequent node interactions.

For message buffers less than 25 MB, GAPR consumes the most power followed by Vector without the message limit. Epidemic uses the third most power under 25 MB followed by Centroid. Vector uses the least amount of power followed by GAPR2. After 25 MB, Epidemic consumes the most power followed by GAPR and Vector with the message limit disabled. GAPR2 consumes more power than Vector, and GAPR2a consumes more power than Centroid. GAPR and Vector without the message limit use more power for buffers between 10 MB and 25 MB, but power consumption remains constant after 50 MB. Epidemic's power consumption increases with buffer size. GAPR2 and Vector maintain consistent power consumption for buffer sizes greater than 10 MB.



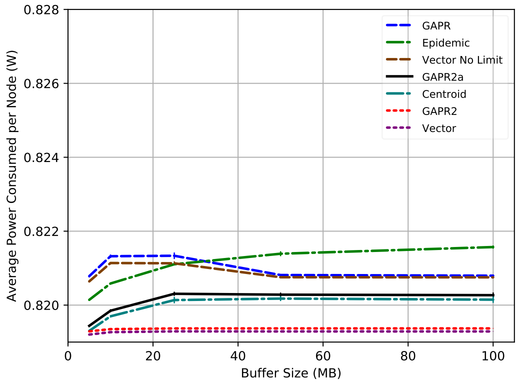
(a) 6-Mbps Base Radio

(b) 12-Mbps Base Radio



(c) 24-Mbps Base Radio

(d) 36-Mbps Base Radio



(e) 54-Mbps Base Radio

Figure 5.18. Helsinki Average Power Consumed per Node vs. Buffer Size

5.1.8 Helsinki Cross-Simulator Protocol Evaluation

While some protocols demonstrate similar performance between simulators, other protocols show significant differences. This subsection inspects the overall results of each protocol to compare performance between simulators. Each protocol contains a table showing the difference in performance in percentage. Section 4.4.2 covers the equation used to generate the tables. A positive percentage in MDR means that the ns-3 version has the higher MDR. A positive percentage in average latency means that the ns-3 version has the higher latency. A positive percentage in message replication overhead shows that the ns-3 version returned higher message replication overhead.

Epidemic

Table 5.1 shows that ns-3's Epidemic returns lower MDR, higher average latency, and lower message replication overhead. Both simulators show that Epidemic's MDR increases as buffer size increases. Link layer overhead and control packets reduce available bandwidth to share messages. The ONE does not include the time or bandwidth consumed by control packets, so the ONE version increases message replication because nodes have more time to share messages. ns-3's increased sensitivity to transmission speed and higher latency highlights the impact of the added overhead.

Table 5.1. Helsinki Epidemic Performance Difference between Simulators

	MDR					Average Latency					Message Replication Overhead Ratio				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-62%	-70%	-78%	-78%	-77%	-2.8%	27%	72%	82%	73%	-27%	-11%	50%	35%	43%
12 Mbps	-32%	-45%	-56%	-62%	-61%	-27%	-5.3%	48%	82%	99%	-56%	-50%	-27%	-15%	-14%
24 Mbps	11%	-10%	-25%	-31%	-36%	-38%	-23%	23%	66%	105%	-69%	-68%	-59%	-55%	-49%
36 Mbps	34%	12%	-2.7%	-12%	-20%	-44%	-29%	12%	56%	95%	-73%	-73%	-69%	-67%	-62%
54 Mbps	50%	38%	17%	8.9%	-4.2%	-47%	-32%	6.8%	42%	80%	-76%	-77%	-76%	-76%	-72%

Vector

ns-3's Vector returns lower MDR, higher average latency, and lower message replication overhead in Table 5.2. As previously discussed, link layer and control packet overhead reduces message replication. The difference in message replication is consistent across all transmission speeds and buffer sizes. Vector's average latency is 250% to 500% times higher in ns-3 than the ONE. The trends with respect to buffer size are the same between simulators. Vector's MDR increases asymptotically with increased buffer size. Average latency decreases exponentially with increased buffer size, and average hop count remains consistent. Vector's message replication overhead remains constant for all buffer sizes studied in Helsinki.

While ns-3's Vector follows similar trends to the ONE, ns-3's Vector returns a MDR significantly lower than the ONE. When the message buffer is greater than 25 MB, Vector returns equivalent performance to GAPR, GAPR2, GAPR2a, and Centroid in the ONE. However, ns-3's Vector is 17% lower than ns-3's GAPR, GAPR2, GAPR2a, and Centroid at the 6 Mbps base radio. As link speed increases, the gap between Vector and the other protocols decreases. At the 54 Mbps base radio, the gap shrinks to 6%. Link speed does not affect the message limit calculation, and node movements are identical between runs using the same movement map. Since average latency goes down and the MDR gap decreases with increases in link speed, the performance gap in ns-3 is due to control packets and link layer overhead reducing the available bandwidth. At higher link speeds, nodes can share more messages for a given contact time.

Table 5.2. Helsinki Vector Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-4.6%	-29%	-41%	-40%	-40%	250%	285%	300%	299%	299%	-90%	-90%	-88%	-88%	-88%
12 Mbps	25%	-5.3%	-26%	-26%	-26%	310%	387%	445%	447%	447%	-91%	-91%	-89%	-89%	-89%
24 Mbps	42%	11%	-19%	-19%	-19%	320%	418%	502%	499%	499%	-90%	-90%	-87%	-88%	-88%
36 Mbps	45%	14%	-16%	-16%	-16%	334%	423%	501%	502%	502%	-89%	-88%	-86%	-86%	-88%
54 Mbps	47%	19%	-14%	-14%	-14%	327%	409%	489%	487%	487%	-87%	-88%	-85%	-84%	-84%

Centroid

While Centroid's trends are similar between the two simulators, ns-3's Centroid returns lower MDR, higher average latency, and lower message replication overhead in Table 5.3. Centroid shows an asymptotic increase in MDR with buffer size. ns-3's average latency is 130% to 270% higher than the ONE. As buffer size increases, average latency decreases. Centroid's message replication overhead increases until the 25 MB buffer. The difference in message replication overhead between simulators is consistent for message buffers greater than 5 MB.

Table 5.3. Helsinki Centroid Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-11%	-16%	-24%	-22%	-22%	133%	212%	238%	234%	234%	-41%	-52%	-50%	-50%	-50%
12 Mbps	4.2%	-2.0%	-15%	-14%	-13%	153%	246%	269%	254%	253%	-54%	-57%	-30%	-32%	-32%
24 Mbps	18%	8.1%	-12%	-9.6%	-9.6%	156%	247%	261%	249%	224%	-59%	-58%	-41%	-42%	-42%
36 Mbps	25%	9.4%	-11%	-8.5%	-8.5%	162%	243%	247%	201%	207%	-59%	-56%	-36%	-37%	-38%
54 Mbps	26%	13%	-9.9%	-7.3%	-7.6%	154%	243%	237%	187%	189%	-59%	-55%	-36%	-35%	-35%

GAPR

As previously seen in other ns-3 protocols, ns-3's GAPR follows similar trends in ONE. GAPR's MDR increases with buffer size, and average latency decreases with buffer size. GAPR's average hop count increases with buffer size, and message replication overhead tends to decrease with larger message buffers. ns-3 returns lower MDR, higher latency, and lower message replication overhead. Table 5.4 illustrates the difference in performance between simulators. Average latency is 90% to 274% higher in ns-3, but larger message buffers and higher transmission speeds reduce the gap in performance. Larger message buffers and higher transmission speeds also reduce the gap in message replication overhead and MDR.

Table 5.4. Helsinki GAPR Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-46%	-30%	-20%	-17%	-18%	157%	274%	267%	251%	252%	-27%	-44%	-48%	-52%	-52%
12 Mbps	-32%	-20%	-16%	-12%	-12%	168%	233%	214%	179%	177%	-35%	-43%	-32%	-40%	-40%
24 Mbps	-26%	-14%	-9.1%	-8.4%	-7.7%	173%	183%	153%	124%	123%	-34%	-39%	-12%	-26%	-26%
36 Mbps	-21%	-13%	-9.9%	-7.6%	-8.0%	163%	171%	142%	105%	105%	-35%	-39%	6.2%	-18%	-18%
54 Mbps	-19%	-12%	-9.6%	-6.5%	-6.6%	151%	161%	131%	90%	90%	-34%	-37%	23%	-12%	-12%

GAPR2

Table 5.5 presents the difference in performance between the ONE and ns-3. GAPR2 returns lower MDR in ns-3, but both versions show that MDR increases as buffer size increases. ns-3's GAPR2 follows the ONE's GAPR2 trend in larger message buffers reducing average latency. Larger message buffers and higher transmission speeds reduce the performance gap. ns-3 average latencies are 178% to 492% higher than the ONE. GAPR2's message replication overhead is constant for all buffers in both simulators. The message replication overhead gap between simulators is like Vector.

Like ns-3's Vector, ns-3's GAPR2 returns a MDR significantly lower than the ONE. When the message buffer is greater than 25 MB, the ONE's GAPR returns equivalent performance to GAPR, GAPR2a, Vector, and Centroid. However, ns-3's GAPR is 18 percent lower than the other protocols at the 6 Mbps base radio. At the 54 Mbps base radio, the gap shrinks to 4 percent. Link speed does not affect the message limit calculation, and node movements are identical between runs using the same movement map. The difference in message replication overhead is consistent for all transmission speeds and buffer sizes. Like Vector, the performance gap in ns-3 is due to control packets and link layer overhead reducing the available bandwidth.

Table 5.5. Helsinki GAPR2 Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-54%	-44%	-42%	-42%	-42%	178%	350%	404%	401%	401%	-88%	-89%	-88%	-88%	-88%
12 Mbps	-42%	-29%	-25%	-25%	-25%	220%	387%	490%	492%	492%	-90%	-91%	-90%	-90%	-90%
24 Mbps	-33%	-20%	-17%	-16%	-16%	238%	368%	480%	476%	476%	-91%	-92%	-90%	-88%	-88%
36 Mbps	-31%	-17%	-14%	-14%	-14%	242%	351%	455%	455%	455%	-91%	-91%	-88%	-88%	-88%
54 Mbps	-29%	-15%	-12%	-12%	-12%	243%	343%	429%	429%	429%	-91%	-92%	-87%	-87%	-87%

GAPR2a

Table 5.6 illustrates the performance gap between ns-3 and the ONE. Both GAPR2a version show similar overall trends, but the ns-3 version returns lower MDR, higher average latency, and lower message replication overhead. Both versions of GAPR2a show MDR increases with larger message buffers and higher transmission speeds. As transmission speed and buffer size increases, the gap in MDR between the ONE and ns-3 decreases. Both simulators show that larger buffer and higher transmission speeds decrease average latency, but ns-3's average latency is 122% to 245% higher than the ONE. The ONE and ns-3 show that message replication overhead increases with larger buffers until 25 MB, but ns-3 has lower message replication overhead. Larger message buffers and higher transmission speeds decrease the gap in message replication overhead between simulators.

Table 5.6. Helsinki GAPR2a Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-45%	-29%	-19%	-19%	-19%	122%	245%	245%	240%	240%	-42%	-55%	-56%	-56%	-56%
12 Mbps	-32%	-20%	-12%	-12%	-11%	141%	233%	218%	196%	198%	-60%	-64%	-51%	-51%	-52%
24 Mbps	-25%	-14%	-9.2%	-7.6%	-8.4%	147%	204%	175%	153%	151%	-66%	-69%	-42%	-44%	-44%
36 Mbps	-22%	-12%	-7.6%	-6.2%	-6.6%	145%	187%	159%	141%	141%	-70%	-71%	-38%	-42%	-42%
54 Mbps	-20%	-11%	-6.9%	-6.6%	-6.5%	141%	178%	145%	122%	123%	-70%	-71%	-34%	-36%	-37%

5.2 Bold Alligator Scenario

Kevin Killeen developed Bold Alligator to study DTN performance in military environments. Bold Alligator constrains two variables. First, Marine and drone node buffer sizes are 5, 10, 25, and 50 MB. Humvee, LCAC, and helicopter message buffers are ten times the size of the Marine node buffer. Ship message buffers are one hundred times the size of the Marine buffer. A randomly selected Marine node generates a 250 KB to 500 KB message using a uniform random number generator every 5 to 10 seconds. A randomly selected Humvee generates a 500 KB to 1 MB message every 10 to 20 seconds, and a randomly selected Ship generates a 500 KB to 1 MB message every 25 to 35 seconds. A node stores 5 to 20 messages for every 5 MB of buffer. Compared to the other scenarios, Bold Alligator generates significantly more messages.

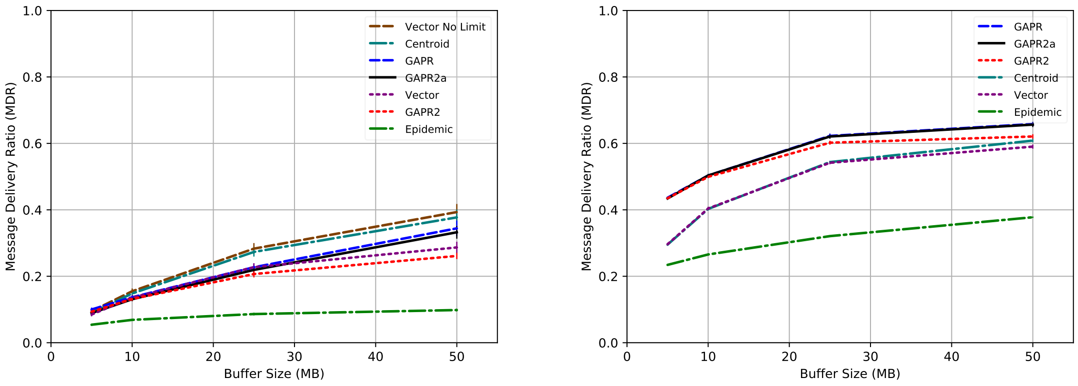
Link speed is the second constrained parameter. Bold Alligator constrains Marine node transmission speeds to 12, 24, 36, and 54 Mbps. Varying the transmission and buffer speeds provides insight into how resources affect protocol performance. Transmission speed affects the number of messages transferred between two connected nodes for a given contact time. Constrained buffers test a protocol's message replacement strategy. Bold Alligator generates more data than Helsinki, so Bold Alligator does not provide an effectively infinite buffer. The length of a Bold Alligator simulation with the 100 MB base buffer in ns-3 is too long to complete in the allotted time. Future work could simulate Bold Alligator with the 100 MB buffer. Instead, Bold Alligator focuses on protocol performance at constrained buffer sizes only.

5.2.1 Data Presentation

The Bold Alligator ONE graphs derive from 960 simulation runs, and each ONE data point is the mean of 10 runs. ns-3 executed 896 simulation runs, and each graph data point is the mean of 8 runs. A ninety-five percent confidence interval generates the error bars for each data point. ns-3's simulation time prevented executing 10 runs per data point, but the confidence interval for each data point is acceptable. The ns-3 error bars are less than 10% for the data point's value, and the ONE's error bars are less than 5% of a data point. Most error bars in the ONE graphs are too small to see. The ONE and ns-3 graphs are side-by-side to demonstrate the similarities and differences between the two simulators.

5.2.2 Analysis of Message Delivery Ratio

Like Helsinki, no protocol delivers all messages because the scenario continues to generate messages until the simulation ends. Messages generated at the end of the simulation have insufficient time to reach its destination. Figure 5.19 plots message delivery ratio versus standard message buffer size in ns-3 and the ONE with the 12 Mbps standard radio. Both simulators show message delivery increases with buffer size. Larger message buffers permit nodes to store more messages, so more messages can propagate throughout the network. As a result, MDR increases with increasing buffer size. As previously seen in Helsinki, all ns-3 protocols return lower MDRs than the ONE.

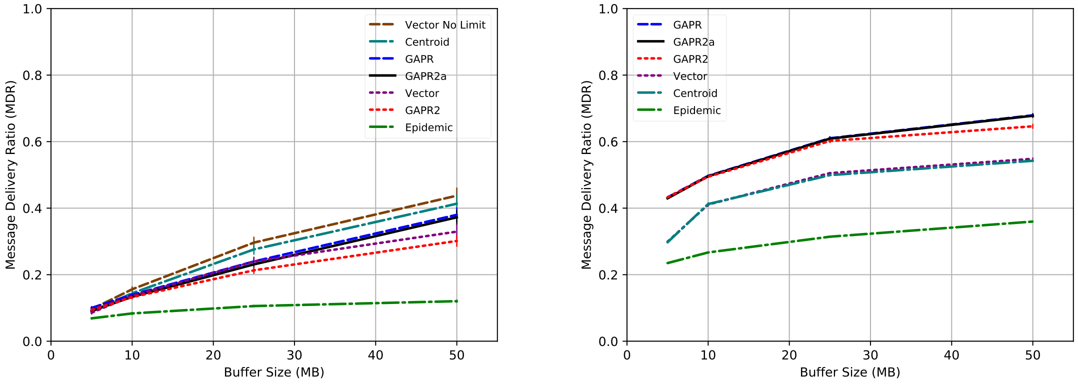


(a) ns-3

(b) ONE

Figure 5.19. Bold Alligator MDR vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

From 24 Mbps to 54 Mbps, the ONE and ns-3 protocols show minor increases in MDR. The 24 Mbps and 36 Mbps graphs are available in the appendices. Figure 5.20 shows the small increase in MDR for the 54 Mbps link. GAPR2a provides similar performance to GAPR in both simulators. ns-3's Centroid performs better GAPR, and Vector performs better than GAPR2. GAPR, GAPR2, and GAPR2a return a similar MDR in the ONE. Higher transmission speeds permit nodes to transfer more messages per interaction, so message delivery increases with higher transmission speeds.



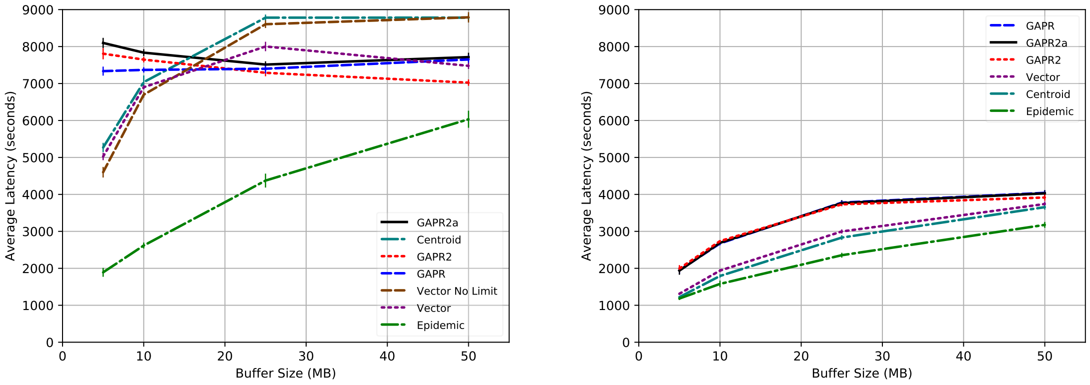
(a) ns-3

(b) ONE

Figure 5.20. Bold Alligator MDR vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.2.3 Analysis of Average Latency

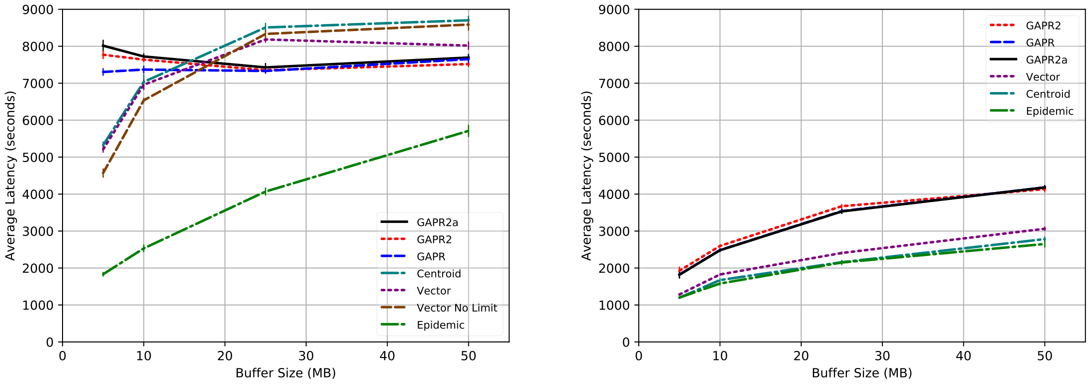
Figure 5.21 plots average latency versus standard buffer size in the ONE and ns-3. All ns-3 protocols experience higher average latencies than the ONE. Vector and Epidemic show an asymptotic increase in both simulators. GAPR2's and GAPR2a's average latency decreases with buffer size in ns-3, but the ONE shows an asymptotic increase. The ONE's GAPR illustrates an asymptotic increase, but ns-3 shows average latency increases slightly with buffer size.



(a) ns-3 (b) ONE

Figure 5.21. Bold Alligator Average Latency vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

The 24 Mbps, 36 Mbps, and 54 Mbps radios continue the same trends from the 12 Mbps link. The higher transmission speeds return small changes in average latency. Figure 5.22 shows average latency for the 54 Mbps base radio. The 24 Mbps and 36 Mbps graphs are available in the appendices.



(a) ns-3 (b) ONE

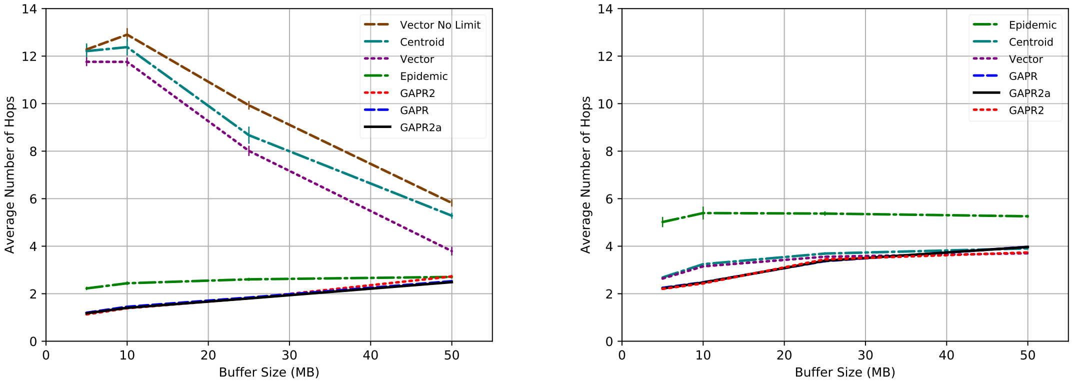
Figure 5.22. Bold Alligator Average Latency vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.2.4 Analysis of Average Hop Count

The line graphs in Figure 5.23 compare average hop count versus buffer size for 12 Mbps base radio. Epidemic shows a similar trend in average hop count in both simulators, but ns-3's Epidemic traverses fewer hops on average compared to the ONE. GAPR, GAPR2, and GAPR2a show that average hop count increases with buffer size in both simulators. Vector and Centroid return significantly different results between the ONE and ns-3. ns-3 shows that average hop count decreases with larger buffers, and ns-3's average hop count is nearly double the average hop count in the ONE. In contrast, the ONE's Vector and Centroid show that average hop count increases with large buffers.

Upon further investigation, ns-3's higher average hop count at small buffers is due to messages circling within clusters of nodes. Bold Alligator forms clusters of nodes that have limited mobility and a few nodes with a large amount of mobility. As a cluster of nodes pass messages, limited buffers force the FIFO buffer management algorithm to remove the oldest message and replace it with the new message. This allows a node to receive and transmit the same message multiple times within the same cluster of nodes. With larger message buffers, nodes replace fewer messages, so the average hop count decreases. The ns-3 GAPR family of protocols does not show this behavior in average hop count because they do not use FIFO. GAPR removes messages according to hop count and delivery probability, so nodes drop high hop count messages first. While the GAPR family of protocols do not show this behavior in average hop count, they do show the behavior in message replication overhead.

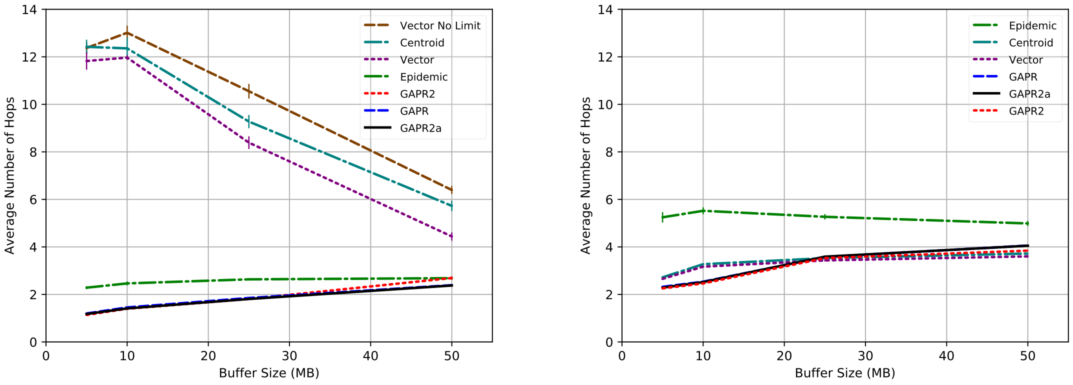
The ONE does not show this behavior because the ONE's Centroid, Vector, GAPR, GAPR2, and GAPR2a determine if a message has traversed the other node. If a message has traversed the other node, then the node does not transmit the message [9], [10]. As a result, messages do not circle around a cluster of nodes like ns-3. The ONE's Epidemic does not check if a message has traversed another node before transmitting, so ns-3's Epidemic matches the ONE. Epidemic's average hop count increases with increasing buffer size because all messages cannot be sent during the limited contact opportunities.



(a) ns-3 (b) ONE

Figure 5.23. Bold Alligator Average Hop Count vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

Figure 5.24 compares average hop count for 54 Mbps base radio. Both simulators continue the same trends observed at the lower transmission speed, and protocols show minimal change in average hop count with the higher transmission speed. The 24 Mbps and 36 Mbps base radio average hop count graphs are available in the graph appendices.



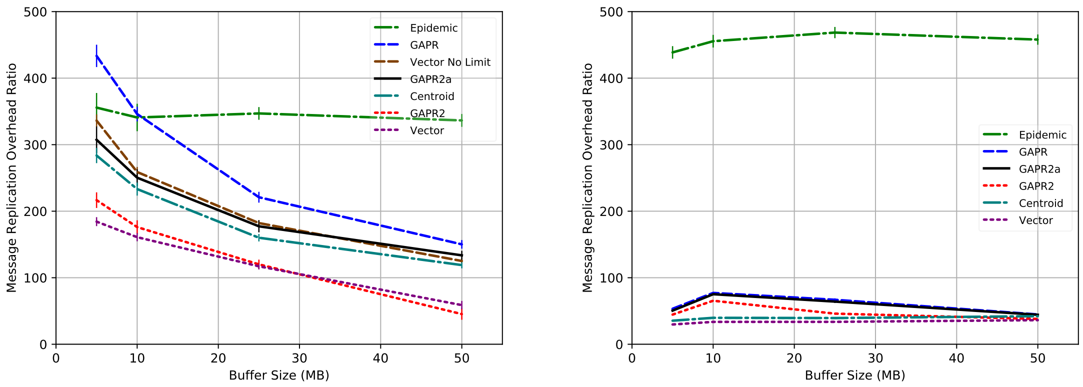
(a) ns-3 (b) ONE

Figure 5.24. Bold Alligator Average Hop Count vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.2.5 Analysis of Message Replication Overhead Ratio

As previously seen in Helsinki, protocols that limit message replication have lower message replication overhead. Figure 5.25 plots message replication overhead versus buffer size for the 12 Mbps base radio. All ns-3 protocols, except for Epidemic, have higher message replication overhead than the ONE. As previously discussed in the average hop count analysis section, the ns-3 protocols have messages circle within clusters of nodes. The ONE's GAPR, GAPR2, GAPR2a, Vector, and Centroid do not transfer a message to another node if the message already traversed the other node. The ONE's Epidemic does not perform this check. As a result, Epidemic shows lower message replication in ns-3 than the ONE.

The added message replication increases the message replication overhead for all ns-3 protocols except for Epidemic. As buffer size increases, the message replication overhead decreases because nodes can store more messages. As a result, nodes remove messages from their buffers less frequently. While the trends between ns-3 and the ONE are different, both simulator shows that GAPR2a has higher message replication overhead then GAPR2. Epidemic has the largest message replication overhead for message buffers greater than 10 MB.

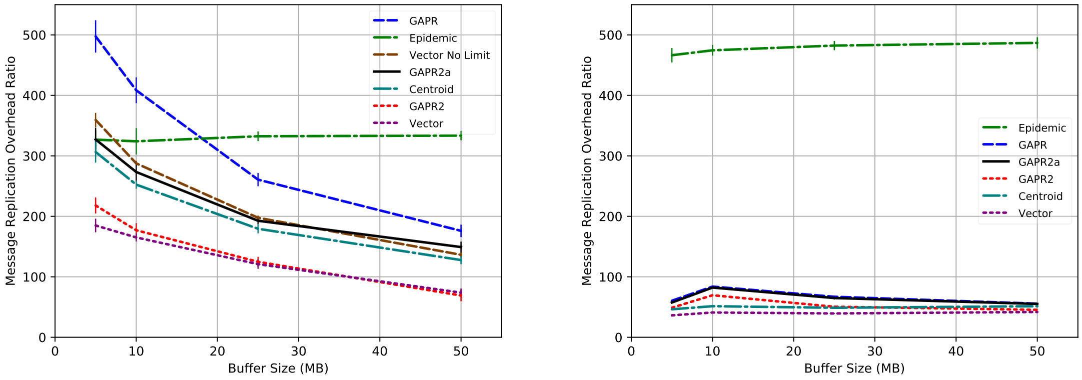


(a) ns-3

(b) ONE

Figure 5.25. Bold Alligator Message Replication Overhead Ratio vs. Buffer Size for 12 Mbps Base Radio in ONE and ns-3

For the 54 Mbps base radio, Figure 5.26 continues previously observed trends in the 12 Mbps base radio. However, both simulators show that faster radios increase message replication overhead. The 24 Mbps and 36 Mbps radios show incremental increases in message replication overhead, and they maintain the trends from the 12 Mbps radio. The 24 Mbps and 36 Mbps message replication overhead graphs are available in the graph appendices.



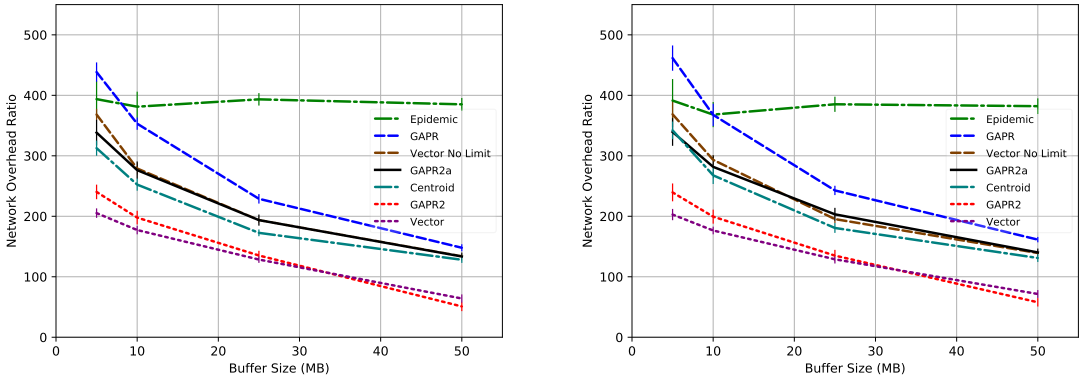
(a) ns-3

(b) ONE

Figure 5.26. Bold Alligator Message Replication Overhead Ratio vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

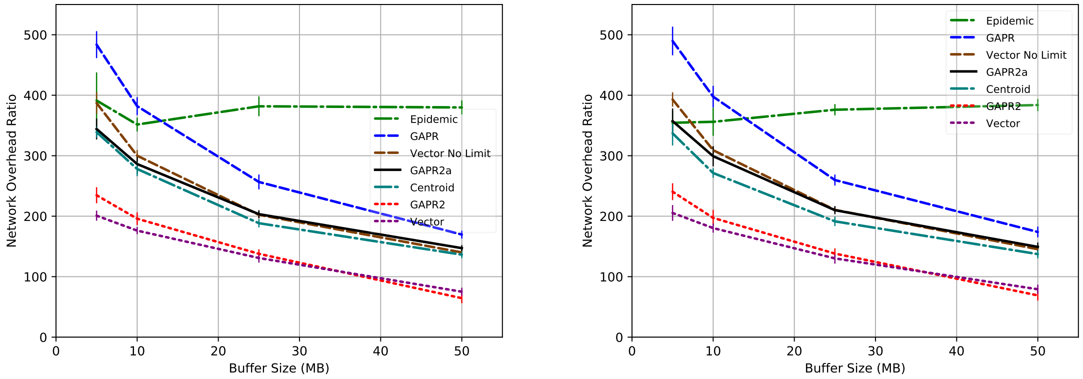
5.2.6 Analysis of Network Overhead Ratio

The network overhead graphs in Figure 5.27 follows the same trends as the message replication overhead graphs for ns-3. The ONE does not generate the network overhead metric. Since network overhead is the bytes transmitted divided the bytes of data delivered, protocols with higher message replication overhead have higher network overhead. While control packets increase the amount of transmitted data, messages are larger than control packets. As a result, message replication contributes more to network overhead than control packets.



(a) 12-Mbps Base Radio

(b) 24-Mbps Base Radio



(c) 36-Mbps Base Radio

(d) 54-Mbps Base Radio

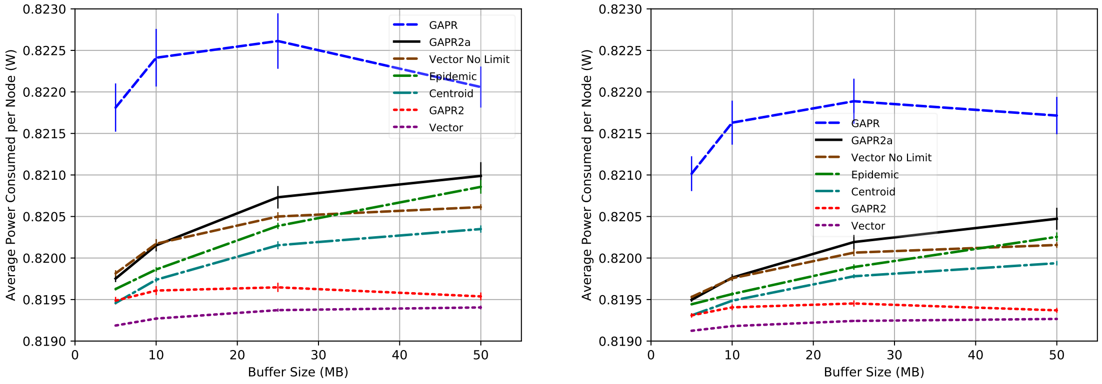
Figure 5.27. Bold Alligator Network Overhead Ratio vs. Buffer Size

5.2.7 Analysis of Average Power Consumption

ns-3's energy module determines power consumption as a function of the radio's mode and corresponding current consumed in that mode. A radio consumes more power transmitting a message than receiving a message. Figure 5.28 graphs the average power consumed in watts per node. Since the radios use the same current for all transmission speeds, no conclusion about changes in power consumption between transmission speeds is possible. However, power consumption between protocols for a given transmission speed is comparable.

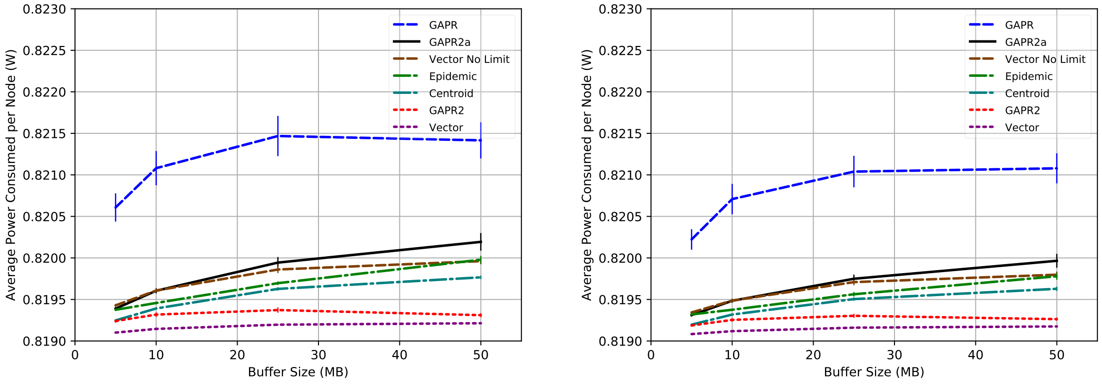
GAPR consumes the most power in ns-3, and Vector consumes the least amount of power.

GAPR2a consumes less power than GAPR, but GAPR2a consumes more power than GAPR2. When comparing protocols that employ the same message limit technique, the protocol with the larger control packets consume more power. GAPR2 and Vector use the same message limit algorithm, but GAPR2 consumes more power than Vector. Centroid and GAPR2a determine the message limit based on the distance between centroids, but GAPR2a consumes more power than Centroid. GAPR and Vector with message limit disabled do not limit message replication, but GAPR consumes more power than Vector with the message limit disabled.



(a) 12-Mbps Base Radio

(b) 24-Mbps Base Radio



(c) 36-Mbps Base Radio

(d) 54-Mbps Base Radio

Figure 5.28. Bold Alligator Average Power Consumed per Node vs. Buffer Size

5.2.8 Bold Alligator Cross-Simulator Protocol Evaluation

The ns-3 protocols demonstrate significant differences from the equivalent ONE versions. As previously discussed in the average hop count and message replication overhead sections, some ONE protocols prevent nodes from transmitting a message that previously traversed the other node. The behavior affects Vector, Centroid, GAPR, GAPR2, and GAPR2a. This section compares the protocol performance between simulators in percent difference. Section 4.4.2 covers the equation used to derive the tables.

Epidemic

In ns-3 and the ONE, Epidemic's MDR and average latency increase asymptotically with buffer size. Epidemic's average hop count increases from the 5 MB to 10 MB buffer, but Epidemic shows minimal change in average hop count for larger message buffers in both simulators. Message replication overhead in the ONE and ns-3 follow the same trend. Larger message buffers return minimal change in message replication overhead.

While both versions of Epidemic share trends, ns-3 consistently returns lower MDR, higher average latency, and lower message replication overhead. To illustrate this observation, Table 5.7 contains the percent difference between ns-3 and the ONE. ns-3's MDR is 66% to 74% percent lower than the ONE. Average latency is 52% to 108% higher. As buffer size increases, the difference in average latency between ns-3 and the ONE increases. Message replication overhead is 19% to 31% lower in ns-3. Larger message buffers and higher speed radios increase the message replication overhead performance gap between simulators.

Table 5.7. Bold Alligator Epidemic Performance Difference between Simulators

	MDR				**Average Latency**				**Message Replication Overhead Ratio**			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-77%	-74%	-73%	-74%	60%	66%	86%	90%	-19%	-25%	-26%	-27%
24 Mbps	-74%	-71%	-69%	-70%	58%	56%	96%	99%	-21%	-28%	-29%	-29%
36 Mbps	-72%	-70%	-67%	-68%	52%	60%	92%	108%	-21%	-32%	-29%	-31%
54 Mbps	-71%	-69%	-66%	-67%	53%	60%	89%	100%	-30%	-32%	-31%	-31%

Centroid

Centroid shows that MDR increases asymptotically with increasing buffer size, but ns-3's MDR is 24% to 70% lower than the ONE. Average latency increases asymptotically with larger message buffers, but ns-3's average latency is higher. As previously discussed, the ONE version does not have nodes retransmit a message that previously traversed the other node. As a result, ns-3's Centroid shows message replication overhead and average hop count decrease with larger message buffers. In Table 5.8, message replication overhead is up 709% higher in ns-3. In contrast, the ONE shows average hop count increases with larger message buffers, and message replication overhead is constant across all buffer sizes.

Table 5.8. Bold Alligator Centroid Performance Difference between Simulators

	MDR				**Average Latency**				**Message Replication Overhead Ratio**			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-70%	-63%	-50%	-38%	332%	293%	210%	140%	709%	497%	310%	183%
24 Mbps	-70%	-65%	-45%	-31%	338%	311%	254%	162%	656%	464%	300%	163%
36 Mbps	-69%	-65%	-44%	-25%	336%	314%	282%	192%	605%	438%	289%	163%
54 Mbps	-70%	-65%	-45%	-24%	344%	320%	294%	212%	565%	394%	273%	149%

GAPR

Table 5.9 shows the difference in performance between the ONE and ns-3 for GAPR. ns-3's GAPR returns lower MDR than the ONE. Average latency is lower in the ONE. GAPR's message buffer algorithm prioritizes messages with lower hop counts and higher delivery probability. Nodes remove messages with high hop counts first, so the effect of messages circling clusters of nodes does not affect average hop count. However, nodes will continuously attempt to retransmit the same message because its neighbor node will not store the high hop count message. As a result, message replication is higher in ns-3. Due to GAPR's message priority algorithm, both simulators show that average hop count increases with larger message buffers.

Table 5.9. Bold Alligator GAPR Performance Difference between Simulators

	MDR				**Average Latency**				**Message Replication Overhead Ratio**			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-77%	-73%	-64%	-48%	276%	176%	96%	89%	717%	349%	235%	241%
24 Mbps	-77%	-72%	-62%	-45%	286%	186%	101%	85%	718%	370%	262%	233%
36 Mbps	-77%	-72%	-61%	-45%	293%	190%	105%	83%	730%	372%	290%	223%
54 Mbps	-77%	-72%	-61%	-44%	300%	197%	107%	83%	728%	386%	288%	214%

GAPR2

Like GAPR, GAPR2 shows different trends between ns-3 and the ONE. Both simulators show that GAPR2's MDR increases with larger message buffers, and average hop count increases with larger message buffers. However, messages replication overhead trends are different. ns-3's message replication is higher and displays steep reduction in message replication overhead with larger message buffers. In contrast, the ONE shows a small decrease in message replication for larger message buffers greater than 10 MB. Table 5.10 shows the performance gap in percent. ns-3's MDR is lower, but larger message buffers reduce the performance gap. Average latency is higher in ns-3, but larger message buffers reduce the difference in average latency between simulators. ns-3 shows significantly higher message replication overhead at small buffer sizes, but the gap between ns-3 and the ONE is reduced with larger message buffers.

Table 5.10. Bold Alligator GAPR2 Performance Difference between Simulators

	MDR				**Average Latency**				**Message Replication Overhead Ratio**			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-78%	-74%	-66%	-58%	292%	179%	95%	79%	380%	170%	161%	18%
24 Mbps	-79%	-73%	-66%	-56%	296%	185%	94%	80%	360%	166%	142%	32%
36 Mbps	-78%	-73%	-65%	-54%	303%	188%	98%	80%	342%	157%	148%	41%
54 Mbps	-78%	-73%	-65%	-53%	304%	194%	100%	82%	342%	151%	143%	53%

GAPR2a

GAPR2a uses the same message priority algorithm as GAPR, and ns-3's GAPR2a does retransmit messages to a node that previously traversed the other node. ns-3 shows a steep decrease in message replication overhead with larger message buffers, but the ONE shows a slight decrease in message replication overhead with larger message buffers. Like GAPR, average hop count trends between ns-3 and the ONE are similar because GAPR2a prioritizes messages with low hop counts. Both versions of GAPR2a show that MDR increases asymptotically with larger message buffers. In Table 5.11, ns-3 returns lower MDR and higher average latency. Larger message buffers decrease the performance gap between ns-3 and the ONE for MDR and average latency.

Table 5.11. Bold Alligator GAPR2a Performance Difference between Simulators

	MDR				Average Latency				Message Replication Overhead Ratio			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-79%	-74%	-65%	-49%	318%	191%	100%	92%	502%	233%	177%	202%
24 Mbps	-79%	-73%	-63%	-47%	330%	201%	102%	88%	472%	228%	186%	186%
36 Mbps	-79%	-73%	-63%	-46%	336%	205%	108%	84%	469%	230%	195%	181%
54 Mbps	-79%	-73%	-62%	-45%	341%	211%	110%	84%	473%	233%	200%	187%

Vector

For Vector, MDR increases asymptotically with increasing buffer size. Average latency increases asymptotically with larger message buffer. While both simulators share the same trends in MDR and average latency, they deviate in average hop count and message replication overhead. The ONE's version does not have nodes retransmit a message that previously traversed the other node. As a result, ns-3's Vector shows message replication overhead and average hop count decrease with larger message buffers. In contrast, the ONE shows average hop count increases with larger message buffers and message replication overhead is constant. Table 5.12 shows the percent difference between the two simulators. ns-3's MDR is 40% to 71% lower than the ONE. ns-3 returns higher average latency. Message replication overhead is up 513% higher in ns-3.

Table 5.12. Bold Alligator Vector Performance Difference between Simulators

	MDR				Average Latency				Message Replication Overhead Ratio			
	5 MB	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**
12 Mbps	-71%	-66%	-58%	-51%	283%	256%	167%	100%	513%	371%	244%	61%
24 Mbps	-71%	-67%	-54%	-46%	289%	269%	206%	122%	452%	344%	240%	74%
36 Mbps	-71%	-66%	-53%	-42%	297%	274%	231%	145%	417%	313%	227%	73%
54 Mbps	-71%	-67%	-52%	-40%	306%	281%	240%	162%	414%	302%	207%	78%

5.3 Omaha Scenario

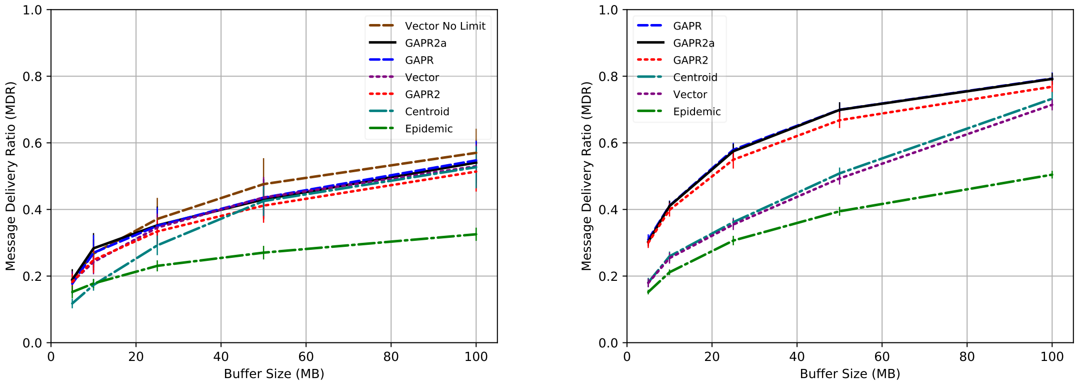
Omaha is another military based scenario for studying DTN performance. The simulation varies base node message buffers from 5 MB to 100 MB for a given link speed. Ship message buffers are ten times the size of the base node buffer. Transmission speed varies from 6 Mbps to 54 Mbps for all nodes, and all nodes have the same transmission range. A randomly selected node generates a 500 KB to 1 MB message using a uniform random number generator every 25 to 35 seconds. As a result, the average message size is 750 KB with a message generated every 30 seconds. While Omaha uses the same message generation rate as Helsinki, Omaha contains fewer nodes.

5.3.1 Data Presentation

The Omaha scenario contains 1800 simulation runs in the ONE, and each data point is the mean of 12 runs. 1750 ns-3 simulation runs generated the ns-3 graphs, and each data point is the mean of 10 runs. A ninety-five percent confidence interval calculates the error bars for each data point. Some graphs contain points with larger than desired error bars. Increasing from 10 runs per data point to 12 runs per data resulted in little change in error for ONE. The ns-3 error bars at 10 runs are comparable to the ONE. Within each set of figures, the graphs illustrate the effects of buffer size for the given metric.

5.3.2 Analysis of Message Delivery Ratio

The MDR graphs for the 6 Mbps radio in Figure 5.29 follow similar trends to Bold Alligator. All protocols show an asymptotic increase in MDR as buffer size increases. All ns-3 protocols return lower MDR compared to the ONE. GAPR, GAPR2, and GAPR2a error bars are too large to identify the best performing protocols in both simulators. Epidemic performs the worst in both simulators. At message buffers greater than 25 MB, Centroid's and Vector's error bars overlap in ns-3. Centroid and Vector have similar performance in ONE.

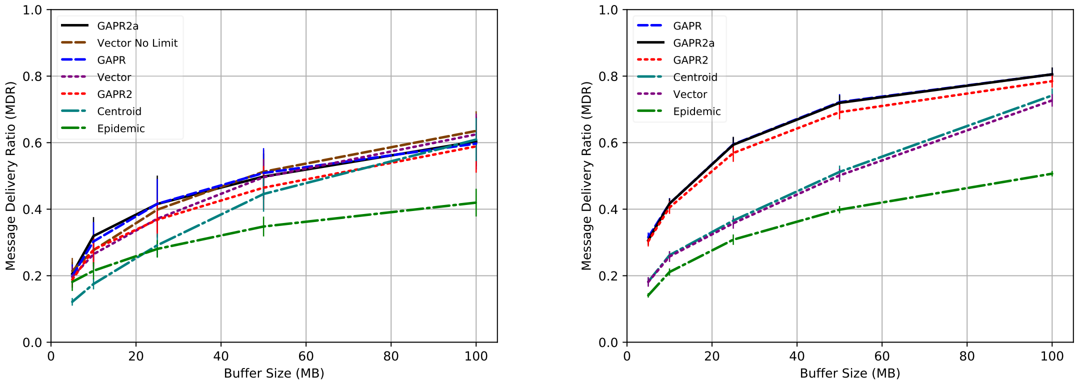


(a) ns-3

(b) ONE

Figure 5.29. Omaha MDR vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

The ONE shows little change in MDR from the 12 Mbps to 54 Mbps radio. All protocols continue the same trends observed from the 6 Mbps radio. While the ONE demonstrated little change in MDR at higher transmission speeds, ns-3 returned incremental increase in MDR with higher transmission speeds. Figure 5.30 plots the 54 Mbps radio, and the graph appendices contain the 12, 24, and 36 Mbps radio graphs. Larger message buffer permit nodes to store more messages, so messages have a higher probability of delivery. Higher transmission speeds permit nodes to transfer more messages per interaction, so MDR increases.

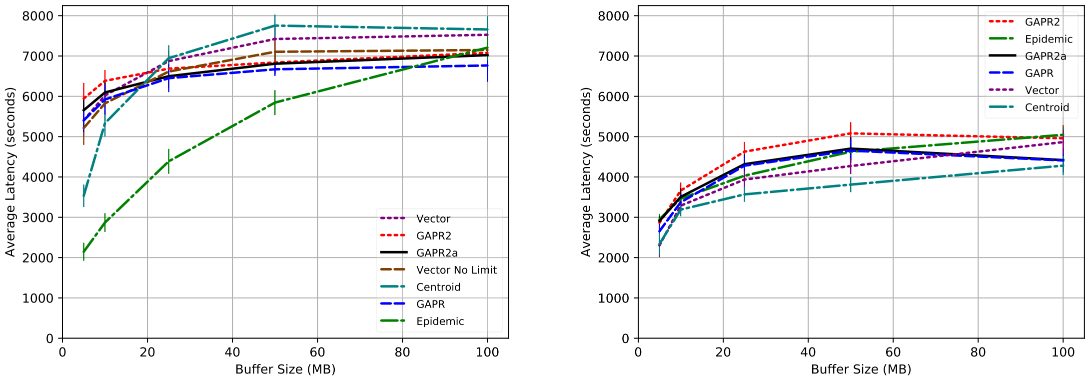


(a) ns-3 (b) ONE

Figure 5.30. Omaha MDR vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.3.3 Analysis of Average Latency

Figure 5.31 plots average latency versus buffer size in the ONE and ns-3. All protocols show that average latency increases asymptotically with larger message buffers. All ns-3 protocols have higher latency than the ONE. GAPR, GAPR2, and GAPR2a experience similar latency. ns-3's Centroid performs worse than Vector at message buffers less than 25 MB, but Centroid performs like Vector at message buffers greater than 25 MB. In the ONE, Vector and Centroid return similar performance.

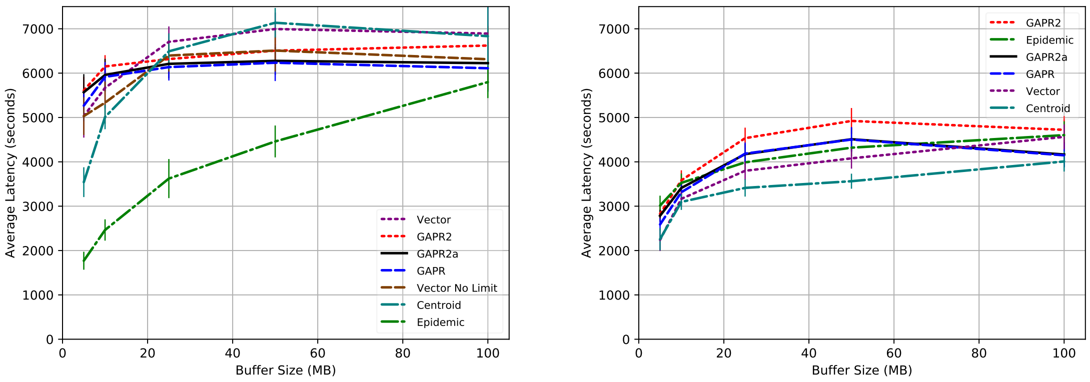


(a) ns-3

(b) ONE

Figure 5.31. Omaha Average Latency vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

From the 12 Mbps radio to the 54 Mbps radio, average latency trends remain unchanged in both simulators. Figure 5.32 plots the 54 Mbps radio. The higher transmission speeds incrementally lowered average latency, but the change in average latency is not as large as the Helsinki scenario. The 12, 24, 36, and 54 Mbps graphs are available in the graph appendices. When unconstrained by buffer size, node mobility determines average latency. Larger message buffers and higher transmission speeds increase average latency because more messages are delivered.



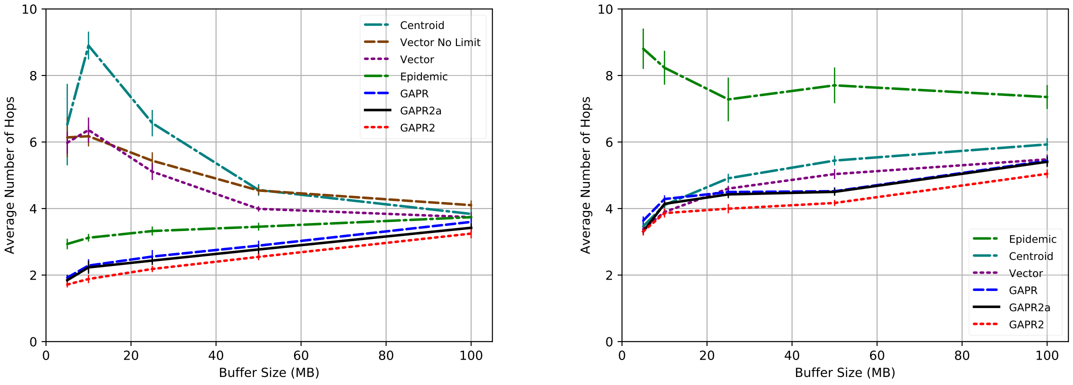
(a) ns-3 (b) ONE

Figure 5.32. Omaha Average Latency vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.3.4 Analysis of Average Hop Count

The graphs in Figure 5.33 compare average hop count versus buffer size for 6 Mbps radio. The GAPR protocols show that buffer size increases average hop count in both simulators, but the ns-3 version traverses fewer hops. ns-3's Centroid and Vector show that hop count decreases with larger buffers, but ONE versions show hop count increasing with buffer size. ns-3's Centroid and Vector traverse more hops than the ONE. The ONE's Epidemic traverses more hops than ns-3's Epidemic.

ns-3's higher average hop count at small buffers is due to messages circling within clusters of nodes. Like Bold Alligator, some nodes form clusters in the Omaha scenario. As a cluster of nodes pass messages, limited buffers force the FIFO buffer management algorithm to remove the oldest message and replace it with the new message. This allows a node to receive and transmit the same message multiple times within the same cluster of nodes. With larger message buffers, nodes replace fewer messages, so the average hop count decreases. The ns-3 GAPR family of protocols did not show this behavior because they do not use FIFO. GAPR removes messages according to hop count and delivery probability, so nodes drop high hop count messages first. As a result, ns-3's GAPR does not show Centroids or Vector's behavior. The ONE versions determine if a message has traversed the other node before. If the message has traversed the other node, then the node does not transmit the message [9], [10]. As a result, the message does not cycle through a cluster of nodes like ns-3. All ONE GAPR protocols contain this check, but the ONE's Epidemic does not check if a message has traversed another node before. The 12 Mbps radio continues the same trends, but average hop count increases. The 12 Mbps average hop count graphs are located in the Omaha graphs appendix.

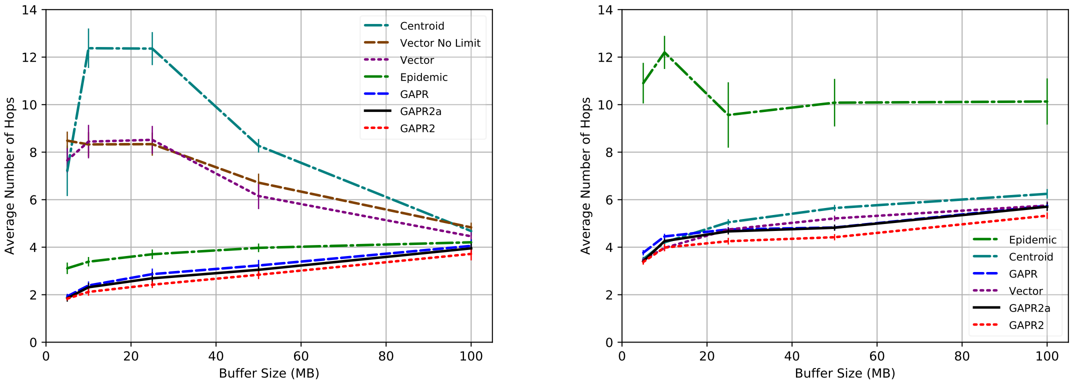


(a) ns-3

(b) ONE

Figure 5.33. Omaha Average Hop Count vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

At 24 Mbps in Figure 5.34, the overall trend in average hop count remains like the slower link speeds. All protocols show a slight increase in average hop count in both simulators. Most ONE protocols converge towards 5 to 6 hops, but the ns-3 protocols converge towards 4 to 5 hops. The 36 Mbps radio continues the same trends, but average hop count increases slightly. The 36 Mbps radio graphs are located in the Omaha graphs appendix.

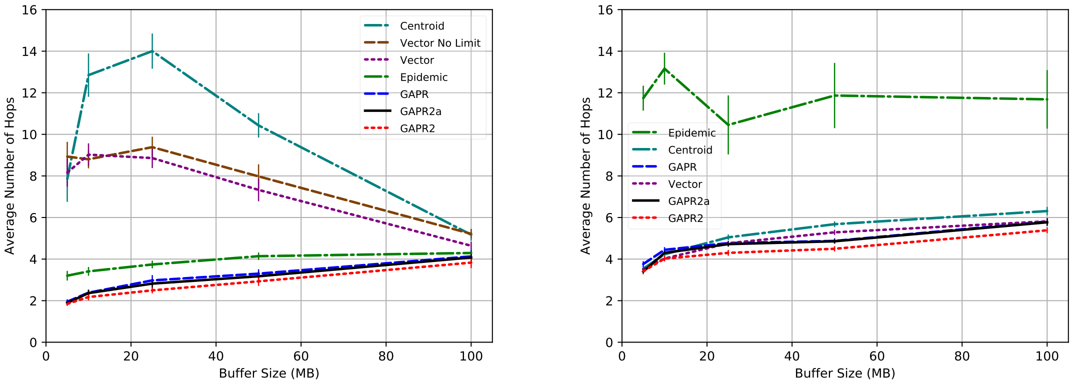


(a) ns-3

(b) ONE

Figure 5.34. Omaha Average Hop Count vs. Buffer Size for 24 Mbps Base Radio in ONE and ns-3

For the 54 Mbps radio in Figure 5.35, ns-3's Vector and Centroid continue to show different trends in average hop count from the ONE. ns-3's Vector and Centroid show that average hop count decreases with increased buffer size, but the ONE's Vector and Centroid show that average hop count increases with larger message buffers. The GAPR family of protocols show that average hop count increases with larger message buffer in the ONE and ns-3. Compared the 36 Mbps radio, all protocols show little change in average hop count. Higher transmission speeds and larger message buffer increase message replication and message delivery, so higher hop count messages are more likely to reach their destination. As a result, average hop count increases.



(a) ns-3

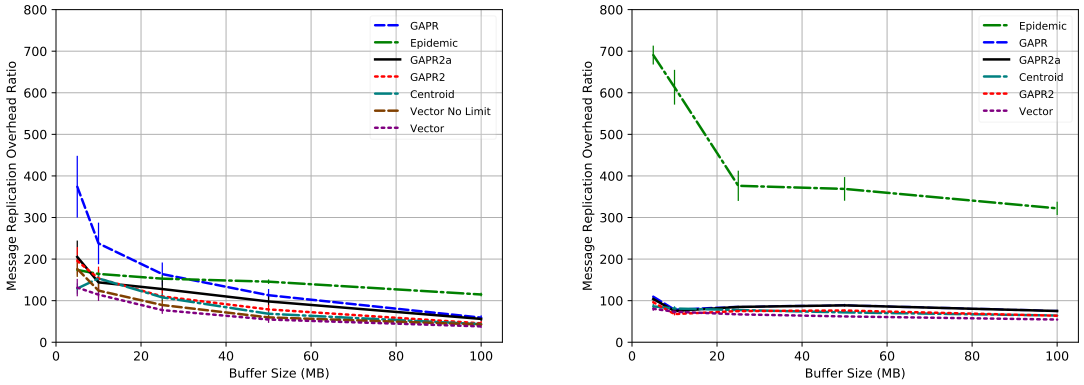
(b) ONE

Figure 5.35. Omaha Average Hop Count vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

5.3.5 Analysis of Message Replication Overhead Ratio

Figure 5.36 plots message replication overhead versus buffer size for the 6 Mbps radio. Message replication overhead in ns-3 is significantly greater than the ONE for most protocols. Epidemic has the largest message replication overhead in the ONE, but ns-3's Epidemic does not have the largest message replication overhead for message buffers less than 50 MB. GAPR has the largest message replication overhead in ns-3 for message buffers less than 50 MB. Like Bold Alligator, most ns-3 protocols have higher message replication overhead because messages circle within clusters of nodes. As a result, the ns-3 protocols show that message replication overhead decreases with larger message buffers. ns-3's Vector, Centroid, GAPR, GAPR2, and GAPR2a show this behavior. The ONE's Centroid, Vector, GAPR, GAPR2, and GAPR2a show minimal changes in message replication overhead with increased buffer sizes.

While protocols that limit message replication do not always have lower message replication overhead, they do reduce the message replication overhead within the same protocol family. GAPR2 and GAPR2a reduce the message replication overhead compared to GAPR. Vector reduces the message replication overhead compared to Vector without the message limit enabled. Vector and Centroid both reduce message replication overhead compared to Epidemic.

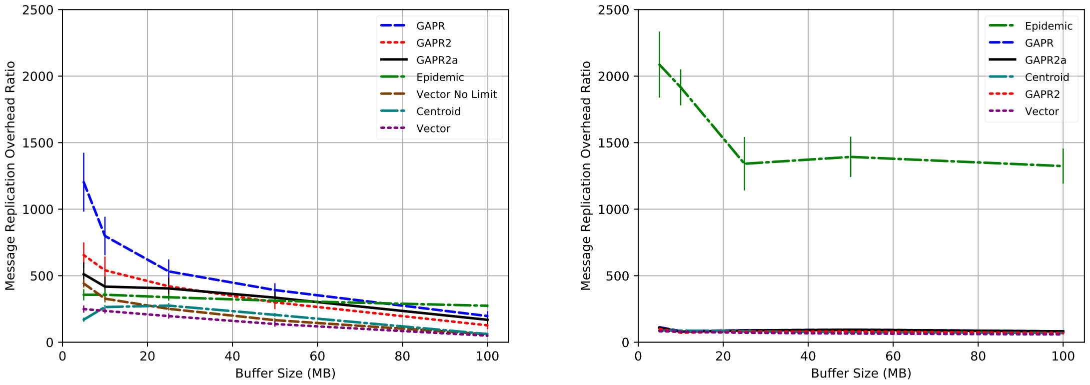


(a) ns-3

(b) ONE

Figure 5.36. Omaha Message Replication Overhead Ratio vs. Buffer Size for 6 Mbps Base Radio in ONE and ns-3

From 12 Mbps to 54 Mbps, the higher transmission speeds incrementally increase message replication overhead all ns-3 DTN protocols and the ONE's Epidemic. All other ONE protocols do not show significant changes with higher transmission speeds. Figure 5.37 plots the 54 Mbps radio. Since the 12, 24, and 36 Mbps radios continue the same trends from the 6 Mbps radio, they are included in the graph appendices. ns-3 shows an increase in message replication overhead, and the ONE's Epidemic increases message replication overhead.



(a) ns-3

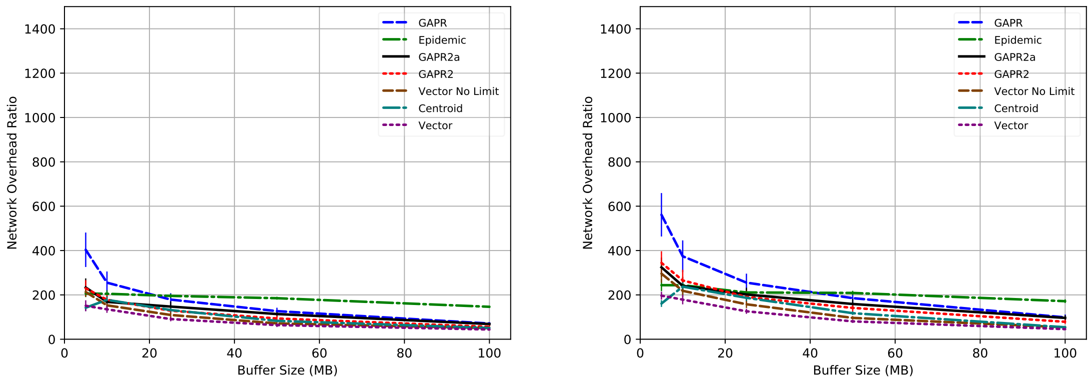
(b) ONE

Figure 5.37. Omaha Message Replication Overhead Ratio vs. Buffer Size for 54 Mbps Base Radio in ONE and ns-3

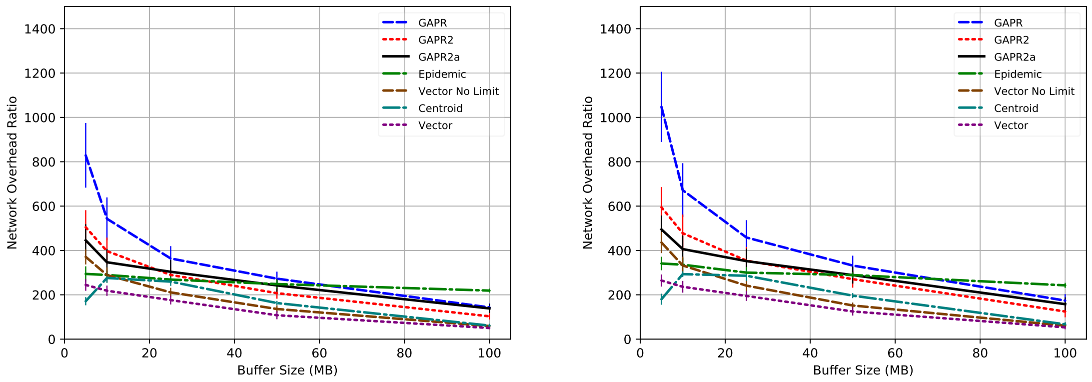
5.3.6 Analysis of Network Overhead Ratio

The network overhead graphs in Figure 5.38 follow the same trends as the message replication overhead graphs for ns-3. Message replication dominates network overhead because messages are significantly larger than control packets. When comparing the GAPR family of protocols, GAPR2 and GAPR2a have less network overhead than GAPR for message buffers less than 50 MB. After 50 MB, error bar overlap shows that the GAPR protocols have similar network overhead. For message buffers less than 100 MB, Vector has lower message replication overhead than Centroid, but Vector and Centroid have lower network overhead than the GAPR family of protocols.

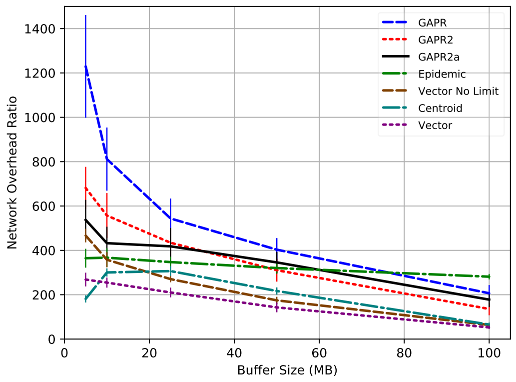
As transmission speed increases, network overhead increases for all protocols. The difference in network overhead between protocols increases as link speed goes up. Higher transmission speeds permit nodes to transfer more messages per interaction, so message replication increases. Increased message replication increases network overhead. At 6 Mbps, the protocols tend to cluster together. After 24 Mbps, the differences in protocol network overhead increase, but they maintain the same trends. In general, all protocols show that larger buffer sizes reduce network overhead. Centroid shows an increase in network overhead from 5 to 10 MB, but network overhead decreases for message buffers greater than 10 MB.



(a) 6-Mbps Base Radio (b) 12-Mbps Base Radio



(c) 24-Mbps Base Radio (d) 36-Mbps Base Radio



(e) 54-Mbps Base Radio

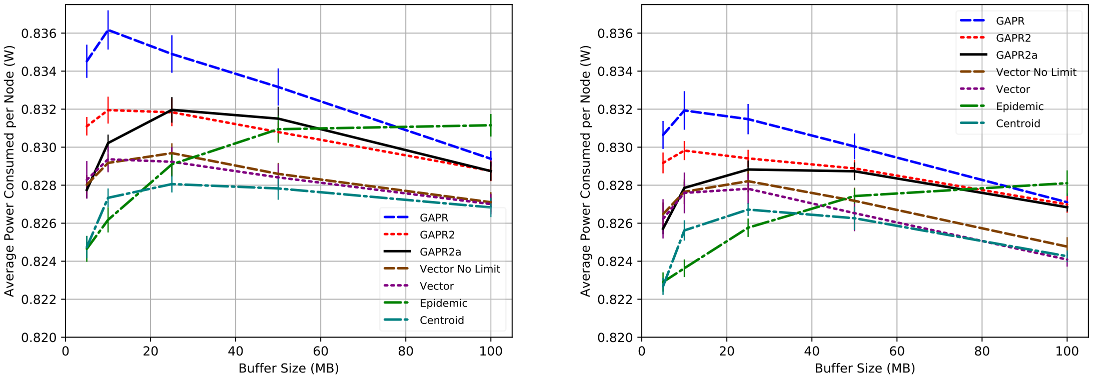
Figure 5.38. Omaha Network Overhead Ratio vs. Buffer Size

5.3.7 Analysis of Average Power Consumption

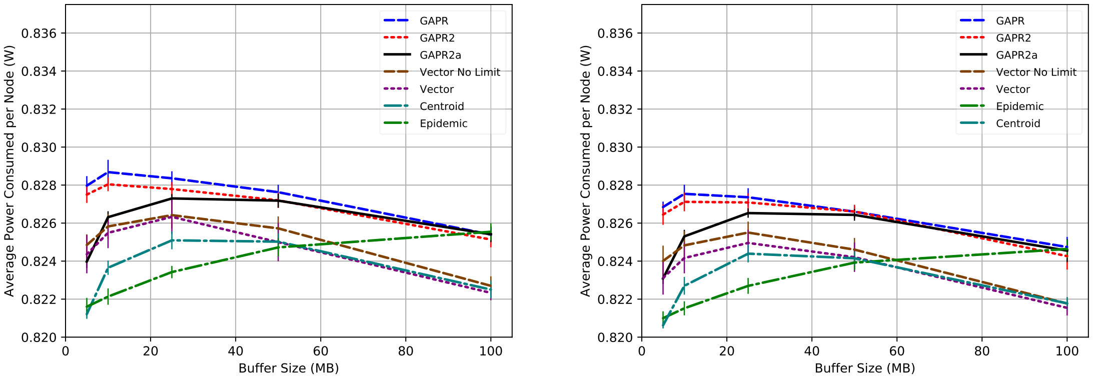
ns-3's energy module determines power consumption as a function of the radio's mode and corresponding current consumed in that mode. A transmitting radio consumes more power than a receiving radio. Figure 5.39 graphs the average power consumed in watts per node. Since the radios use the same current for all transmission speeds, no conclusion about changes in power consumption between transmission speeds is possible. Power consumption between protocols for a given transmission speed is comparable.

When comparing the GAPR family of protocols, GAPR consumes the most power. At message buffers less than 25 MB, GAPR2a consumes less power than GAPR2. After 25 MB, GAPR2 and GAPR2a consume the same amount of power. All GAPR protocols show that power consumption increases with larger buffers up to 25 MB. After 25 MB, power consumption lowers with larger message buffers.

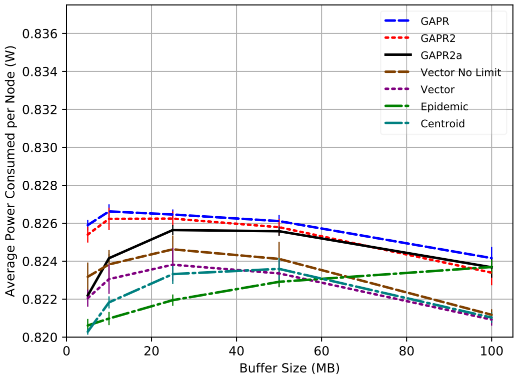
For message buffers less than 25 MB, Centroid consumes less power than Vector. After 25 MB, Vector and Centroid have similar power consumption. Vector and Vector without the message limit have similar power consumption because their error bars overlap. When comparing protocols that employ the same strategy to limit message replication, the protocol with more control packets have higher power consumption. GAPR2 consumes more power than Vector, and GAPR2a consumes more power than Centroid.



(a) 6-Mbps Base Radio (b) 12-Mbps Base Radio



(c) 24-Mbps Base Radio (d) 36-Mbps Base Radio



(e) 54-Mbps Base Radio

Figure 5.39. Omaha Average Power Consumed per Node vs. Buffer Size

5.3.8 Omaha Cross-Simulator Protocol Evaluation

In the Omaha scenario, some ns-3 protocols demonstrate significant differences from the equivalent ONE versions. As previously discussed, some ONE protocols prevent nodes from transmitting a message that previously traversed the other node. Epidemic does not have this behavior. The behavior affects Vector, Centroid, GAPR, GAPR2, and GAPR2a. This section compares the protocol implementation performance in percentage between the two simulators. Section 4.4.2 covers the equation used to derive the tables.

Epidemic

Epidemic's MDR and average latency increase asymptotically with buffer size. Message replication overhead decrease with larger message buffers, the ONE shows a steep decrease compared to ns-3's shallow decrease in message replication overhead. Both versions of Epidemic show that average latency increases asymptotically with larger message buffers. Epidemic's performance in ns-3 is close to the ONE in Table 5.13. ns-3's MDR is within 35% of the ONE, and the simulators match at several data points. At small buffer sizes, ns-3 has lower latency than the ONE, but large message buffers show ns-3 has higher latency. With respect of message replication overhead, ns-3's message replication overhead is 60% to 83% lower than the ONE. Higher transmission speeds increase the performance gap in message replication overhead between ns-3 and the ONE.

Table 5.13. Omaha Epidemic Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	0%	-16%	-25%	-31%	-35%	-27%	-17%	8.8%	26%	43%	-74%	-73%	-60%	-61%	-65%
12 Mbps	10%	-8.1%	-15%	-21%	-26%	-35%	-22%	0%	13%	33%	-77%	-75%	-65%	-68%	-71%
24 Mbps	19%	0%	-15%	-16%	-20%	-39%	-30%	-10%	3.7%	29%	-79%	-79%	-69%	-74%	-75%
36 Mbps	23%	0%	-9.1%	-11%	-16%	-42%	-29%	12%	5.7%	29%	-80%	-79%	-72%	-75%	-78%
54 Mbps	29%	1.9%	-8.8%	-13%	-17%	-41%	-30%	-9.1%	3.2%	26%	-83%	-81%	-75%	-78%	-79%

Centroid

Table 5.14 shows the difference between ns-3 and the ONE for Centroid. Both versions of Centroid show that MDR increases asymptotically with buffer size, but ns-3 returns lower MDR. Larger message buffers reduce the MDR gap between simulators. Centroid's average latency increases asymptotically with buffer size in both simulators, but ns-3's average latency is 51% to 105% higher. ns-3's Centroid returns higher message replication overhead at small buffers, but the ONE returns higher message replication overhead at large message buffers. The performance difference is due to messages circling around clusters of nodes in ns-3. Larger message buffers do not require nodes to remove messages, so the ONE returns higher message replication overhead.

Table 5.14. Omaha Centroid Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-35%	-33%	-19%	-16%	-18%	51%	67%	95%	104%	79%	50%	89%	39%	-4.2%	-33%
12 Mbps	-34%	-35%	-18%	-19%	-21%	54%	67%	97%	105%	71%	65%	155%	116%	47%	-26%
24 Mbps	-33%	-34%	-23%	-15%	-20%	53%	63%	97%	98%	71%	81%	186%	195%	107%	-16%
36 Mbps	-34%	-33%	-19%	-16%	-19%	55%	64%	97%	99%	75%	90%	201%	216%	146%	-8.7%
54 Mbps	-33%	-33%	-21%	-13%	-18%	57%	62%	90%	100%	70%	92%	203%	235%	170%	-12%

GAPR

As previously discussed, ns-3's GAPR returns higher message replication overhead than the ONE because of messages circling within clusters of nodes. As a result, ns-3 and the ONE show different trends in message replication overhead. At small buffer sizes in Table 5.15, ns-3's message replication overhead gap is significantly higher. At large message buffers, nodes remove messages less frequently, resulting a small gap in message replication overhead. Despite the difference in behavior, both version show that MDR increases asymptotically with buffer size. However, ns-3's MDR is lower. Average latency is also higher in ns-3, but both simulators show that average latency increases asymptotically with buffer size.

Table 5.15. Omaha GAPR Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-43%	-34%	-39%	-38%	-31%	104%	76%	51%	43%	53%	243%	203%	92%	28%	-21%
12 Mbps	-37%	-31%	-33%	-34%	-27%	109%	80%	49%	37%	48%	363%	328%	171%	84%	12%
24 Mbps	-36%	-29%	-30%	-32%	-25%	100%	77%	47%	35%	48%	613%	542%	294%	178%	68%
36 Mbps	-40%	-27%	-31%	-31%	-24%	96%	73%	45%	38%	45%	814%	698%	399%	243%	102%
54 Mbps	- 37%	-27%	-30%	-30%	-26%	103%	78%	47%	38%	47%	973%	861%	498%	322%	141%

GAPR2

Like GAPR, GAPR2 returns higher message replication overhead than the ONE because of messages circling within clusters of nodes. At small buffer sizes in Table 5.16, ns-3's message replication overhead gap is significantly higher. At large message buffers, nodes remove messages less frequently causing a smaller gap in message replication overhead. Despite the difference in behavior, both version show that MDR increases asymptotically with buffer size. However, ns-3's MDR is lower. Average latency is also higher in ns-3, but both simulators show that average latency increases asymptotically with buffer size.

Table 5.16. Omaha GAPR2 Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-39%	-38%	-39%	-38%	-33%	108%	74%	44%	35%	42%	103%	128%	49%	2.3%	-29%
12 Mbps	-37%	-33%	-36%	-36%	-30%	103%	74%	38%	33%	44%	222%	249%	126%	61%	4.5%
24 Mbps	-38%	-33%	-35%	-34%	-27%	83%	70%	40%	34%	42%	379%	432%	254%	144%	40%
36 Mbps	-37%	-30%	-33%	-37%	-26%	95%	73%	41%	32%	39%	469%	538%	337%	224%	69%
54 Mbps	-38%	-31%	-35%	-33%	-25%	99%	72%	39%	32%	40%	555%	661%	438%	269%	87%

GAPR2a

In Table 5.17, GAPR2a returns higher message replication overhead than the ONE because of messages circling within clusters of nodes. At small buffer sizes, ns-3's message replication overhead gap is significantly higher. At large message buffers, nodes remove messages less frequently causing a smaller gap in message replication overhead. Despite the difference in behavior, both version show that MDR increases asymptotically with buffer size. ns-3's MDR is lower by 22% to 39%. Average latency is also higher in ns-3, but both simulators show that average latency increases asymptotically with buffer size.

Table 5.17. Omaha GAPR2a Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	-38%	-31%	-39%	-38%	-32%	94%	74%	51%	45%	59%	97%	91%	51%	11%	-25%
12 Mbps	-36%	-26%	-33%	-32%	-26%	101%	79%	52%	42%	54%	178%	185%	110%	57%	10%
24 Mbps	-36%	-25%	-31%	-33%	-26%	98%	77%	50%	41%	51%	291%	320%	230%	146%	61%
36 Mbps	-36%	-26%	-29%	-31%	-22%	95%	80%	49%	39%	48%	340%	388%	285%	199%	85%
54 Mbps	-33%	-24%	-30%	-31%	-25%	100%	75%	49%	39%	49%	373%	429%	359%	260%	107%

Vector

From Table 5.18, ns-3's Vector shows a small gap in MDR from the ONE for message buffers less than 100 MB. ns-3's MDR is within 10% of the ONE, but the 100 MB buffer shows that ns-3 returns lower MDR. While the simulators return similar performance in

MDR, ns-3's average latency is higher. Both simulators show that average latency and MDR increase asymptotically with larger message buffers. Like Centroid, ns-3's Vector returns higher message replication overhead than the ONE for small message buffers. Larger message buffers reduce messages continually circulating within a cluster of nodes because the nodes do not need to remove messages. As a result, the ONE's message replication is greater than ns-3's message replication overhead for 100 MB buffers.

Table 5.18. Omaha Vector Performance Difference between Simulators

	MDR					**Average Latency**					**Message Replication Overhead Ratio**				
	5 MB	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**	**5 MB**	**10 MB**	**25 MB**	**50 MB**	**100 MB**
6 Mbps	1.7%	-4.7%	-2.5%	-7.1%	-26%	135%	83%	75%	74%	55%	64%	56%	15%	-13%	-30%
12 Mbps	0%	-2.3%	0%	-8.2%	-21%	125%	81%	78%	77%	53%	121%	113%	68%	17%	-26%
24 Mbps	4.9%	4.7%	5.0%	-4.4%	-18%	134%	85%	75%	73%	51%	180%	161%	134%	59%	-19%
36 Mbps	3.9%	4.3%	3.1%	-2.8%	-16%	133%	87%	76%	70%	49%	195%	181%	159%	84%	-16%
54 Mbps	8.3%	2.7%	3.6%	-1.2%	-14%	125%	79%	77%	72%	51%	203%	197%	176%	109%	-16%

5.3.9 Effective Message Throughput

Unlike Helsinki and Bold Alligator, all nodes in the Omaha scenario use the same radio. Homogeneous radio interfaces permit calculating the effective throughput for transmitting messages between connected nodes (Single-hop throughput) from ns-3 trace files. As previously discussed in Section 3.2, the ns-3 protocols use an IP convergence layer adapter by defining messages as groups of packets. Packet headers and link layer overhead reduce the available bandwidth for a given transmission speed. Table 5.19 contains the effective throughput observed in the Omaha scenario from the routing layer. Routing protocol trace file analysis calculates the effective throughput by dividing the message's size by reception time minus time of transmission. As transmission speed increases, the effective throughput increases. However, effective throughput as a percentage of the radio's transmission speed decreases with faster radios. Slower radios yield a greater percentage of effective throughput. All transmission speeds use the same guard interval, so the effective throughput percentage is lower at higher transmission speeds.

Table 5.19. Effective Message Throughput

Radio	**Effective Throughput**	**Percentage**
6 Mbps	3.71 +/- 0.06 Mbps	61.89%
12 Mbps	6.31 +/- 0.07 Mbps	52.59%
24 Mbps	11.11 +/- 1.36 Mbps	46.27%
36 Mbps	13.62 +/- 0.09 Mbps	37.82%
54 Mbps	17.29 +/- 0.06 Mbps	32.03%

The ONE abstracts the link layer and does not include link layer protocol overhead. In addition, messages are treated as a single object. The ONE scenarios specify a radio's bandwidth, but do not specify the radio type. The ONE treats messages as a single object, and messages do not have headers or accompanying data structures that consume bandwidth, and as a result the effective message throughput of the ONE is equal to the ONE's radio bandwidth. Given the same radio transmission speed in both simulators, ns-3's effective throughput is 40% to 70% lower than the ONE's bandwidth.

5.4 Scenario Comparison

The section compares protocol performance between scenarios in ns-3. To compare overall protocol performance between scenarios, bar graphs plot average latency, MDR, network overhead ratio, and protocol efficacy ratio. The bar graphs also show the percentage of all transmitted data consumed by control packets and message headers. The bar graphs are an aggregate of all buffer sizes and transmission speeds, and they represent overall protocol performance in a scenario. While the graphs include each scenario, the values between scenarios are not the same because the scenarios have different node mobility, node density, message buffers sizes, and transmission speeds. The section also compares the aggregate power consumed per node as a table.

Figure 5.40 plots MDR. The Helsinki scenario returns the highest MDR of the scenarios. Helsinki's overall MDR is 3.7 times higher than Bold Alligator and 2 times higher than Omaha. Bold Alligator and Omaha scenarios form clusters of nodes, but Helsinki does not form clusters of nodes. In Bold Alligator, a few nodes with the greatest mobility serve as data mules to send data between clusters. In Omaha, nodes cluster together and a few nodes break away from the cluster to become isolated from the network or serve as data mules. Compared to the military scenarios, Helsinki nodes have the greatest mobility and higher probability of meeting new nodes. Node isolation coupled with node clustering reduces Omaha's and Bold Alligator's MDR. Between Omaha and Bold Alligator, Omaha forms fewer but larger node clusters than Bold Alligator. As a result, Omaha's overall MDR is 1.8 times higher than Bold Alligator.

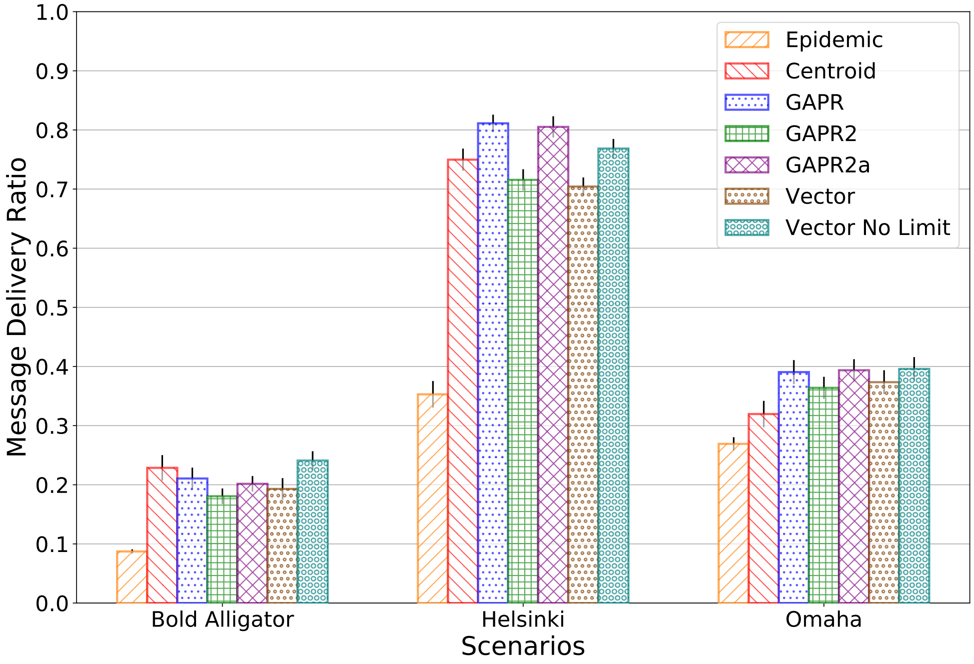


Figure 5.40. MDR Scenario Comparison

Across all scenarios, Epidemic yields the lowest MDR of all protocols. GAPR2a provides similar MDR to GAPR. GAPR2's MDR matches Vector's performance in all scenarios. In the Helsinki scenario, GAPR and GAPR2a provide the highest MDR followed by Vector with the message limit disabled. Centroid provides the third best MDR followed by GAPR2 and Vector. In Omaha, Vector with the message limit disabled, GAPR, and GAPR2a provided the highest MDR. GAPR2 and Vector provide the second highest MDR followed by Centroid. Bold Alligator shows that Centroid and Vector with the message limit disabled provide the highest MDR. GAPR, GAPR2a, and Vector provide the second highest MDR followed by GAPR2.

Figure 5.41, plots the average latency observed in Bold Alligator, Helsinki, and Omaha scenarios. Helsinki's overall average latency is 0.7 times lower than Bold Alligator and 0.85 times lower than the Omaha scenario. The military scenarios show that most protocol average latencies are within 500 seconds of each other. However, Helsinki shows the greatest variation between protocols. The Helsinki scenario confines node movements to a city grid. Nodes moving in a city grid tend to meet in parallel or perpendicular directions. Bold Alligator and Omaha nodes follow paths that do not form a grid pattern and most nodes form clusters. Vector and GAPR2 limit message replication based on a nodes direction of movement, so they return average latency 1.5 to 2 times higher than other protocols in Helsinki because of reduced message replication. Nodes serving as data mules between clusters drives Bold Alligator's and Omaha's average latency between protocols. As a result, most protocols in the military scenarios return similar average latencies, and the military scenarios return higher overall average latency.

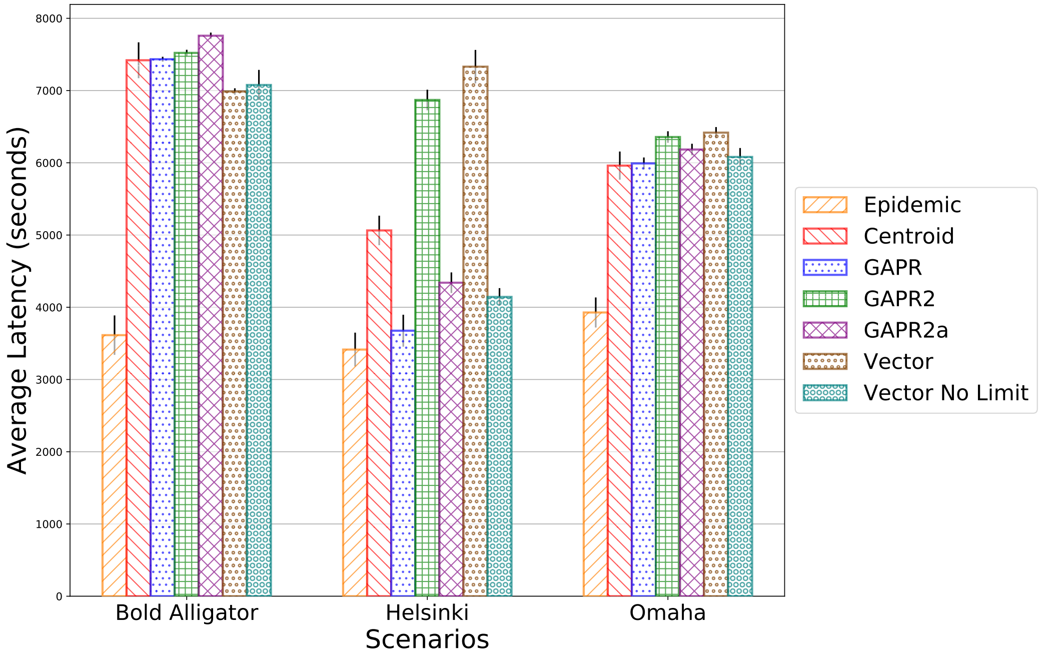


Figure 5.41. Average Latency Scenario Comparison

Across all scenarios, Epidemic provides the lowest average latency. Within the Omaha scenario, Vector and GAPR2 have this highest average latency followed by GAPR2a. GAPR and Centroid return lower average latency than GAPR2a. The Helsinki scenario shows the greatest variation in average latency. Vector returns the highest average latency followed by GAPR2. Centroid has the third highest average latency in the Helsinki scenario. GAPR2a and Vector with the message limit disabled provide lower latency than Centroid, but higher than GAPR. In Bold Alligator, GAPR2a returns the highest average latency followed by Centroid, GAPR and GAPR2. Both versions of Vector return the third highest average latency.

Network overhead in Figure 5.42 includes the cost of message replication and control packets. Helsinki returns the lowest network overhead of all scenarios. Bold Alligator's network overhead is 3.2 times higher than Helsinki, and Omaha's network overhead is 3.3 times greater than Helsinki. Bold Alligator and Omaha form clusters of nodes. Within those clusters, protocols that use FIFO for buffer management replicate more messages because messages loop within those clusters of nodes. The GAPR protocols replicate more messages because their buffer management algorithm does not store the high hop count messages. As a result, the higher message replication increases network overhead in Bold Alligator and Omaha. Helsinki does not form node clusters, and Helsinki returns lower message replication with higher MDR. Acknowledgements remove delivered messages from nodes' buffers to further reduce message replication compared to the military scenarios. Helsinki's grid layout significantly reduces Vector's and GAPR2'a network overhead because nodes typically meet in perpendicular or parallel directions. Helsinki's GAPR2 and Vector network overhead is 75% to 80% lower than the network overhead of out protocols in the Helsinki scenario.

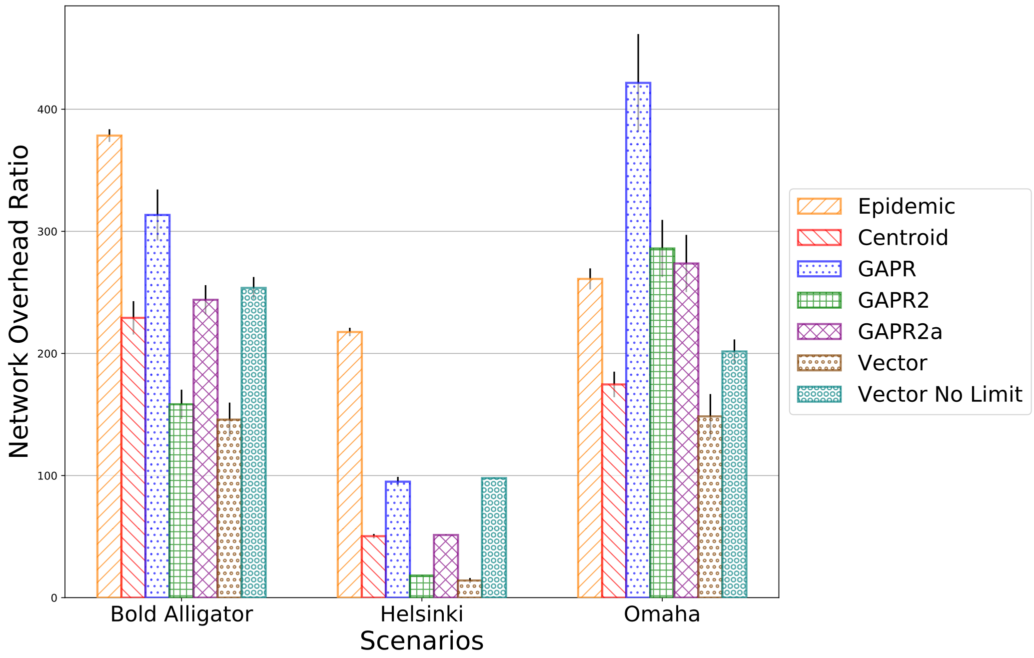


Figure 5.42. Network Overhead Ratio Scenario Comparison

When comparing network overhead in Figure 5.42, Vector returns the lowest network overhead in all scenarios. In Helsinki, Epidemic returns the highest network overhead. GAPR and Vector with the message limit disabled have the second highest network overhead. Centroid and GAPR2a have the third highest network overhead followed by GAPR2 and Vector. Within the Omaha scenario, GAPR has the highest network overhead. GAPR2 and GAPR2a have the second highest network overhead followed by Epidemic. Vector with the message limit disabled returns the fourth highest overhead. GAPR2 and Vector return the lowest network overhead. In Bold Alligator, Epidemic returned the highest network overhead followed by GAPR. Vector with the message limit disabled and GAPR2a have the third highest network overhead followed by Centroid. GAPR2 and Vector have the lowest network overhead.

In our ns-3 DTN protocols, we use an IP convergence layer by defining groups of DTN data packets as messages. The DTN data packet header identifies each data packet belonging to a message. Figure 5.43 graphs the DTN data packet header contribution to all transmitted data within the scenarios in percentages. The graph includes the DTN data packet's IP and UDP header, but the graph does not include the first data packet's headers belonging to a message. The graph does not include control packets. Bold Alligator shows that the header accounts for approximately 2.5% of all transmitted data. In Helsinki, most protocols show that the header contributes 2.5% to 3% of all transmitted data. Most protocols in Omaha also show that the header contributes 2.5% to 3% of all transmitted data. Centroid, Vector, and Vector with the message limit disabled show that the header contributes 4.5% to 5.5% of all transmitted data.

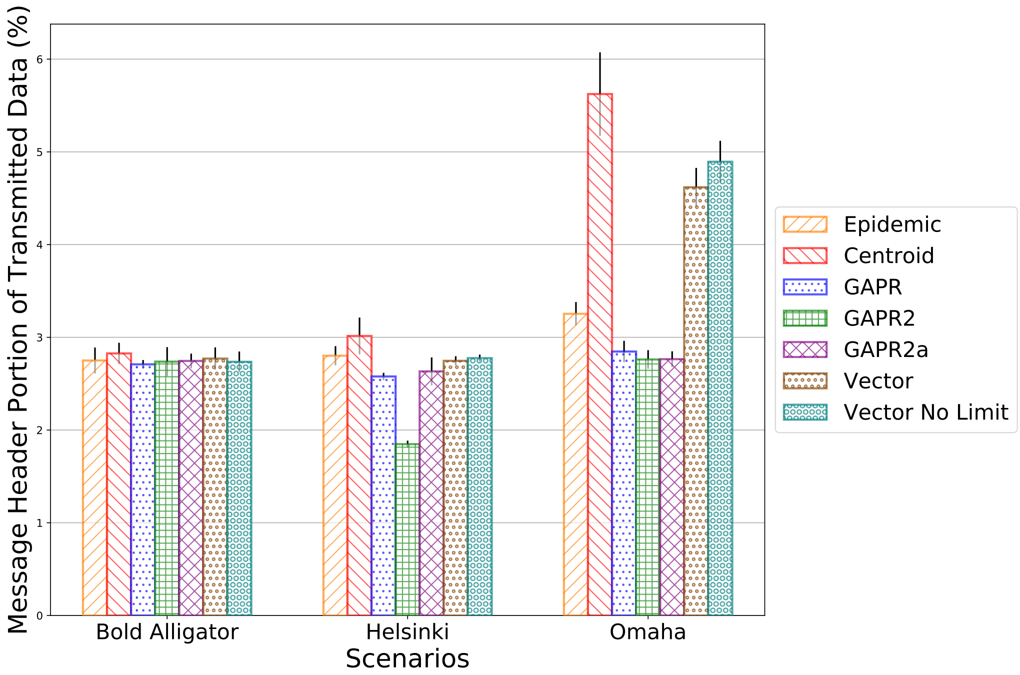


Figure 5.43. DTN Data Packet Header Contribution to Transmitted Data

Helsinki and Omaha use one message generator that generates a 500 KB to 1 MB message every 25 to 35 seconds. Bold Alligator uses three message generators. Marine nodes generate smaller but more frequent messages. The other message generators generate larger, but less frequent messages. As a result, message headers represent a different fraction of a message in Bold Alligator. Since Omaha and Helsinki generate the same size messages, the message headers for GAPR family of protocols are a smaller fraction of all transmitted data. Centroid and Vector are higher than the GAPR protocols because they have less control packet overhead as shown in Figure 5.44. GAPR2's message header is the lowest in Helsinki because of low message replication overhead coupled with large control packet overhead.

All ns-3 DTN routing protocols use control packets to share routing information and discover other nodes. Figure 5.44 plots the control packet contribution to all transmitted data. The GAPR family of protocols share the most information to make forwarding decisions. GAPR2's control packets are a large portion of transmitted data (up to 33%). GAPR2 has the lowest message replication overhead of the GAPR protocols, so its control packets are a larger fraction of transmitted data. GAPR2's message replication nearly equals Vector, so GAPR2's control packets are a high portion of the transmitted data. The low message replication is a function of node mobility determining the message limit. GAPR2a returns second highest control packet fraction of transmitted data (11%). GAPR2a's message replication overhead is between GAPR and GAPR2, so GAPR2a's control packets represent a larger fraction of transmitted data than GAPR. Vector's control packet fraction of transmitted data is higher than Centroid because Vector replicates fewer messages, so control packets are larger fraction of the transmitted data. Epidemic has the smallest control packets (0.05% to 0.16%), and usually has the highest message replication overhead. As a result, Epidemic's control packets contribute the least to the total transmitted data.

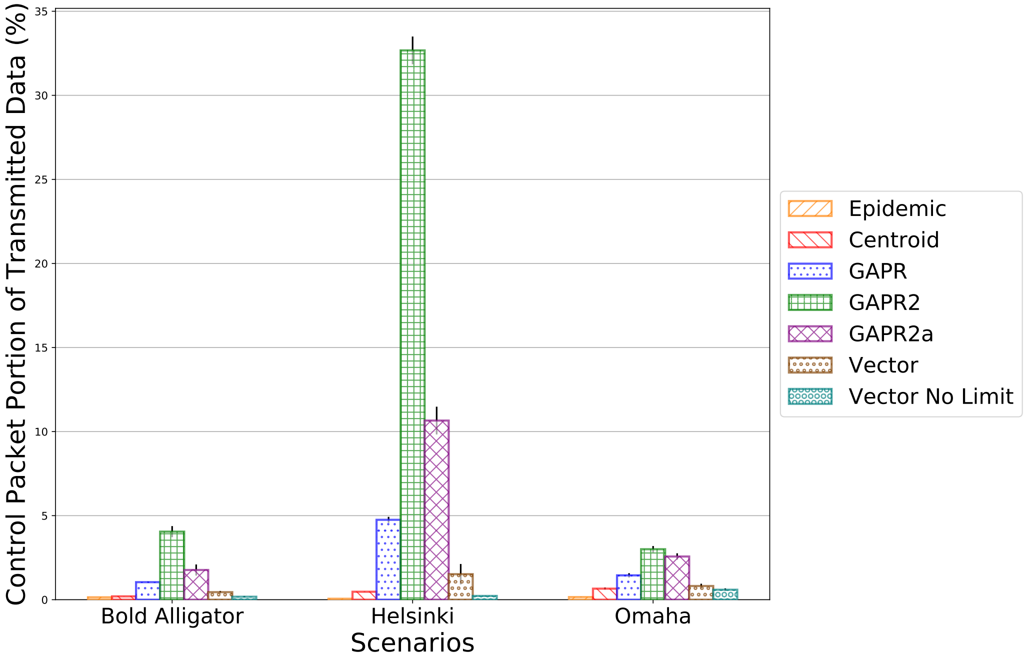


Figure 5.44. Control Packet Contribution to Transmitted Data

Overall, control packets consume 7.19% of transmitted data in Helsinki. Bold Alligator shows that control packets consume 1.19% of transmitted data, and Omaha shows that control packets consume 1.32% of transmitted data. Helsinki delivers more messages and returns lower message replication overhead than Bold Alligator and Omaha. As a result, control packets represent a larger fraction of transmitted data. GAPR2's control packet percentage is significantly higher in Helsinki. GAPR2's message replication matches Vector, but GAPR2's control packets are larger than Vector. For similar MDR and network overhead, GAPR2 transmits 21.3 times more control packet data than Vector.

Protocol efficacy in Figure 5.45 is a single metric that captures the goal of high delivery ratio and low overhead. Section 4.3 discusses the protocol efficacy calculation. As a ratio of message delivery ratio over network overhead, an efficacy of 1 is the ideal case and an efficacy of 0 is the worst case. The Helsinki scenario returns the highest efficacy of the scenarios because Helsinki delivers more messages with lower network overhead. Helsinki protocol efficacy is 16 times higher than Bold Alligator and 6.4 times higher than Omaha.

Omaha's efficacy is 152% higher than Bold Alligator because Omaha returns a higher MDR. Vector and GAPR2 have the highest efficacy in Helsinki because they delivered more messages with less message replication. Vector is 45% higher than GAPR2 because Vector uses fewer control packets. Bold Alligator and Omaha show minimal differences in efficacy between protocols because of high network overhead with low MDR.

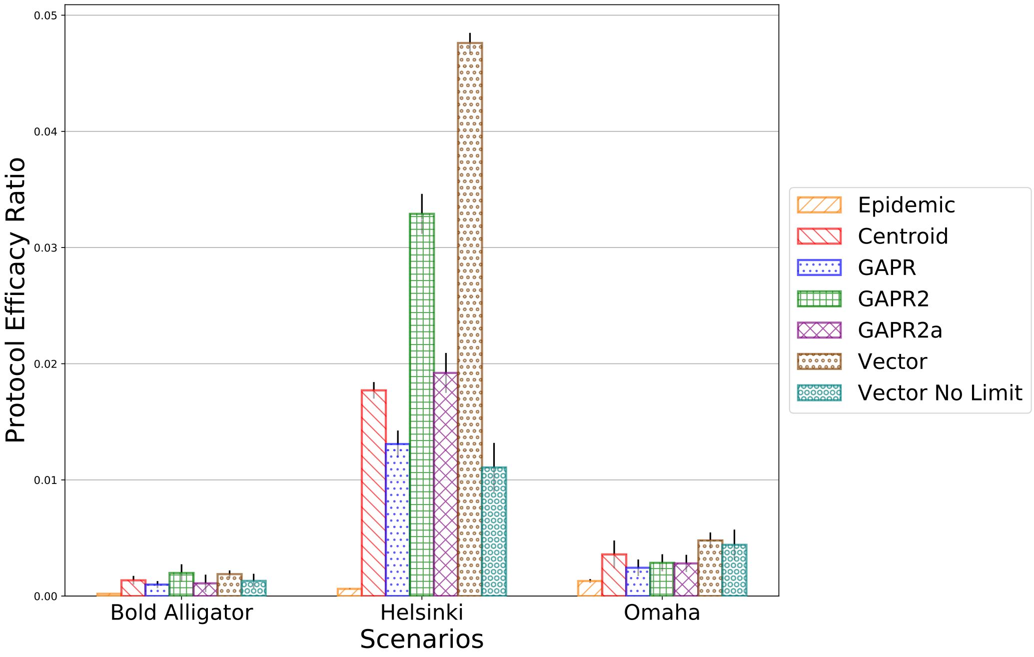


Figure 5.45. Protocol Efficacy Ratio

Within the Helsinki scenario, Vector returns the highest efficacy followed by GAPR2. GAPR2a returns the third highest efficacy followed by Centroid. Across all scenarios, Epidemic returns the lowest efficacy. In Bold Alligator, GAPR2 and Vector return the highest efficacy followed by Vector with the message limit disabled and centroid. Omaha shows that Vector and Vector with the message limit disabled return the highest efficacy. Centroid provides the third highest efficacy in Omaha.

Table 5.20 compares the aggregate power consumed per node. Each value in the table is an average of all buffer sizes and transmission speeds for a given protocol and scenario. To simplify the table, the 95% confidence intervals are not included in the table. However, the 95% confidence intervals for all values in the table are less than 0.5% of a cell's value. Omaha consumes the most power per node out of the scenarios. Omaha forms larger clusters of nodes than Bold Alligator, and Omaha returns higher network overhead and message replication overhead. Helsinki does not form clusters, but Helsinki contains more nodes than the other scenarios and each node has greater mobility. While message replication overhead is lower in Helsinki, control packets consume a larger fraction of power compared to message replication because node interactions occur more frequently. Bold Alligator returns the lowest power consumed per node. While Bold Alligator does form cluster, these clusters are smaller than Omaha and they remain fragmented from other clusters. Node clusters rely on data mule nodes to transfer data between clusters. Network fragmentation reduces Bold Alligator's average power consumed per node.

Table 5.20. Aggregate Power Consumption

Average Power Consumed per Node (Watts)				
Protocol	**Bold Alligator**	**Helsinki**	**Omaha**	**Average per Protocol**
Epidemic	0.8198	0.8231	0.8244	0.8230
Centroid	0.8196	0.8213	0.8241	0.8221
GAPR	0.8214	0.8231	0.8288	0.8252
GAPR2	0.8194	0.8198	0.8277	0.8231
GAPR2a	0.8199	0.8214	0.8266	0.8233
Vector	0.8192	0.8197	0.8252	0.8219
Average per Scenario	0.8199	0.8214	0.8261	

Between protocols, the GAPR family of protocols consume the most power per node when average across all scenarios. GAPR does not limit message replication, so GAPR's power consumption is higher than GAPR2 and GAPR2a. GAPR2's power consumption is lower than GAPR2a, and Vector's power consumption is lower than Centroid. GAPR2 uses Vector's message limit, but GAPR2 consumes more power than Vector. GAPR2a uses Centroid's message limit algorithm, but GAPR2a consumes more power per node than Centroid. The GAPR family of protocols have the largest control packets, and highest power consumption per node. Epidemic's power consumption per node is the fourth highest because Epidemic does not limit message replication or remove delivered messages from the network, but Epidemic contains the smallest control packets.

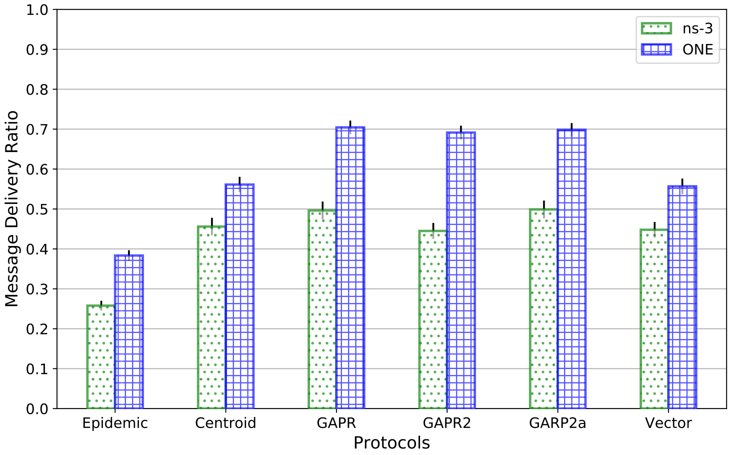
In the urban based scenario, nodes tend to meet in parallel or perpendicular directions. Vector and GAPR2 perform poorly with respect to MDR and average latency. Centroid and GAPR2a perform better, but they increase network overhead and power consumption due to increased message replication. However, they provide similar performance to protocols that do not limit message replication with decreased power consumption and network overhead. GAPR2a performs better than Centroid, but GAPR2a's large control packets affect scalability. GAPR2a returns the best overall performance for the Helsinki scenario.

The military scenario consists of clusters of nodes with limited mobility and a few nodes with high mobility. The nodes with high mobility serve to move data between clusters of nodes. GAPR, GAPR2a, and Vector with the message limit disabled return the highest MDR in both military scenarios. Vector's and GAPR2's MDR is close to GAPR, but the GAPR family of protocols and vector with the message limit disabled consume more power and network overhead. Vector returns the highest efficacy in all scenarios. Vector provides the best overall performance in the military scenarios because Vector returns low network overhead and power consumption while returning MDR within 2% of GAPR in the military scenarios.

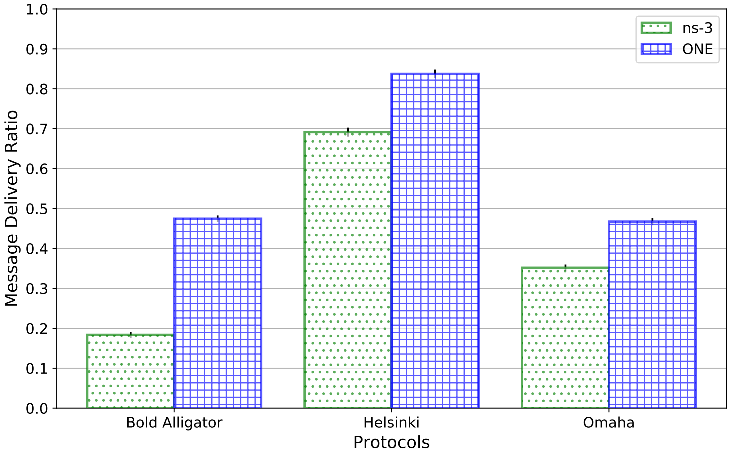
5.5 Simulator Comparison

This section compares overall protocol and scenario performance between the ONE and ns-3. Sections 5.1, 5.2, and 5.3 focused on protocol trends between protocols and simulators for a given scenario, and each scenario section contains tables that breaks down protocol performance between simulators. This section studies the overall performance between ns-3 and the ONE for MDR, average latency, average hop count, and message replication overhead. The section does not present metrics that are specific to ns-3. Two bar graphs per metric compare overall performance between simulators. The first bar graph is an average of all buffer sizes, transmission speeds, and scenario data points for each protocol. The aggregate protocol metric bar graph compares the overall protocol performance differences between simulators. The second bar graph is an average of all buffer sizes, transmission speeds, and protocol data points for each scenario. Each bar graph uses a 95% confidence interval. The aggregate scenario metric bar graph compares the overall scenario performance differences between simulators.

Figure 5.46 compares aggregate protocol and scenario MDR between the ONE and ns-3. Within Bold Alligator, ns-3 delivers 61% fewer messages than the ONE, and 24% fewer messages in Omaha. ns-3 delivers 17% fewer messages in Helsinki. The GAPR protocols share the most information to make routing decisions, and they deliver 29% to 36% fewer messages in ns-3 than the ONE. Centroid and Vector share more information than the Epidemic, but limit message replication. The Centroid and Vector protocols deliver 19% to 20% fewer messages in ns-3. Epidemic is 33% lower in ns-3. Protocols that share more information and limit message replication return a larger difference in performance between simulators. Across all scenarios and protocols, ns-3 delivers 31% fewer messages than the ONE.



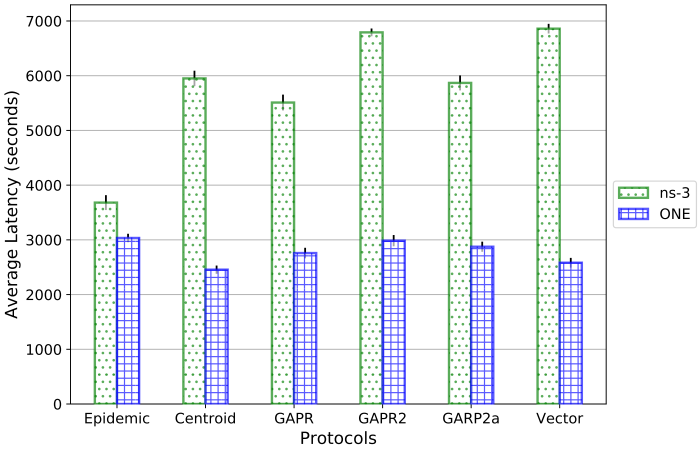
(a) Aggregate Protocol MDR between ns-3 and the ONE



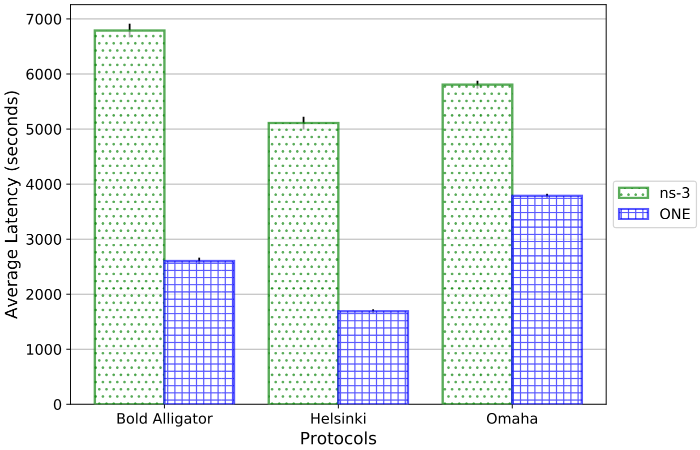
(b) Aggregate Scenario MDR between ns-3 and the ONE

Figure 5.46. Aggregate Message Delivery Ratio between Simulators

Figure 5.47 compares aggregate average latency for protocols and scenarios between simulators. Epidemic's average latency is 21% higher in ns-3 than the ONE. Vector shows the largest difference between simulators with 165% higher average latency in ns-3. Centroid's average latency is 142% higher in ns-3. GAPR and GAPR2a are 100% to 104% higher in ns-3. In relation to network overhead in Figure 5.48, protocols with higher message replication overhead tend to return a smaller difference between simulators. Helsinki's average latency in ns-3 is 202% higher than the ONE. Bold Alligator's average latency is 160% higher in ns-3 and Omaha's average latency is 53% higher in ns-3. Across all scenarios and protocols, ns-3's average latency is 119% higher than the ONE.



(a) Aggregate Protocol Average Latency between ns-3 and the ONE

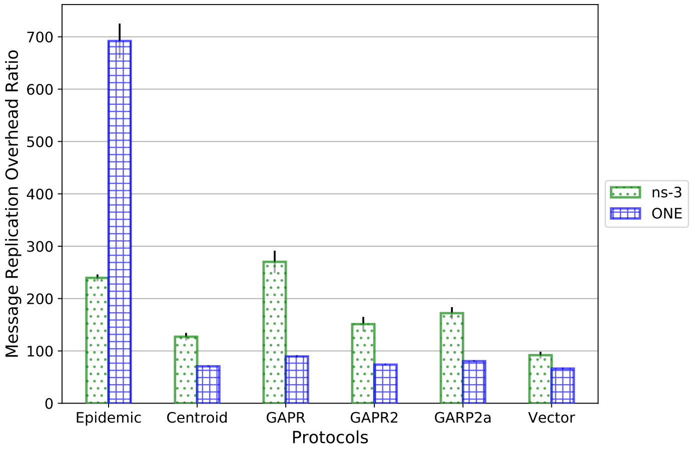


(b) Aggregate Scenario Average Latency between ns-3 and the ONE

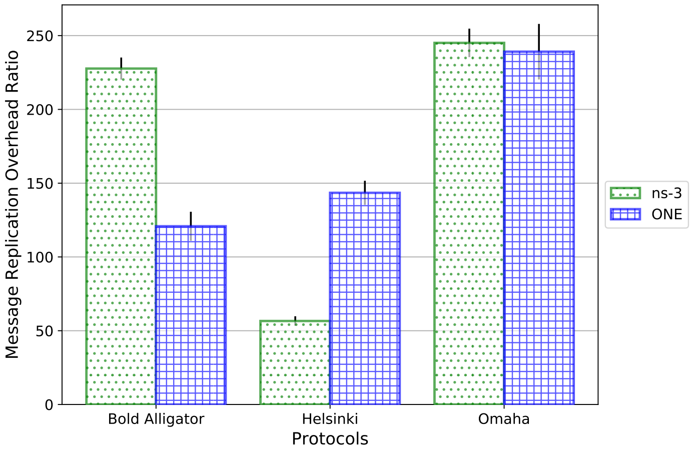
Figure 5.47. Aggregate Average Latency between Simulators

Unlike MDR and average latency, message replication overhead in Figure 5.48 displays different trends between military and urban scenarios. ns-3 returns lower message replication overhead than the ONE by 61%. However, ns-3's message replication overhead is 88%

higher in Bold Alligator and 2.5% higher in Omaha. As previously discussed, the ns-3 protocols increase message replication overhead due to messages circling within clusters of nodes. The ONE protocols, except for Epidemic, do not have this behavior because nodes check whether a message traversed the other node. If the message already traversed the other nodes, then the node does not transmit the message. Helsinki does not form node clusters, so ns-3's Helsinki does not return the higher message replication overhead.



(a) Aggregate Protocol Message Replication Overhead between ns-3 and the ONE

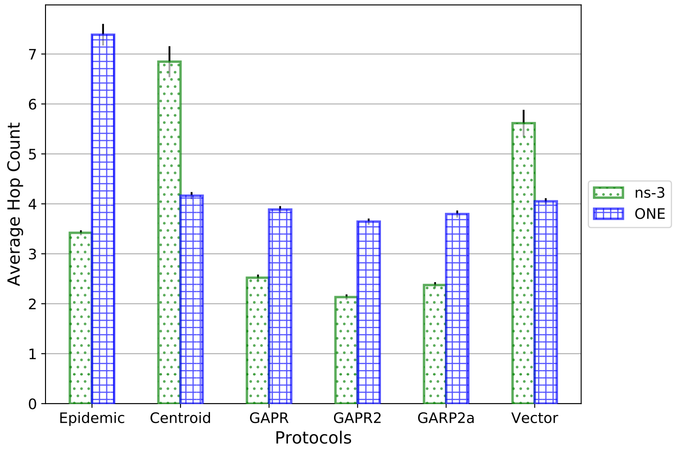


(b) Aggregate Scenario Message Replication Overhead between ns-3 and the ONE

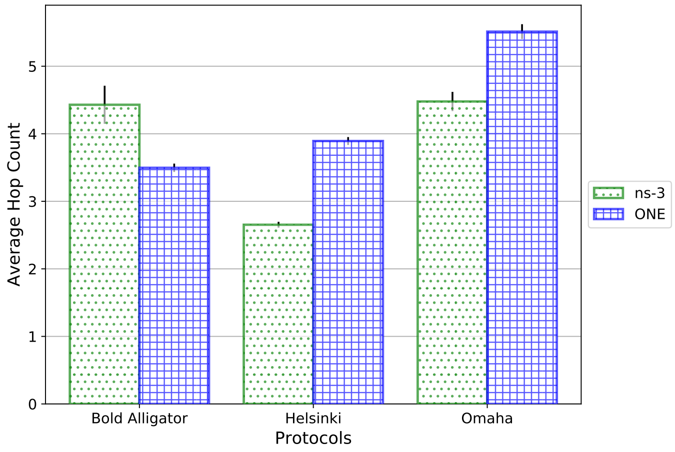
Figure 5.48. Aggregate Message Replication Overhead between Simulators

The average hop count graphs in Figure 5.49 illustrates the effect of cyclic message forwarding. Both versions of Epidemic experience cyclic message forwarding. The ONE protocols transfer more messages per contact interaction than ns-3, so the ONE's Epidemic cycles more messages than ns-3. ns-3's average hop count is 54% lower than the ONE. The ns-3 GAPR protocols also experience message cycling within clusters of nodes, but the ONE's GAPR protocols do not experience message cycling. The GAPR algorithm removes high hop count message first, so the ns-3 GAPR protocols do not show an increase in average hop count. Instead, GAPR traverses 35% fewer hop and GAPR2 traverses 41% few hops in ns-3. GAPR2a traverses 37% fewer hops in ns-3. Since ns-3 transfers fewer messages per interaction and the GAPR protocols transmit low hop count messages first, the ns-3 GAPR protocols tend to return lower average hop counts. ns-3's Vector and Centroid also suffer from message cycling, but the ONE versions do not. As a result, ns-3's Vector traverses 38% more hop on average, and Centroid traverses 64% more hop on average than the ONE.

Unlike the military scenarios, Helsinki does not form clusters of nodes. As a result, Helsinki does not suffer from message cycling within clusters of nodes. ns-3's Helsinki scenario messages traverse 31% fewer hops on average than the ONE. Bold Alligator forms multiple clusters, so ns-3's Bold Alligator messages traverses 26% more hops than the hop because of message cycling. Omaha forms larger, but fewer clusters than Bold Alligator. The ONE's Epidemic's average hop count dominates all of the other protocol's average hop count. As a result, ns-3's Omaha messages traverse 19% fewer hops than the ONE.



(a) Aggregate Average Hop Count between ns-3 and the ONE



(b) Aggregate Average Hop Count between ns-3 and the ONE

Figure 5.49. Aggregate Average Hop Count between Simulators

Due to the difference in behavior between implementations, most ns-3 protocols return higher message replication overhead. The GAPR family of protocols show the largest difference ranging from 104% to 202%. Centroid's message replication overhead is 80% higher in ns-3, and Vector is 38% higher in ns-3. Messages circling within clusters does occur with the ONE's Epidemic, so the ns-3's message replication overhead is 65% lower than the ONE. Across all scenarios and protocols, ns-3's message replication overhead is

5% higher than the ONE.

In summary, ns-3 delivers fewer messages and experiences higher average latency than the ONE. Protocols that share more data to make routing decisions tend to deliver fewer messages in ns-3 than the ONE. Message replication overhead depends on node mobility because of implementation differences. Scenarios that form clusters of nodes return higher message replication overhead in ns-3. Scenarios that do not form clusters of nodes return lower message replication overhead in ns-3.

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CHAPTER 6:
Conclusions

This research studied the evolution and strategies of DTN routing protocols, and discussed two network simulators. The thesis discussed and implemented several DTN protocols in ns-3. The protocols include Epidemic, Vector, Centroid, GAPR, and GAPR2. The ns-3 protocol discussion included control packets, node discovery, and message handling. One urban map-based mobility scenario and two military map-based mobility scenarios simulated the protocols in the ONE and ns-3 to compare trends between protocols and simulators. Finally, the research extended Kevin Killeen's GAPR2 [9] protocol to create GAPR2a. GAPR2a combines Rohrer's Centroid [10] DTN protocol with the GAPR [5] protocol. Analysis focused on message delivery ratio, message replication overhead, average latency, power consumption, and network overhead. We introduced the protocol efficacy metric to capture the goal of high message delivery with low overhead.

6.1 Simulator Comparison Findings

ns-3 and the ONE employ different levels of abstraction to simulate network protocols. The ONE focuses on simulating the behavior of opportunistic routing protocols, so the ONE abstracts everything below the routing layer. In contrast, ns-3 simulates the entire network stack. The ns-3 routing protocols require packets for messages, node discovery, and sharing routing information between nodes. The ONE does not include link layer overhead, packet header overhead, or control packet overhead.

The ONE sends DTN data as a single object called a message, and the ONE shares routing information by directly accessing communicating nodes' memory data structures. Our ns-3 DTN protocols assume an IP convergence layer adapter by defining groups of packets that compose a DTN message. Control packets share routing information between nodes in ns-3. When comparing the effective throughput of messages transmitted between two connected nodes, the addition of packet headers and link layer overhead reduces effective throughput by 40% to 70% relative to the ONE's radio bandwidth. Depending on the scenario and protocol, packet headers added during message segmentation in ns-3 make up 2% to 5.5% of all transmitted data. Depending on the routing protocol and scenario, ns-3's control packets can consume a significant portion of transmitted data. Control packets make up 0.1% to 33% of all transmitted data in ns-3. Protocols that share less information for routing decisions transmit fewer/smaller control packets. While control packets contribute to network overhead, message replication represents a larger fraction of network overhead. For protocols that use the same message limit algorithm, ns-3 protocols with more control packets consume more power.

When comparing the ONE and ns-3 DTN protocols, the ns-3 protocols returned 31% lower MDR and 119% higher average latency aggregated across all protocols and scenarios. Message replication overhead varies between scenarios. In Helsinki, the ns-3 protocols return lower message replication overhead than the ONE. Bold Alligator and Omaha returned higher message replication overhead for Vector, Centroid, GAPR, GAPR2, and GAPR2a in ns-3. Unlike Helsinki, Bold Alligator and Omaha form clusters of nodes. The ONE's implementation of Vector, Centroid, GAPR, GAPR2, and GAPR2a keeps track of every message each node has received. If a particular message has been seen by the other node in an exchange, then the message is never transmitted to that node again. The ns-3 protocols do not store this information, so the ns-3 protocols have higher message replication overhead in the military scenarios, due to forwarding loops. While the ns-3 protocols implemented a summary vector to prevent loops between connected nodes, the summary vectors failed to prevent forwarding loops when more than two nodes are connected.

Both simulators demonstrate sensitivity to buffer size. Larger message buffers return higher MDR. In Helsinki, larger message buffers reduce average latency. Bold Alligator and Omaha show that larger message buffers increase average latency. ns-3 shows greater sensitivity to transmission speed than the ONE. In ns-3, higher transmission speeds return higher MDR, lower average latency, and increase message replication overhead. Higher transmission speeds in the ONE return small changes in MDR, slightly reduces average latency, and increases message replication overhead. ns-3's increased sensitivity to transmission speed is due to control packets, packet headers, and link layer overhead.

Based on our findings, we recommend future DTN protocol development should continue in ns-3 instead of the ONE. The ONE permits faster development of new protocols. ns-3's simulations take 25 to 50 times longer than the ONE. ns-3 requires a separate program to analyze the large trace files, but the ONE generates the reports without requiring a separate program. As a result, new protocols are easier to test in the ONE. However, the ONE's abstraction may not reflect actual protocol performance. The sharing of routing information via shared data structures can result in protocols with very large control packets in ns-3. As observed with the GAPR protocols, control packets impact protocol performance. Link layer overhead also significantly reduces message replication, so the ONE results may not be accurate. Developing new protocols in the ONE should consider these factors, but the protocol should ultimately be developed in ns-3.

6.2 ns-3 Protocol Findings

When comparing the GAPR family of protocols, node mobility affects protocol performance. GAPR2 demonstrates large changes in performance between urban and military based mobility models. In military based scenarios, GAPR2's MDR is 3% lower than GAPR and average latency is within 400 seconds of GAPR. GAPR2 diverges significantly from GAPR in the urban based scenario. GAPR2's MDR is 10% lower and average latency is 3100 seconds higher than GAPR. In contrast, GAPR2a's performance is consistent across all scenarios. GAPR2a's MDR is within 1% of GAPR, and average latency is within 200 to 600 seconds of GAPR in all scenarios. However, GAPR2a consumes more power and increases network overhead compared to GAPR2. GAPR2's efficacy ratio is higher than GAPR2a. GAPR2a's and GAPR2's power consumption and network overhead is lower than GAPR.

Vector with the message limit disabled illustrates Epidemic routing with acknowledgments. When comparing Epidemic to Vector with the message limit disabled, acknowledgements increased MDR, increased average latency, and decreased message replication overhead in all scenarios. Epidemic returned the lowest MDR in all scenarios, but Vector with the message limit disabled maintained MDR like GAPR with lower power consumption. Vector and Centroid both limit message replication and use FIFO for message buffer management. Across all scenarios, Centroid returns higher network overhead and power consumption than Vector due to higher message replication overhead. Centroid returns higher MDR and lower average latency in urban based mobility scenarios. In Bold Alligator, Centroid returns higher MDR and higher average latency than Vector. In Omaha, Vector returns higher MDR and higher average latency. Across all scenarios, Vector returns the highest efficacy ratio.

6.3 Scenario Comparison Findings

In the urban based scenario, nodes tend to meet in parallel or perpendicular directions when confined to a city grid. Unlike the military scenarios, nodes do not form clusters. However, higher node mobility coupled with more nodes increased power consumption per node and message delivery. Vector and GAPR2 return the highest network efficacy and lowest network overhead, but reduced message replication increases average latency and reduces MDR. Centroid and GAPR2a return higher MDR and lower average latency, but they increase network overhead and power consumption due to increased message replication. However, GAPR2a provides similar performance to protocols that do not limit message replication with decreased power consumption and network overhead. GAPR2a returns the best overall performance in Helsinki.

The military scenarios consist of clusters of nodes with limited mobility and a few nodes with high mobility. The nodes with high mobility serve to move data between clusters of nodes. Most protocols return similar average latency due to the data mule nodes. Node clustering increases message replication overhead, but message delivery goes down due to network fragmentation. Bold Alligator shows that power consumption decreases when networks are more fragmented. GAPR, GAPR2a, and Vector with the message limit disabled return the highest MDR in both military scenarios. Vector's and GAPR2's MDR is close to GAPR, but the GAPR family of protocols and Vector with the message limit disabled consume more power and network overhead. Vector provides the best overall performance in the military scenarios because Vector consumes the least network overhead and power while returning MDR within 2% of GAPR. As a result, Vector's efficacy ratio is higher than most protocols.

6.4 Recommendations for Future Work

ns-3 is a useful simulator to develop and study networking protocols. As this research has shown, factors other than the underlying routing algorithm affect DTN performance. The ONE simulator is a great tool for developing a routing protocol algorithm because it simplifies the implementation, but the interaction with the link and physical layers of the network stack affect the performance of a DTN protocol. This thesis provides a starting point to further research the development of DTN protocols that includes all layers of the network stack. Here are several suggestions for future work.

The ns-3 DTN protocol implementations introduced in this work use UDP packets because UDP packets have a small header and lower overhead than TCP. UDP packets simplify the DTN routing protocol implementations in ns-3. UDP does not implement reliability, so the DTN layer must manage per-connection reliability. Our packet headers for messages can tolerate some loss, but they do not recover the lost packets. The packet header that define messages can identify lost packets, but the protocol implementation does not recover the lost packets. Future work could implement reliability by recovering dropped packets and study the impact on protocol performance. Another option is to switch packets to TCP. TCP handles the recovery of dropped packets, so TCP would add reliability to control of data packets.

This research uses a propagation-loss model based purely on range. Nodes within a specified range received packets at the full transmission signal to noise ratio. The research did not focus on studying the effects of dropped packets, so ns-3 used the simplest physical layer model based on range without signal attenuation. Since ns-3 models the physical layer, introducing other physical layer disruptions or models could change protocol performance. This future work would coincide with the research into implementing connection reliability.

Another area to further research is network scalability. The GAPR protocols require nodes to share large databases of locations, delivery probabilities, and timestamps. As a result, the number of control packets exchanged during an interaction relates to the number of nodes in the network. The ONE does not account for the overhead. This research does not vary the number of nodes in each scenario because of the time required to generate sufficient data. Future work could study the effects of network size on overhead. Limiting the size of a node's databases is a potential solution to reducing GAPR's control packet overhead.

In our research, we compared protocols using the same radio transmission speeds in both simulators. Control packets, packet headers, and link layer protocols reduce the available bandwidth between connected nodes. The observed throughput when transferring messages between connected nodes is the effective message throughput. We showed that the effective message throughput for a given radio bandwidth in ns-3 is significantly lower than the ONE's radio bandwidth. Instead of comparing against the ns-3 radio bandwidth, future work would directly compare the ONE's bandwidth against the ns-3 effective throughput.

In the related works section, several researchers proposed methods to reduce power consumption. Solutions include adaptive beaconing and multiple radios. Future protocol development could implement these solutions and study the effects on performance and power consumption. As previously discussed, message limits reduce message replication overhead. However, this thesis did not vary the message limit calculation for Vector or Centroid. Vector, Centroid, GAPR2, and GAPR2a message limit optimization could improve performance. Further simulation could determine the optimal solution to improve performance while minimizing overhead.

Within this thesis, several DTN protocols from [10] show tolerance to GPS errors. However, the research did not study the effects of GPS error on protocol performance for the ns-3 protocols. Potential work includes introducing GPS errors into the simulations and studying their effect on protocol performance. Previous research in the ONE shows that Vector is relatively intolerant to GPS error, but Centroid tolerates GPS errors well. Understanding the effects of GPS errors would provide further insight into protocol development in ns-3.

APPENDIX A:
ONE Helsinki Data Tables

ONE Helsinki, Epidemic, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.3197	0.44058	0.64702	0.77495	0.85571
CI	0.00470701913362	0.00541944565867	0.00942867699233	0.00869346857109	0.00648104658115
Average Latency (seconds)	2568.01652	2987.49161	3308.0466499999998	3729.9771	4025.65755
CI	58.0410137118	39.9865121209	54.4595504786	51.728412972	53.3065354153
Median Latency (seconds)	1887.53	2235.66	2604.5099999999998	3099.59	3381.71
CI	83.0522852101	76.4147240859	46.4623473529	55.4426537356	46.7151662906
Average Hop Count	6.42483	5.28669	3.37837	2.84457	2.56273
CI	0.147640582962	0.123388638241	0.0372937738089	0.0264429310204	0.0184542108195
Median Hop Count	5.0	4.1	3.0	2.8	2.0
CI	0.0	0.21137981146	0.0	0.281839748613	0.0
Message Replication Overhead Ratio	218.87278	190.58512	115.58033	98.93643	89.77903
CI	5.05462882331	4.23357244049	2.08913790061	1.5400406201	1.51099880318

ONE Helsinki, Epidemic, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.28110999999999997	0.40066999999999997	0.58768	0.7215	0.841
CI	0.00664997363099	0.00573087101899	0.00828680755698	0.0122448748618	0.00750555443202
Average Latency (seconds)	2507.42544	2679.31954	2636.69442	2808.53811	3022.58421
CI	81.2233015712	48.2414922338	51.5473624328	64.1973033353	33.6870955064
Median Latency (seconds)	1810.47	1948.39	2079.62	2283.58	2516.3
CI	56.3786942793	87.4377583095	43.0857739599	59.4230203463	22.8748161552
Average Hop Count	7.7814700000000006	6.72211	4.2418700000000005	3.55965	3.1393
CI	0.256515799326	0.206204273718	0.0642026373459	0.0458017910095	0.0328239112712
Median Hop Count	5.8	5.1	4.0	3.0	3.0
CI	0.422759622919	0.21137981146	0.0	0.0	0.0
Message Replication Overhead Ratio	359.55351	341.71317	235.93447	202.78883	177.33366999999998
CI	9.70206256972	7.18554741699	3.02845783132	3.80350677125	2.07861149086

ONE Helsinki, Epidemic, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.23778	0.35599000000000003	0.5223099999999999	0.64778	0.78343
CI	0.0053962192643	0.0068819883804	0.00799653238299	0.00649415904664	0.00955760154057
Average Latency (seconds)	2412.7912699999997	2537.0605100000002	2337.21875	2325.7399	2437.52066
CI	122.300957046	94.6536575174	31.3538534657	35.1657323972	28.1081024984
Median Latency (seconds)	1760.38	1863.05	1833.69	1910.2	2009.45
CI	140.991650476	75.7413468871	30.7630127103	43.0731110628	42.9113657057
Average Hop Count	7.8373	7.53295	5.14847	4.34343	3.74733
CI	0.303120649431	0.288426275889	0.0899178735913	0.0396340378236	0.034375612548
Median Hop Count	5.9	5.9	4.1	4.0	3.3
CI	0.21137981146	0.21137981146	0.21137981146	0.0	0.322887995466
Message Replication Overhead Ratio	530.804	535.23985	443.14413	395.14119	338.42566
CI	16.9952332946	11.0602321347	7.85819440786	5.15974031516	4.23564087127

ONE Helsinki, Epidemic, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.22033	0.32861	0.48706	0.61026	0.75161
CI	0.00509255745753	0.0048400848464	0.00531822718719	0.00709620773461	0.00793063762457
Average Latency (seconds)	2442.19816	2455.84027	2215.647	2163.70305	2203.00137
CI	79.4980788285	80.0646217786	44.9666391302	46.6525040145	35.5935287919
Median Latency (seconds)	1726.52	1797.82	1736.61	1759.12	1826.2
CI	74.4287483434	79.5689055356	28.55772545	47.2637653563	40.3755851849
Average Hop Count	7.73862	7.6894	5.6365300000000005	4.81786	4.11918
CI	0.20786976163	0.200395055108	0.0667598445353	0.0846780958271	0.0235820430944
Median Hop Count	6.0	6.1	5.0	4.0	4.0
CI	0.0	0.21137981146	0.0	0.0	0.0
Message Replication Overhead Ratio	622.50223	657.52363	594.23425	552.3381400000001	471.04466
CI	11.932877983	9.34446956075	7.96934773836	7.56990257468	6.76774573272

ONE Helsinki, Epidemic, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.21383	0.30321	0.45783	0.57624	0.72156
CI	0.00445594904133	0.0052576004004	0.00980978712244	0.0109161613893	0.00486400210718
Average Latency (seconds)	2408.9538199999997	2379.3244	2107.81416	2060.3128500000003	2040.17624
CI	104.563561867	65.7048252475	48.6191655043	37.1017447523	27.3069330796
Median Latency (seconds)	1756.15	1765.85	1637.54	1680.59	1696.46
CI	82.7863018973	74.3495263397	33.6293580793	41.7932147605	44.2113305223
Average Hop Count	7.80765	7.36703	5.99764	5.31161	4.47455
CI	0.311498610812	0.194619846414	0.0998105994084	0.0836448634202	0.0306781344561
Median Hop Count	6.2	6.0	5.0	5.0	4.0
CI	0.281839748613	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	715.90197	803.52855	784.12423	750.68622	638.88905
CI	17.345927988	19.6984519848	16.8423976719	18.7826697341	6.83392643899

ONE Helsinki, Centroid, 6 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.50177	0.75312	0.94026	0.93969	0.93969
CI	0.00959058103961	0.00988439161353	0.00377683666408	0.00257953627834	0.00257953627834
Average Latency (seconds)	3119.70712	2441.30837	2147.38391	2138.43922	2138.43922
CI	120.909000568	51.5286741049	38.1891728985	34.5228113613	34.5228113613
Median Latency (seconds)	2483.22	2154.75	2024.36	2017.95	2017.95
CI	85.7878471018	48.3866528934	39.0340191778	35.3049603017	35.3049603017
Average Hop Count	2.8815	3.09343	2.9546	2.9589	2.9589
CI	0.0735015356372	0.0363112132943	0.0284100897396	0.0371950527044	0.0371950527044
Median Hop Count	2.8	3.0	3.0	3.0	3.0
CI	0.281839748613	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	33.90916	47.81585	47.82431	47.66682	47.66682
CI	1.84989293973	1.2053059853	0.801717385523	0.813220041914	0.813220041914

ONE Helsinki, Centroid, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.47679	0.71552	0.96379	0.96481	0.96481
CI	0.0120174354496	0.0098782117988	0.00154416613476	0.00181574861587	0.00181574861587
Average Latency (seconds)	2529.21764	1778.98832	1395.36743	1394.21735	1394.21735
CI	112.462955934	47.8989153826	25.5363615568	21.05281343	21.05281343
Median Latency (seconds)	1917.16	1490.63	1286.2	1282.64	1282.64
CI	76.098436193	31.6371402656	29.585136725	28.4309679338	28.4309679338
Average Hop Count	3.46469	3.80303	3.58456	3.57616	3.57616
CI	0.102965806295	0.0330958815295	0.0381652830152	0.0284512514897	0.0284512514897
Median Hop Count	3.0	3.9	3.2	3.0	3.0
CI	0.0	0.21137981146	0.281839748613	0.0	0.0
Message Replication Overhead Ratio	53.75046	75.92117999999999	72.94839999999999	72.59898	72.59898
CI	4.15899487378	2.42398913815	0.746520214405	0.80638501116	0.80638501116

ONE Helsinki, Centroid, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.45264	0.68858	0.9723700000000001	0.97298	0.97298
CI	0.0126475567563	0.00961987434421	0.00215290565689	0.00234575512297	0.00234575512297
Average Latency (seconds)	2273.76698	1489.87538	1106.96963	1104.8983	1104.8983
CI	103.546534069	51.6126944243	21.7142337297	21.4445611697	21.4445611697
Median Latency (seconds)	1688.44	1194.29	986.57	985.1899999999999	985.1899999999999
CI	84.6308510235	27.6810442908	24.6295741459	23.759096032	23.759096032
Average Hop Count	3.85738	4.33598	4.02863	4.02106	4.02106
CI	0.10516550456	0.0681509681852	0.0557353428376	0.0554257070261	0.0554257070261
Median Hop Count	3.4	4.0	4.0	4.0	4.0
CI	0.345181786668	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	69.61899	95.86278	87.9671	87.67528	87.67528
CI	4.74440310487	2.69822455371	0.755401638176	0.864411102102	0.864411102102

ONE Helsinki, Centroid, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.44504	0.68105	0.97433	0.97558	0.97558
CI	0.00947670176672	0.00709488184316	0.00204917316169	0.00219893712693	0.00219893712693
Average Latency (seconds)	2122.08744	1412.1622300000001	1034.95269	1033.37935	1033.37935
CI	91.8087656665	43.9366194521	21.1778536072	20.7386423272	20.7386423272
Median Latency (seconds)	1564.22	1102.81	912.86	913.9300000000001	913.9300000000001
CI	60.7908297014	31.1793533676	20.0431759498	20.8879443317	20.8879443317
Average Hop Count	3.9096800000000003	4.47057	4.13982	4.14204	4.14204
CI	0.124083997606	0.0623019821015	0.045328239542	0.0484272455144	0.0484272455144
Median Hop Count	3.4	4.0	4.0	4.0	4.0
CI	0.345181786668	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	73.58018	101.86953	92.37432	92.15573	92.15573
CI	5.56482290839	2.96689811998	0.90943878103	0.845246174213	0.845246174213

ONE Helsinki, Centroid, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.44181	0.67837	0.97466	0.97631	0.97631
CI	0.00621554499011	0.00812150040186	0.00241117158181	0.00239573111719	0.00239573111719
Average Latency (seconds)	2108.41419	1359.72729	994.65282	992.6451	992.6451
CI	112.122606113	47.5993445615	21.6122359543	21.498462863	21.498462863
Median Latency (seconds)	1518.52	1064.96	874.2	873.04	873.04
CI	77.781042168	29.5641903115	18.1538766684	17.4083449007	17.4083449007
Average Hop Count	3.94808	4.54467	4.23762	4.23427	4.23427
CI	0.0960280013981	0.0945814580171	0.0477793587598	0.050766412101	0.050766412101
Median Hop Count	3.7	4.0	4.0	4.0	4.0
CI	0.322887995466	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	78.86533	104.76992	94.76749	94.46352	94.46352
CI	5.95736060246	3.06430513278	0.747667478659	0.727561452187	0.727561452187

ONE Helsinki, GAPR, 6 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.92115	0.96023	0.9676400000000001	0.96809	0.96809
CI	0.00630765999541	0.00214736412243	0.0016209461299	0.00171912139399	0.00171912139399
Average Latency (seconds)	2754.78933	1665.35737	1395.10872	1392.56193	1392.56193
CI	47.8231524944	24.4392776359	18.5815189476	18.5704042297	18.5704042297
Median Latency (seconds)	2115.9100000000003	1484.73	1273.43	1269.41	1269.41
CI	48.3918053282	24.7987159673	21.1707911874	23.855875346	23.855875346
Average Hop Count	2.35803	2.70021	3.21512	3.21642	3.21642
CI	0.0242375434716	0.0268353485759	0.0151103236761	0.0187375429159	0.0187375429159
Median Hop Count	2.0	3.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	59.8735	61.87314	57.85707	57.76024	57.76024
CI	0.568832620826	0.534107318225	0.362786586084	0.401151213307	0.401151213307

ONE Helsinki, GAPR, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.93539	0.9666	0.97611	0.97611	0.97611
CI	0.00548624164687	0.00380118137229	0.00211437345912	0.0020695200267	0.0020695200267
Average Latency (seconds)	2227.81056	1404.60547	1079.76953	1079.82954	1079.82954
CI	34.9949806207	23.3756534027	15.0964776333	14.2045735653	14.2045735653
Median Latency (seconds)	1736.32	1232.95	960.23	960.9	960.9
CI	22.4324079945	21.3055110055	15.0079021079	12.3125186887	12.3125186887
Average Hop Count	2.55059	2.86876	3.78662	3.78391	3.78391
CI	0.0213754698166	0.0187012991341	0.0366304644839	0.0392590408785	0.0392590408785
Median Hop Count	2.0	3.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	96.62846	103.54265	81.4902	81.3271	81.3271
CI	0.932165297705	1.01726814787	0.546257090991	0.517093099406	0.517093099406

ONE Helsinki, GAPR, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.93034	0.97089	0.97926	0.97934	0.97934
CI	0.00614143945245	0.00247201939133	0.00219744652098	0.00236481016459	0.00236481016459
Average Latency (seconds)	1983.53862	1299.15547	952.68792	952.3497	952.3497
CI	36.8341596079	29.7304204712	12.2867354041	12.9555294029	12.9555294029
Median Latency (seconds)	1561.61	1128.8700000000001	834.45	833.78	833.78
CI	22.1092560851	25.8750542471	12.0451978701	12.4582972316	12.4582972316
Average Hop Count	2.75655	2.9436999999999998	4.14428	4.14664	4.14664
CI	0.0225119278673	0.0412681752659	0.0414842691906	0.0368972689606	0.0368972689606
Median Hop Count	2.0	3.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	137.65125	152.04232	93.96038	93.56646	93.56646
CI	1.24238647503	1.63206481004	0.514177389747	0.487128810313	0.487128810313

ONE Helsinki, GAPR, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.92108	0.97229	0.98002	0.98002	0.98002
CI	0.00617027932401	0.00300385016945	0.00220434901532	0.00220434901532	0.00220434901532
Average Latency (seconds)	1929.15542	1246.95762	918.4609	917.90014	917.90014
CI	35.9516470159	28.525514251	11.0571721385	11.4031416258	11.4031416258
Median Latency (seconds)	1515.93	1082.82	802.53	802.46	802.46
CI	36.3372498209	20.7156960437	10.2414942626	11.6232929984	11.6232929984
Average Hop Count	2.89927	2.97485	4.2357499999999995	4.2411900000000005	4.2411900000000005
CI	0.0297446614261	0.0227330063544	0.0416789587149	0.0399831610708	0.0399831610708
Median Hop Count	2.8	3.0	4.0	4.0	4.0
CI	0.281839748613	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	158.50155	178.88682	97.31139	96.86676	96.86676
CI	1.90151587994	1.94976090852	0.483483077253	0.434671137633	0.434671137633

ONE Helsinki, GAPR, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.91423	0.97161	0.9805	0.98049	0.98049
CI	0.00762310420241	0.00328383373109	0.0020050773805	0.00207574783516	0.00207574783516
Average Latency (seconds)	1893.72241	1216.12879	897.03503	897.29304	897.29304
CI	41.3715592681	27.7915875238	12.1988109254	12.3671955966	12.3671955966
Median Latency (seconds)	1469.64	1053.22	782.68	782.52	782.52
CI	32.8413789747	24.6944700333	9.73453439178	9.88584808023	9.88584808023
Average Hop Count	3.0252600000000003	3.01229	4.29282	4.2993999999999994	4.2993999999999994
CI	0.0179202823632	0.0299415513161	0.0340625490858	0.0306211137149	0.0306211137149
Median Hop Count	3.0	3.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	173.99935	201.52543	99.24168	98.7041	98.7041
CI	2.346492568	2.58378625878	0.546787228929	0.456702042808	0.456702042808

ONE Helsinki, GAPR2, 6 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.91589	0.95673	0.96222	0.9612	0.9612
CI	0.00700964479614	0.0036138530163	0.00175664409638	0.00197639809722	0.00197639809722
Average Latency (seconds)	2919.42208	1846.35497	1653.02986	1665.32106	1665.32106
CI	91.9494704395	17.2542085169	17.7280610579	22.8073752444	22.8073752444
Median Latency (seconds)	2286.48	1652.66	1506.64	1518.92	1518.92
CI	72.6316589519	23.2279857903	26.3426741877	32.3251854355	32.3251854355
Average Hop Count	2.27315	2.6567	2.97286	2.974	2.974
CI	0.0276849681966	0.0277360600162	0.0182870673514	0.0176023815432	0.0176023815432
Median Hop Count	2.0	3.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	42.576769999999996	43.91439	43.17381	43.21522	43.21522
CI	0.364502835919	0.403272667831	0.335009210864	0.368266077386	0.368266077386

ONE Helsinki, GAPR2, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.93435	0.96426	0.9724200000000001	0.9721299999999999	0.9721299999999999
CI	0.00639070076286	0.00244348723009	0.00213315641497	0.00212411878657	0.00212411878657
Average Latency (seconds)	2424.95333	1548.57595	1274.09913	1269.6671999999999	1269.6671999999999
CI	45.6780431932	27.3539927353	20.4211658702	20.9550508738	20.9550508738
Median Latency (seconds)	1920.03	1365.48	1151.46	1148.83	1148.83
CI	31.9147591158	27.0976276978	24.6271380424	24.9764933799	24.9764933799
Average Hop Count	2.47033	2.84017	3.51381	3.5093	3.5093
CI	0.0170839137395	0.0305788342459	0.0347211878912	0.0292081044196	0.0292081044196
Median Hop Count	2.0	3.0	3.1	3.1	3.1
CI	0.0	0.0	0.21137981146	0.21137981146	0.21137981146
Message Replication Overhead Ratio	67.7846	73.71856	66.92912	66.86384	66.86384
CI	0.492299024721	0.50304232115	0.41754098589	0.408879915263	0.408879915263

ONE Helsinki, GAPR2, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.92833	0.96803	0.97583	0.97618	0.97618
CI	0.00488435785649	0.00235847208167	0.00249313703616	0.00241232434635	0.00241232434635
Average Latency (seconds)	2156.56431	1415.18428	1096.3758	1099.54346	1099.54346
CI	42.0222153403	23.5100435669	16.8841691209	18.0856810237	18.0856810237
Median Latency (seconds)	1723.8700000000001	1243.74	970.3100000000001	973.74	973.74
CI	20.5150746943	26.69983909	14.1214599479	16.0002773521	16.0002773521
Average Hop Count	2.65339	2.93749	3.96001	3.9699	3.9699
CI	0.0142158559017	0.0236504622655	0.0318315109012	0.0303114030885	0.0303114030885
Median Hop Count	2.0	3.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	96.34297000000001	108.85148	83.32761	83.19217	83.19217
CI	0.558399540741	0.418442923106	0.393856528441	0.421172036819	0.421172036819

ONE Helsinki, GAPR2, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.92189	0.96865	0.97691	0.97706	0.97706
CI	0.005029818036	0.00280997374251	0.0025021612406	0.00236355020917	0.00236355020917
Average Latency (seconds)	2078.59781	1368.22652	1044.18172	1045.09196	1045.09196
CI	72.6830973157	26.4237479315	16.2137105388	15.9841712544	15.9841712544
Median Latency (seconds)	1661.78	1203.03	917.59	918.33	918.33
CI	31.2342440254	25.1764122396	16.7630528504	16.433518735	16.433518735
Average Hop Count	2.78192	2.97333	4.1102	4.11088	4.11088
CI	0.0255385500062	0.0236894241083	0.0277611973551	0.0292223583159	0.0292223583159
Median Hop Count	2.1	3.0	4.0	4.0	4.0
CI	0.21137981146	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	110.42147	128.38258	88.25482	88.05704	88.05704
CI	0.448014188934	0.567331810351	0.485811431611	0.411242892697	0.411242892697

ONE Helsinki, GAPR2, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.91575	0.9694	0.97774	0.97774	0.97774
CI	0.00556198533316	0.00348032150439	0.00225806235561	0.00217176683614	0.00217176683614
Average Latency (seconds)	2022.13027	1317.8065	1013.18925	1012.04503	1012.04503
CI	47.8088490391	27.3619923683	15.5460361575	15.6769509298	15.6769509298
Median Latency (seconds)	1621.81	1159.75	890.78	889.94	889.94
CI	39.4864610432	27.9534072152	14.0016429835	13.3436760356	13.3436760356
Average Hop Count	2.90528	2.99791	4.19988	4.21113	4.21113
CI	0.0127049172898	0.0301151813346	0.0253560204244	0.0205732652342	0.0205732652342
Median Hop Count	3.0	3.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	120.85541	144.49656000000002	90.93485	90.54853	90.54853
CI	0.816875509903	0.779111931336	0.427992452876	0.353161669718	0.353161669718

ONE Helsinki, GAPR2A, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.86415	0.94298	0.9538	0.95477	0.95477
CI	0.0097358322527	0.00131358187015	0.00165363333033	0.00214481946753	0.00214481946753
Average Latency (seconds)	3413.29076	1974.94027	1664.85651	1665.52433	1665.52433
CI	142.852954167	42.5367875633	37.5720907433	37.0031886564	37.0031886564
Median Latency (seconds)	2610.27	1708.01	1468.82	1469.79	1469.79
CI	85.775636962	42.9598166013	38.7760028295	34.8594221112	34.8594221112
Average Hop Count	2.19543	2.64137	3.04441	3.05162	3.05162
CI	0.049759843753	0.021804021945	0.0219488404288	0.0267459239164	0.0267459239164
Median Hop Count	2.0	3.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	30.787	46.60714	48.25989	48.3286	48.3286
CI	1.36023336835	1.24073993307	0.905044681302	0.794631007997	0.794631007997

ONE Helsinki, GAPR2A, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.89665	0.95776	0.96879	0.96866	0.96866
CI	0.00864019558148	0.00215201766335	0.00174918124415	0.00198271809305	0.00198271809305
Average Latency (seconds)	2835.47765	1594.98181	1227.07907	1226.8175	1226.8175
CI	86.791429414	29.143442449	26.4628248928	26.3404668576	26.3404668576
Median Latency (seconds)	2193.86	1388.86	1075.59	1072.04	1072.04
CI	51.8764817453	28.6696315321	26.2590951748	24.2823835609	24.2823835609
Average Hop Count	2.44383	2.8604	3.6378399999999997	3.65342	3.65342
CI	0.0461295353884	0.0323866094703	0.0462008037653	0.0471414135439	0.0471414135439
Median Hop Count	2.0	3.0	3.8	3.8	3.8
CI	0.0	0.0	0.281839748613	0.281839748613	0.281839748613
Message Replication Overhead Ratio	50.101729999999996	80.09404	73.9481	73.71368	73.71368
CI	2.63037357441	1.87588397115	1.11634916084	1.11634586851	1.11634586851

ONE Helsinki, GAPR2A, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.90122	0.96255	0.97394	0.9738600000000001	0.9738600000000001
CI	0.00651781459488	0.00275718116039	0.00201574538806	0.00216283316258	0.00216283316258
Average Latency (seconds)	2558.83588	1444.5398500000001	1059.61355	1057.56122	1057.56122
CI	107.502651396	33.3491781467	26.9527757629	26.1169773422	26.1169773422
Median Latency (seconds)	2018.1200000000001	1248.6100000000001	916.74	914.73	914.73
CI	77.122202867	35.2802333632	20.6583489087	19.8603316444	19.8603316444
Average Hop Count	2.60664	2.97357	4.04121	4.03425	4.03425
CI	0.0519201219357	0.0414179315223	0.0543478231812	0.0490579330084	0.0490579330084
Median Hop Count	2.1	3.0	4.0	4.0	4.0
CI	0.21137981146	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	70.85375	117.69043	88.5056	88.12319	88.12319
CI	3.51297551892	3.14016536552	1.07690997818	0.977111441672	0.977111441672

ONE Helsinki, GAPR2A, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.90097	0.96331	0.97518	0.97517	0.97517
CI	0.00627101753298	0.0025785737935	0.00204790083103	0.00205763526063	0.00205763526063
Average Latency (seconds)	2479.84321	1398.4619	1010.12277	1009.18154	1009.18154
CI	91.9016139855	37.6943462656	25.8703075412	26.2668485209	26.2668485209
Median Latency (seconds)	1942.99	1209.28	875.33	874.35	874.35
CI	70.0653944535	33.5689479795	19.2311243871	19.6218274665	19.6218274665
Average Hop Count	2.70538	2.99952	4.15823	4.16138	4.16138
CI	0.049054700107	0.0392515583036	0.0582651114091	0.0546225846906	0.0546225846906
Median Hop Count	2.3	3.0	4.0	4.0	4.0
CI	0.322887995466	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	81.57726	138.48038	92.93083	92.25492	92.25492
CI	4.03798507749	3.16132168173	1.08609135279	1.00291716583	1.00291716583

ONE Helsinki, GAPR2A, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.89842	0.96482	0.9761	0.9761	0.9761
CI	0.00617663238825	0.00183352949087	0.0020201246138	0.00203213103961	0.00203213103961
Average Latency (seconds)	2454.91509	1359.72001	983.1086	983.09288	983.09288
CI	95.6384085299	38.8703943549	25.1477185894	25.1207658288	25.1207658288
Median Latency (seconds)	1918.87	1173.53	851.3	850.9399999999999	850.9399999999999
CI	59.7218364964	37.4953606533	18.728696635	18.3419058602	18.3419058602
Average Hop Count	2.75188	3.03134	4.22543	4.2296	4.2296
CI	0.0519805434877	0.0446484246045	0.0688761080344	0.0649271326916	0.0649271326916
Median Hop Count	2.5	3.0	4.0	4.0	4.0
CI	0.352299685766	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	90.19552	154.46699	95.38367	94.51222	94.51222
CI	4.41288657258	4.42880176155	0.977574077195	0.882064831433	0.882064831433

ONE Helsinki, Vector, 6 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.46031	0.77317	0.94784	0.94839	0.94839
CI	0.00497613298239	0.0087510589535	0.00294303321943	0.00381089264608	0.00381089264608
Average Latency (seconds)	2246.48792	2232.24835	2189.67805	2198.0825800000002	2198.0825800000002
CI	39.0713240667	30.8468472278	17.9708898364	23.6075002004	23.6075002004
Median Latency (seconds)	1775.27	2064.31	2133.35	2141.43	2141.43
CI	42.1099032254	32.6396021337	26.3340986965	30.8786612952	30.8786612952
Average Hop Count	3.6604900000000002	3.09312	2.85591	2.84911	2.84911
CI	0.0418870720098	0.0207238187273	0.0236307009446	0.021704164343	0.021704164343
Median Hop Count	3.0	3.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	63.08099	49.46942	43.01835	42.94198	42.94198
CI	0.592116484476	0.640878280675	0.405251347794	0.351621393937	0.351621393937

ONE Helsinki, Vector, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.44140999999999997	0.71787	0.96639	0.96618	0.96618
CI	0.0111305493809	0.00715111436541	0.00179595455302	0.00168214891724	0.00168214891724
Average Latency (seconds)	1834.87175	1654.91949	1489.32521	1483.17882	1483.17882
CI	38.2382771612	31.1985489111	16.4990741066	20.1425222644	20.1425222644
Median Latency (seconds)	1393.47	1436.01	1414.13	1407.57	1407.57
CI	27.6580348492	23.087485156	19.5964286346	23.0001363856	23.0001363856
Average Hop Count	4.32472	3.78692	3.3835100000000002	3.40295	3.40295
CI	0.0578342769794	0.0285227499932	0.0208318578586	0.0190120248071	0.0190120248071
Median Hop Count	4.0	3.8	3.0	3.0	3.0
CI	0.0	0.281839748613	0.0	0.0	0.0
Message Replication Overhead Ratio	87.60899	77.43046	65.86993	65.82708	65.82708
CI	1.6113391285	0.547418929014	0.334448246444	0.346931708374	0.346931708374

ONE Helsinki, Vector, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.43067	0.6864	0.97379	0.9744	0.9744
CI	0.00523807437605	0.00988962384981	0.00183153826819	0.0017955536811	0.0017955536811
Average Latency (seconds)	1695.6634	1388.94617	1175.26774	1178.22228	1178.22228
CI	38.6253279469	35.6724441303	18.5027141425	20.6652774031	20.6652774031
Median Latency (seconds)	1205.56	1131.32	1061.81	1069.43	1069.43
CI	36.3906333118	28.6791298403	17.1843813206	19.1388191275	19.1388191275
Average Hop Count	4.63217	4.4051	3.89884	3.90294	3.90294
CI	0.0745647860277	0.0299043959861	0.0204156911018	0.028550992529	0.028550992529
Median Hop Count	4.0	4.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	103.33381	97.74511	82.58475	82.58499	82.58499
CI	1.20467847697	1.12856652229	0.427836463576	0.449093790222	0.449093790222

ONE Helsinki, Vector, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.4258	0.68584	0.97584	0.97657	0.97657
CI	0.00696185540966	0.0110942611203	0.00230678560008	0.00251553817365	0.00251553817365
Average Latency (seconds)	1611.99023	1317.50003	1087.06056	1086.05598	1086.05598
CI	51.5497000413	27.3947651341	15.0457484237	15.3279479201	15.3279479201
Median Latency (seconds)	1156.01	1050.66	971.52	970.4	970.4
CI	31.139696485	24.7310404713	13.4052803434	13.6628340707	13.6628340707
Average Hop Count	4.69582	4.5204	4.0743599999999995	4.07247	4.07247
CI	0.0674039940424	0.0462844886075	0.025759100728	0.026285203032	0.026285203032
Median Hop Count	4.0	4.0	4.0	4.0	4.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	108.16384000000001	103.23017	87.71247	87.61051	87.61051
CI	1.34039448367	0.979472800224	0.38928433761	0.347712314664	0.347712314664

ONE Helsinki, Vector, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.43027	0.67665	0.97692	0.97734	0.97734
CI	0.00697439849791	0.0109155724154	0.00232171640709	0.00238550335335	0.00238550335335
Average Latency (seconds)	1609.29709	1270.10206	1038.0807	1036.66064	1036.66064
CI	39.1428518045	29.3485798262	14.6879516355	14.6621877188	14.6621877188
Median Latency (seconds)	1119.05	1007.84	918.24	917.35	917.35
CI	19.5434134651	17.0609160787	15.3049688361	15.6330658379	15.6330658379
Average Hop Count	4.80405	4.63431	4.1813	4.18143	4.18143
CI	0.0385960762673	0.0343667496572	0.0199704643502	0.0235448403487	0.0235448403487
Median Hop Count	4.2	4.0	4.0	4.0	4.0
CI	0.281839748613	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	110.82457	106.89842	90.5497	90.40751	90.40751
CI	0.92685427226	1.45871528616	0.421997205974	0.426875728426	0.426875728426

APPENDIX B:
NS-3 Helsinki Data Tables

NS-3 Helsinki, Epidemic, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.12152052887961029	0.1284794711203897	0.14170146137787057	0.16901530967292971	0.2012874043145442
CI	0.00635555009255	0.0062791182997	0.00369805134613	0.00533316030198	0.0107152489369
PDR	0.13834959818975873	0.1387369749229437	0.1461348462132993	0.1743898350855302	0.20920764696570412
CI	0.00772304475878	0.00631092383176	0.00447924282132	0.00475294736734	0.0108781677369
Average Latency (seconds)	2495.6735068096805	3785.2553702244822	5683.010654418113	6803.322249948757	6967.026930806132
CI	49.0883059878	110.607514501	205.40847273	236.639645052	179.295798339
Median Latency (seconds)	2315.696538076375	3736.8396822124378	5345.79745051	5871.632195403876	5744.114892802063
CI	65.5274283689	137.420188554	220.398066669	261.162794703	176.895489198
Maximum Latency (seconds)	10859.881046884126	13409.060823539501	16530.47624906075	17547.071155614376	17942.83948831875
CI	1920.73682836	2775.16983468	1086.22840277	195.667399017	27.6288341432
Average Hop Count	3.1798984102166097	3.4295801359160842	3.6861392905919166	3.65775040235424	3.567614427150623
CI	0.0761779384223	0.114526172207	0.0651768461419	0.0458399006375	0.0579037209457
Median Hop Count	3.0	3.125	3.5625	3.375	3.1875
CI	0.0	0.269633668931	0.377899615741	0.394703275768	0.283710854949
Maximum Hop Count	8.875	9.0	10.0	9.375	9.375
CI	0.269633668931	1.22294337099	1.15300206752	0.698673112283	0.698673112283
Message Replication Overhead Ratio	157.8961906341142	169.0316800503873	172.52730959870328	153.70513307758853	128.9912444937292
CI	9.32762342985	7.18964486721	2.28737665505	4.10243443691	3.16489361331
Network Overhead Ratio	250.1916527651902	276.2036631725565	286.9780038024283	248.18418825671964	206.2767964351244
CI	13.9645661341	11.5524399596	3.78568501494	5.1798157126	5.03958369145
Average Power Consumed per Node (Watts)	0.8257757040895062	0.8263966049382716	0.8269504726080247	0.8270206404320988	0.8269724151234568
CI	0.000140767760786	0.000135216930961	0.00019680229441	0.000162992416816	0.000309554349073

NS-3 Helsinki, Epidemic, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19076200417536535	0.22103340292275575	0.258785664578984	0.2730514961725818	0.32541753653444677
CI	0.00516451028509	0.0114774226177	0.0105016597066	0.00950618182933	0.00651807840445
PDR	0.20435379787501512	0.23409078210989953	0.26582401363268116	0.2786370112395124	0.33065374479695314
CI	0.00556154756886	0.0113546000376	0.00965791848528	0.00931271353358	0.0050481396411
Average Latency (seconds)	1825.0851309796544	2535.5488885479176	3904.954548605182	5114.4836880035955	6008.989743540906
CI	51.6577772936	53.1711374922	72.2993336108	177.547975432	173.647995424
Median Latency (seconds)	1693.6712698063116	2473.3389344106254	3736.9678383400624	4533.570889460938	4763.644472673687
CI	55.8018846683	93.6567857902	95.8734422624	119.580492024	161.790554545
Maximum Latency (seconds)	7869.339125604375	11112.638780921501	13571.47717527075	14414.01987581625	17570.65840950325
CI	1733.96573933	1038.62788403	1099.20614638	929.268584675	203.088440961
Average Hop Count	3.3207499061623333	3.470393491916668	3.7290104975653082	3.820260713860561	3.8343117553132218
CI	0.0449037311502	0.0556588630136	0.0337446854942	0.062591944297	0.060230293403
Median Hop Count	3.0	3.0	3.75	4.0	3.875
CI	0.0	0.0	0.353033342224	0.0	0.269633668931
Maximum Hop Count	8.875	9.75	9.875	9.75	10.125
CI	0.755799231481	0.97750506164	0.636439908668	0.676007383574	0.755799231481
Message Replication Overhead Ratio	160.63929902744428	171.49321905658886	173.45760609491043	172.42596586773894	153.2907906644249
CI	3.93019363882	7.72237586664	4.70727064429	3.99551794447	3.30968687167
Network Overhead Ratio	214.92594284164713	226.03593969397812	232.71261351411465	230.55589624147004	203.36798735843664
CI	5.65715344104	8.53368344551	5.42746416641	5.42872673012	3.97588263318
Average Power Consumed per Node (Watts)	0.822983699845679	0.8237022569444444	0.8244584297839506	0.8245621141975309	0.8247767168209876
CI	0.00010926622351	0.000142848414546	8.77757934426e-05	9.12615364528e-05	7.93393532538e-05

NS-3 Helsinki, Epidemic, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.26383089770354906	0.320285316631872	0.3937891440501044	0.4482428670842032	0.4979123173277662
CI	0.00574714085473	0.00583270662281	0.0153356059378	0.011615074718	0.006867159465
PDR	0.276228710575571	0.3312348098967306	0.40224883367942715	0.4560609094041289	0.5024287869334848
CI	0.00646810187512	0.00713868191107	0.0154154172876	0.0120885748415	0.00686347636074
Average Latency (seconds)	1489.6838818442952	1954.0542610658536	2881.273111145614	3852.340227120865	4994.032938588767
CI	32.2919278295	36.6432488331	49.3005984123	65.0528089231	82.1020087658
Median Latency (seconds)	1340.0304670853125	1891.1156249618753	2797.7267066535	3551.099903162438	4087.9765060954996
CI	36.4076656033	27.4173912252	89.157408087	94.5065299535	91.0503323157
Maximum Latency (seconds)	6464.203393017375	9503.577047084626	13740.023816430876	14693.97113149175	15458.399316517125
CI	602.418459821	1692.79578336	1653.63877264	1999.43235322	940.93938005
Average Hop Count	3.5337385755927277	3.7163404724667366	3.8850226410606306	3.992749794175806	4.059548002798945
CI	0.0597147811562	0.0530715501135	0.0558591083197	0.0410734758309	0.045528531911
Median Hop Count	3.0	3.75	4.0	4.0	4.0
CI	0.0	0.353033342224	0.0	0.0	0.0
Maximum Hop Count	9.5	10.625	10.125	10.625	10.625
CI	0.576501033758	1.28506076298	0.636439908668	0.567421709899	0.394703275768
Message Replication Overhead Ratio	164.65425052811426	172.64316876947888	183.24722013056623	175.71871814134357	171.7935565679121
CI	2.91766419192	2.7556514398	6.73026425326	3.28224489291	1.28704192115
Network Overhead Ratio	197.05778721258025	206.69249062649646	217.6840259850679	208.67671257924732	204.20431342460876
CI	3.30143584625	3.25635246118	6.63966295309	3.66164788783	1.38194903366
Average Power Consumed per Node (Watts)	0.8212808641975309	0.8218940489969135	0.8225267650462963	0.8228329957561729	0.8231025752314814
CI	2.43135875881e-05	4.04453736975e-05	9.4059145375e-05	5.63162597189e-05	6.10475787262e-05

NS-3 Helsinki, Epidemic, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.2951461377870564	0.36778009742519135	0.4745998608211552	0.5367084203201113	0.5982080723729993
CI	0.0116462109063	0.00930538743828	0.0117889328297	0.0113392084103	0.0090863356705
PDR	0.30488388009945155	0.375703517120003	0.4809887418636918	0.5433582582946112	0.6027325889988733
CI	0.0121188784856	0.00848967335983	0.0117983764049	0.0108758741354	0.00999911637478
Average Latency (seconds)	1371.432190569885	1753.3548036566956	2535.543578566152	3357.790843748625	4301.8309030442115
CI	23.1594349266	35.3486471172	42.0605812642	70.7773508377	111.588143062
Median Latency (seconds)	1224.1560439593125	1672.6429199232498	2492.071253013	3193.464470017875	3621.2851022292502
CI	25.2726871246	22.0902265308	47.2790348658	95.8202741175	98.4934601275
Maximum Latency (seconds)	5897.646315665124	8307.523127240374	11181.319630531376	13463.219035542876	13900.886767892374
CI	677.259640832	1529.15888371	2464.6683424	1950.82133091	1410.72334383
Average Hop Count	3.5851503231771207	3.7540502634788115	3.958459995652427	4.046220054908116	4.154539187273527
CI	0.0646632137321	0.0504842038621	0.0328537607089	0.0237004348579	0.0558554155044
Median Hop Count	3.25	3.6875	4.0	4.0	4.0
CI	0.353033342224	0.349336556141	0.0	0.0	0.0
Maximum Hop Count	9.625	10.625	11.875	10.875	11.375
CI	0.905813203564	0.567421709899	1.03429330521	0.636439908668	0.567421709899
Message Replication Overhead Ratio	168.17317808302943	177.15921669648642	182.18756857078995	179.28877672996907	177.46937441735304
CI	4.40102265432	3.81854886726	1.94164495914	2.08945259393	1.99177212624
Network Overhead Ratio	193.46420775103394	205.54161938678567	209.767186744017	205.5078593400375	203.34396302467624
CI	5.38669030719	4.20489493172	1.79877410298	2.39628308836	2.10755626794
Average Power Consumed per Node (Watts)	0.820599681712963	0.8211248553240741	0.8217351466049383	0.822023292824074	0.82228515625
CI	2.03761859948e-05	2.23585340248e-05	5.89348675225e-05	6.83653612245e-05	6.32807217732e-05

NS-3 Helsinki, Epidemic, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.32193806541405706	0.4169276270006959	0.5379262352122477	0.6274356297842728	0.6920668058455115
CI	0.0086368136757	0.00887803163895	0.00954446386014	0.0191771230408	0.0124010559796
PDR	0.33060741789196285	0.42436469284563594	0.5451349765804692	0.6337695201556957	0.6955977800333367
CI	0.00924134376227	0.0100006550807	0.00968182012045	0.0199276229568	0.0121817907779
Average Latency (seconds)	1272.008743143374	1622.344068916967	2252.3311153376967	2927.7987177488385	3672.2844956280765
CI	24.9548324634	18.4882098475	26.6063967793	58.4606616427	79.9202270146
Median Latency (seconds)	1118.1517277781254	1537.7486608198128	2213.0428721913127	2776.05982395525	3214.3180190993126
CI	26.6967102396	23.0661133002	34.0342757171	68.9345040185	63.5711881785
Maximum Latency (seconds)	6158.231973970001	7571.511505104125	10306.564123317876	10683.60222394225	11666.770168206
CI	2158.75283753	493.608265227	1315.23210988	2936.13594314	1300.41006563
Average Hop Count	3.645693807767112	3.825811563196147	4.023038092132912	4.136213913330548	4.253811413436431
CI	0.0602599521727	0.0680514898094	0.0452200745002	0.0662378100936	0.0305756680402
Median Hop Count	3.25	3.875	4.0	4.0	4.0
CI	0.353033342224	0.269633668931	0.0	0.0	0.0
Maximum Hop Count	9.625	10.75	11.0	11.25	11.75
CI	0.698673112283	0.539267337861	0.706066684447	0.539267337861	0.888447761307
Message Replication Overhead Ratio	172.02745634570738	180.99638561024767	187.592739313322	182.9307565089363	180.82458448459124
CI	2.93165075432	3.23534068353	1.87085984639	1.42675150022	2.30514481708
Network Overhead Ratio	191.7470683634132	203.72607413127287	210.14440501751758	204.63585164794648	201.57294008329484
CI	3.82685152485	3.43730774829	2.31566399417	2.13248618313	2.69528349539
Average Power Consumed per Node (Watts)	0.8201427469135802	0.820584731867284	0.8211055652006173	0.8213903356481481	0.8215706983024691
CI	1.37556403673e-05	1.40324079671e-05	2.54983354813e-05	6.65146532453e-05	4.3440476092e-05

NS-3 Helsinki, Centroid, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.44575891131214723	0.6297842727905358	0.711358540168561	0.7334725121781489	0.7333951905976959
CI	0.0112547362665	0.0265661406688	0.0182695153094	0.0121586948602	0.0122974175824
PDR	0.4688876679899969	0.652775113528077	0.7293395454324414	0.7504995856186388	0.7503491460433047
CI	0.0120943434983	0.0256668554029	0.0180558341642	0.0114745443797	0.0118266202266
Average Latency (seconds)	7275.991015392179	7611.830588349347	7266.2315780897825	7149.224064560468	7143.2590598661345
CI	97.6230970568	115.445213869	149.440211854	86.4630646128	86.6433800789
Median Latency (seconds)	6760.320718130334	7245.7309230304445	6984.891109879667	6913.375765892221	6907.352694820611
CI	139.281902449	139.891240074	159.540205395	142.512316551	138.56288938
Maximum Latency (seconds)	17850.785919037113	17885.38248937289	17849.68667264311	17838.95663563778	17838.956266998666
CI	61.7151831543	30.3110331117	93.281530536	127.866878289	127.86669003
Average Hop Count	3.578174278565369	3.122991354993375	2.267300135238922	2.184173533822398	2.183552326714143
CI	0.16503249554	0.0757980903738	0.0511517167125	0.0276747522141	0.0274037396571
Median Hop Count	3.0	3.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	19.0	13.777777777777779	6.888888888888889	6.222222222222222	6.222222222222222
CI	3.51891114204	1.76940169645	0.427214204283	0.473951605892	0.473951605892
Message Replication Overhead Ratio	20.439971648292374	22.8988434179966	24.133858456126653	23.61847607254311	23.608899713044686
CI	1.36663585756	1.12795482767	1.4443524818	0.793490656584	0.787577610551
Network Overhead Ratio	31.555859282480032	36.4926611824852	38.79796961864966	38.1693256861575	38.1604516622049
CI	1.71098190608	1.50209691034	2.06663314786	1.14141980296	1.13459920316
Average Power Consumed per Node (Watts)	0.8214594050068588	0.8232053755144033	0.8240192043895748	0.8240717163923182	0.8240710733882031
CI	0.000121515152649	0.00014016528774	0.000221619305784	0.000170685138579	0.000170511967527

NS-3 Helsinki, Centroid, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.4971004407330086	0.7017706641923761	0.8146601716539086	0.8326760998994819	0.8385525400139179
CI	0.0133187234727	0.0166895613159	0.0122239432268	0.0124080462091	0.00727522699144
PDR	0.5046999434040937	0.7082837989821014	0.8200306052451057	0.8361495745995089	0.8420388597632077
CI	0.013747924757	0.0170559025384	0.0128532919423	0.0124592549181	0.00767086446929
Average Latency (seconds)	6387.865368195021	6164.861786426165	5143.838804340152	4933.791947353514	4924.438736565514
CI	116.413607657	90.3053461946	72.7469793114	126.156716732	141.835099667
Median Latency (seconds)	5903.178819588889	5902.283975166944	5008.484822281111	4829.277825723778	4831.809091895056
CI	159.034804383	101.849178467	74.8481211084	111.959459658	137.163659079
Maximum Latency (seconds)	17764.160917376666	17598.349328093776	15060.017244618888	14935.672762612667	14603.319716119779
CI	193.164424605	290.092554359	809.801918918	1304.05225508	1147.49631099
Average Hop Count	3.7942615830485837	3.6309037393983044	2.6158580624616095	2.4572690518142504	2.4572028672745847
CI	0.0985047764324	0.124318368181	0.0671366363249	0.03339985675	0.035444158022
Median Hop Count	3.0	3.0	2.3333333333333335	2.0	2.111111111111111
CI	0.0	0.0	0.355463704419	0.0	0.236975802946
Maximum Hop Count	19.0	15.555555555555555	10.11111111111111	6.444444444444445	6.444444444444445
CI	2.41087214039	2.27916029149	2.76358901444	0.374691643828	0.374691643828
Message Replication Overhead Ratio	24.924910044582152	32.516587589319386	37.649491888120295	37.478341017931605	37.23116679217252
CI	1.32659438091	1.66297982759	1.7735461157	2.28453069254	1.93113879306
Network Overhead Ratio	33.07161581908974	43.53939657202654	50.72844806902888	50.34370161262699	50.03283503318272
CI	1.67070582954	2.13591657231	2.40792789244	3.16796599596	2.66096986362
Average Power Consumed per Node (Watts)	0.8202593449931412	0.8215262774348422	0.8224909979423868	0.8225302211934157	0.8225323645404664
CI	6.60053322418e-05	0.000110168149132	0.000152265731978	0.000206429162951	0.000196996852115

NS-3 Helsinki, Centroid, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.533141962421712	0.7452157272094642	0.8557759220598469	0.8795233124565066	0.8777835768963117
CI	0.00689311129784	0.0178818117075	0.00892464766437	0.00542294100687	0.00992853770753
PDR	0.533631470634795	0.7469838624067642	0.8572144260585348	0.8810662637700323	0.8787627224389836
CI	0.00680768294211	0.0176236114696	0.00886207481511	0.00523172413016	0.00967416875069
Average Latency (seconds)	5823.523722223185	5171.663860567609	4001.2303437924556	3581.9013596729055	3577.295701446191
CI	93.4199229471	100.943468497	115.394099471	115.613837933	126.401858187
Median Latency (seconds)	5256.293965910938	4908.8654446357505	3890.713818291813	3513.4726523008744	3510.0280961002504
CI	125.443231039	127.877695116	120.635138623	116.318553787	116.007816151
Maximum Latency (seconds)	17423.93223417725	16551.763355315376	11888.38104218075	10858.295945535125	11098.63538088975
CI	332.944432555	649.460006441	1124.18025362	622.831048781	1621.92809681
Average Hop Count	3.912279770258178	3.8377668063741375	2.9444395627290256	2.745300194747665	2.742462436250195
CI	0.141943618395	0.150196304324	0.064458599198	0.054430288533	0.053247219572
Median Hop Count	3.125	3.375	3.0	3.0	3.0
CI	0.269633668931	0.394703275768	0.0	0.0	0.0
Maximum Hop Count	20.5	15.625	10.75	7.5	7.625
CI	3.69140774216	1.62740329677	0.97750506164	0.407647790332	0.394703275768
Message Replication Overhead Ratio	28.859142700234038	39.67560827191874	51.69956828155478	50.73141744849527	51.01425216665411
CI	1.48047109111	2.05369346534	2.59601682562	2.03180510493	2.47722328859
Network Overhead Ratio	34.693520412843206	47.78565117494521	62.564402766523386	61.213398722794174	61.7253668105297
CI	1.92595262843	2.29983044147	3.00162444177	2.44391130396	2.97316379933
Average Power Consumed per Node (Watts)	0.819639274691358	0.8203829089506173	0.8211658468364198	0.8211863425925926	0.8211962287808642
CI	4.32568172281e-05	6.95959813352e-05	9.21111050942e-05	9.99849926127e-05	0.000115365490383

NS-3 Helsinki, Centroid, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.5557101987164618	0.7452253924070208	0.861594370988943	0.8929869326529034	0.8934508621356221
CI	0.011902122451	0.0214901010119	0.0156456141734	0.00868522138346	0.00870867386913
PDR	0.5546481586671923	0.7472579955944174	0.862884363285708	0.8938409789539794	0.894562343960327
CI	0.0106139261345	0.0214002328141	0.0154293618471	0.0086152538228	0.00872272617096
Average Latency (seconds)	5569.892731638516	4848.565352232074	3592.445912741532	3106.2746612313376	3173.4883704283375
CI	100.194094347	108.779801568	89.6257310046	91.0620975629	130.879619775
Median Latency (seconds)	5169.964086450778	4565.743861200722	3501.8405613768336	3036.8983183016103	3096.6286639053883
CI	142.026729225	123.178519642	99.1172644525	98.8699469837	117.940001603
Maximum Latency (seconds)	17310.321280424778	16075.407896252333	11118.15094398089	9323.780080153001	10022.296406715222
CI	384.860247426	966.431159235	1331.57116291	973.151953908	1752.52416496
Average Hop Count	3.9238322044724137	3.936911153278053	3.067267658106412	2.8898979739279054	2.8793423544526755
CI	0.17222870824	0.123148749442	0.0806631898607	0.0372870102328	0.0319679772772
Median Hop Count	3.111111111111111	3.3333333333333335	3.0	3.0	3.0
CI	0.236975802946	0.355463704419	0.0	0.0	0.0
Maximum Hop Count	19.11111111111111	18.77777777777778	10.666666666666666	8.11111111111111	8.11111111111111
CI	1.5266098205	2.63085836148	0.50270159172	0.427214204283	0.427214204283
Message Replication Overhead Ratio	30.449736931573813	44.75520556021974	58.97034911486904	58.14147894107895	56.94069740109308
CI	1.80175675168	2.30365145745	3.54223271356	1.78965446256	2.36235189513
Network Overhead Ratio	35.33497138948999	52.055811950428364	68.46332129599855	67.7213624709391	66.34675727777353
CI	2.00402787984	2.90860905435	4.02819179722	2.19025783978	2.80474746606
Average Power Consumed per Node (Watts)	0.8194350137174211	0.8199847822359396	0.8205952074759945	0.8206530778463649	0.8206149262688615
CI	3.13733568789e-05	4.86090919006e-05	8.15546638744e-05	5.89780887255e-05	7.63888143613e-05

NS-3 Helsinki, Centroid, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.5566283924843424	0.7674843423799582	0.8783924843423799	0.9048364648573417	0.9024008350730689
CI	0.0113806058513	0.0233815402385	0.0157403917458	0.00691242028093	0.00604943310023
PDR	0.5556958813286277	0.768953756902476	0.8791775693972381	0.9055296631871048	0.9038888992354897
CI	0.0115953714915	0.0236247479526	0.0158544962878	0.00695224456268	0.00641475741499
Average Latency (seconds)	5361.869892690488	4661.335130341064	3352.2257075388416	2852.826835223122	2872.772792086262
CI	137.007348417	138.350800849	92.771089343	112.819481716	133.301979877
Median Latency (seconds)	4874.887396857125	4382.695001018313	3244.3265387901247	2771.9374942447494	2762.8923769658127
CI	215.379563053	90.0276559862	100.227326114	103.112433334	115.531965618
Maximum Latency (seconds)	17279.8514571555	16037.003235498625	10486.926884375624	9259.6487985205	9128.081240833875
CI	263.533967395	891.807946544	1001.92731782	1088.50387552	1131.36573134
Average Hop Count	3.895984630801921	3.965390309288411	3.0864506004543393	2.9925190329427895	2.9958318572796845
CI	0.159260387862	0.139561733423	0.0740306176401	0.0394582348933	0.0376930017728
Median Hop Count	3.0	3.75	3.0	3.0	3.0
CI	0.0	0.353033342224	0.0	0.0	0.0
Maximum Hop Count	17.375	16.5	10.5	9.125	8.875
CI	1.57552047571	1.77689552261	1.41213336889	0.85872533401	0.85872533401
Message Replication Overhead Ratio	32.0075699028005	46.76535946189819	61.4421760934824	61.49145772782305	60.63323927112937
CI	1.27214128013	1.99322159436	4.7448495269	3.0396557088	3.76924407045
Network Overhead Ratio	36.255972566907715	52.84150523626248	69.66269141038995	69.67845941033424	68.64248777901179
CI	1.33816152919	2.33286055981	5.53372724622	3.43516179148	4.26742770391
Average Power Consumed per Node (Watts)	0.8193029031635802	0.8196971450617284	0.8201367187499999	0.8201762635030865	0.8201475694444444
CI	2.08634992431e-05	3.44923380258e-05	8.77077412187e-05	6.64504177732e-05	8.75721401032e-05

NS-3 Helsinki, GAPR, 6 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.49834725121781487	0.6702331245650661	0.7767919276270007	0.8010612386917189	0.7965379262352122
CI	0.017778002613	0.0160985129754	0.019484792539	0.0194200229663	0.0200951359322
PDR	0.5372694130683776	0.6982398104088873	0.7896467515294863	0.810539487284545	0.8070980267997654
CI	0.0167498978578	0.0169707749907	0.017578573231	0.0178205820548	0.0188927355978
Average Latency (seconds)	7076.675698722413	6219.178009972946	5144.170940605397	4890.323973703959	4896.090533274935
CI	201.292067166	162.602706684	133.17916583	92.5030694848	84.3298631666
Median Latency (seconds)	6283.610272084938	5459.538063621125	4637.944291623688	4461.775123933688	4481.80131537025
CI	257.671636311	182.689045254	135.498250117	77.2608295039	83.6776304046
Maximum Latency (seconds)	17907.436453685	17780.301459304126	17379.700696075375	16967.9004084005	16791.796209902248
CI	41.0168660301	79.9220236025	455.438106701	558.906004549	546.898633324
Average Hop Count	1.770644891193887	1.9712883310545934	2.323692863050308	2.477292756863023	2.4814638908135667
CI	0.0416705962501	0.0352343182041	0.0223216106044	0.0157033558328	0.0154716482675
Median Hop Count	2.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	5.125	5.625	6.5	6.5	6.5
CI	0.48875253082	0.567421709899	0.576501033758	0.576501033758	0.576501033758
Message Replication Overhead Ratio	44.086887578178356	35.440468923768485	30.458372307074374	28.041073637260705	27.77400424770574
CI	1.4098471041	0.645095767302	1.66548284448	0.831926279396	0.922877489195
Network Overhead Ratio	72.52746310039679	59.33292559532389	52.45679183978068	49.56101134212641	49.139884217096665
CI	1.55349152677	0.959907047851	1.96450704438	1.00798587302	1.12776856057
Average Power Consumed per Node (Watts)	0.8261475212191358	0.8265868537808642	0.8265909529320988	0.8264219232253086	0.8263541666666666
CI	0.000179750133313	0.000197160944302	0.000147541625472	0.000171468227233	0.000168284205259

NS-3 Helsinki, GAPR, 12 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6316109951287404	0.7753131524008351	0.8228079331941545	0.8595163535142658	0.8589944328462074
CI	0.0306438961083	0.029877332452	0.0129095713021	0.0166707110764	0.0150882892374
PDR	0.6470970024862881	0.7832196500572685	0.8260201231038561	0.8604880388121688	0.8608484109173193
CI	0.0285735291342	0.0287576819535	0.0133065334277	0.0168293933436	0.0154418774145
Average Latency (seconds)	5966.206599182691	4681.460442512873	3392.2471363998693	3014.95945880889	2992.1448954899183
CI	183.771351961	209.391509571	108.953352323	63.4549180243	37.0079505972
Median Latency (seconds)	5040.849855379937	4003.2164989318753	3084.2181137155626	2859.5693361435	2835.554862183688
CI	256.921953299	188.014524005	77.1018741813	70.4507589607	45.7717622597
Maximum Latency (seconds)	17888.431423314	17684.053760828	14995.52150578775	10758.403922146124	11781.820557515875
CI	68.8879087334	210.165362049	1440.809172	1229.43566367	1908.41626585
Average Hop Count	1.9049784271990524	2.115035139123434	2.5505403349381353	2.8599705782702194	2.885344171350603
CI	0.0469689187724	0.0395641987073	0.0416632657054	0.02769603762	0.0222846229308
Median Hop Count	2.0	2.0	2.625	3.0	3.0
CI	0.0	0.0	0.394703275768	0.0	0.0
Maximum Hop Count	5.75	6.25	7.0	7.25	7.125
CI	0.676007383574	0.353033342224	0.706066684447	0.676007383574	0.636439908668
Message Replication Overhead Ratio	62.965540838930224	58.829883735974754	55.11660519361333	48.50738201146728	48.53591152694861
CI	2.43235905524	1.54882200797	0.757824286876	1.09490481856	1.47388603924
Network Overhead Ratio	87.87376915709262	81.76871641764494	76.74074332000745	69.28684232340538	69.22764123848043
CI	2.78902814525	1.54172849187	0.92228170099	1.27496677458	1.60149216177
Average Power Consumed per Node (Watts)	0.8238327064043209	0.8244355227623457	0.824461082175926	0.8241779996141976	0.8241632908950618
CI	7.40281152507e-05	0.000122948560477	0.000103530595693	9.05726881084e-05	7.03064841664e-05

NS-3 Helsinki, GAPR, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6899791231732777	0.8306367432150313	0.8903966597077244	0.8970076548364648	0.9039665970772442
CI	0.0234940952886	0.0240826182994	0.0214492652808	0.0188684351519	0.0144091438619
PDR	0.6975383884755422	0.8337450763113541	0.8916038886664369	0.8978289210254309	0.904364972203857
CI	0.0224746122491	0.0244727162934	0.021515445361	0.0193159963149	0.0146552613639
Average Latency (seconds)	5420.623843566189	3675.1109156281555	2405.8099345742653	2137.3612419248425	2121.666151898614
CI	177.480127107	164.222403727	125.823165202	50.5671668576	39.4772903185
Median Latency (seconds)	4441.4697908115	3113.7873874019997	2214.1651485548755	2010.8805503562496	1998.60152198925
CI	196.39331423	109.354719682	98.9690027532	49.2805175163	42.9484159754
Maximum Latency (seconds)	17850.94808614662	17006.4576503425	10051.979204992624	6756.777517292501	6986.713491864
CI	132.058406635	907.96614853	1676.37931982	299.359585302	227.935481734
Average Hop Count	1.9470991240222773	2.205217116421343	2.8424839703034026	3.294858540401696	3.3106207893182407
CI	0.0278857265528	0.0513965173161	0.102326989221	0.050373437433	0.0274284121765
Median Hop Count	2.0	2.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	6.25	6.875	7.875	8.625	8.625
CI	0.539267337861	0.48875253082	0.48875253082	0.394703275768	0.394703275768
Message Replication Overhead Ratio	90.97154830813804	91.54050315403886	82.68023897617857	70.2146866887075	69.55763056989385
CI	3.02027619194	3.93360052393	3.12974385103	1.62549435434	0.959077126467
Network Overhead Ratio	114.27660609407855	113.00025953071221	103.0773109738855	89.10449276295358	88.30138712506273
CI	3.38545231523	3.9829439772	3.60885388879	1.89595274071	1.09364252701
Average Power Consumed per Node (Watts)	0.8221800250771605	0.8227177372685185	0.8227387152777778	0.8222967303240741	0.8222952835648148
CI	3.74031686089e-05	8.86962508353e-05	8.81834421991e-05	5.69441157103e-05	5.08855260637e-05

NS-3 Helsinki, GAPR, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.7292971468336813	0.845946416144746	0.8825678496868476	0.9055323590814196	0.9021398747390397
CI	0.0186539654078	0.0216489420173	0.0241240392587	0.0186534261434	0.0174571117974
PDR	0.733941558260157	0.8486583821434225	0.8835520863403141	0.9053923120617567	0.9014684930486363
CI	0.0187059465194	0.0210128175204	0.0236831664461	0.0180480304596	0.0172764450477
Average Latency (seconds)	5082.044711249609	3371.435025005393	2220.8651008731517	1890.6221336584467	1881.9252316921124
CI	148.580404648	212.362179624	113.06886562	31.9071687519	26.5871905598
Median Latency (seconds)	4025.035857093813	2850.891760177875	2020.2522689557497	1775.0004089018123	1766.6683882642494
CI	160.383572832	140.898237402	70.5005369936	36.6510549412	30.7045758734
Maximum Latency (seconds)	17859.153136461	16790.052816491	8996.67986527525	6939.393887091251	6771.99451242375
CI	116.176535215	1049.55937193	1222.7000613	1046.42413416	1099.7739148
Average Hop Count	2.002500538044307	2.257444783446048	2.871177914424895	3.4467661790759756	3.475330482863141
CI	0.0203855664082	0.0261102042807	0.0799821810249	0.0486563980805	0.0380720997253
Median Hop Count	2.0	2.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	6.625	7.125	7.625	9.75	10.125
CI	1.46625759246	0.48875253082	0.808901006792	0.888447761307	0.755799231481
Message Replication Overhead Ratio	103.49485807545649	108.20810549711351	102.88528612611935	80.18374476147092	79.15666345074958
CI	6.07632904252	2.30088832579	4.29368901156	1.7008837042	0.805583856078
Network Overhead Ratio	124.35282270155935	128.2119610970302	123.11446081072503	97.81037947492611	96.65570704828261
CI	5.8395509895	2.53219385947	5.0136355461	1.81740318162	0.911541478062
Average Power Consumed per Node (Watts)	0.8213756269290123	0.8219369695216049	0.8219733796296296	0.821486786265432	0.8214515817901235
CI	2.62039739815e-05	4.63846858509e-05	5.60745217601e-05	2.64659285148e-05	4.31423052675e-05

NS-3 Helsinki, GAPR, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.7439979123173278	0.850991649269311	0.8868302018093249	0.9156228253305497	0.9151878914405011
CI	0.0234331101183	0.0216999937989	0.0239620191555	0.0158041699314	0.0159124803058
PDR	0.7479388019257094	0.8524958329065361	0.8872621963143339	0.9156007598543612	0.9153979923455847
CI	0.0235353107454	0.0219941006781	0.024504375164	0.0159919846612	0.0157269519248
Average Latency (seconds)	4755.294990774784	3172.066559340362	2069.5133891616333	1705.8048658082096	1705.7021382599373
CI	144.244900952	210.846629552	121.915104886	34.8653084844	40.3191062145
Median Latency (seconds)	3741.036837623563	2704.6994951872502	1870.853110830812	1606.475973887063	1609.9860345264383
CI	112.803462496	158.864359278	84.1995659444	29.1139423983	41.5819685839
Maximum Latency (seconds)	17885.7706272515	15644.385643718124	9708.733368877376	6004.077067721124	5977.751836595625
CI	63.876903692	1343.87119953	2514.57004433	381.330674439	415.793351953
Average Hop Count	2.0192683088724097	2.27778986955722	2.9279060503715453	3.6289400349206256	3.635586227347114
CI	0.0256424789889	0.0448324633141	0.138681517574	0.0433356863651	0.0377075208747
Median Hop Count	2.0	2.0	3.0	3.5	3.5
CI	0.0	0.0	0.0	0.407647790332	0.407647790332
Maximum Hop Count	6.625	7.125	8.0	9.5	9.75
CI	0.567421709899	0.636439908668	1.15300206752	0.576501033758	0.539267337861
Message Replication Overhead Ratio	114.67122785699368	127.46760604271462	121.73769639715069	87.29921700530059	86.56901388440555
CI	4.38545159368	4.416411504	8.19004388172	1.53436520216	1.29307006641
Network Overhead Ratio	133.7586945388078	147.4281239509786	140.98500733617337	103.69035564749643	102.8029357241294
CI	4.65421264665	4.13398809013	8.86904462828	1.71787440875	1.3225153125
Average Power Consumed per Node (Watts)	0.8207831790123457	0.8213225790895062	0.8213355999228396	0.8208138020833333	0.8207966820987654
CI	3.2307720781e-05	4.70432325954e-05	8.8816430202e-05	2.25650042842e-05	3.04148652328e-05

NS-3 Helsinki, GAPR2, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.4224947807933194	0.5338378566457899	0.5561934585942937	0.5555845511482255	0.5555845511482255
CI	0.0176963359438	0.0116289233161	0.0113887789566	0.0112365023289	0.0112365023289
PDR	0.46750551732486567	0.5799045991675125	0.5997583551387945	0.5992517855646295	0.5992517855646295
CI	0.0181082329549	0.0119208379057	0.0119384817276	0.0118933506238	0.0118933506238
Average Latency (seconds)	8122.772611398167	8315.291745173334	8332.11553390092	8338.189857205005	8338.189857205005
CI	213.316696717	161.858668978	132.814446679	134.527177878	134.527177878
Median Latency (seconds)	7654.553669759188	7988.382089466375	8040.127828412938	8044.283833682937	8044.283833682937
CI	285.442859472	257.732178219	250.298912389	253.734172855	253.734172855
Maximum Latency (seconds)	17937.847349093	17973.327735193627	17960.533559992	17960.533559992	17960.533559992
CI	46.3921477843	20.2890054068	33.1689323976	33.1689323976	33.1689323976
Average Hop Count	1.3780747297485625	1.5778083998219075	1.6286347788905124	1.6308063567072515	1.6308063567072515
CI	0.0142417121638	0.0193443086958	0.0192884753595	0.0222949177768	0.0222949177768
Median Hop Count	1.0	1.375	1.875	1.875	1.875
CI	0.0	0.394703275768	0.269633668931	0.269633668931	0.269633668931
Maximum Hop Count	3.875	4.25	4.75	4.75	4.75
CI	0.48875253082	0.353033342224	0.353033342224	0.353033342224	0.353033342224
Message Replication Overhead Ratio	5.071843966623198	4.678137671052282	4.621440599109981	4.634833201373551	4.634833201373551
CI	0.275097409207	0.230472976325	0.240415396955	0.246037785325	0.246037785325
Network Overhead Ratio	18.37690471421478	15.84316837238847	15.510072208871119	15.523937493545542	15.523937493545542
CI	0.736130589352	0.526660442951	0.456331304529	0.46661310686	0.46661310686
Average Power Consumed per Node (Watts)	0.8206365740740741	0.820740981867284	0.8207624421296297	0.8207614776234569	0.8207614776234569
CI	2.01098566061e-05	1.7661345318e-05	2.1674817731e-05	2.12425745724e-05	2.12425745724e-05

NS-3 Helsinki, GAPR2, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.5434933890048712	0.6839770354906054	0.7284272790535838	0.7266005567153793	0.7266005567153793
CI	0.0200029424019	0.0169032128557	0.0138270232591	0.0156575735616	0.0156575735616
PDR	0.5629240424996973	0.7001569062008213	0.7416681410572777	0.7405264971272663	0.7405264971272663
CI	0.0203467873126	0.0170136575066	0.0137853932152	0.0157543598825	0.0157543598825
Average Latency (seconds)	7746.001600265328	7536.605050246787	7514.718165552629	7510.403556917481	7510.403556917481
CI	147.244443873	106.170956388	143.448982318	140.899110108	140.899110108
Median Latency (seconds)	7234.69556875925	7067.713797694438	7060.612928070438	7060.327184483625	7060.327184483625
CI	248.39676619	166.384182578	201.474759508	196.458702247	196.458702247
Maximum Latency (seconds)	17957.9225820585	17955.76986556025	17930.7001883865	17940.708916626125	17940.708916626125
CI	35.4537158363	24.4008748841	25.3651524488	22.1308575339	22.1308575339
Average Hop Count	1.4953940324023371	1.7379815747468723	1.8677890599543874	1.8658030344055172	1.8658030344055172
CI	0.0124979346889	0.0249296912969	0.029899672247	0.0298560945161	0.0298560945161
Median Hop Count	1.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	4.5	4.625	5.25	5.25	5.25
CI	0.407647790332	0.808901006792	0.539267337861	0.539267337861	0.539267337861
Message Replication Overhead Ratio	6.955385925451397	6.5189815418833845	7.071935956516038	7.097502106090997	7.097502106090997
CI	0.548804778244	0.352633527188	1.36385925503	1.41571326957	1.41571326957
Network Overhead Ratio	18.51623711574922	16.124160282945287	16.472473009862387	16.500886402638272	16.500886402638272
CI	1.00684501132	0.555173578593	1.67787388525	1.73768824557	1.73768824557
Average Power Consumed per Node (Watts)	0.8199628665123457	0.8200610050154321	0.820094280478395	0.820094280478395	0.820094280478395
CI	7.85374058101e-06	1.12297126951e-05	1.86324861984e-05	2.01932824476e-05	2.01932824476e-05

NS-3 Helsinki, GAPR2, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6188239387613083	0.7793145441892833	0.811499652052888	0.81419624217119	0.81419624217119
CI	0.0159082126361	0.0135972216537	0.0115351226343	0.00956972494674	0.00956972494674
PDR	0.6258243395506058	0.7825980780154392	0.8140852415051821	0.8169335313672723	0.8169335313672723
CI	0.0154178696466	0.0141106685323	0.0111114912732	0.00979507193753	0.00979507193753
Average Latency (seconds)	7290.382705283326	6619.601723056623	6353.693554019953	6331.310191365308	6331.310191365308
CI	146.405856414	91.0564507282	96.2787781648	99.7465419516	99.7465419516
Median Latency (seconds)	6630.546188384187	6067.936924228062	5850.738028748688	5855.044738102812	5855.044738102812
CI	191.114450875	133.319391884	110.195626153	144.72637597	144.72637597
Maximum Latency (seconds)	17924.163483655877	17940.324296175124	17907.463788909125	17835.880177452123	17835.880177452123
CI	35.5869872596	48.0017783302	45.361169704	110.420856243	110.420856243
Average Hop Count	1.5845714570043161	1.8773427723780378	2.059048894840352	2.0609045571128726	2.0609045571128726
CI	0.0243511925339	0.0183596857862	0.0287893814184	0.0276851304929	0.0276851304929
Median Hop Count	1.5625	2.0	2.0	2.0	2.0
CI	0.377899615741	0.0	0.0	0.0	0.0
Maximum Hop Count	4.75	5.25	5.625	5.625	5.625
CI	0.676007383574	0.676007383574	0.567421709899	0.567421709899	0.567421709899
Message Replication Overhead Ratio	8.840650800210108	8.988700255557575	8.986223208008282	9.607526959681712	9.607526959681712
CI	0.365706521463	0.632345966842	0.244121206261	1.06741029279	1.06741029279
Network Overhead Ratio	19.257641362711432	17.814292249355333	17.55924404022455	18.218541818467266	18.218541818467266
CI	0.749723049618	0.802380989695	0.486232367665	1.22082602707	1.22082602707
Average Power Consumed per Node (Watts)	0.8195457175925926	0.8196308352623457	0.8196501253858024	0.8196515721450617	0.8196515721450617
CI	8.32202681884e-06	8.01689569124e-06	6.94213947892e-06	5.09238662083e-06	5.09238662083e-06

NS-3 Helsinki, GAPR2, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6370041753653445	0.8068893528183716	0.8384655532359082	0.8401183020180932	0.8401183020180932
CI	0.00979388648735	0.00867893126336	0.00603403217217	0.00558604239799	0.00558604239799
PDR	0.6414204434346162	0.8094569741779885	0.8398830420247884	0.8415664081051132	0.8415664081051132
CI	0.00972602383698	0.00918770650351	0.0065729771288	0.00579291149692	0.00579291149692
Average Latency (seconds)	7100.49803875181	6175.756775791049	5797.163531162242	5801.359546567103	5801.359546567103
CI	138.596653036	58.9274353492	103.920067914	99.1440854044	99.1440854044
Median Latency (seconds)	6383.140298828	5642.874676739563	5386.758233552875	5381.448390392625	5381.448390392625
CI	191.439228993	104.169412398	97.2582651793	90.3318973623	90.3318973623
Maximum Latency (seconds)	17900.6045655655	17908.615649682877	17810.981433106128	17750.886572782998	17750.886572782998
CI	66.563054712	63.8849908965	131.735460216	179.280151129	179.280151129
Average Hop Count	1.6160713481812161	1.9359400629710746	2.137845119714658	2.1499450917181777	2.1499450917181777
CI	0.0247789725976	0.0189619592748	0.0292774549009	0.0271840019276	0.0271840019276
Median Hop Count	2.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	4.75	5.5	5.875	5.75	5.75
CI	0.676007383574	0.576501033758	0.48875253082	0.353033342224	0.353033342224
Message Replication Overhead Ratio	10.053132647362858	10.83061173436455	10.683887633072926	10.799350860498505	10.799350860498505
CI	0.300091576002	0.949823639592	0.436012012983	1.00075755035	1.00075755035
Network Overhead Ratio	19.872554710181756	19.393608415460196	18.922044833670117	19.06630504135044	19.06630504135044
CI	0.623792039848	1.24315693459	0.542479499651	1.14102065805	1.14102065805
Average Power Consumed per Node (Watts)	0.8193959780092592	0.8194716917438272	0.8194924286265433	0.8194897762345679	0.8194897762345679
CI	6.16363435648e-06	5.90750344444e-06	7.99758947249e-06	9.56645333558e-06	9.56645333558e-06

NS-3 Helsinki, GAPR2, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.649008350730689	0.8203723034098818	0.8628218510786361	0.8621259568545581	0.8621259568545581
CI	0.0207841395513	0.0186009079882	0.00882347751314	0.00886442458329	0.00886442458329
PDR	0.6516174840998612	0.8206224566761959	0.8636017189842535	0.862692407974746	0.862692407974746
CI	0.0219255427209	0.018519047989	0.00911329027284	0.00901387969086	0.00901387969086
Average Latency (seconds)	6949.471364526573	5845.009892739697	5361.875828198145	5356.676679455602	5356.676679455602
CI	90.4639709718	82.7502337752	104.431230226	112.117322719	112.117322719
Median Latency (seconds)	6183.832167937938	5325.560804354937	4968.247344329062	4983.922197916375	4983.922197916375
CI	133.519475044	103.144812728	106.54435025	110.937316073	110.937316073
Maximum Latency (seconds)	17935.134996615125	17844.512660633874	17496.74896752325	17437.324260349375	17437.324260349375
CI	45.2197554379	66.4510277234	122.307270399	285.197851999	285.197851999
Average Hop Count	1.6382751330626892	1.9766668130069125	2.220932557597829	2.2290494082180965	2.2290494082180965
CI	0.0306949295612	0.0272504351157	0.030158534113	0.0350692808393	0.0350692808393
Median Hop Count	2.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	4.75	5.75	6.5	6.375	6.375
CI	0.539267337861	0.676007383574	0.576501033758	0.698673112283	0.698673112283
Message Replication Overhead Ratio	11.23085794280021	11.417868638894761	12.112473121992943	12.158679456681506	12.158679456681506
CI	0.532440801485	0.412047309424	0.56918446279	0.563509473339	0.563509473339
Network Overhead Ratio	20.83084435673899	19.526123819322798	20.11943378961792	20.18287347560996	20.18287347560996
CI	1.02287947744	0.496433329654	0.772381970804	0.737020677453	0.737020677453
Average Power Consumed per Node (Watts)	0.8192910879629629	0.8193504050925926	0.8193689718364198	0.8193699363425926	0.8193699363425926
CI	4.08603405351e-06	3.9903291096e-06	5.12265367259e-06	5.21240041727e-06	5.21240041727e-06

NS-3 Helsinki, GAPR2a, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.47792468878063865	0.6697595298847908	0.7679579370602335	0.7751488440423723	0.774994200881466
CI	0.0172620776615	0.0117936660687	0.0132175207681	0.0133220411271	0.0136925039493
PDR	0.5187022051710242	0.6984135557024773	0.7846990329032252	0.7903902841280039	0.7903186856506098
CI	0.0172478545766	0.0119984923226	0.0131567370961	0.0128366816749	0.0131186858993
Average Latency (seconds)	7589.540886154222	6801.636360198572	5750.4996007260215	5654.659138718254	5657.034516086683
CI	232.768421176	118.579563206	103.939693207	117.219965729	112.542911134
Median Latency (seconds)	6940.5933083455	6081.275561562556	5156.103313283278	5061.755560942834	5059.8089670613335
CI	292.457049171	170.759633904	115.871370643	140.545540314	139.229669131
Maximum Latency (seconds)	17900.96936526178	17916.36837288489	17895.471818974333	17892.334871788556	17889.664074950222
CI	50.3719833951	40.721673986	97.7232030484	75.7961971125	75.6792612411
Average Hop Count	1.5592788035388232	1.8406556748331617	2.179570343098092	2.2398416202587272	2.239446090716466
CI	0.0235672948753	0.0226854901042	0.0163872723065	0.0309425610645	0.0312620113449
Median Hop Count	1.3888888888888888	2.0	2.0	2.0	2.0
CI	0.345448626805	0.0	0.0	0.0	0.0
Maximum Hop Count	4.222222222222222	4.555555555555555	5.222222222222222	5.555555555555555	5.555555555555555
CI	0.473951605892	0.374691643828	0.473951605892	0.374691643828	0.374691643828
Message Replication Overhead Ratio	17.730820951209846	20.69596419580862	21.471265778115566	20.966496566817582	20.944591020870803
CI	1.32320527134	0.747521985965	1.20768234381	0.98341683064	0.993715613681
Network Overhead Ratio	33.0860904401229	36.47419050004088	37.22327079966262	36.72132468639935	36.671317546654514
CI	1.80419513233	0.851409699895	1.65627685922	1.35610389111	1.34569097269
Average Power Consumed per Node (Watts)	0.8218171296296296	0.823391846707819	0.8240974365569272	0.8240880058299039	0.8240775034293553
CI	0.000104317906347	0.000132164714996	0.000172306349622	0.000146611513145	0.000140131366517

NS-3 Helsinki, GAPR2a, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6065588030619345	0.7703549060542798	0.8491649269311065	0.8535142658315936	0.8614300626304802
CI	0.010865110057	0.0261785839369	0.01774246144	0.0200150081167	0.00975477870896
PDR	0.6234369907532429	0.7799171702874597	0.8527693711646445	0.8567362579035097	0.8642365605415825
CI	0.012630084966	0.0253408929841	0.0182347076115	0.0197923901897	0.0102555620543
Average Latency (seconds)	6828.293790005716	5312.561324338611	3901.191558258207	3631.229212414183	3654.9472027960433
CI	139.54441884	128.391802908	72.7182730985	101.033570126	68.8776754784
Median Latency (seconds)	6028.896102609313	4598.931154374437	3582.2338981800003	3363.455050982937	3370.6655380518123
CI	187.150122754	132.008878589	56.529600346	96.8235550758	68.2778099198
Maximum Latency (seconds)	17921.88545569525	17815.324211238752	15336.5168309265	13660.498660392126	13863.067172305375
CI	61.3332189739	130.365051981	842.820740605	1415.07273807	1092.88981642
Average Hop Count	1.687121512348773	1.968597654515604	2.3894790102485137	2.5459808913309256	2.5420545143521847
CI	0.0302817646961	0.0279099349728	0.031476330632	0.0280434011053	0.0322120627422
Median Hop Count	2.0	2.0	2.0	2.875	2.875
CI	0.0	0.0	0.0	0.269633668931	0.269633668931
Maximum Hop Count	4.5	4.5	5.25	6.125	6.125
CI	0.407647790332	0.576501033758	0.353033342224	0.269633668931	0.269633668931
Message Replication Overhead Ratio	20.323042189493552	29.039921060767423	35.854708149322555	35.56967561164367	34.52702237794642
CI	1.40190599918	1.78000327371	2.90626889858	2.84785510253	1.61362730514
Network Overhead Ratio	33.29639590907327	43.01125647241906	51.45891007107536	51.43440859720065	49.971845332303204
CI	1.94843739038	2.12824264856	3.77730569288	3.66175037704	1.98924100103
Average Power Consumed per Node (Watts)	0.8206086033950617	0.8217522665895062	0.8226405767746914	0.8227211130401235	0.8226658950617284
CI	9.77427022428e-05	0.000102627766195	0.0002248535096	0.000201525428256	0.000131930093697

NS-3 Helsinki, GAPR2a, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6735386221294364	0.8286360473208072	0.883785664578984	0.9004001391788448	0.8924843423799582
CI	0.0232105467078	0.0159284344129	0.015099119131	0.00814036062693	0.00843440511588
PDR	0.6804877594539478	0.8319036400376203	0.8860474536498152	0.9011248824367486	0.8932970322844984
CI	0.0234416313348	0.0150503911028	0.0151179962846	0.00787517034144	0.00906812679529
Average Latency (seconds)	6322.4975090800945	4388.442578817377	2914.620491667868	2677.5946061145296	2653.849040885626
CI	206.16346933	166.429477091	44.6400833389	105.072834586	105.99743957
Median Latency (seconds)	5479.895931394874	3802.2826642732516	2675.290995200188	2469.8973558221246	2446.3918531598742
CI	215.792278943	117.529461034	69.9476747956	97.1074368299	90.746715451
Maximum Latency (seconds)	17921.830700623374	17081.200761340126	11970.47699494175	10591.60709178325	11051.8782601335
CI	43.3779110716	616.715699998	1532.9994364	1013.35941327	1872.4364586
Average Hop Count	1.7719742481696714	2.063639107096134	2.559168207255299	2.825446657647057	2.8317585920118775
CI	0.0486922239907	0.0547664093227	0.0369637453364	0.0332356702973	0.0404673374581
Median Hop Count	2.0	2.0	2.875	3.0	3.0
CI	0.0	0.0	0.269633668931	0.0	0.0
Maximum Hop Count	4.625	5.0	5.5	7.125	7.0
CI	0.394703275768	0.815295580663	0.407647790332	0.269633668931	0.0
Message Replication Overhead Ratio	23.75299304948908	37.37573203404702	52.110064145900395	48.50087072170085	49.35938045918324
CI	1.62296256587	1.99763500947	2.27655651016	1.88862102237	1.87156612538
Network Overhead Ratio	34.73358800019455	49.562299317767625	66.38692220714604	62.728991113967325	63.80150758349559
CI	2.02853876157	2.44197640064	2.82480732488	2.20865882633	2.10168723904
Average Power Consumed per Node (Watts)	0.8198615933641975	0.8206223476080247	0.8213787615740741	0.8213194444444445	0.8213445216049383
CI	4.84153049346e-05	8.22935084308e-05	8.53324840408e-05	8.5846341225e-05	8.19624587615e-05

NS-3 Helsinki, GAPR2a, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6986004793937989	0.8439650506456352	0.9011056986004794	0.9142503672775072	0.9107708961571175
CI	0.0130763409077	0.0128291149067	0.0115640079038	0.0089830600856	0.0145520892985
PDR	0.7025002560783693	0.8459635323708925	0.9025066709708526	0.9148491310407335	0.9114041268451869
CI	0.0125239793336	0.0132174752816	0.0120042704706	0.00899321581002	0.0145864068456
Average Latency (seconds)	6085.813193145856	4011.255074586955	2612.7505869977404	2433.361589678825	2429.1835995125766
CI	124.454675604	139.399412303	56.5877979216	39.6851569821	59.0933516289
Median Latency (seconds)	5202.842971676056	3469.4522691791108	2383.3090659084996	2238.690072508777	2224.7842455824443
CI	192.894622793	119.335004645	50.7576225537	38.9683578489	44.7812717064
Maximum Latency (seconds)	17909.268693107668	17236.611061194002	10797.472272583333	10447.735482449	10224.79138034189
CI	40.633065267	640.714896801	1189.08951238	1500.16642915	1236.20421877
Average Hop Count	1.8353764082830637	2.107623097326931	2.6662287716696134	2.938647938616553	2.946430344023731
CI	0.0273543134249	0.0355255968822	0.0259356828768	0.0319579275762	0.0298596035194
Median Hop Count	2.0	2.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	5.0	5.0	6.222222222222222	7.555555555555555	7.777777777777778
CI	0.355463704419	0.50270159172	0.473951605892	0.516476788552	0.592439507364
Message Replication Overhead Ratio	25.466036246857076	40.34332540913531	57.63200074945958	52.73936454011968	53.3909421863155
CI	1.42462743474	1.40936311061	3.44647177717	2.60777154579	2.87461379603
Network Overhead Ratio	35.74530226717004	51.53658174448715	70.88112823004931	65.8044828921671	66.38657888084843
CI	1.68995557598	1.77591558701	4.01682654693	2.9611738568	3.50723615393
Average Power Consumed per Node (Watts)	0.819607981824417	0.820170396090535	0.8207497427983539	0.8206605795610425	0.8206738683127572
CI	2.63950086309e-05	4.31388103808e-05	8.72206920594e-05	8.05160863414e-05	8.97604448774e-05

NS-3 Helsinki, GAPR2a, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.7219902574808629	0.8586464857341685	0.9091858037578289	0.9115344467640919	0.9130132219902575
CI	0.0148816997894	0.00883259326686	0.0094555186136	0.0178885609408	0.00821692465699
PDR	0.7256276248032852	0.85995818938625	0.9093773570849901	0.9114953579975602	0.9126765776755533
CI	0.0155895859693	0.00879934354466	0.0096259495719	0.0179735380448	0.00818552084842
Average Latency (seconds)	5909.617719439671	3783.474462392025	2404.452656616457	2188.0776898375198	2196.905717171007
CI	140.320261767	162.749126767	54.021619464	76.8675169416	87.0013892857
Median Latency (seconds)	5084.555447116312	3313.6269557488126	2195.7811776758745	1998.6817542561246	2004.1797715425632
CI	159.669824176	121.42016205	53.8162500458	64.8102206204	73.0523726548
Maximum Latency (seconds)	17868.377664703123	16482.825906013375	9458.130826963752	8045.99629263375	8587.011463002125
CI	52.8416798983	917.457067067	1018.50086339	993.334590296	1334.67600462
Average Hop Count	1.8656882240911863	2.1630377539915515	2.7358153870204984	3.048777328441014	3.057144488010986
CI	0.0202512858469	0.0499312400504	0.0238386461983	0.0466401059953	0.0563174142259
Median Hop Count	2.0	2.0	3.0	3.0	3.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	5.0	5.5	6.125	7.75	7.875
CI	0.0	0.576501033758	0.636439908668	0.888447761307	0.48875253082
Message Replication Overhead Ratio	26.741020963102557	43.67939245651372	63.00773451535674	60.65811695483346	60.04886040701045
CI	1.34688333407	1.94209104211	2.94554834451	3.04669152304	3.46899821333
Network Overhead Ratio	36.34820932822779	54.07420411406408	75.59106554118976	73.32181203928413	72.64914428707804
CI	1.42083769712	2.16458928791	3.3939461576	3.43937204292	3.84470098162
Average Power Consumed per Node (Watts)	0.8194396219135802	0.8198480902777777	0.8203064718364197	0.8202828414351852	0.820268856095679
CI	2.01252252416e-05	4.04630474274e-05	5.65764361577e-05	5.65190265847e-05	7.47574994929e-05

NS-3 Helsinki, Vector, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.4394572025052192	0.5457550452331246	0.5644572025052192	0.5645441892832289	0.5645441892832289
CI	0.0133419984463	0.00944593909096	0.0132130140223	0.013171266036	0.013171266036
PDR	0.483530436078183	0.5875864846492658	0.605840682006537	0.605936594995763	0.605936594995763
CI	0.0130934489424	0.0116125441952	0.0131409468688	0.0131169911812	0.0131169911812
Average Latency (seconds)	7875.1345037564115	8594.222066429887	8752.39846945272	8753.08303624048	8753.08303624048
CI	156.406272378	113.748416352	134.972369344	135.304311419	135.304311419
Median Latency (seconds)	7430.854558181188	8474.204987645688	8704.261611327312	8705.633938356563	8705.633938356563
CI	242.705501474	184.348728544	209.15420735	208.771755761	208.771755761
Maximum Latency (seconds)	17930.161757400627	17979.234285125	17955.470226084624	17955.470226084624	17955.470226084624
CI	56.0907066371	14.9633789622	28.5592545364	28.5592545364	28.5592545364
Average Hop Count	1.9780364789136187	1.7141292806712785	1.6586990796080474	1.6578119024430522	1.6578119024430522
CI	0.0462560652327	0.0329862108206	0.0200433655237	0.0199863584342	0.0199863584342
Median Hop Count	2.0	1.875	1.375	1.375	1.375
CI	0.0	0.269633668931	0.394703275768	0.394703275768	0.394703275768
Maximum Hop Count	8.0	5.25	5.0	5.0	5.0
CI	0.815295580663	0.353033342224	0.576501033758	0.576501033758	0.576501033758
Message Replication Overhead Ratio	6.043679981747312	5.395521802993423	5.288538656688027	5.287744835560553	5.287744835560553
CI	0.304225702776	0.178158190995	0.162975955561	0.163698172918	0.163698172918
Network Overhead Ratio	12.39643731969607	11.270611412646396	11.00771303014733	11.007992519668694	11.007992519668694
CI	0.3616734569	0.258680275497	0.27782804704	0.277721071678	0.277721071678
Average Power Consumed per Node (Watts)	0.8203151523919753	0.8204253472222223	0.8204381269290123	0.8204386091820988	0.8204386091820988
CI	1.81022444815e-05	2.51265562971e-05	2.4772605277e-05	2.48162492389e-05	2.48162492389e-05

NS-3 Helsinki, Vector, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.552366040361865	0.6798886569241476	0.715205288796103	0.7143354210160056	0.7143354210160056
CI	0.0122533559493	0.0154025300235	0.0118051340398	0.012025478411	0.012025478411
PDR	0.5677036288632914	0.6941041447448062	0.7285864939612064	0.7276413319799979	0.7276413319799979
CI	0.0133934776498	0.0157284698816	0.0122815257293	0.0127542903205	0.0127542903205
Average Latency (seconds)	7524.204089101556	8060.1230091449825	8115.974341168591	8112.969123609037	8112.969123609037
CI	118.855670922	98.6990219539	119.611845455	113.75182369	113.75182369
Median Latency (seconds)	6960.745714614624	7818.4341182845	7988.384602337125	7987.9061917325	7987.9061917325
CI	183.422534759	132.18488912	159.599595645	153.545138113	153.545138113
Maximum Latency (seconds)	17961.94835324875	17953.685957651625	17936.974926992	17936.975455993	17936.975455993
CI	18.6211688391	40.2513245782	28.8736214507	28.8739381151	28.8739381151
Average Hop Count	2.4292841887570926	2.033437127141815	1.8803565689703283	1.8791689639597209	1.8791689639597209
CI	0.0606553067616	0.0448409740185	0.0370652903271	0.035800965892	0.035800965892
Median Hop Count	2.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	9.0	6.5	5.875	5.875	5.875
CI	0.815295580663	0.407647790332	0.636439908668	0.636439908668	0.636439908668
Message Replication Overhead Ratio	7.775064998692998	7.481231333159254	7.452482950176374	7.448522663677921	7.448522663677921
CI	0.269011793175	0.232940290905	0.114110989749	0.0994737650715	0.0994737650715
Network Overhead Ratio	12.800579438368082	12.238180922090514	12.108041321120242	12.107571626156881	12.107571626156881
CI	0.330262249468	0.283212819803	0.121852841341	0.115040615291	0.115040615291
Average Power Consumed per Node (Watts)	0.8197432002314815	0.8198640046296296	0.8198912519290124	0.8198893229166666	0.8198893229166666
CI	3.08964502212e-06	8.09604721653e-06	8.7189118791e-06	7.45745266344e-06	7.45745266344e-06

NS-3 Helsinki, Vector, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6122999304105776	0.7603514265831594	0.7877522616562282	0.7921016005567154	0.7921016005567154
CI	0.0147825116544	0.0166211578046	0.0142603749748	0.0121411947246	0.0121411947246
PDR	0.6152760059223943	0.7653660989486819	0.7910228235666595	0.7958927357550587	0.7958927357550587
CI	0.0137072915939	0.0166667052977	0.0147856659863	0.0127005372134	0.0127005372134
Average Latency (seconds)	7119.2074247950795	7196.41094893276	7072.344205415095	7054.827332755923	7054.827332755923
CI	157.744865685	117.613960528	132.644542844	106.564241439	106.564241439
Median Latency (seconds)	6529.39715184225	6865.287092245376	6837.223711984812	6813.969215665063	6813.969215665063
CI	189.155583583	175.755374898	174.917386585	159.626275077	159.626275077
Maximum Latency (seconds)	17948.403713801126	17896.523123594	17820.173649295375	17821.259609151377	17821.259609151377
CI	43.6403455626	130.274392818	118.770710326	118.663163578	118.663163578
Average Hop Count	2.9097118204279044	2.313914904061005	2.056586483248415	2.0487564407040826	2.0487564407040826
CI	0.0479544485833	0.0308932429299	0.0200473502457	0.0186496536658	0.0186496536658
Median Hop Count	2.875	2.0	2.0	2.0	2.0
CI	0.269633668931	0.0	0.0	0.0	0.0
Maximum Hop Count	11.5	8.25	6.0	6.0	6.0
CI	1.28909550058	0.789406551536	0.576501033758	0.576501033758	0.576501033758
Message Replication Overhead Ratio	10.219534616035727	9.951230270361599	10.83699852998912	10.363529682177202	10.363529682177202
CI	0.281173659453	0.318601080021	0.983120982359	0.330733014537	0.330733014537
Network Overhead Ratio	14.235365908122098	13.904151977298767	14.792552812927259	14.303369656327234	14.303369656327234
CI	0.368919968812	0.358459672672	1.00092314101	0.395508707056	0.395508707056
Average Power Consumed per Node (Watts)	0.8194070698302469	0.8195011091820987	0.8195293209876543	0.8195293209876543	0.8195293209876543
CI	6.28778850215e-06	6.23842335378e-06	8.05776781901e-06	8.17206810701e-06	8.17206810701e-06

NS-3 Helsinki, Vector, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6187369519832986	0.7839248434237995	0.8223729993041058	0.8159359777313848	0.8159359777313848
CI	0.0125315747106	0.0132238583204	0.00733601519039	0.0127592828722	0.0127592828722
PDR	0.6203556695750961	0.7860467552542626	0.8248351786495823	0.8182921435156301	0.8182921435156301
CI	0.0126379263772	0.0137869198088	0.00772270286442	0.0130781390647	0.0130781390647
Average Latency (seconds)	6987.619405218053	6891.269461788932	6533.122944981587	6537.811897417728	6537.811897417728
CI	182.62577473	136.936023922	100.02436887	105.295661149	105.295661149
Median Latency (seconds)	6348.110660258562	6513.7600552045005	6291.596382640625	6289.3492381285	6289.3492381285
CI	186.683276174	106.480774749	127.162506431	131.315978392	131.315978392
Maximum Latency (seconds)	17936.2782326965	17935.010883285875	17656.877929914375	17673.82312172075	17673.82312172075
CI	51.4156024283	72.5389505022	165.649470927	146.163264999	146.163264999
Average Hop Count	3.141856778603601	2.451843241028005	2.1469326718547532	2.1371156449390796	2.1371156449390796
CI	0.0476921786531	0.040919111801	0.0175970043357	0.0191975916608	0.0191975916608
Median Hop Count	3.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	12.125	7.75	6.75	6.625	6.625
CI	1.11172809722	0.789406551536	0.539267337861	0.567421709899	0.567421709899
Message Replication Overhead Ratio	11.610418988690997	11.812703262898586	11.786996100839993	11.846954749532285	11.846954749532285
CI	0.377629304114	0.957761493786	0.297672494082	0.34559635327	0.34559635327
Network Overhead Ratio	15.332540525542518	15.435132014556114	15.40715400339946	15.491364375912951	15.491364375912951
CI	0.426644733049	0.91466675305	0.312893062267	0.355845266783	0.355845266783
Average Power Consumed per Node (Watts)	0.8192867476851852	0.8193660783179012	0.8193921199845678	0.819391155478395	0.819391155478395
CI	2.18912696721e-06	2.21545008094e-06	5.00048637987e-06	3.92687029051e-06	3.92687029051e-06

NS-3 Helsinki, Vector, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6316979819067502	0.802713987473904	0.8356819763395964	0.8403792623521225	0.8403792623521225
CI	0.00984638452271	0.00735928897439	0.00821906675236	0.00734252558606	0.00734252558606
PDR	0.6327175036549367	0.8041079626404939	0.8373199303466835	0.7380541768710017	0.7380541768710017
CI	0.0106046027235	0.00838913551851	0.00833764800315	0.227569540033	0.227569540033
Average Latency (seconds)	6883.09654042732	6464.195700797564	6110.726363963504	6082.136666286244	6082.136666286244
CI	147.539774556	103.179561139	87.2418763022	79.2897471545	79.2897471545
Median Latency (seconds)	6244.992399405	6092.2109121506255	5897.5453814480625	5881.643929405062	5881.643929405062
CI	176.537977088	91.3896320528	102.995779148	90.9526150641	90.9526150641
Maximum Latency (seconds)	17932.481944506875	17791.347296150874	17663.0167349185	17466.618256039	17466.618256039
CI	42.578743001	105.170551925	161.851419768	320.90611972	320.90611972
Average Hop Count	3.349662835959171	2.615608722248038	2.2170728630339984	2.2153455621555738	2.2153455621555738
CI	0.0388733499881	0.054229902933	0.0254127652122	0.0210879694857	0.0210879694857
Median Hop Count	3.0	2.0	2.0	2.0	2.0
CI	0.0	0.0	0.0	0.0	0.0
Maximum Hop Count	12.875	8.75	7.125	6.625	6.625
CI	0.950571365144	0.676007383574	0.636439908668	0.567421709899	0.567421709899
Message Replication Overhead Ratio	13.513281434121696	12.932087517158571	13.890304066197112	14.232388922183342	14.232388922183342
CI	1.42518934337	0.388689994373	1.14268838682	1.92159228627	1.92159228627
Network Overhead Ratio	16.709409628910027	16.33340921559361	17.296830145625187	15.537940312291086	15.537940312291086
CI	1.37268780948	0.39736170518	1.30097248875	5.26452142842	5.26452142842
Average Power Consumed per Node (Watts)	0.8192030767746914	0.8192684220679012	0.8192894000771604	0.8192874710648148	0.8192874710648148
CI	2.14453722458e-06	2.69549811837e-06	4.37383814516e-06	3.84733049938e-06	3.84733049938e-06

NS-3 Helsinki, Vector No Limit, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.45572372999304106	0.6241301322199025	0.7366040361864996	0.7448677800974252	0.753044537230341
CI	0.0189565950159	0.0159881598496	0.0208576965648	0.0141440384166	0.0161981816225
PDR	0.47249625194386763	0.6426456620324241	0.7491668141057277	0.7541733790239223	0.761794969689633
CI	0.0185412223458	0.0142571246602	0.0209316754643	0.014660017562	0.0160237353838
Average Latency (seconds)	7093.493355030227	7184.996620839474	6552.342567017114	6330.026026378615	6319.304298925308
CI	162.256433841	121.660917595	166.136724487	137.972757347	124.22818487
Median Latency (seconds)	6475.490440172187	6760.785429604813	6309.760997616688	6184.538288027876	6168.637890385499
CI	235.613359254	170.18203336	193.695279224	158.93339361	146.1885675
Maximum Latency (seconds)	17895.993497640375	17896.05806411375	17580.526140085	17239.636132500127	17491.3391406195
CI	77.3081794919	74.2498118925	262.195115682	605.418093472	406.466767708
Average Hop Count	7.231703830670911	4.624901028969181	2.6403759324739235	2.4045253254081986	2.401451620632617
CI	0.168700938464	0.172215621126	0.0279775569135	0.0269033887752	0.0287484406951
Median Hop Count	6.0	4.0	2.625	2.0	2.0
CI	0.0	0.0	0.394703275768	0.0	0.0
Maximum Hop Count	36.125	20.25	8.0	7.125	7.125
CI	4.67352680119	2.43737928407	0.407647790332	0.48875253082	0.48875253082
Message Replication Overhead Ratio	52.32284929598731	39.59012662247597	32.50025223869843	31.49472102434808	31.274739786396292
CI	1.64145750301	1.28208288273	1.04984308009	0.899005571444	0.844283009197
Network Overhead Ratio	84.93734247389249	66.07001950981748	55.99794918946232	54.98089375715614	54.598163648524704
CI	2.57725528084	1.33922839051	1.34509010994	0.816200307507	0.801601799774
Average Power Consumed per Node (Watts)	0.8265248842592592	0.826902488425926	0.8267693865740741	0.8267575713734568	0.8267833719135802
CI	0.000174328585463	0.000133925152457	0.000210554136089	0.000158314779561	0.000166035086769

NS-3 Helsinki, Vector No Limit, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.5370563674321504	0.691544885177453	0.802713987473904	0.8327244258872651	0.8375956854558106
CI	0.029962476817	0.0135744536286	0.0308403068695	0.0280196579368	0.0263714424341
PDR	0.5372829153823948	0.6952246040097216	0.80733501569062	0.8356996526646118	0.8402126847256237
CI	0.0285840758275	0.0144954135155	0.0300029976591	0.0278665482202	0.0264601430161
Average Latency (seconds)	5813.938063923179	5348.7198191820735	4360.520180864971	3852.208396402624	3852.7320169060076
CI	133.972410782	94.7779036763	262.496349266	125.695495276	119.377460189
Median Latency (seconds)	5127.11870627025	4966.804881219187	4193.944804537312	3801.4696044023744	3809.1596650886877
CI	118.66735678	91.8794543979	215.682633432	140.351015948	118.661678768
Maximum Latency (seconds)	17856.027022728624	17401.597927613875	13953.3048778025	11492.02877627675	12330.151595239126
CI	57.5120385672	542.323436663	1441.9516361	1037.16944325	1513.48428703
Average Hop Count	9.073398143237691	5.978893979387813	3.1814450457262544	2.81443346239402	2.8268466025675547
CI	0.24863519166	0.148106077772	0.0690164517471	0.0521635082748	0.057678605809
Median Hop Count	7.375	5.0	3.0	3.0	3.0
CI	0.394703275768	0.0	0.0	0.0	0.0
Maximum Hop Count	42.375	29.625	10.75	7.875	7.625
CI	2.7021083763	3.86594346073	0.888447761307	0.48875253082	0.698673112283
Message Replication Overhead Ratio	76.21808605400886	66.75491558146528	56.540663181202376	52.02873659130738	52.05441045725402
CI	2.76018020486	1.84852461973	1.82688416666	0.807583513105	0.859412618649
Network Overhead Ratio	102.61100390892021	90.34934527540362	76.70556220459326	71.7198931053124	71.87566077313869
CI	3.12144664316	2.14757786345	1.84785423122	0.792840676564	0.782037477756
Average Power Consumed per Node (Watts)	0.8237227527006172	0.8243453414351851	0.8242992862654321	0.8242298418209877	0.8242438271604938
CI	0.000141643587216	0.000127772678502	0.000135271225427	0.000108262768844	0.000110359345834

NS-3 Helsinki, Vector No Limit, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.5987299930410578	0.726687543493389	0.8785664578983995	0.8942240779401531	0.8992693110647182
CI	0.0161097564818	0.0299396385361	0.0205212443581	0.0300057546122	0.0244717970612
PDR	0.5946202590581904	0.7268214156012255	0.8801506672005512	0.8944570672973955	0.8995206678523872
CI	0.0162215338468	0.029844751408	0.0203143946978	0.0297160043133	0.0239874076695
Average Latency (seconds)	4942.435464754266	4170.7671568259775	2985.655681740116	2542.912450670924	2531.708637822792
CI	158.943709089	176.224729939	114.355080934	59.9603716915	53.3220209521
Median Latency (seconds)	4388.984226762313	3826.775208304812	2917.2905434305	2500.374929598875	2485.3047393629995
CI	149.97280963	159.374542378	109.423491005	78.8888930182	73.586158249
Maximum Latency (seconds)	17507.743651594126	14298.638644505125	9032.303745436126	7276.427820383249	7236.117475033125
CI	336.940508552	850.492970096	935.467648224	493.196919885	483.185327135
Average Hop Count	10.578672762333001	7.130042439313611	3.694568844581655	3.271657822592325	3.2780254805913134
CI	0.225777813593	0.278863603842	0.0883287870779	0.0524971917296	0.044533091861
Median Hop Count	8.375	6.125	3.25	3.0	3.0
CI	0.394703275768	0.269633668931	0.353033342224	0.0	0.0
Maximum Hop Count	47.625	34.0	14.625	9.875	9.875
CI	1.34816834465	4.09680959006	2.90940315598	0.48875253082	0.48875253082
Message Replication Overhead Ratio	104.00892961422166	99.56867273642547	82.62363720091935	73.01169336104032	72.86614948176646
CI	3.73491815276	3.76240106276	2.22599696519	1.08445793767	0.914405539731
Network Overhead Ratio	126.17380412122981	120.65768012907714	99.91712379200919	88.98491726357081	88.85655841231276
CI	4.31241978302	3.97769434564	2.71034644442	1.17758340302	1.00132198348
Average Power Consumed per Node (Watts)	0.8219921875	0.8225043402777777	0.8225535300925926	0.8222562210648149	0.8222694830246914
CI	4.84982516169e-05	6.36549086527e-05	6.31428521161e-05	7.88044023445e-05	5.99697583201e-05

NS-3 Helsinki, Vector No Limit, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.636482254697286	0.7352122477383438	0.8776096033402923	0.9063152400835073	0.9061412665274878
CI	0.016613893709	0.019756008017	0.0178480272578	0.0168638898421	0.0183898825698
PDR	0.631660831183827	0.734117321140899	0.878651910344635	0.906171954296995	0.9059549860786487
CI	0.0161427613215	0.0198493707652	0.0177153230402	0.016587028996	0.0179919673781
Average Latency (seconds)	4482.277424494943	3903.756623992357	2659.866513282177	2167.117793006079	2158.4244066181086
CI	149.701808056	110.52214232	109.625996204	50.4200314807	42.12678616
Median Latency (seconds)	4014.4717941654994	3549.529826281813	2557.708517289	2101.9787363111877	2091.7676327159375
CI	131.204708744	126.373896451	105.548828735	60.2858589655	49.7505562367
Maximum Latency (seconds)	16492.238751716	14953.357613953376	8326.381597990627	6515.73231820575	6595.388933835
CI	550.787907992	1601.47565657	568.709779912	573.139473735	629.434173158
Average Hop Count	10.783543609286458	8.039978877557171	3.9816409791462175	3.491573283292132	3.5041463522502796
CI	0.188268170192	0.247277728643	0.0793394731617	0.039573827911	0.0320373462503
Median Hop Count	9.0	6.875	4.0	3.0	3.0
CI	0.0	0.269633668931	0.0	0.0	0.0
Maximum Hop Count	45.375	36.25	14.125	10.375	10.5
CI	2.67118193995	5.23236225605	1.1841098273	0.567421709899	0.576501033758
Message Replication Overhead Ratio	112.99515329377446	118.07468181140504	98.76956916068195	80.63279339550948	80.82502199627028
CI	1.83449304611	2.75315518691	3.6092401197	0.664908280371	0.763716712344
Network Overhead Ratio	132.06919549540865	137.73483082719693	114.90250956779924	94.69430064098141	94.85500454454642
CI	1.59704688929	2.5490778014	4.19266248851	0.736282803837	0.787725665322
Average Power Consumed per Node (Watts)	0.8212263695987654	0.8217539544753086	0.821734905478395	0.8213736979166667	0.8213739390432099
CI	2.30437669676e-05	3.49354362826e-05	5.72473613297e-05	2.84769779316e-05	3.92529528983e-05

NS-3 Helsinki, Vector No Limit, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.6350904662491301	0.779053583855254	0.8812630480167015	0.9232776617954072	0.9202331245650661
CI	0.0268597494684	0.0241827621577	0.0261415731468	0.00777794813423	0.0122769352978
PDR	0.6309240238758159	0.7779909953533416	0.880933103018	0.923181377980985	0.9198763374274833
CI	0.0269738794919	0.0232655459428	0.0262862896366	0.00741863183569	0.0122661976956
Average Latency (seconds)	4478.367501926332	3512.541766660643	2465.9521966086495	1936.3934690671242	1935.3335116514413
CI	154.45963766	119.609485527	125.220148116	59.840144796	52.2064499252
Median Latency (seconds)	4009.8679159939375	3245.44176127075	2349.099911141437	1865.32540418575	1865.6074803263123
CI	117.930282797	124.018716518	96.7219622977	61.712849323	56.5028001474
Maximum Latency (seconds)	16193.554555010125	12282.69618615475	8669.056645450752	7359.258617159001	6010.9468663863745
CI	1007.31976462	1061.46339293	1965.0787211	2799.19010088	568.497324361
Average Hop Count	11.540716875555288	8.341015915237357	4.288968224919875	3.632965669871559	3.6310354897562016
CI	0.385323390425	0.168736293543	0.129774100322	0.0395360817677	0.0371985207218
Median Hop Count	9.375	7.125	4.0	3.375	3.5
CI	0.394703275768	0.269633668931	0.0	0.394703275768	0.407647790332
Maximum Hop Count	48.5	36.875	17.25	10.125	9.75
CI	0.911528170059	3.51706975572	3.15104095141	0.48875253082	0.539267337861
Message Replication Overhead Ratio	125.14917413898935	131.19637855159195	113.47357146229406	87.5390980289879	87.72459856462068
CI	3.71615776022	2.65564026456	5.44487368453	0.828413903022	0.901809563018
Network Overhead Ratio	142.8816685169881	148.58322052112277	128.67871003688506	99.72702844380669	99.9551830930816
CI	4.40056366725	2.88674485907	6.03358502329	0.904690810033	0.913445525704
Average Power Consumed per Node (Watts)	0.8206418788580246	0.8211388406635802	0.8211311246141975	0.8207540027006173	0.8207515914351852
CI	2.58034359526e-05	2.8373647425e-05	5.36509018681e-05	1.94444711237e-05	2.14768864028e-05

APPENDIX C:
ONE Bold Alligator Data Tables

ONE Bold Alligator, Epidemic, 12 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.2343	0.26567	0.3209	0.37771
CI	0.00214226020273	0.00173309962377	0.00254242261873	0.00205869660616
Average Latency (seconds)	1182.94956	1578.4122	2355.0882	3175.28182
CI	37.8888938096	83.8361310845	61.2491794073	74.6082087368
Median Latency (seconds)	197.17	287.51	537.18	981.21
CI	13.3405448119	16.805971218	32.4320255893	54.1088502877
Average Hop Count	5.01778	5.39489	5.37403	5.26002
CI	0.201646260318	0.254142411073	0.0865150712891	0.060717816419
Median Hop Count	1.0	1.0	1.9	2.0
CI	0.0	0.0	0.21137981146	0.0
Message Replication Overhead Ratio	438.68474000000003	455.53714	468.51234	457.9633
CI	8.79574432264	8.89247089057	7.88221627149	7.24093344825

ONE Bold Alligator, Epidemic, 24 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.23373	0.2698	0.31354	0.37213
CI	0.00175869188754	0.00266353474178	0.00294337058009	0.00376087793775
Average Latency (seconds)	1175.18012	1641.82406	2145.87318	2962.43695
CI	51.4385807827	62.07917666	74.7029469752	93.962485953
Median Latency (seconds)	192.59	303.61	492.74	910.04
CI	11.006079002	15.282968271	33.8643417882	60.4973812902
Average Hop Count	5.13821	5.61632	5.22344	5.22633
CI	0.135543700522	0.235397203442	0.139485009416	0.0862149590509
Median Hop Count	1.0	1.0	1.8	2.0
CI	0.0	0.0	0.281839748613	0.0
Message Replication Overhead Ratio	451.02344	460.04753999999997	475.59434	466.88513
CI	11.2083215101	10.9193710664	8.15826808937	5.07230940911

ONE Bold Alligator, Epidemic, 36 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.23331	0.26692	0.31406	0.36617
CI	0.00274168841558	0.00250837376265	0.00306564700802	0.00280675636271
Average Latency (seconds)	1182.92283	1592.56892	2138.34055	2784.67391
CI	64.7727441923	62.8488071632	74.2400538638	68.7346614976
Median Latency (seconds)	194.57	289.12	496.93	859.75
CI	17.5090902319	18.8854662161	33.6351275874	52.2003931631
Average Hop Count	5.01823	5.57694	5.24535	5.11222
CI	0.213735696492	0.165750655246	0.115945106534	0.092497012388
Median Hop Count	1.0	1.0	1.8	2.0
CI	0.0	0.0	0.281839748613	0.0
Message Replication Overhead Ratio	458.40206	467.74082	476.66392	474.3729
CI	7.29822628378	11.6140836265	8.37834041743	5.43766420207

ONE Bold Alligator, Epidemic, 54 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.23489	0.26687	0.31418999999999997	0.3597
CI	0.00213307495614	0.00268119272318	0.00242477408912	0.003351997752
Average Latency (seconds)	1199.86984	1579.75074	2149.44137	2650.51459
CI	31.814850454	47.7953595364	65.4110538526	91.4820173922
Median Latency (seconds)	197.95	289.41	487.81	802.97
CI	13.3776777541	16.4198096594	30.2120584728	52.9939492499
Average Hop Count	5.2457	5.52015	5.26701	4.98808
CI	0.205739944701	0.135499073039	0.10707719684	0.101222721191
Median Hop Count	1.0	1.0	1.8	2.0
CI	0.0	0.0	0.281839748613	0.0
Message Replication Overhead Ratio	466.39748	474.5041	482.35011	486.75157
CI	11.1210703804	8.21928185357	7.17109145482	8.77707323893

ONE Bold Alligator, Centroid, 12 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29539	0.40273000000000003	0.54373	0.60843
CI	0.00344828513688	0.00434619030474	0.0037735292811	0.00473719821918
Average Latency (seconds)	1220.28106	1793.19913	2832.15194	3655.20767
CI	30.6542286096	42.6630207407	59.7818254196	63.5883899453
Median Latency (seconds)	0.51	675.96	1291.98	1617.57
CI	0.266353474178	26.4758630728	45.0335779451	52.4284627597
Average Hop Count	2.68319	3.2441	3.69124	3.9063499999999998
CI	0.0387927286365	0.0399602773107	0.0484649364994	0.0472847734854
Median Hop Count	1.0	2.0	3.0	3.4
CI	0.0	0.0	0.0	0.345181786668
Message Replication Overhead Ratio	35.41575	39.74458	39.39411	42.1933
CI	0.648239091367	0.714780103541	0.627302848615	0.567341619204

ONE Bold Alligator, Centroid, 24 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29771000000000003	0.40855	0.51736	0.5857
CI	0.00356466703583	0.00600567124996	0.00332779829077	0.00509352736497
Average Latency (seconds)	1207.02356	1715.72355	2452.16264	3352.16614
CI	34.4821769475	49.6939395261	66.3298147281	81.5504218943
Median Latency (seconds)	1.07	696.26	1159.52	1498.95
CI	1.2576852071	24.2666765013	45.9657625171	48.5107047402
Average Hop Count	2.70717	3.26205	3.59917	3.85349
CI	0.0319513254584	0.039159719398	0.0414406998087	0.0467220098283
Median Hop Count	1.0	2.2	3.0	3.1
CI	0.0	0.281839748613	0.0	0.21137981146
Message Replication Overhead Ratio	40.91606	43.94288	42.07299	45.55314
CI	0.729319798417	0.600625586979	0.720686128121	0.643635788647

ONE Bold Alligator, Centroid, 36 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29797	0.41033000000000003	0.50429	0.55642
CI	0.00332673144124	0.00532670134759	0.0021153124608	0.0038792402932
Average Latency (seconds)	1199.76826	1690.5851	2243.83913	2973.59663
CI	25.4293744671	37.6853046419	45.696068311	71.5045972892
Median Latency (seconds)	2.52	698.64	1092.72	1349.35
CI	4.34136145372	23.0852003028	41.2997037383	45.5967398431
Average Hop Count	2.71148	3.26527	3.5502700000000003	3.76421
CI	0.0282202524732	0.0427353320162	0.0437900323961	0.0414731218228
Median Hop Count	1.0	2.2	3.0	3.0
CI	0.0	0.281839748613	0.0	0.0
Message Replication Overhead Ratio	44.49731	48.20175	45.90596	48.9814
CI	0.824969863841	0.816719825765	0.846799759954	0.681604205381

ONE Bold Alligator, Centroid, 54 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29754	0.41232	0.49933	0.54242
CI	0.00353961439538	0.00490684540229	0.00163887148073	0.00327556115275
Average Latency (seconds)	1198.11403	1674.05609	2157.84625	2783.27218
CI	24.2544432638	43.5191537121	42.4747029105	62.5828809079
Median Latency (seconds)	3.69	709.78	1067.51	1277.58
CI	6.90783776192	24.2338511098	39.9063394375	42.909613479
Average Hop Count	2.71991	3.27263	3.52797	3.72094
CI	0.0307118604391	0.0377599930875	0.0424784612367	0.0436780485481
Median Hop Count	1.0	2.3	3.0	3.0
CI	0.0	0.322887995466	0.0	0.0
Message Replication Overhead Ratio	46.33153	51.41207	48.81881	51.35001
CI	0.878036448483	0.848660872334	0.90446518596	0.755362951256

ONE Bold Alligator, GAPR, 12 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43647	0.50335	0.62248	0.65832
CI	0.00288525484603	0.0036002545845	0.00665992156471	0.00625276266482
Average Latency (seconds)	1946.70994	2674.02626	3778.01484	4041.72284
CI	93.5482710686	47.3358708436	62.5436372102	69.195152267
Median Latency (seconds)	905.2	1237.62	1718.13	1854.52
CI	32.4486638715	42.3769376209	50.5511336363	49.5965570705
Average Hop Count	2.24878	2.4811	3.37272	3.97295
CI	0.0400861042035	0.0320092290215	0.0560821955931	0.0418731882355
Median Hop Count	2.0	2.0	3.0	3.9
CI	0.0	0.0	0.0	0.21137981146
Message Replication Overhead Ratio	53.34839	77.16969	66.88192000000001	44.7948
CI	0.899122297691	1.1701663987	1.99109931892	0.503173894126

ONE Bold Alligator, GAPR, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43443	0.5008900000000001	0.61954	0.6736
CI	0.00255314963299	0.00409316445222	0.00497580872488	0.00739299022894
Average Latency (seconds)	1885.11415	2600.23335	3702.03469	4154.41251
CI	98.7294574623	48.9081999703	53.8563223833	66.7484660747
Median Latency (seconds)	880.12	1213.81	1689.02	1937.12
CI	34.8922104986	33.8673360152	52.2585142224	53.4209177493
Average Hop Count	2.27041	2.50201	3.46033	4.02276
CI	0.0408223064807	0.0297794812867	0.0593022749009	0.046910247141
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	56.84198	79.48639	66.42557000000001	49.12919
CI	0.982020507255	1.20762168747	2.17150740146	0.622435647511

ONE Bold Alligator, GAPR, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43318	0.49861	0.61352	0.67843
CI	0.00239165563932	0.00282568946393	0.0056194881037	0.00678848128476
Average Latency (seconds)	1852.36597	2547.81928	3598.8171700000003	4181.57435
CI	95.2969238789	44.5920959474	62.8708304252	51.147726232
Median Latency (seconds)	868.43	1196.01	1638.19	1958.1399999999999
CI	34.4062885853	44.7791549098	50.8053227384	47.283334525
Average Hop Count	2.30071	2.51535	3.5426	4.04505
CI	0.0351546431783	0.0296515851232	0.0506523153655	0.046151035622
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	58.93709	82.13348	65.13992	52.60375
CI	0.9743434826	1.2783951573	2.13106404247	0.642757775928

ONE Bold Alligator, GAPR, 54 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43234	0.49706	0.6101099999999999	0.67914
CI	0.00237820815524	0.00330639589668	0.00594895965796	0.00628794838039
Average Latency (seconds)	1824.2177	2485.29325	3539.73189	4182.04311
CI	98.9333344569	51.4964745897	63.6830027145	53.9415599583
Median Latency (seconds)	856.01	1171.98	1618.41	1962.1499999999999
CI	33.5036141714	42.8688448963	50.7224781393	52.3113312738
Average Hop Count	2.31919	2.5364299999999997	3.5784000000000002	4.05602
CI	0.0341709839868	0.0342271145909	0.0425304725414	0.0437060871701
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	60.44409	83.82616	67.01881	55.6244
CI	1.11554477666	1.54495348519	1.71241193271	0.734647777382

ONE Bold Alligator, GAPR2, 12 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43481	0.49929	0.60209	0.62081
CI	0.00277623776242	0.0036525781726	0.00554044994365	0.00632339760821
Average Latency (seconds)	1994.06494	2736.63746	3731.4604	3916.25138
CI	87.9316169702	26.6349018819	48.5102773854	82.6752223213
Median Latency (seconds)	961.93	1292.18	1714.83	1800.28
CI	36.7375713644	36.3260140344	43.6416934713	57.7836596281
Average Hop Count	2.20385	2.43266	3.44773	3.73746
CI	0.0311016619493	0.0295695130935	0.0381195950604	0.0328759331769
Median Hop Count	2.0	2.0	3.0	3.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	44.56776	65.42914	46.0402	38.06425
CI	0.52172390373	1.02406431606	1.47025723382	0.421555132734

ONE Bold Alligator, GAPR2, 24 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43342	0.49704	0.60854	0.64062
CI	0.0027100617548	0.00357936480738	0.00584683334432	0.00740706549562
Average Latency (seconds)	1956.03383	2682.42584	3793.76695	4096.89791
CI	88.9719689481	38.8811221035	61.8083151741	86.8001676056
Median Latency (seconds)	948.39	1274.48	1756.53	1910.8600000000001
CI	35.2325536569	35.2262452768	55.9026055302	65.182976455
Average Hop Count	2.22313	2.43905	3.45778	3.81647
CI	0.0350663760568	0.0269722121139	0.0547292934412	0.0282628333938
Median Hop Count	2.0	2.0	3.0	3.2
CI	0.0	0.0	0.0	0.281839748613
Message Replication Overhead Ratio	46.68248	66.90186	50.00235	41.17836
CI	0.509617251696	1.01086571053	2.1112261035	0.444372647115

ONE Bold Alligator, GAPR2, 36 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43252	0.49601	0.60348	0.64593
CI	0.00316706248741	0.00334806315484	0.00604781081627	0.00603410690723
Average Latency (seconds)	1926.18796	2643.18715	3703.13323	4143.40546
CI	87.1118024444	41.6465170101	61.9842300371	69.8520986245
Median Latency (seconds)	944.94	1265.09	1717.99	1941.25
CI	32.723497359	39.0275353043	54.7397664983	65.1736993882
Average Hop Count	2.23344	2.45873	3.49823	3.83453
CI	0.0386178722086	0.0268543896633	0.050732270843	0.0331541977443
Median Hop Count	2.0	2.0	3.0	3.2
CI	0.0	0.0	0.0	0.281839748613
Message Replication Overhead Ratio	48.0043	68.05461	49.80525	43.52021
CI	0.517212119673	0.734036466176	1.91590801533	0.420135476679

ONE Bold Alligator, GAPR2, 54 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43267	0.49464	0.602	0.6461
CI	0.002541651183	0.00387442530445	0.00597440439589	0.00703668685703
Average Latency (seconds)	1925.73867	2597.52661	3672.9596500000002	4134.12145
CI	103.319601154	33.6327553656	52.5742833335	80.3710250792
Median Latency (seconds)	942.52	1248.93	1707.27	1942.17
CI	36.0851307376	33.9686626254	47.3323830534	64.6811865066
Average Hop Count	2.25354	2.46236	3.52926	3.8424300000000002
CI	0.0354005786432	0.0277655283391	0.0470380133864	0.0290429339653
Median Hop Count	2.0	2.0	3.0	3.3
CI	0.0	0.0	0.0	0.322887995466
Message Replication Overhead Ratio	48.88584	69.53596	50.503569999999996	45.45019
CI	0.587156055793	1.01667713577	1.84071960267	0.439900051799

ONE Bold Alligator, GAPR2A, 12 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43416	0.50343	0.62079	0.65656
CI	0.00233650931113	0.00394815264909	0.00628409818173	0.00690731669109
Average Latency (seconds)	1937.7104	2690.43453	3765.11025	4028.94283
CI	104.45098495	43.8101291037	69.4178652803	76.1585099265
Median Latency (seconds)	891.23	1241.13	1703.79	1846.6399999999999
CI	38.7928514949	37.8480856717	53.7718503825	61.4818344002
Average Hop Count	2.2200699999999998	2.47013	3.38807	3.96627
CI	0.0385321689896	0.0366829760175	0.0577194890513	0.0463412821183
Median Hop Count	2.0	2.0	3.0	3.9
CI	0.0	0.0	0.0	0.21137981146
Message Replication Overhead Ratio	50.54605	75.23384	64.14513	44.31701
CI	0.944625048184	1.32012491289	1.98419719257	0.528858013465

ONE Bold Alligator, GAPR2A, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43229	0.49957	0.6197	0.67211
CI	0.00245266375568	0.00296435431456	0.00580651445814	0.00761126818009
Average Latency (seconds)	1876.8959300000001	2598.78094	3708.39421	4140.30396
CI	94.7881370026	37.224216174	72.1701821257	69.1870335218
Median Latency (seconds)	876.24	1204.06	1690.89	1933.74
CI	35.2210077514	40.4297768635	59.0798270715	56.6836089097
Average Hop Count	2.25092	2.48942	3.4522	4.01984
CI	0.0348910152926	0.0322981127534	0.0656126173256	0.0467086592181
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	53.894059999999996	77.75005	65.15801	48.53181
CI	0.916864616501	1.15340070376	2.73453499509	0.587155962151

ONE Bold Alligator, GAPR2A, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.43122	0.49689	0.6124	0.67764
CI	0.00184325134847	0.00329093166736	0.00589366944748	0.00770183517648
Average Latency (seconds)	1842.50994	2541.78765	3601.09104	4184.6355
CI	91.3283582691	43.2384333041	63.5779148145	60.4105440403
Median Latency (seconds)	864.03	1185.9	1635.6200000000001	1958.82
CI	38.2494161949	40.6565315954	50.3755517156	53.1427025895
Average Hop Count	2.27846	2.50149	3.55171	4.04084
CI	0.034394297873	0.032436658139	0.0500587923221	0.0521925362899
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	55.88645	79.74915	63.5856	52.19715
CI	1.03471626977	1.24891798422	2.34446360507	0.667788556653

ONE Bold Alligator, GAPR2A, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.42965	0.49597	0.60895	0.67792
CI	0.00231431667452	0.003516939141	0.00554249259509	0.0060556862569
Average Latency (seconds)	1817.31727	2481.0836600000002	3531.69945	4180.79105
CI	98.5711749793	43.4194612187	65.7073444198	59.8107678804
Median Latency (seconds)	854.4300000000001	1172.68	1615.9	1958.45
CI	34.5349741468	39.03854167	51.5723615137	52.830466665
Average Hop Count	2.28513	2.51841	3.58929	4.049329999999999
CI	0.0343587832382	0.0320346156572	0.0493560111266	0.047104331423
Median Hop Count	2.0	2.0	3.0	4.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	57.50877	82.22589	64.91867	55.18133
CI	1.08752886554	1.42157593862	2.11514294081	0.688820621086

ONE Bold Alligator, Vector, 12 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29646	0.4041	0.54167	0.59027
CI	0.00398247642917	0.0047964538061	0.00439627662085	0.00578390255569
Average Latency (seconds)	1311.6753800000001	1938.57958	2997.37523	3740.57249
CI	25.5774220364	39.9332532085	52.6865355965	62.4452869498
Median Latency (seconds)	3.9099999999999997	758.36	1401.82	1664.06
CI	7.39651155667	25.4313759896	42.5492363299	49.274505592
Average Hop Count	2.63735	3.15144	3.55807	3.70254
CI	0.0306608786632	0.0301961434929	0.035361413689	0.0387882075621
Median Hop Count	1.0	2.0	3.0	3.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	29.739	33.64066	33.68794	36.22126
CI	0.469099241408	0.447843375179	0.444785444367	0.507228878735

ONE Bold Alligator, Vector, 24 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.298	0.40857	0.52073	0.58229
CI	0.00434698412268	0.0062124770724	0.00372812975728	0.00583308282621
Average Latency (seconds)	1296.36771	1870.9781	2664.17271	3540.7611
CI	35.2211520768	31.7515783748	54.3478412305	66.3026572226
Median Latency (seconds)	3.83	774.52	1282.77	1617.53
CI	7.11059469438	24.9356672331	42.014499555	50.1217053902
Average Hop Count	2.63617	3.16236	3.48849	3.699
CI	0.0275554581328	0.0313871491196	0.0401775072973	0.0377851620504
Median Hop Count	1.0	2.0	3.0	3.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	33.198	36.31176	35.21073	38.49668
CI	0.631135811753	0.549214283426	0.437218350451	0.466232279466

ONE Bold Alligator, Vector, 36 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.29876	0.40971	0.50881	0.56067
CI	0.00391191642051	0.00584617524729	0.00247623326903	0.00436647569817
Average Latency (seconds)	1282.16106	1834.59255	2469.22419	3229.44684
CI	25.8360488378	32.9132850961	37.600426826	63.3331133148
Median Latency (seconds)	5.76	778.34	1220.77	1500.82
CI	11.2127952459	24.011485382	42.8179426293	45.3142071403
Average Hop Count	2.6443399999999997	3.15993	3.4546	3.64372
CI	0.0351017122276	0.0353882893191	0.0415028767716	0.0439927923958
Median Hop Count	1.0	2.0	3.0	3.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	35.46722	38.97201	37.44821	40.49803
CI	0.622237160655	0.672406927959	0.494371234428	0.562467076887

ONE Bold Alligator, Vector, 54 Mbps				
Buffer Size (MB)	**5**	**10**	**25**	**50**
MDR	0.299	0.41095	0.5053300000000001	0.54836
CI	0.00393441626606	0.00590698478354	0.0031351188427	0.00376564694846
Average Latency (seconds)	1283.85942	1825.49438	2407.14991	3062.77013
CI	33.8861921026	31.4666284169	40.0709921606	56.293673038
Median Latency (seconds)	5.0	784.36	1199.62	1431.74
CI	9.49004070229	27.2692009353	45.0795034954	44.8494209689
Average Hop Count	2.65378	3.16834	3.43152	3.6010400000000002
CI	0.0328722271766	0.0362519382658	0.0439611603509	0.045027342212
Median Hop Count	1.0	2.0	3.0	3.0
CI	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	36.27241	41.01506	39.42567	41.86041
CI	0.672747408223	0.754343826672	0.537563841006	0.590335113777

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APPENDIX D:
NS3 Bold Alligator Data Tables

NS-3 Bold Alligator, Epidemic, 12 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.05416352167349579	0.06878100064697003	0.08629636618503343	0.09835966141902092
CI	0.00326385664226	0.00304248365425	0.0041255411263	0.00396402418013
PDR	0.06528670103581018	0.08174930710514702	0.10207106058537453	0.11460831105257203
CI	0.004045591879	0.00387752652104	0.00460712135451	0.0043990532196
Average Latency (seconds)	1891.461269071633	2616.6574225302606	4374.157138176684	6033.943206190271
CI	120.504376668	80.1978821656	188.205249348	230.753805674
Median Latency (seconds)	1560.8307995000023	2381.2187032499987	4081.9334093750017	5461.47212475
CI	51.1067153899	68.5165573776	168.964199186	277.420609565
Maximum Latency (seconds)	16862.840988250002	16734.55071625	19256.258439	17904.730615
CI	515.422001434	577.095201777	3564.42323861	67.5382577185
Average Hop Count	2.2237231359958494	2.440608857312833	2.6056318785033508	2.706337761098026
CI	0.0714984361864	0.0785179870081	0.0668432427701	0.068225756135
Median Hop Count	2.0	2.0	2.125	2.25
CI	0.0	0.0	0.269633668931	0.353033342224
Maximum Hop Count	8.125	9.5	9.625	9.875
CI	0.755799231481	1.07853467572	1.07370899301	0.636439908668
Message Replication Overhead Ratio	355.7212426532093	340.8677452401571	346.96248471843285	336.46458542458873
CI	21.9775574272	20.5985111598	9.52955469957	9.6749150447
Network Overhead Ratio	393.68761587237293	381.2195107981595	393.3585123902691	385.0925574965804
CI	29.3151128859	24.8155278051	10.2880093028	10.4731638469
Average Power Consumed per Node (Watts)	0.8196265294312169	0.8198617311507936	0.8203864914021164	0.820857101521164
CI	1.69906397035e-05	2.78798467795e-05	3.85887955232e-05	8.25969473305e-05

NS-3 Bold Alligator, Epidemic, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.060983664006901014	0.07721856803968083	0.09643896916109554	0.11055100280353677
CI	0.00280005458223	0.00272143541818	0.00319813764234	0.00437671163958
PDR	0.07431836029184907	0.09172737443429521	0.11136643799039389	0.12596461346800933
CI	0.00355949369522	0.00325825627662	0.00393299595965	0.00491973479014
Average Latency (seconds)	1860.44715470331	2565.734567589263	4213.803764138215	5892.377961579843
CI	80.5995140697	46.6897751285	93.1628049278	260.851891923
Median Latency (seconds)	1531.9624489999999	2330.3537971250003	3992.7153062499992	5396.542919249999
CI	40.6003566945	56.6665021713	101.123956845	257.751746548
Maximum Latency (seconds)	16811.401965999998	17428.838938499997	19204.852356	17933.220938500002
CI	811.896801297	293.522077602	3584.31571977	42.1670440161
Average Hop Count	2.2616054388090836	2.43995805077804	2.607312002825058	2.7057335996216887
CI	0.0522572967642	0.0703136834431	0.0493368527971	0.0626004392457
Median Hop Count	2.0	2.0	2.0	2.125
CI	0.0	0.0	0.0	0.269633668931
Maximum Hop Count	8.0	9.25	10.0	11.25
CI	0.815295580663	1.94435603784	0.815295580663	1.98662958874
Message Replication Overhead Ratio	357.5507777487378	332.96962730607476	337.134284502412	331.53531535669913
CI	31.7446705131	18.1452075091	8.25038813132	8.87141685516
Network Overhead Ratio	391.32801965307834	368.123948028416	385.2065205616876	382.0495614007501
CI	35.587524933	20.8213722235	12.5492122049	12.9652521862
Average Power Consumed per Node (Watts)	0.8194432043650793	0.8195663855820106	0.8198914930555555	0.8202548363095238
CI	1.285508081e-05	2.120489202e-05	3.33619027999e-05	5.40707443855e-05

NS-3 Bold Alligator, Epidemic, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.06555962907051974	0.07990753720077637	0.10286823377183524	0.11591546258356696
CI	0.00379545345244	0.00371430904759	0.00477924050978	0.00459155963721
PDR	0.08047237822993429	0.0953718963393236	0.1193982371431272	0.13158916403006313
CI	0.00513287116083	0.00475020674677	0.00577658314982	0.00504283819796
Average Latency (seconds)	1793.171544014139	2541.558356034312	4096.62980005094	5799.62008744811
CI	89.2651572095	78.3761041699	98.9485898874	188.540203196
Median Latency (seconds)	1522.0916331249998	2334.744796000001	3910.18880375	5370.052608124999
CI	51.6876979767	56.9212857548	109.084802857	206.527138589
Maximum Latency (seconds)	17106.96923725	17074.493624000002	19053.754155250004	17885.2853075
CI	457.04919197	626.040786804	3635.11528175	70.1002076619
Average Hop Count	2.2952523240734926	2.4552138602956886	2.655620106655888	2.67645896896337
CI	0.0763806761942	0.0867672204923	0.077803302689	0.0760285726691
Median Hop Count	2.0	2.0	2.25	2.25
CI	0.0	0.0	0.353033342224	0.353033342224
Maximum Hop Count	7.75	8.75	9.75	9.875
CI	0.353033342224	0.789406551536	0.888447761307	0.950571365144
Message Replication Overhead Ratio	361.59241797164	319.313305011139	336.57783875807155	328.6948540974928
CI	41.0784034496	5.57506326609	12.8283109266	8.79182628087
Network Overhead Ratio	391.25932722819675	351.5520459178847	381.72446425357947	379.8402648660713
CI	46.5299339814	11.3882461011	16.4584696802	11.5823884548
Average Power Consumed per Node (Watts)	0.8193756200396826	0.8194576719576719	0.8196961805555556	0.8199789186507936
CI	1.22058731111e-05	1.49960164976e-05	2.18069433238e-05	4.67497943023e-05

NS-3 Bold Alligator, Epidemic, 54 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.06875404356264826	0.08354674358421393	0.10568524908345914	0.12032294587017468
CI	0.00386642474627	0.00445849645484	0.00401582776357	0.00504244057948
PDR	0.08449039557672809	0.10013933195563492	0.12282954538924472	0.13647779556099465
CI	0.00495258399426	0.00534679951803	0.00479683842748	0.00583650219235
Average Latency (seconds)	1831.8014714716796	2531.6326253091515	4069.1254548175552	5711.240751022223
CI	63.8207075884	102.52024165	109.184551117	165.697224775
Median Latency (seconds)	1530.0167993749997	2336.7441688749996	3874.139283375	5294.693241874998
CI	30.8847240122	64.7488846731	100.618421477	184.489691229
Maximum Latency (seconds)	17104.513317	17537.81096525	19221.268676	17843.991624000002
CI	393.461987154	458.937322802	3581.2807418	99.7818325396
Average Hop Count	2.2841572755712036	2.46358585780337	2.634835476386266	2.6843172762940566
CI	0.0637220973147	0.0824374080667	0.0469733453975	0.0506678559194
Median Hop Count	2.0	2.0	2.125	2.125
CI	0.0	0.0	0.269633668931	0.269633668931
Maximum Hop Count	8.25	8.25	9.75	9.875
CI	0.97750506164	0.789406551536	0.97750506164	0.48875253082
Message Replication Overhead Ratio	326.7857156844989	324.07871658531684	332.39138260012453	333.4834759339328
CI	15.6866428034	21.8528984948	7.99168425608	7.73483650394
Network Overhead Ratio	354.4878460377872	356.07373520292515	376.0483000534991	383.83167429957973
CI	19.6294727653	23.1668820374	9.30147415111	10.0579047541
Average Power Consumed per Node (Watts)	0.8193200231481481	0.8193760333994708	0.8195626653439153	0.8197794725529101
CI	1.00596336841e-05	1.44079340098e-05	2.76512881565e-05	4.21407900401e-05

NS-3 Bold Alligator, Centroid, 12 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08940317015311625	0.1482504852275178	0.27325722449859824	0.3772778736251887
CI	0.00482584602608	0.00908211754959	0.0139506579189	0.0233247255088
PDR	0.1058638759587927	0.16900833455363146	0.29898962782921745	0.4074809509646234
CI	0.00574250791105	0.0104823263882	0.0160348903525	0.0260580395526
Average Latency (seconds)	5268.709543230444	7038.185431953791	8782.602189794534	8782.600505646295
CI	127.073430732	179.461705902	83.8749315445	83.9933899354
Median Latency (seconds)	4205.161494999999	6245.361643875	8616.2627975	8441.289549125
CI	129.168717027	215.094511366	180.301185204	127.425523634
Maximum Latency (seconds)	17950.211309749997	18188.138757250003	17995.5340795	17996.55329625
CI	41.5247870855	435.513816263	2.81960006149	2.78803108786
Average Hop Count	12.210853322089644	12.378831098571816	8.672209848444274	5.28324373867045
CI	0.323536605978	0.352929251241	0.361546084606	0.126864484022
Median Hop Count	7.875	9.5	7.125	4.75
CI	0.48875253082	0.576501033758	0.48875253082	0.353033342224
Maximum Hop Count	50.0	49.875	40.25	22.75
CI	0.0	0.269633668931	3.0709166245	1.1348434198
Message Replication Overhead Ratio	283.6968833456403	233.27146769112215	160.1260283081722	119.00666418459465
CI	11.4493557515	9.81494089802	5.55698964655	4.86546691842
Network Overhead Ratio	312.64463156647025	252.3843457177921	172.60709009693346	128.1056647589121
CI	12.4634071163	10.0492727807	5.57906512659	5.17273691626
Average Power Consumed per Node (Watts)	0.8194582919973545	0.8197383432539682	0.8201539765211641	0.8203488756613756
CI	1.57053720675e-05	3.09077315057e-05	4.77767973666e-05	4.39614544877e-05

NS-3 Bold Alligator, Centroid, 24 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08842597584645245	0.14397778736251887	0.28183631658399827	0.404396700452879
CI	0.00517026999972	0.00837770947858	0.0178474690137	0.0241056567858
PDR	0.10526470792800116	0.1671042236318014	0.30434109746777077	0.42352726033724614
CI	0.00657621839382	0.010151070329	0.020077582598	0.0249626960671
Average Latency (seconds)	5286.3000743816565	7050.586333250434	8680.75178872492	8773.849408399179
CI	150.273995991	145.557831405	140.742364927	103.012926657
Median Latency (seconds)	4233.277538249999	6250.92099725	8452.13524625	8473.029654499998
CI	140.488603326	205.669806466	243.764427929	167.141186959
Maximum Latency (seconds)	17869.7584635	17986.27834975	18883.773559	19316.042803
CI	103.148209297	12.8155146503	1490.05474521	1211.38884325
Average Hop Count	12.32435826799892	12.62755447905704	9.100272051322035	5.5522004277635935
CI	0.306655619115	0.339454865685	0.241031590242	0.157598195624
Median Hop Count	7.875	9.75	7.75	5.0
CI	0.48875253082	0.539267337861	0.353033342224	0.0
Maximum Hop Count	50.0	49.75	39.0	25.125
CI	0.0	0.353033342224	1.57881310307	2.55999891268
Message Replication Overhead Ratio	310.666178652443	248.41175633043255	168.16777680564178	121.69455764713105
CI	12.5170313318	12.2094508932	7.5158579052	6.38791889773
Network Overhead Ratio	342.08095374831254	267.6986095391191	180.67955780602176	131.0636155825632
CI	14.5927739526	14.3136534145	8.10921027275	6.58140134485
Average Power Consumed per Node (Watts)	0.819309482473545	0.8194859871031746	0.8197802992724867	0.8199377893518518
CI	1.01089079526e-05	1.6027493665e-05	2.57757889693e-05	2.70360285934e-05

NS-3 Bold Alligator, Centroid, 36 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.0906297174897563	0.14310842139314212	0.27970670692257926	0.4149369204226871
CI	0.00519359987249	0.00912351247382	0.0141083814395	0.0246491554643
PDR	0.10817261726305394	0.16659588442155193	0.3032617280887793	0.4325586223623479
CI	0.00654817666726	0.0109817566609	0.0161249563798	0.0265954726726
Average Latency (seconds)	5227.380367236963	7004.085217220023	8567.470810744331	8676.466697182184
CI	109.531026153	135.341562825	105.09241627	141.672629717
Median Latency (seconds)	4174.9040215	6187.473616625	8279.7413835	8328.31329625
CI	70.1345934669	188.690034743	158.111770018	211.85160564
Maximum Latency (seconds)	17913.66818225	17982.703491	18566.64715425	20337.9048955
CI	71.7120086189	12.1453990308	1233.38418453	2409.68819106
Average Hop Count	12.257641394803953	12.65282096777507	9.201545000798841	5.691760923848365
CI	0.377393529625	0.418191102001	0.30499634144	0.198442859245
Median Hop Count	7.875	10.0	8.0	5.0
CI	0.48875253082	0.407647790332	0.407647790332	0.0
Maximum Hop Count	50.0	49.625	39.625	25.625
CI	0.0	0.394703275768	1.28506076298	2.73268483332
Message Replication Overhead Ratio	310.22786233890656	258.07005636129065	175.62391088572977	126.7777177556856
CI	8.95218644175	10.8846572949	6.60945395339	5.56101269354
Network Overhead Ratio	339.01318133228955	278.0716090940995	188.43273781655944	136.38596501122336
CI	9.07663341555	11.7738847327	6.84212887879	5.77214123698
Average Power Consumed per Node (Watts)	0.8192476851851852	0.8193915343915343	0.8196271494708995	0.8197664517195767
CI	8.0318850113e-06	1.26995252702e-05	2.06980368796e-05	2.21582741937e-05

NS-3 Bold Alligator, Centroid, 54 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08909316368341601	0.14429453310329954	0.275979890015096	0.4133868880741859
CI	0.00485753394445	0.00928413267169	0.0159902907948	0.0288499547861
PDR	0.1063919810263622	0.16845853162765048	0.30305998259019323	0.4300253230850748
CI	0.00643802003401	0.0112313054203	0.0184413904759	0.0303865538189
Average Latency (seconds)	5323.760121360608	7037.015172373149	8508.159940663543	8702.776355022042
CI	101.232438094	207.8511816	125.204256334	121.831041968
Median Latency (seconds)	4262.741365125	6248.331251250001	8182.465964875	8395.78363775
CI	110.074070648	222.361253108	203.055064431	204.148601958
Maximum Latency (seconds)	17940.671984499997	18131.967632	18134.49158075	19545.907459
CI	35.1687060765	356.492132937	250.273880339	1363.82346419
Average Hop Count	12.421480787292928	12.355598764021327	9.274259611495397	5.726459684775273
CI	0.299152754409	0.444941283837	0.27863506479	0.219282213224
Median Hop Count	8.25	9.375	8.125	5.0
CI	0.353033342224	0.567421709899	0.269633668931	0.0
Maximum Hop Count	50.0	49.5	38.875	25.75
CI	0.0	0.576501033758	2.52733411166	2.36821965461
Message Replication Overhead Ratio	306.41081190187793	252.46937014103625	179.44982537955875	127.7128559655262
CI	17.5380796925	6.67781164091	7.60373135914	6.93464658384
Network Overhead Ratio	337.0026334985316	271.4061811813029	191.4986305159795	137.33242375681385
CI	20.0974450251	7.90200214432	7.85141381107	7.011860808
Average Power Consumed per Node (Watts)	0.8191968419312169	0.8193183697089947	0.8195045882936508	0.8196283895502645
CI	6.24152011414e-06	1.20147873793e-05	2.10456187046e-05	2.58225635311e-05

NS-3 Bold Alligator, GAPR, 12 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.10005795773129178	0.13683416001725254	0.22716061030838905	0.34425544533103297
CI	0.00572215227002	0.00655924316619	0.0105478319085	0.0235052617781
PDR	0.13136903975186368	0.1747979969012684	0.2786092455466384	0.383364375802152
CI	0.00763542699195	0.00865796818816	0.0130880376354	0.0236692640052
Average Latency (seconds)	7335.696994929683	7368.595023267213	7400.37017594144	7650.818054329053
CI	122.041742323	71.6698273444	126.610613964	113.932362171
Median Latency (seconds)	6368.442615500001	6521.79828175	6565.521011749999	6766.2923951249995
CI	217.7570068	159.476144926	195.847859815	188.490549825
Maximum Latency (seconds)	17994.860044499997	17989.558938249997	17993.172135250003	17995.890085
CI	2.40754101406	6.42195912076	5.19453271506	2.59366389294
Average Hop Count	1.1995979072908665	1.4514917348023038	1.839587072965493	2.526882350629749
CI	0.0180599143797	0.0194936298739	0.0235960076812	0.0462421411763
Median Hop Count	1.0	1.0	2.0	2.75
CI	0.0	0.0	0.0	0.353033342224
Maximum Hop Count	4.875	6.875	7.625	8.75
CI	0.85872533401	0.636439908668	0.394703275768	0.353033342224
Message Replication Overhead Ratio	433.456843436724	346.03930905766805	221.00078324848957	150.17720665342128
CI	16.7857872421	11.0198310133	8.13419279972	6.45666766172
Network Overhead Ratio	438.43172470526355	353.13595490734536	228.92138458168594	147.95151950778043
CI	15.9706095175	10.1275523472	7.9121772366	5.82360174131
Average Power Consumed per Node (Watts)	0.821811755952381	0.8224117476851852	0.8226128472222223	0.8220587384259259
CI	0.000290466805915	0.000346900735575	0.000334085100125	0.00024731828639

NS-3 Bold Alligator, GAPR, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.10006469700237222	0.1393748652145784	0.23667646107397025	0.3702622924304507
CI	0.00556255980031	0.00790106318549	0.0131843486059	0.0240972311611
PDR	0.13138506545322468	0.17726771352723755	0.28511872691630236	0.4017682961989513
CI	0.00733254406873	0.0102165931141	0.0158917818588	0.0241122191836
Average Latency (seconds)	7279.537669471443	7429.132782183149	7427.541995113854	7671.99124259348
CI	109.231541912	69.8776129698	153.249792957	97.0981352668
Median Latency (seconds)	6267.224950625001	6633.40063675	6633.982603125001	6886.415172500001
CI	192.06897781	166.053341507	215.460697251	164.070361529
Maximum Latency (seconds)	18099.5654505	17990.76742425	18064.618608	18049.7437215
CI	235.068384937	8.62449305973	146.439186689	76.8756896029
Average Hop Count	1.2011272151188785	1.4532107960672014	1.849937789921376	2.4586531399449987
CI	0.0199630252277	0.0242832632198	0.0274440425975	0.0493866117921
Median Hop Count	1.0	1.0	2.0	2.125
CI	0.0	0.0	0.0	0.269633668931
Maximum Hop Count	4.5	6.5	7.625	9.375
CI	1.15300206752	0.911528170059	0.993314794369	0.567421709899
Message Replication Overhead Ratio	466.4000722293225	371.06802552735905	239.24975985329246	163.75044352109762
CI	24.0373553615	18.7692136801	8.68161348168	5.82210324814
Network Overhead Ratio	461.5499355747112	367.6813337162287	242.7666092655313	161.3959120081932
CI	20.9018110772	18.4970277576	7.70921293229	4.43635988503
Average Power Consumed per Node (Watts)	0.821015625	0.8216298776455027	0.8218880208333333	0.8217154431216931
CI	0.000209509643242	0.000264889966834	0.000271316141929	0.000224561240881

NS-3 Bold Alligator, GAPR, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.10040166055639421	0.13965791459995688	0.24028871037308605	0.37578175544533104
CI	0.00456173059225	0.00714338617053	0.0123453616744	0.0224700111049
PDR	0.1316817514669833	0.1776114363367991	0.28864239967613714	0.4048214276160434
CI	0.00600745113875	0.0095272231055	0.0149041421083	0.0228276465032
Average Latency (seconds)	7287.342892244092	7380.687874025925	7380.949654267593	7667.029608862241
CI	141.932916876	115.355868334	120.431187934	114.858527227
Median Latency (seconds)	6315.056674125	6554.589512625001	6598.823759375001	6924.739190625
CI	208.063829413	228.681429932	204.111997972	175.986867201
Maximum Latency (seconds)	18053.60904075	17994.043669500003	17995.48953875	18094.2313785
CI	137.080428255	4.98646195339	1.83000789923	210.883604431
Average Hop Count	1.2051526256846152	1.4588490852478464	1.8490512217229196	2.422626790766067
CI	0.0195962273599	0.0235395423422	0.0228678661204	0.0471936270115
Median Hop Count	1.0	1.0	2.0	2.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	5.0	5.625	8.125	8.875
CI	0.706066684447	0.567421709899	1.11172809722	0.85872533401
Message Replication Overhead Ratio	490.49866754709416	387.94779092241123	254.8091396751091	171.9540176749933
CI	26.4823634096	17.1064789565	12.9453282158	8.03395895467
Network Overhead Ratio	483.6660132836612	381.9381351065632	256.5873847037531	169.67443921695383
CI	22.2735560059	14.8118048833	12.3268412537	6.61092538816
Average Power Consumed per Node (Watts)	0.8206076388888889	0.8210807291666666	0.8214680472883598	0.8214157572751323
CI	0.000169720797385	0.000205982501414	0.000242213146085	0.00021792537754

NS-3 Bold Alligator, GAPR, 54 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.10000404356264826	0.13931421177485442	0.2397428294155704	0.37991966788872117
CI	0.00588609999519	0.00648499741811	0.0122129576102	0.022415512567
PDR	0.13133864788854077	0.17729453861931474	0.2866599188638803	0.4066078103175199
CI	0.00790834525075	0.00890690736732	0.0147269643803	0.022925522899
Average Latency (seconds)	7304.8178883436385	7369.517620362418	7332.037375841987	7652.356603683774
CI	102.67116138	106.255796824	67.4870638355	116.028032605
Median Latency (seconds)	6323.507198374998	6522.314692	6535.973903249999	6915.0500974999995
CI	159.269813964	193.925880108	139.004015117	190.458095991
Maximum Latency (seconds)	18108.29078925	18293.87224625	17995.5010235	17994.483276749997
CI	246.128465634	325.230269527	4.25771960185	3.38737891383
Average Hop Count	1.1977671164738384	1.4529331812049562	1.8501923424162579	2.389755665093284
CI	0.0213972414586	0.0189675861732	0.0241891642281	0.0433642929425
Median Hop Count	1.0	1.0	2.0	2.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.875	5.625	8.0	9.125
CI	0.48875253082	0.567421709899	0.576501033758	0.636439908668
Message Replication Overhead Ratio	497.5289679926913	408.4234745823764	260.7002929481008	176.01437101308287
CI	26.7090360164	21.3167056491	10.9871221738	10.3432023557
Network Overhead Ratio	489.7114479499498	397.6157648071628	259.7753580570988	173.93341073247078
CI	23.6602868109	17.8754144756	9.06317783273	8.83973785553
Average Power Consumed per Node (Watts)	0.8202228009259259	0.8207084986772487	0.8210395998677249	0.821078869047619
CI	0.000123656186865	0.000182617354858	0.000189800899212	0.00018142431924

NS-3 Bold Alligator, GAPR2, 12 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09349390769894328	0.1316516605563942	0.2067675760189778	0.26124784343325425
CI	0.00459647182258	0.00600548120916	0.0101789529944	0.00948395386133
PDR	0.12310168508144424	0.16940176923743025	0.2621860473457178	0.3209721096322441
CI	0.00607595963986	0.00814943814439	0.0138784917711	0.0125557104279
Average Latency (seconds)	7807.029133245333	7647.672944143872	7289.983130191849	7024.2820193718435
CI	152.409473338	75.3255624005	93.7021970122	86.0518886926
Median Latency (seconds)	7135.14059	6989.3778942499985	6491.571793875	5879.785980749999
CI	250.430885227	104.46999316	146.683193353	180.612161342
Maximum Latency (seconds)	17989.496278	17991.574801000002	17992.735304	17996.988312999998
CI	7.53906152935	6.94283490113	4.29800714412	2.46998604778
Average Hop Count	1.1311999866054923	1.3890434336629178	1.8072978466213188	2.7263845908332653
CI	0.00857587930425	0.00924964380494	0.0294119206743	0.0665321131014
Median Hop Count	1.0	1.0	2.0	3.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.375	6.125	7.5	9.0
CI	0.698673112283	1.03429330521	0.706066684447	0.998529081085
Message Replication Overhead Ratio	216.60510489963085	176.1257318083205	120.09111411979038	45.34055768559624
CI	11.7385523653	10.2091874059	7.11176129131	8.47088211505
Network Overhead Ratio	240.27150943412707	197.82766283577004	135.19211981499018	50.89483551218008
CI	12.0613153478	11.3004091558	7.79228643805	7.73303267889
Average Power Consumed per Node (Watts)	0.8194868138227513	0.8196083416005291	0.8196469907407408	0.819538070436508
CI	4.5058367259e-05	5.3593927262e-05	5.5829921824e-05	4.72725426442e-05

NS-3 Bold Alligator, GAPR2, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09317716195816261	0.13158426784558983	0.2097058982100496	0.2840131011429804
CI	0.0041145682653	0.00568473989936	0.00903150899848	0.0132974012965
PDR	0.12254482292070612	0.16877795580810057	0.2641880958613366	0.33773779218048816
CI	0.00566089196719	0.00758696086626	0.0121054102908	0.0152174010154
Average Latency (seconds)	7749.978447122209	7649.224261465766	7362.421445188181	7360.253845943872
CI	153.898892125	67.4173033334	80.4547590734	68.1828413228
Median Latency (seconds)	7000.9565840000005	6937.712378625001	6553.663280125001	6302.229739
CI	269.164397061	155.255369041	161.250693205	131.381646313
Maximum Latency (seconds)	17987.99184	17995.759607250002	17988.31631425	17994.154852
CI	11.9412479393	3.42434638469	12.4985395505	4.18086121245
Average Hop Count	1.1346705108588686	1.3975651599503738	1.8127338392659607	2.740699288124364
CI	0.00642362168585	0.0105617151972	0.0311342547329	0.0832536234613
Median Hop Count	1.0	1.0	2.0	3.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.375	6.125	7.25	9.5
CI	0.698673112283	0.755799231481	1.27287981734	1.07853467572
Message Replication Overhead Ratio	216.61172622269945	178.29422824975518	121.08206560227157	54.95039807784804
CI	13.4918288178	10.6673305545	8.73412783105	7.95910576773
Network Overhead Ratio	239.507571485657	199.39621685730725	134.98258917668124	57.802317665183395
CI	14.7640039219	11.5850457765	9.51799198824	6.99482234491
Average Power Consumed per Node (Watts)	0.8193092757936508	0.8194060019841269	0.8194529183201058	0.8193702463624339
CI	2.73850767884e-05	3.48655144015e-05	3.70186413807e-05	2.97749220555e-05

NS-3 Bold Alligator, GAPR2, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09486871899935304	0.13295233987491914	0.21369554668967006	0.29549681906405
CI	0.00451827835828	0.00600598640063	0.0095773858787	0.0148465106117
PDR	0.1247690515618396	0.17052173540858653	0.2687617121373857	0.34675290558102606
CI	0.00602239345176	0.00799722553397	0.0128435600113	0.0166449066301
Average Latency (seconds)	7765.047453629163	7630.809781123506	7332.5925289622055	7439.587649935205
CI	146.780420947	92.901450479	112.045478237	81.4563305101
Median Latency (seconds)	7086.56188175	6933.241775125	6534.493745624999	6426.93560925
CI	228.335136405	145.252515107	165.565957819	132.65979269
Maximum Latency (seconds)	17993.37995575	17991.377227	18065.87808575	17997.42476625
CI	4.26089691444	7.10016510339	157.038107782	1.18076977499
Average Hop Count	1.1376980451360266	1.392941507607687	1.8177488128326218	2.715615299234985
CI	0.00898636319337	0.0108994536621	0.0299611088533	0.0874076312318
Median Hop Count	1.0	1.0	2.0	3.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.5	5.875	7.625	8.5
CI	0.706066684447	0.950571365144	1.07370899301	0.407647790332
Message Replication Overhead Ratio	212.2514102472308	175.2266065248524	124.05377778126555	62.843484249390045
CI	12.6769894944	9.66571221064	7.02863048288	9.45459821083
Network Overhead Ratio	234.69183482895772	195.88916015000717	137.7963877144638	64.45999335984196
CI	13.2756006101	10.4296004403	7.56413438769	8.38672215037
Average Power Consumed per Node (Watts)	0.8192402447089947	0.8193179563492063	0.8193723131613757	0.8193111359126984
CI	1.98350023413e-05	2.68172207824e-05	3.15275894119e-05	2.37819293468e-05

NS-3 Bold Alligator, GAPR2, 54 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09414761699374596	0.1325951585076558	0.2132035799007979	0.30135998490403276
CI	0.00493315350493	0.00618218434373	0.0109920943176	0.017328819834
PDR	0.12387185997807229	0.17003566374937804	0.26743816754353095	0.3500972242395396
CI	0.00676475098305	0.00853307523354	0.0143337094501	0.0191947261265
Average Latency (seconds)	7770.750800054196	7638.396149729484	7352.665608926974	7517.980062601529
CI	115.649405081	66.2923231871	97.1945209827	82.4133763586
Median Latency (seconds)	7077.385615000002	6931.476937	6555.251972374999	6571.6691565
CI	213.614362208	110.999368288	151.521597407	133.845103007
Maximum Latency (seconds)	17989.9037895	17991.468816	17986.973047999996	18156.24227525
CI	7.80167096487	7.06817111327	11.6156088143	346.638665424
Average Hop Count	1.136989100333921	1.3986986140296835	1.8071015670132646	2.6900320724295534
CI	0.00997088773174	0.0127187828781	0.0234593275314	0.0774412524223
Median Hop Count	1.0	1.0	2.0	3.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	5.0	6.5	7.25	8.625
CI	0.576501033758	0.706066684447	0.97750506164	0.698673112283
Message Replication Overhead Ratio	217.93095333572663	176.9825967316532	124.84560819049585	69.04783654724497
CI	13.2562571244	11.8279581703	8.19914295253	9.56692859966
Network Overhead Ratio	240.50991151227157	197.21661533658397	138.19571801038208	69.03906325732352
CI	13.9338998609	13.2718197824	8.65451790644	8.51264205668
Average Power Consumed per Node (Watts)	0.8191871279761905	0.8192540922619048	0.8193032820767195	0.8192629794973545
CI	1.53838884035e-05	2.04044426295e-05	2.43202692214e-05	1.89416639484e-05

NS-3 Bold Alligator, GAPR2a, 12 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08907294587017468	0.13095077636402846	0.21919479189130903	0.33245498166918264
CI	0.00442955709231	0.00603184521157	0.0109060662949	0.0192972391527
PDR	0.1165635704648355	0.16707809207857754	0.27005147148138514	0.373684183410511
CI	0.00592734578834	0.0080983076758	0.0133159673592	0.0199600682301
Average Latency (seconds)	8098.528497222283	7835.462359889361	7513.217580950119	7714.704347262904
CI	137.068367989	92.2769545372	87.7733850929	118.445239367
Median Latency (seconds)	7589.4523755	7239.810170000001	6728.38799225	6862.6025683749995
CI	239.862201686	153.184022485	151.023892678	207.289132957
Maximum Latency (seconds)	18098.464675249998	17994.62838375	17995.33084875	18834.9461285
CI	235.614725638	3.20122935165	2.32783089518	1242.74659674
Average Hop Count	1.178074789245284	1.4060839308016566	1.8016361435778971	2.4873702768695054
CI	0.0169481775216	0.0131777012136	0.024830219943	0.0340856832774
Median Hop Count	1.0	1.0	2.0	2.375
CI	0.0	0.0	0.0	0.394703275768
Maximum Hop Count	4.5	5.625	7.125	8.5
CI	0.706066684447	0.567421709899	0.755799231481	0.706066684447
Message Replication Overhead Ratio	307.38079763318217	250.3738170122061	177.30901426567416	133.64485284681712
CI	19.9445834001	12.5876003828	9.05806256251	6.81413623933
Network Overhead Ratio	338.3169111914252	276.3004579381414	193.68131588957166	133.54775783023732
CI	21.1066238155	14.3508478427	9.18759988383	6.50278023873
Average Power Consumed per Node (Watts)	0.8197523974867725	0.8201525297619048	0.8207314401455027	0.8209887566137566
CI	4.22151780769e-05	7.26091252255e-05	0.000135476402815	0.000165678923654

NS-3 Bold Alligator, GAPR2a, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09015122924304507	0.13279059736898857	0.22697864998921716	0.35747789519085615
CI	0.00487314266503	0.00649987725737	0.012720283663	0.0219058514401
PDR	0.1178562773489616	0.16903736410849246	0.2768227637681828	0.39122048670178877
CI	0.0065896188957	0.00863487627384	0.0152163097838	0.0221277641682
Average Latency (seconds)	8069.625039521471	7812.554359907308	7483.082856591632	7769.838957964635
CI	127.706543735	113.081457525	94.7231048513	63.8451622011
Median Latency (seconds)	7546.2990785	7183.536578749999	6693.58648125	7038.328232250002
CI	261.483127673	218.282899082	177.270774062	111.916574351
Maximum Latency (seconds)	17991.899083	18154.21161925	17992.18189825	18157.621896999997
CI	5.96611496905	350.068020698	5.12889679321	346.264940717
Average Hop Count	1.1766470638422162	1.4114069530199458	1.8014236537613897	2.417999465903132
CI	0.0155432614308	0.0156256026646	0.0260119365898	0.0458721941277
Median Hop Count	1.0	1.0	2.0	2.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.75	6.0	7.375	8.625
CI	1.1348434198	0.576501033758	0.905813203564	0.698673112283
Message Replication Overhead Ratio	309.1743028502849	256.6000931370471	186.29420807310518	140.6779801620836
CI	21.1717012581	17.3007392001	9.91142419151	7.11662281625
Network Overhead Ratio	339.41890124181515	281.7289581308069	203.24690858732234	140.21593042992123
CI	22.8762500937	18.9193955686	10.7172167653	6.42855765261
Average Power Consumed per Node (Watts)	0.8194965277777778	0.8197641782407408	0.8201924189814814	0.8204726769179894
CI	2.41803500403e-05	4.04352807078e-05	8.60583315447e-05	0.00013233216971

NS-3 Bold Alligator, GAPR2a, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08994905111063187	0.13241993745956437	0.22805019409100713	0.36811920422687083
CI	0.00467909004763	0.00599900294901	0.0129795893202	0.0251397142644
PDR	0.11753606055267914	0.16831147662149878	0.2771187067045986	0.3997841806165402
CI	0.00619141245225	0.00824018156516	0.016111948812	0.0257102111104
Average Latency (seconds)	8031.841667197941	7740.965952515708	7497.994469919096	7713.281640658641
CI	186.442480539	142.524831789	145.158400185	104.242950764
Median Latency (seconds)	7501.845598500001	7106.629029250002	6759.951259124999	6977.397098374999
CI	333.949034361	254.953011005	195.57617305	174.202937659
Maximum Latency (seconds)	18052.081843	18105.921704	17993.7262535	17996.06532825
CI	137.566167449	246.920980848	3.16338167717	1.46968908247
Average Hop Count	1.1793917664776186	1.416226730596942	1.799887784233649	2.405047575974879
CI	0.015547933635	0.0141099748623	0.0235142058301	0.047384257165
Median Hop Count	1.0	1.0	2.0	2.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	5.0	5.5	6.75	8.375
CI	0.706066684447	0.576501033758	0.676007383574	0.698673112283
Message Replication Overhead Ratio	313.9141486905688	261.0870355598267	186.83666734452504	146.96468085056304
CI	16.2731489912	14.6125320223	5.91200556702	6.41756075941
Network Overhead Ratio	344.18078738050485	286.25983684886126	203.36701019166338	147.18112262524588
CI	17.288861289	15.6736125421	6.48308281533	4.95444893517
Average Power Consumed per Node (Watts)	0.8193896742724868	0.819604828042328	0.819943783068783	0.8201934523809524
CI	1.84887915455e-05	3.0872802311e-05	6.70608373933e-05	0.00010650168788

NS-3 Bold Alligator, GAPR2a, 54 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09077798145352599	0.1335521350010783	0.2310154733664007	0.3724862518869959
CI	0.00469865356361	0.00670895746867	0.0121926647915	0.0223297524736
PDR	0.11888714854670915	0.16974834051013943	0.27978838544353096	0.4024309973425573
CI	0.00633226702456	0.00872229210875	0.0159602030888	0.0230207800066
Average Latency (seconds)	8016.570077186799	7723.743238946016	7427.4239397344945	7694.068581026869
CI	159.369729733	82.9741046614	119.872586988	99.9335869918
Median Latency (seconds)	7494.708406750002	7064.81057525	6659.25775825	6966.87106425
CI	267.4590998	175.414064394	187.210493734	141.271681967
Maximum Latency (seconds)	17991.903924	17990.7613415	17994.7465805	17996.262951
CI	6.31939270175	7.00373543731	5.20420740857	1.18771276108
Average Hop Count	1.1772063007913705	1.4106244104894814	1.8081843166641307	2.375880333321032
CI	0.0155338110177	0.0194312297627	0.0190037346625	0.043814875119
Median Hop Count	1.0	1.0	2.0	2.0
CI	0.0	0.0	0.0	0.0
Maximum Hop Count	4.625	5.5	7.125	8.625
CI	0.394703275768	0.706066684447	0.636439908668	0.808901006792
Message Replication Overhead Ratio	327.1408017757206	273.31159562847114	192.71712913529703	149.20791172865307
CI	19.669864053	15.4561886482	5.91709432675	8.97164076789
Network Overhead Ratio	357.2610904470093	299.1981453570619	209.95850573321115	149.27331718180886
CI	20.9017886688	16.6260348895	6.77926247976	7.15335962856
Average Power Consumed per Node (Watts)	0.8193111359126984	0.8194843336640212	0.8197492972883598	0.8199654844576719
CI	1.29989506169e-05	2.33821843478e-05	5.01180483059e-05	8.32939138962e-05

NS-3 Bold Alligator, Vector, 12 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08488111925814104	0.1357626159154626	0.2274234418805262	0.28683685572568474
CI	0.00551104168093	0.00762637698013	0.0120329404284	0.0171707025058
PDR	0.10512567815715233	0.16676510790176557	0.2810610292393999	0.3553230890379051
CI	0.00731426508745	0.0101024858067	0.0160298746291	0.0231097749154
Average Latency (seconds)	5024.982058278306	6899.829457322517	8002.403571346715	7478.644983774663
CI	99.1597057686	56.7699172928	127.830335783	85.3361759689
Median Latency (seconds)	3927.8158651250005	6014.190202000001	7426.5304824999985	6455.5690589999995
CI	88.2463458777	111.396194236	195.173542454	167.888618347
Maximum Latency (seconds)	17915.231014	17973.71328825	18188.851756750002	17994.452955
CI	61.4915000345	15.6531060662	412.489435762	3.3520567729
Average Hop Count	11.761254031787185	11.757386549695966	8.012172995123073	3.7934969114142607
CI	0.183700080973	0.184734535918	0.215185848016	0.182461659323
Median Hop Count	7.1875	8.25	6.25	3.125
CI	0.496657397185	0.353033342224	0.353033342224	0.269633668931
Maximum Hop Count	50.0	49.875	39.0	17.875
CI	0.0	0.269633668931	2.54575963467	1.7022651297
Message Replication Overhead Ratio	184.3148403264122	160.96224808296327	117.16218715591266	58.86017592228688
CI	6.72033989805	6.14468311584	4.68736074414	6.29691257722
Network Overhead Ratio	205.25297126768905	177.27485478743515	128.46944688940357	64.04790777416864
CI	7.82597566493	7.07356228998	5.46341645228	6.81155900669
Average Power Consumed per Node (Watts)	0.8191871279761905	0.8192708333333334	0.8193725198412698	0.8194049685846561
CI	9.95037142824e-06	1.6162451416e-05	1.97776590518e-05	2.30100628098e-05

NS-3 Bold Alligator, Vector, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08542700021565668	0.13708351304722882	0.23774126590467975	0.31348393357774423
CI	0.00454848861979	0.00810371017681	0.0132825995791	0.0201078446664
PDR	0.10607929408048736	0.167426719198602	0.2883841555302491	0.37518626472060984
CI	0.00603458201473	0.0100577359682	0.0174468255044	0.0258448731404
Average Latency (seconds)	5035.284556890578	6908.3442915864935	8164.767433166152	7847.476883498348
CI	114.50355852	116.94190921	96.749618631	51.236494571
Median Latency (seconds)	3901.5091176250007	6034.3031978750005	7647.657951	6929.528141874999
CI	105.458473078	181.513802942	178.491588977	104.296234772
Maximum Latency (seconds)	17952.925087249998	18149.09996	18292.6598615	18260.92223375
CI	26.3883727498	362.609139956	367.494355621	565.741449138
Average Hop Count	11.66389173633222	11.83279969878614	8.2396641376779	4.1362757136722
CI	0.276707014399	0.284756836525	0.136811404969	0.156214144662
Median Hop Count	7.0	8.5	6.875	3.875
CI	0.576501033758	0.576501033758	0.269633668931	0.269633668931
Maximum Hop Count	50.0	49.875	39.625	18.75
CI	0.0	0.269633668931	4.19575337418	1.1348434198
Message Replication Overhead Ratio	182.58644102922887	160.85984175106256	119.03831376194552	66.25281468072625
CI	7.66913921102	5.38447496843	6.0947074834	5.99661865679
Network Overhead Ratio	202.85324253435786	176.51992436441648	128.89749179649806	71.52757393019243
CI	9.33246018818	6.31669177578	6.95128586969	6.5175763101
Average Power Consumed per Node (Watts)	0.8191240906084656	0.8191803075396825	0.8192427248677249	0.8192662863756613
CI	5.42366924034e-06	9.45432833372e-06	1.18097987748e-05	1.14533967872e-05

NS-3 Bold Alligator, Vector, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08618853784774638	0.13801353245632952	0.2409424196678887	0.3225212960966142
CI	0.0062138253388	0.00876088175375	0.0164691139074	0.0207999652922
PDR	0.10716785284928548	0.16889546110525125	0.2905788096931368	0.3795525624180014
CI	0.00768627393858	0.010846442803	0.0204355712255	0.0263278293023
Average Latency (seconds)	5094.90819050236	6873.636366099832	8179.549949084057	7907.6173477005295
CI	96.5150664207	47.0273482283	80.8615635049	101.311402349
Median Latency (seconds)	3979.3796941249993	6010.33805325	7693.52846075	7082.956469250001
CI	86.3716492931	75.6454200048	140.979521614	178.133371643
Maximum Latency (seconds)	17948.92038975	17992.523548999998	18122.7426895	18138.4917365
CI	19.8956630886	3.87277920038	275.124833327	309.485823206
Average Hop Count	11.76104644270902	11.75653441420179	8.397727001608377	4.337508303664205
CI	0.427913862591	0.174648614779	0.271622657087	0.204994658443
Median Hop Count	7.1875	8.375	7.0	4.0
CI	0.574244660976	0.394703275768	0.0	0.0
Maximum Hop Count	50.0	49.5	38.0	18.25
CI	0.0	0.407647790332	1.86807685608	1.94435603784
Message Replication Overhead Ratio	181.54961987391047	161.3065417273075	121.38248859329768	69.9188227034839
CI	7.42109174562	5.34340241827	6.94300941531	6.22208357513
Network Overhead Ratio	200.90755601794447	176.19567372709378	130.90639989234066	75.13708039923272
CI	8.42633107058	5.95781313476	7.68186964334	6.62547019224
Average Power Consumed per Node (Watts)	0.8191011491402116	0.8191455853174603	0.8191964285714286	0.8192137896825397
CI	4.15152506442e-06	7.09324854284e-06	8.8397001477e-06	8.96726374165e-06

NS-3 Bold Alligator, Vector, 54 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.08562917834806988	0.13656458917403494	0.23959456545180075	0.3294290489540651
CI	0.00544157277372	0.00792906120676	0.0146351973259	0.022072554634
PDR	0.10568803909022761	0.1668512057965581	0.28823920590990215	0.3838598102358805
CI	0.00723042911426	0.0102247409287	0.0175717806656	0.0274734466336
Average Latency (seconds)	5209.431266236014	6959.042109894545	8183.818434994546	8017.952739921979
CI	89.4969808551	138.115838061	88.5803120325	116.11279959
Median Latency (seconds)	4062.9512907499993	6112.928542625	7678.483509875001	7243.365978874999
CI	88.0729543868	206.565419326	167.655161993	191.086455723
Maximum Latency (seconds)	17946.990751999998	17987.087193	20240.16896675	19098.53081675
CI	19.9548618542	9.39750452024	3565.31091749	989.517347877
Average Hop Count	11.823251677179405	11.967942042114501	8.387830095422206	4.439933516851659
CI	0.365704838123	0.100869416308	0.266600109734	0.175800046987
Median Hop Count	7.375	8.875	6.75	4.0
CI	0.567421709899	0.269633668931	0.353033342224	0.0
Maximum Hop Count	50.0	49.75	39.25	21.625
CI	0.0	0.353033342224	3.04373983672	1.99445613089
Message Replication Overhead Ratio	184.8764452704704	165.1476258898058	120.96348749411972	73.784966534263
CI	11.3107169078	6.63471414333	7.76750258513	7.01489372344
Network Overhead Ratio	205.34128048637368	180.37260623804144	130.2553221597779	79.18673780791009
CI	13.0411962976	7.56846212899	8.76157238636	7.62937017562
Average Power Consumed per Node (Watts)	0.8190833746693121	0.8191183035714286	0.8191604662698413	0.819175140542328
CI	2.85465919437e-06	5.03263861892e-06	6.49127890099e-06	6.92103204445e-06

NS-3 Bold Alligator, Vector No Limit, 12 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09487545827043346	0.15492910286823378	0.2831706922579254	0.3932971209833944
CI	0.00559847009757	0.00831328794276	0.0167646955343	0.0243227211913
PDR	0.10666000902393125	0.1705134129423465	0.31021044247580687	0.4281577963377582
CI	0.00672221174526	0.00979811604986	0.0184057742258	0.0275951215148
Average Latency (seconds)	4600.107664969562	6697.6312554084025	8604.925815706758	8790.795574772108
CI	142.957453391	77.220228549	103.178750818	139.868594186
Median Latency (seconds)	3523.662293875	5773.767691375	8373.109159500002	8508.907502
CI	101.069513364	103.446915671	179.3752996	216.72997728
Maximum Latency (seconds)	17916.07263825	17989.1718785	17998.071837	17996.8551805
CI	60.4298749151	9.64990301034	2.50173814861	1.49605663663
Average Hop Count	12.279862624558236	12.90469945742759	9.929690050483735	5.8213618761412
CI	0.201702940805	0.274147558311	0.181973427967	0.152729894594
Median Hop Count	8.1875	9.75	8.0	5.0
CI	0.283710854949	0.539267337861	0.407647790332	0.0
Maximum Hop Count	49.875	50.0	45.5	30.25
CI	0.269633668931	0.0	1.68077489759	4.696803137
Message Replication Overhead Ratio	336.2318064002681	258.8902511979254	182.16883101166155	125.16089460029636
CI	9.29091758161	7.65482039385	4.33680957161	3.26263602263
Network Overhead Ratio	368.23610916838754	278.9867434230051	193.73923644019857	133.87404983876078
CI	9.46691515243	9.78375605784	4.8524963861	3.46049748863
Average Power Consumed per Node (Watts)	0.819815021494709	0.8201725777116402	0.8204999586640211	0.8206132192460317
CI	3.80892587049e-05	5.49892666264e-05	5.19605682008e-05	3.47525388339e-05

NS-3 Bold Alligator, Vector No Limit, 24 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09540786068578823	0.15602086478326505	0.2955709510459349	0.4234755768816045
CI	0.00588690005688	0.00838216048406	0.015284816305	0.0277404391603
PDR	0.10683057004336202	0.17222179729206763	0.3160146691393639	0.44740793321260475
CI	0.00698031726105	0.0097905134439	0.0173642521357	0.0294840333491
Average Latency (seconds)	4598.627962493462	6562.555513968084	8419.146861390285	8756.728744960908
CI	99.0988184132	120.292749591	107.169135002	96.4094315743
Median Latency (seconds)	3499.777047250001	5557.746104125001	8083.15015125	8493.021957
CI	81.9651213528	189.388848052	166.100656046	161.265262491
Maximum Latency (seconds)	17892.58130825	17977.56880275	18323.22305225	18256.94634975
CI	97.1511697132	11.372246437	702.8483174	429.558093419
Average Hop Count	12.242209506288267	13.273204001189402	10.133221949221644	6.1599293563946675
CI	0.182565848362	0.364875818707	0.430005660614	0.120748392718
Median Hop Count	8.0	10.0	8.5	5.125
CI	0.407647790332	0.576501033758	0.407647790332	0.269633668931
Maximum Hop Count	50.0	49.875	46.125	32.625
CI	0.0	0.269633668931	1.88743568251	5.3140997844
Message Replication Overhead Ratio	337.18654015375785	274.73743326179397	184.12195077239113	130.39194652644792
CI	18.9659182008	6.41072699039	6.15980255331	4.29914286165
Network Overhead Ratio	368.617961869874	293.28272373130426	195.36156921387598	139.28659343222648
CI	21.1178648081	7.84628985021	6.77450131428	4.39821274866
Average Power Consumed per Node (Watts)	0.8195310433201057	0.8197563244047619	0.8200648974867725	0.8201570767195767
CI	1.6916949051e-05	2.7336821109e-05	4.23762950472e-05	3.49257270082e-05

NS-3 Bold Alligator, Vector No Limit, 36 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09507763640284667	0.15450452879016605	0.294654410178995	0.42927135001078287
CI	0.00485241009326	0.00837591471769	0.0165982698538	0.0265398190602
PDR	0.10650995693916336	0.16931475488058154	0.3138970720969306	0.4515820958783779
CI	0.00623713998774	0.0101334209573	0.0179249105545	0.0278433070474
Average Latency (seconds)	4591.8271082309375	6487.263521644092	8454.38017148479	8640.631112646222
CI	86.1449536836	99.1198260516	163.358540588	141.158815626
Median Latency (seconds)	3514.1859288750006	5485.9482903749995	8144.0706228750005	8327.679809624999
CI	67.8463836322	117.954126148	278.104984278	221.005525801
Maximum Latency (seconds)	17913.96574575	18038.08962275	18634.598394	20335.73088725
CI	86.813457866	111.651687554	674.585931852	1597.61413753
Average Hop Count	12.17030032168842	13.149435635544764	10.270844546452752	6.286353903466211
CI	0.446715973741	0.248813193154	0.450666299725	0.247104161822
Median Hop Count	7.875	10.25	8.75	5.625
CI	0.48875253082	0.539267337861	0.353033342224	0.394703275768
Maximum Hop Count	50.0	50.0	45.75	31.625
CI	0.0	0.0	1.90114273029	5.61811275588
Message Replication Overhead Ratio	353.0159588035191	278.18460515550805	189.7595241542187	131.48198316160187
CI	15.9392693127	7.64267558973	6.06738510634	5.79356330381
Network Overhead Ratio	387.16699739277334	300.03158420210934	202.32866038990974	140.1395971175359
CI	17.7907524908	9.24455958488	6.30510093634	6.17916777935
Average Power Consumed per Node (Watts)	0.8194287367724867	0.8196068948412698	0.8198606977513228	0.8199615575396825
CI	1.75763125344e-05	2.41309807457e-05	4.22151780769e-05	3.76170649811e-05

NS-3 Bold Alligator, Vector No Limit, 54 Mbps				
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**
MDR	0.09601439508302782	0.15612869312055208	0.29646053482855295	0.43755391416864353
CI	0.00486009073847	0.00869441234077	0.0178344970399	0.0242523702935
PDR	0.10724733735572659	0.17176827242047635	0.31701725385959323	0.4592145404978143
CI	0.0060376373501	0.0105211933842	0.0196807122989	0.026128296632
Average Latency (seconds)	4570.239416941788	6537.116250456427	8333.718624755249	8587.1934631993
CI	125.930978589	70.3943024475	116.505694566	164.848282382
Median Latency (seconds)	3510.6565171250013	5557.938857875	7960.130795249998	8259.12473575
CI	74.5677604452	147.185005478	194.510078477	218.605190384
Maximum Latency (seconds)	17916.14032675	17979.2812075	18440.36873125	18772.6907635
CI	84.2118033429	12.9231065605	659.473057279	1187.81955354
Average Hop Count	12.373990980852616	13.012851374979277	10.551845833316388	6.395051298297852
CI	0.229931531591	0.298366912246	0.308839071008	0.168052016442
Median Hop Count	8.0	10.0	9.0	5.5
CI	0.407647790332	0.407647790332	0.407647790332	0.407647790332
Maximum Hop Count	50.0	49.875	46.375	36.25
CI	0.0	0.269633668931	1.62740329677	6.09770787389
Message Replication Overhead Ratio	359.38075979218996	287.54671673695873	197.6328353599734	136.38683656816525
CI	11.7135599451	4.23025760963	3.67558552842	4.36817123402
Network Overhead Ratio	392.99087854499686	309.1094999141755	210.45106003742188	145.45188868664982
CI	11.8955427465	4.86414017105	3.9684495646	4.58966780049
Average Power Consumed per Node (Watts)	0.8193437913359789	0.8194861937830688	0.8197089947089947	0.8197982804232804
CI	1.53912694227e-05	1.8700282134e-05	3.76427200141e-05	3.75218374925e-05

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APPENDIX E:
ONE Omaha Data Tables

ONE Omaha, Epidemic, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.15205	0.21140833333333334	0.306625	0.3944916666666667	0.504475
CI	0.00659640856771	0.00800454118791	0.0133948297636	0.0126327168468	0.0108639465781
Average Latency (seconds)	2948.9297666666666	3463.786775	4031.9022999999997	4625.575575	5045.973033333334
CI	127.989503374	94.5318840606	158.319008229	181.747653774	187.691684713
Median Latency (seconds)	1137.9416666666666	1442.65	1901.0833333333333	2824.4166666666665	3588.1916666666666
CI	114.529664944	115.692392436	162.249470885	200.650622039	177.271673347
Average Hop Count	8.8043	8.233166666666667	7.28065	7.704525	7.3525583333333335
CI	0.574954128405	0.482769462459	0.623494000996	0.509046087015	0.340079870076
Median Hop Count	3.6666666666666665	4.0	4.166666666666667	4.916666666666667	5.416666666666667
CI	0.296498870984	0.0	0.234402938994	0.173837872154	0.310085941581
Message Replication Overhead Ratio	690.6496833333333	613.3190333333333	376.2540833333333	368.7946916666667	322.0228333333333
CI	21.5356990825	39.618407285	34.4908806721	26.9633149368	15.1615067385

ONE Omaha, Epidemic, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.14624166666666666	0.211	0.310525	0.3912333333333333	0.5062916666666667
CI	0.00742341007167	0.00958010288894	0.0142590479111	0.0148094359599	0.0108819970805
Average Latency (seconds)	3050.5913416666667	3499.0695083333335	4082.5697333333333	4483.418308333334	4884.6030083333335
CI	181.46559283	261.053373979	210.049582369	227.317574412	234.555310237
Median Latency (seconds)	1173.125	1500.025	2018.8	2644.225	3398.85
CI	128.418371283	164.60794967	205.005510123	173.908527236	246.721952713
Average Hop Count	10.292	10.287958333333334	8.482366666666667	9.149325000000001	8.736191666666667
CI	0.735707451293	0.900401563287	0.75455096489	0.60946151272	0.572458536342
Median Hop Count	4.333333333333333	4.833333333333333	4.25	5.166666666666667	5.75
CI	0.296498870984	0.502738295659	0.272351603708	0.234402938994	0.272351603708
Message Replication Overhead Ratio	1004.7856833333333	902.0977416666666	544.1676916666667	582.701125	523.39525
CI	31.0669681146	47.5893381725	47.2114900497	48.8546214896	35.7203236014

ONE Omaha, Epidemic, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.14694166666666666	0.212225	0.315225	0.3956666666666667	0.4991833333333333
CI	0.00842710840297	0.00991922089106	0.0142836032712	0.0126016990786	0.0151748016442
Average Latency (seconds)	2985.9044583333334	3723.984683333333	4134.662666666667	4485.540958333333	4678.48445
CI	190.668484917	204.243221291	160.988849981	261.531135061	262.725921739
Median Latency (seconds)	1137.625	1630.15	2081.8333333333335	2674.7166666666667	3174.008333333333
CI	143.24066395	177.583353157	170.197317459	182.49823532	256.428443628
Average Hop Count	10.904916666666667	12.198333333333334	9.564925	10.083333333333334	10.132091666666668
CI	0.809613199374	0.660773887504	1.30515835496	0.94875007382	0.921544451638
Median Hop Count	4.583333333333333	5.416666666666667	4.583333333333333	5.333333333333333	6.166666666666667
CI	0.477515090764	0.477515090764	0.310085941581	0.296498870984	0.347675744308
Message Replication Overhead Ratio	1380.011325	1300.054825	839.7155416666667	898.02505	835.8299916666666
CI	100.831264204	62.5009654862	103.380482705	93.8902626669	68.1136817451

ONE Omaha, Epidemic, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.145725	0.21006666666666668	0.30918333333333337	0.392275	0.49924999999999997
CI	0.00658102897173	0.0098813670332	0.0128518110264	0.0108408292998	0.0129397938288
Average Latency (seconds)	3166.7166833333335	3513.2758583333334	4032.2021083333334	4386.679925	4598.390766666666
CI	164.756102386	212.591834339	217.769553326	218.789737912	273.267939569
Median Latency (seconds)	1147.75	1537.8916666666667	1912.4833333333333	2597.3166666666666	3134.05
CI	143.980204742	144.340682333	102.414085189	188.96343838	249.614470282
Average Hop Count	11.745841666666667	12.812566666666667	9.919516666666667	10.801875	10.53595
CI	0.603649502341	1.13726440635	1.23030204716	1.08149862905	0.791540004516
Median Hop Count	4.666666666666667	5.5	4.5	5.416666666666667	6.25
CI	0.392231138317	0.31448454343	0.31448454343	0.310085941581	0.374311476465
Message Replication Overhead Ratio	1630.1985333333334	1594.117825	1023.7580583333333	1119.9373333333333	1058.4710333333333
CI	146.88622422	88.5358807381	126.201281356	110.173701493	89.1587736088

ONE Omaha, Epidemic, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.14106666666666667	0.211075	0.308375	0.39845833333333336	0.5067416666666666
CI	0.00642428285001	0.0102673985968	0.014897743367	0.0103559990415	0.00782051077271
Average Latency (seconds)	3014.7575666666667	3526.1015666666667	3988.4714916666667	4319.510608333333	4602.261716666667
CI	210.981853773	200.142943633	197.9712432	186.694021884	296.073673872
Median Latency (seconds)	1141.275	1459.1083333333333	1946.3583333333333	2496.4833333333336	3107.1
CI	147.59523003	154.724495789	196.980244098	114.933279819	230.700595299
Average Hop Count	11.738991666666667	13.15945	10.45405	11.867333333333333	11.683283333333334
CI	0.567657286677	0.724068973533	1.34432525967	1.48616152875	1.33341826807
Median Hop Count	4.583333333333333	5.5	4.5	5.666666666666667	6.416666666666667
CI	0.402600268923	0.405997799781	0.31448454343	0.296498870984	0.402600268923
Message Replication Overhead Ratio	2086.6231916666666	1915.7216166666667	1341.5795583333334	1392.9565333333333	1323.9168333333332
CI	235.12137942	128.487667595	190.281718905	143.840489833	125.044428781

ONE Omaha, Centroid, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.18074166666666666	0.25929166666666664	0.3618	0.5083333333333333	0.7324333333333334
CI	0.0132666379285	0.0136314318023	0.0127901035219	0.0166146747687	0.0194314183333
Average Latency (seconds)	2338.5261	3190.4027	3567.9477916666665	3810.580125	4281.04995
CI	252.619204608	156.675595019	175.577307292	177.727481377	222.609963893
Median Latency (seconds)	749.3083333333333	1032.6166666666666	1650.1916666666666	2439.1583333333333	3264.758333333333
CI	63.0023793943	83.4977757199	120.113509944	151.400167951	257.283878343
Average Hop Count	3.4675	4.106158333333333	4.90935	5.442308333333333	5.927808333333333
CI	0.0888235858702	0.0803386963142	0.129733984367	0.139541247598	0.179335347822
Median Hop Count	3.0	3.1666666666666665	4.0	4.916666666666667	5.166666666666667
CI	0.0	0.234402938994	0.0	0.173837872154	0.234402938994
Message Replication Overhead Ratio	86.2893	81.09384166666666	77.41953333333333	71.776275	64.297
CI	5.5079173717	5.21324375681	3.05118846719	1.97222990522	1.8593802533

ONE Omaha, Centroid, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.17888333333333334	0.26238333333333336	0.36495	0.5097833333333334	0.7397750000000001
CI	0.0110940065765	0.0127431018648	0.0126634482095	0.0175780043958	0.0189758198854
Average Latency (seconds)	2259.229925	3104.75815	3465.3856416666667	3666.4722166666666	4129.927908333333
CI	213.707408641	172.698194168	169.893459988	149.754337196	216.547858856
Median Latency (seconds)	726.55	1001.2833333333333	1569.325	2309.95	3091.7916666666665
CI	69.988790086	82.3379907166	104.465533277	135.193608421	233.654339706
Average Hop Count	3.4937583333333335	4.195983333333333	5.022183333333333	5.580616666666667	6.132383333333333
CI	0.118416426796	0.102722747925	0.136256575137	0.148467749568	0.200142664235
Median Hop Count	3.0	3.4166666666666665	4.083333333333333	4.916666666666667	5.833333333333333
CI	0.0	0.310085941581	0.173837872154	0.173837872154	0.234402938994
Message Replication Overhead Ratio	89.17760833333334	83.904825	80.45239166666667	74.74541666666667	66.81294166666666
CI	5.59424262631	5.81352886104	3.52540956541	2.08214955728	1.97442720969

ONE Omaha, Centroid, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.182425	0.262625	0.36669999999999997	0.5110083333333333	0.740875
CI	0.0122868410831	0.0134741886502	0.0129061330131	0.0157207770723	0.0187672038305
Average Latency (seconds)	2249.7813333333334	3121.807041666667	3403.097008333333	3615.2543833333334	4039.7185
CI	229.846532692	171.766525474	160.954218638	150.919881877	214.133775616
Median Latency (seconds)	722.55	986.3916666666667	1530.55	2248.5666666666666	2988.4166666666665
CI	66.2876749231	79.0800570022	108.856023778	117.210548978	205.466314346
Average Hop Count	3.495625	4.204533333333333	5.048108333333333	5.649258333333333	6.245966666666667
CI	0.0980886688983	0.0829635114272	0.12391547023	0.127575373925	0.191963756444
Median Hop Count	3.0	3.25	4.0	5.0	5.833333333333333
CI	0.0	0.272351603708	0.0	0.0	0.234402938994
Message Replication Overhead Ratio	88.034525	86.0047	81.20715	75.65559166666667	68.53784166666667
CI	5.73935177429	6.04434404389	3.37391005254	2.28171865382	1.97314132488

ONE Omaha, Centroid, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.182025	0.2611583333333333	0.36611666666666665	0.5116499999999999	0.7426166666666667
CI	0.013611045205	0.0132782871979	0.0131682514135	0.0169769134177	0.0177501909948
Average Latency (seconds)	2255.525375	3066.6840583333333	3419.0355583333335	3591.0965166666665	4021.16515
CI	249.479888414	196.101997092	178.615724238	149.481258526	223.537531445
Median Latency (seconds)	730.275	960.5416666666666	1539.3833333333332	2225.4416666666666	2959.925
CI	82.1932979736	84.9266910217	108.445828522	116.237620909	212.402992754
Average Hop Count	3.5473333333333334	4.2186916666666665	5.072291666666667	5.661608333333334	6.291566666666666
CI	0.103897213058	0.0984449361989	0.123757267871	0.127231718387	0.191332607005
Median Hop Count	3.0	3.3333333333333335	4.0	5.0	5.833333333333333
CI	0.0	0.296498870984	0.0	0.0	0.234402938994
Message Replication Overhead Ratio	88.91138333333333	86.91004166666667	82.04095833333334	76.153325	69.27425
CI	5.03841896965	5.61206597992	3.61932773747	2.31517066903	2.10544274142

ONE Omaha, Centroid, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.182025	0.26169166666666666	0.36575	0.5120666666666667	0.74185
CI	0.011723712848	0.0108347861839	0.0140145006689	0.0179974631512	0.0196923665459
Average Latency (seconds)	2256.59855	3096.232475	3412.6694916666665	3563.3165583333334	4008.643975
CI	240.233733081	170.340022274	185.500890407	160.723618787	215.526181661
Median Latency (seconds)	713.775	976.25	1526.725	2224.8	2939.225
CI	77.7765699768	77.7354668977	108.054195545	123.276229532	211.932234557
Average Hop Count	3.536575	4.2287	5.045858333333333	5.678266666666667	6.309433333333333
CI	0.115068801819	0.10735921044	0.129869194917	0.13168359815	0.19184798607
Median Hop Count	3.0	3.4166666666666665	4.0	5.0	5.833333333333333
CI	0.0	0.310085941581	0.0	0.0	0.234402938994
Message Replication Overhead Ratio	88.78023333333333	87.26706666666666	82.36189166666666	76.55884166666667	69.60140833333334
CI	5.91835642633	6.02380824184	3.35532813521	2.1096097899	2.0177554827

ONE Omaha, GAPR, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30948333333333333	0.41125	0.5791499999999999	0.699425	0.7930083333333333
CI	0.0150481611669	0.014772463014	0.0199744728406	0.0208473940243	0.0175042495832
Average Latency (seconds)	2654.828075	3372.2810083333334	4280.98095	4654.484008333333	4409.748683333333
CI	163.617957729	198.437221159	243.483097479	282.264212571	278.894314473
Median Latency (seconds)	1167.3583333333333	1683.45	2710.8	3328.133333333333	3383.45
CI	78.3277591739	124.076805522	196.583202249	266.733872197	273.238065418
Average Hop Count	3.639308333333333	4.2858583333333335	4.495825	4.520491666666667	5.435433333333333
CI	0.116768274608	0.10593070478	0.107510919273	0.111532986974	0.141615217966
Median Hop Count	3.0	4.0	4.0	4.0	5.0
CI	0.0	0.0	0.0	0.0	0.0
Message Replication Overhead Ratio	109.476925	78.25879166666667	85.10451666666667	88.86219166666666	75.257275
CI	2.64457774029	3.28453558563	2.59704415656	3.27195746373	2.92973535428

ONE Omaha, GAPR, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.3099916666666667	0.41614166666666663	0.5878166666666667	0.7108916666666667	0.7999916666666667
CI	0.0138275116246	0.0162855724577	0.0207898123247	0.0205497856177	0.0186816429225
Average Latency (seconds)	2622.1217083333336	3330.833275	4180.457466666667	4556.058758333334	4256.269416666667
CI	140.02646634	186.300515075	221.160302997	263.184747929	265.233978175
Median Latency (seconds)	1133.0666666666666	1605.8166666666666	2600.0166666666664	3216.325	3240.983333333333
CI	73.8013296278	107.994715182	147.245771298	243.722767374	250.6364811
Average Hop Count	3.6946916666666665	4.3879166666666665	4.659125	4.705966666666667	5.620025
CI	0.1181233737	0.116858954961	0.113941174744	0.102398792304	0.16407760651
Median Hop Count	3.0	4.0	4.0	4.083333333333333	5.083333333333333
CI	0.0	0.0	0.0	0.173837872154	0.173837872154
Message Replication Overhead Ratio	112.98216666666667	81.15334166666666	87.61545	92.06885	78.71095
CI	3.50820932744	3.56193918164	2.98100274385	3.2794090688	3.20187429278

ONE Omaha, GAPR, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.3139	0.42083333333333334	0.5930666666666666	0.71775	0.8042916666666666
CI	0.0134933293934	0.0155249722278	0.0213801900465	0.0214202299893	0.0180939597534
Average Latency (seconds)	2655.2543666666666	3294.115366666667	4149.0771583333335	4511.314666666666	4185.027691666666
CI	158.515170913	163.792679481	233.644084326	266.623024232	258.637903008
Median Latency (seconds)	1134.7666666666667	1626.6416666666667	2585.9083333333333	3158.55	3157.525
CI	74.6719176731	98.9793441508	160.898673657	228.35973788	238.77430287
Average Hop Count	3.7677666666666667	4.454325	4.746975	4.829883333333333	5.745416666666666
CI	0.107217340222	0.104104239554	0.10147545142	0.112858779787	0.157796387499
Median Hop Count	3.1666666666666665	4.0	4.166666666666667	4.25	5.25
CI	0.234402938994	0.0	0.234402938994	0.272351603708	0.272351603708
Message Replication Overhead Ratio	112.35750833333333	81.77431666666666	88.76135	93.21658333333333	80.61331666666666
CI	2.96767324751	3.47119674762	2.88502193616	3.36591660948	3.14453706078

ONE Omaha, GAPR, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.3151333333333333	0.4188	0.5937	0.7183333333333334	0.8051666666666667
CI	0.0143103099843	0.016449816416	0.0203556300402	0.021095847789	0.0192626225518
Average Latency (seconds)	2624.8745	3318.1757916666666	4146.005025	4497.056791666667	4173.035691666667
CI	162.178855746	161.836140872	253.833969958	265.922712322	257.308625056
Median Latency (seconds)	1115.775	1590.1083333333333	2578.8416666666667	3120.9833333333336	3144.05
CI	79.9835455141	95.0214287595	160.490726809	226.310286581	238.924339179
Average Hop Count	3.783558333333333	4.452983333333333	4.774758333333333	4.856066666666667	5.7813083333333335
CI	0.106784366175	0.125206079619	0.0997673436119	0.110031771679	0.164078686128
Median Hop Count	3.0833333333333335	4.0	4.166666666666667	4.333333333333333	5.25
CI	0.173837872154	0.0	0.234402938994	0.296498870984	0.272351603708
Message Replication Overhead Ratio	112.49123333333334	82.68683333333334	89.25376666666666	93.82879166666667	81.021475
CI	2.72641489939	3.57831362748	3.2628276442	3.44877723913	3.15768551569

ONE Omaha, GAPR, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.31565	0.4168166666666667	0.5948166666666667	0.7218166666666667	0.8055166666666667
CI	0.0133879952197	0.0158194547617	0.0197891146429	0.0229851247897	0.0192166239956
Average Latency (seconds)	2588.2003666666665	3314.5455166666666	4185.152775	4502.984225	4147.52425
CI	132.890472334	170.450728893	238.594127573	266.873670913	259.917475389
Median Latency (seconds)	1106.875	1593.5083333333334	2590.758333333333	3139.625	3127.8333333333335
CI	63.3963770322	94.6586546074	164.437877144	226.174348259	240.680035519
Average Hop Count	3.761041666666667	4.443533333333333	4.77025	4.872941666666667	5.804691666666667
CI	0.127488745916	0.124286043108	0.0995728107524	0.118907531766	0.161267028829
Median Hop Count	3.0	4.0	4.0	4.333333333333333	5.333333333333333
CI	0.0	0.0	0.0	0.296498870984	0.296498870984
Message Replication Overhead Ratio	112.88605833333332	83.50661666666667	89.208825	93.91575	81.71895833333333
CI	3.33403029945	3.90175507235	2.97538839648	3.26085376828	3.12422846966

ONE Omaha, GAPR2, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30016666666666664	0.3986166666666667	0.5494666666666667	0.6680083333333333	0.7685666666666666
CI	0.0150163945431	0.0187083298612	0.0252996815784	0.0223329120777	0.0163720611695
Average Latency (seconds)	2863.237616666667	3662.6282	4627.605608333333	5081.762	4959.204883333334
CI	150.07648139	189.926057424	229.453261061	263.002192445	311.841516704
Median Latency (seconds)	1324.6166666666666	1880.475	3146.1666666666665	3787.45	3977.3083333333334
CI	66.5051701601	116.122556747	240.48834526	276.846507107	343.335999079
Average Hop Count	3.3126	3.8633583333333332	3.996008333333333	4.167766666666667	5.0431
CI	0.116982983267	0.128138165614	0.13266774755	0.0873433639131	0.122372443321
Median Hop Count	2.9166666666666665	3.3333333333333335	3.75	3.9166666666666665	4.833333333333333
CI	0.173837872154	0.296498870984	0.272351603708	0.173837872154	0.234402938994
Message Replication Overhead Ratio	96.132375	67.7632	74.992525	76.367275	63.800758333333334
CI	2.89001576457	3.02813622362	2.61746091305	2.60774881169	2.59960202023

ONE Omaha, GAPR2, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30005	0.39985	0.5594333333333333	0.6800416666666667	0.77975
CI	0.0155696106772	0.0199396510293	0.0239293647454	0.0202888350421	0.0163070976007
Average Latency (seconds)	2881.5987166666664	3629.777108333333	4611.236775	5010.023325	4835.712866666667
CI	139.716096427	200.500901594	216.523886871	261.454099477	307.797253445
Median Latency (seconds)	1272.6833333333334	1897.3	3052.6666666666665	3708.383333333333	3843.3583333333336
CI	53.1973687259	103.972090613	220.964170804	279.584228853	331.955520464
Average Hop Count	3.348516666666667	3.9469166666666666	4.1653	4.327025	5.240258333333333
CI	0.123938830261	0.152363088487	0.141011500424	0.0957267812131	0.134156836794
Median Hop Count	3.0	3.5	3.8333333333333335	4.0	5.0
CI	0.0	0.31448454343	0.234402938994	0.0	0.0
Message Replication Overhead Ratio	99.37895833333333	70.418425	77.19216666666667	79.53418333333333	66.12259166666666
CI	3.45963442172	3.04012007165	2.43224687262	2.89879137553	2.73334366633

ONE Omaha, GAPR2, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30185	0.4017083333333333	0.5620833333333334	0.6877166666666666	0.7824833333333333
CI	0.0137805605455	0.0187800110746	0.0270637394343	0.0215729953176	0.0170525810183
Average Latency (seconds)	2843.6739666666667	3636.610741666667	4525.60275	4964.3352	4761.573108333333
CI	154.259829116	204.245414707	253.946061134	264.506788218	301.272698147
Median Latency (seconds)	1287.9083333333333	1874.8166666666666	2951.0916666666667	3632.8333333333335	3765.4166666666665
CI	54.9505593461	115.274064757	250.497393749	279.124967048	324.34944717
Average Hop Count	3.378075	3.9832166666666664	4.25295	4.420541666666667	5.325558333333333
CI	0.109183103898	0.146682607528	0.133746771321	0.124777111604	0.127407805985
Median Hop Count	3.0	3.5833333333333335	3.8333333333333335	4.0	5.0
CI	0.0	0.310085941581	0.234402938994	0.0	0.0
Message Replication Overhead Ratio	100.46071666666667	71.82463333333334	78.49355833333334	80.53055833333333	67.85444166666667
CI	3.52222843701	2.92072548074	2.65661920595	2.90643362606	2.91938448427

ONE Omaha, GAPR2, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.302725	0.4016	0.5655749999999999	0.6925583333333334	0.783125
CI	0.0153771284788	0.0186424888258	0.0251881260757	0.0204618937138	0.0184480883619
Average Latency (seconds)	2847.27895	3558.3039583333334	4538.231775	4958.903658333334	4721.387425
CI	154.664347145	193.89573039	242.907853819	269.783763992	294.190445631
Median Latency (seconds)	1289.5666666666666	1836.0583333333334	2969.6	3634.008333333333	3736.6916666666666
CI	70.9091090586	108.334779405	239.498168851	289.340535807	323.506384559
Average Hop Count	3.41045	4.010508333333333	4.2633833333333335	4.456858333333333	5.3676916666666665
CI	0.113646317859	0.12522406604	0.12433027757	0.115616450334	0.144730282124
Median Hop Count	3.0	3.6666666666666665	4.0	4.0	5.0
CI	0.0	0.296498870984	0.0	0.0	0.0
Message Replication Overhead Ratio	100.47744166666666	72.0677	78.62625833333334	80.73275833333334	68.329575
CI	3.96103455992	2.95768539612	2.39381357308	2.8398459095	2.90474582414

ONE Omaha, GAPR2, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.303475	0.4051416666666667	0.5688416666666667	0.6916833333333333	0.7848666666666667
CI	0.014734356006	0.0181377436311	0.0251001678088	0.0202962817013	0.0183708748038
Average Latency (seconds)	2825.8012083333333	3583.1179333333334	4533.771566666666	4922.345283333333	4721.909125
CI	170.473916245	214.375183019	224.679688463	275.891757499	295.14536378
Median Latency (seconds)	1282.8416666666667	1857.5583333333334	3013.3333333333335	3625.425	3743.0166666666664
CI	60.0239618007	118.564035831	205.045628715	270.927368998	324.791172172
Average Hop Count	3.413875	4.021958333333333	4.299408333333333	4.495666666666667	5.385383333333333
CI	0.135391115141	0.121730705502	0.133592943875	0.119026084442	0.130497249575
Median Hop Count	3.0	3.5833333333333335	3.9166666666666665	4.0	5.0
CI	0.0	0.310085941581	0.173837872154	0.0	0.0
Message Replication Overhead Ratio	100.29098333333333	71.89925833333334	78.71055833333332	81.26070833333333	68.7602
CI	3.45388713246	3.37743481963	2.48973847744	2.98537000826	3.06589373092

ONE Omaha, GAPR2A, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30295	0.41020833333333334	0.5747083333333334	0.698975	0.7919
CI	0.0129242689614	0.0145320096019	0.021118887239	0.0217854821645	0.0170267945677
Average Latency (seconds)	2909.9451666666664	3505.6851083333336	4316.619641666667	4703.308116666666	4418.454116666667
CI	111.538467824	205.328535139	229.592527114	269.632810567	283.264944847
Median Latency (seconds)	1284.4583333333333	1778.9	2748.4583333333335	3369.0750000000003	3407.95
CI	80.3280881118	121.174372936	187.384577357	258.978875191	283.249040224
Average Hop Count	3.311758333333333	4.1418333333333335	4.425825	4.5023583333333335	5.405766666666667
CI	0.0953182105779	0.106706570002	0.108569608818	0.112830169023	0.147052244657
Median Hop Count	3.0	3.75	4.0	4.0	5.0
CI	0.0	0.272351603708	0.0	0.0	0.0
Message Replication Overhead Ratio	104.03221666666667	75.23450833333334	84.92905	88.70465833333333	75.15003333333334
CI	3.85115656635	3.580978986	2.70520569153	3.09677149697	2.9539704108

ONE Omaha, GAPR2A, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30201666666666666	0.41323333333333334	0.5841416666666667	0.7115333333333334	0.8005083333333334
CI	0.0139613625471	0.0157325972212	0.0219434274091	0.0199199308169	0.0174179294228
Average Latency (seconds)	2792.977766666667	3425.343191666667	4244.126975	4565.093791666667	4273.4690083333335
CI	136.788262932	178.466029812	225.911293413	276.287530238	269.162543466
Median Latency (seconds)	1237.2666666666667	1726.2166666666667	2676.791666666667	3240.95	3261.65
CI	93.8277107048	111.034648311	173.406947319	247.642332889	256.745053495
Average Hop Count	3.3363	4.222183333333334	4.582825	4.6878166666666665	5.593275
CI	0.0896824970668	0.0970324407448	0.109543404248	0.108348226961	0.161250973936
Median Hop Count	3.0	3.8333333333333335	4.0	4.083333333333333	5.0
CI	0.0	0.234402938994	0.0	0.173837872154	0.0
Message Replication Overhead Ratio	108.53020833333333	78.51859999999999	87.25823333333334	91.31249166666667	78.374575
CI	3.99906002991	3.61341268671	2.60452802384	3.28457004403	3.20274903939

ONE Omaha, GAPR2A, 24 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30585833333333334	0.4165333333333333	0.5871166666666667	0.7161166666666667	0.8034833333333333
CI	0.0130736954782	0.0172108464446	0.0229093278024	0.0206832961487	0.0183088683041
Average Latency (seconds)	2834.4325333333336	3434.5113499999998	4161.115141666667	4532.157433333334	4197.07355
CI	134.773832366	153.238787737	217.912849845	272.864203868	257.0037466
Median Latency (seconds)	1262.4416666666666	1747.075	2586.925	3199.6666666666665	3181.85
CI	73.5143948595	99.5774081445	140.013925158	249.503500439	246.699470223
Average Hop Count	3.4032666666666667	4.257041666666667	4.666225	4.819841666666667	5.705391666666666
CI	0.0938595240274	0.102850477802	0.121975145773	0.120753963312	0.170223373869
Median Hop Count	3.0	3.8333333333333335	4.0	4.25	5.25
CI	0.0	0.234402938994	0.0	0.272351603708	0.272351603708
Message Replication Overhead Ratio	108.24916666666667	79.38548333333334	88.37235	93.15163333333334	80.26991666666666
CI	3.75942114661	3.55123303033	2.86530270744	3.28897936207	3.09376761275

ONE Omaha, GAPR2A, 36 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.3072083333333333	0.413925	0.5934	0.7192	0.804875
CI	0.0128294137696	0.0141998767955	0.0225254955654	0.0209460871416	0.0195230343818
Average Latency (seconds)	2821.3871166666668	3410.8703	4231.27945	4520.670566666667	4165.702041666666
CI	149.367555522	159.297800152	223.848342011	263.321037641	260.97910224
Median Latency (seconds)	1255.3583333333333	1692.975	2623.7916666666665	3171.0583333333334	3162.366666666667
CI	89.0277043221	100.912512362	154.1474115	229.710000934	256.170670095
Average Hop Count	3.4339833333333334	4.309808333333334	4.75405	4.847083333333333	5.771475
CI	0.0916012838091	0.0907730801712	0.109083567119	0.10648736364	0.169594953151
Median Hop Count	3.0	4.0	4.166666666666667	4.333333333333333	5.25
CI	0.0	0.0	0.234402938994	0.296498870984	0.272351603708
Message Replication Overhead Ratio	107.941	80.01085833333333	88.36571666666667	93.52304166666667	80.98712499999999
CI	3.81715376992	3.540824554	2.96053138467	3.44244881691	2.95013314686

ONE Omaha, GAPR2A, 54 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.30633333333333335	0.41675833333333334	0.5936333333333333	0.7196750000000001	0.8054583333333334
CI	0.0130043404312	0.0146064322126	0.0227532458923	0.0219165588477	0.019609894766
Average Latency (seconds)	2784.1426	3411.013033333333	4173.481533333334	4510.22055	4165.2771
CI	126.816121694	145.937910639	222.144566023	250.03134296	262.543266357
Median Latency (seconds)	1228.725	1684.2083333333333	2605.4666666666667	3173.991666666667	3151.6083333333336
CI	85.924721052	82.8851183707	144.488962826	226.856220053	249.668808904
Average Hop Count	3.398416666666667	4.300216666666667	4.720125	4.856225	5.770316666666667
CI	0.0874362571249	0.0995448943538	0.116788743407	0.108338104396	0.163469894201
Median Hop Count	3.0	4.0	4.0	4.333333333333333	5.333333333333333
CI	0.0	0.0	0.0	0.296498870984	0.296498870984
Message Replication Overhead Ratio	108.53056666666667	79.68945	88.315725	93.86225833333333	81.71198333333334
CI	3.60417579806	3.74916118087	2.75477952975	3.29538894744	3.10938196029

ONE Omaha, Vector, 6 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.1794	0.2539416666666667	0.35475833333333334	0.4931333333333333	0.7142833333333334
CI	0.012114446428	0.0154881314019	0.0155625361255	0.0173796335744	0.0157194847283
Average Latency (seconds)	2301.9315333333334	3287.9727333333335	3935.93735	4271.335491666667	4864.96855
CI	276.737924733	138.462408709	213.529757584	187.207468482	289.934994686
Median Latency (seconds)	781.5583333333333	1134.1166666666666	1967.3416666666667	2875.3583333333336	3860.2916666666665
CI	80.8108181105	95.7561379501	153.041854698	178.230992928	327.422283012
Average Hop Count	3.380425	3.8944166666666664	4.6002833333333335	5.036041666666667	5.4789916666666665
CI	0.101313430338	0.101574927188	0.0795535417088	0.141999225219	0.138946053534
Median Hop Count	2.9166666666666665	3.0833333333333335	4.0	4.416666666666667	5.0
CI	0.173837872154	0.173837872154	0.0	0.310085941581	0.0
Message Replication Overhead Ratio	80.45235	73.41578333333334	67.04240833333333	62.069825	54.61830833333333
CI	4.65681515901	4.23132459513	1.84123539056	1.42550260457	1.37045431131

ONE Omaha, Vector, 12 Mbps					
Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.182725	0.25585833333333335	0.35668333333333335	0.499075	0.7213083333333333
CI	0.0130127995142	0.0150376555654	0.015997690622	0.0195875173245	0.0178161245586
Average Latency (seconds)	2297.992333333333	3195.8011666666666	3875.174175	4180.3386083333335	4703.010891666667
CI	249.220990691	155.106758833	205.650120391	204.287762309	267.404144739
Median Latency (seconds)	775.65	1081.6166666666666	1881.825	2776.05	3684.983333333333
CI	82.7168622432	92.0593608422	158.104272103	153.839747477	303.506147206
Average Hop Count	3.4466	3.917825	4.68475	5.158858333333333	5.685766666666667
CI	0.120990840225	0.103922472949	0.0868668911363	0.142656519721	0.159400887745
Median Hop Count	3.0	3.0833333333333335	4.0	4.666666666666667	5.0
CI	0.0	0.173837872154	0.0	0.296498870984	0.0
Message Replication Overhead Ratio	81.26759166666666	76.91366666666667	69.44964166666666	63.81245	56.841566666666665
CI	3.74788975535	5.12390837556	2.28794480405	1.29112488048	1.4781733583

ONE Omaha, Vector, 24 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.183125	0.2576	0.35685833333333333	0.49977499999999997	0.725025
CI	0.0118790855928	0.015456864655	0.0155989713994	0.0191297464953	0.0178734623423
Average Latency (seconds)	2231.1116166666666	3179.153325	3843.4472166666665	4124.179383333333	4614.754133333333
CI	258.225708764	161.758966333	197.70480264	207.961297576	269.034224083
Median Latency (seconds)	750.6333333333333	1089.0333333333333	1873.2583333333334	2698.825	3599.1583333333333
CI	81.0623683757	98.8670528074	147.538913255	158.315384316	299.569517353
Average Hop Count	3.4619416666666667	3.9692833333333333	4.744858333333333	5.212208333333333	5.754975
CI	0.0960454106354	0.100799790315	0.0885404725174	0.110816042864	0.157057038402
Median Hop Count	3.0	3.1666666666666665	4.0	4.666666666666667	5.0
CI	0.0	0.234402938994	0.0	0.296498870984	0.0
Message Replication Overhead Ratio	81.83453333333333	77.43049166666667	70.86619166666667	64.82895833333333	57.98894166666667
CI	4.96089358945	4.61435858403	2.61661546372	1.49126614215	1.7511505663

ONE Omaha, Vector, 36 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.17998333333333333	0.2564416666666667	0.3576666666666667	0.5008916666666666	0.7253166666666667
CI	0.0136132420429	0.0154207020115	0.0155801269946	0.0189544795351	0.0186410711276
Average Latency (seconds)	2210.5592333333334	3169.1323333333335	3790.363733333333	4106.9151249999995	4601.489683333333
CI	233.833665777	190.096121969	201.420275697	211.009091184	260.505393525
Median Latency (seconds)	738.7	1071.25	1858.9416666666666	2708.4333333333334	3579.975
CI	82.7593188904	111.038628759	141.339450128	148.328648464	285.810600884
Average Hop Count	3.4168083333333334	3.986866666666667	4.75155	5.263633333333333	5.792941666666667
CI	0.103358346891	0.12267818685	0.0981235637723	0.111202079438	0.15059404771
Median Hop Count	2.9166666666666665	3.0833333333333335	4.0	4.75	5.083333333333333
CI	0.173837872154	0.173837872154	0.0	0.272351603708	0.173837872154
Message Replication Overhead Ratio	83.76553333333334	78.81591666666667	70.76779166666667	64.92399999999999	58.516325
CI	4.15809560106	4.92158547772	2.5182597876	1.4668963491	1.72257525704

ONE Omaha, Vector, 54 Mbps

Buffer Size (MB)	**5**	**10**	**25**	**50**	**100**
MDR	0.181325	0.25766666666666665	0.35760833333333333	0.50153333333333333	0.7270666666666666
CI	0.0137290453709	0.0154054490663	0.0155064684145	0.0183506214904	0.0177711007908
Average Latency (seconds)	2240.7994750000003	3166.178066666667	3798.301725	4078.9062416666666	4562.986091666667
CI	238.818475086	168.192988473	197.353979037	220.105295691	267.246368578
Median Latency (seconds)	764.5416666666666	1073.625	1853.3666666666668	2691.1833333333334	3536.475
CI	80.8332359802	87.9490127468	156.972910022	162.169334802	286.920430209
Average Hop Count	3.5054583333333333	4.024025	4.761908333333333	5.286441666666667	5.817141666666666
CI	0.0952400797053	0.121587669385	0.0957063616119	0.121346083641	0.155740390763
Median Hop Count	3.0	3.25	4.0	4.75	5.166666666666667
CI	0.0	0.272351603708	0.0	0.272351603708	0.234402938994
Message Replication Overhead Ratio	82.97135833333334	79.00897499999999	71.04293333333334	65.18276666666667	58.76756666666667
CI	4.76836304539	5.45075339507	2.47842913621	1.46734768838	1.76524424084

APPENDIX F:
NS-3 Omaha Data Tables

NS-3 Omaha, Epidemic, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.15216783216783217	0.17783216783216782	0.2306993006993007	0.27034965034965036	0.3255244755244755
CI	0.0188079712089	0.0138596447252	0.0165565747612	0.0204065065077	0.019813807457
PDR	0.15302955566029808	0.17893652237775268	0.23151483263728273	0.2727698063846657	0.327129713870224
CI	0.0189961239955	0.0144517684785	0.0164076602019	0.0202418420466	0.0195057112102
Average Latency (seconds)	2144.769304877231	2869.5356254525914	4387.402419286355	5844.171245889086	7207.709558516859
CI	224.164434597	233.037340421	309.490552096	309.869166012	316.738964486
Median Latency (seconds)	1572.51016176445	2191.0382831492498	3647.0180265895	5285.93812864385	6611.2825166212
CI	214.315142989	183.59226858	313.341672171	418.696163849	440.584942444
Maximum Latency (seconds)	11696.1586530337	14842.8642005425	17286.6974851207	17716.9832482036	17938.0180274426
CI	2046.92937024	1692.01235108	491.346543189	150.765170278	48.0061899892
Average Hop Count	2.934514678753839	3.1215025336406974	3.3243486284703976	3.4536300330915424	3.740314274133347
CI	0.158804617482	0.116695242425	0.135488192571	0.119260852225	0.0786444676094
Median Hop Count	2.5	2.9	3.0	3.0	3.0
CI	0.352299685766	0.21137981146	0.0	0.0	0.0
Maximum Hop Count	9.5	10.5	11.3	12.3	12.8
CI	1.10287246415	0.905074280211	1.04746226965	1.13831512161	0.614255491238
Message Replication Overhead Ratio	173.89951252846302	164.33552990348264	152.88725725264982	145.68126799128507	114.83809383286003
CI	13.9919018819	11.5817819201	8.26965831945	5.4115242286	4.39377740315
Network Overhead Ratio	206.05993160984158	205.10527892866818	195.43338815669594	185.09489624225813	146.36370184899874
CI	16.0694059758	16.048519008	9.07899380026	6.62457955196	4.81481429658
Average Power Consumed per Node (Watts)	0.8246522516835016	0.8261752946127946	0.8290966961279461	0.8309448653198653	0.8311526725589226
CI	0.000682284157061	0.00066263051778	0.000643997563448	0.000711834297094	0.000593683550113

NS-3 Omaha, Epidemic, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.16104895104895103	0.19384615384615383	0.26363636363636367	0.31489510489510486	0.3739160839160839
CI	0.0171041516917	0.0192741234564	0.0237778350641	0.0260149035989	0.0303809547851
PDR	0.16197280104645087	0.19413965588427656	0.264350334506206	0.31567849404611836	0.37582384256468154
CI	0.0170391742951	0.0187210541256	0.0239335222975	0.0262050579708	0.0307003195447
Average Latency (seconds)	1989.4903401566687	2718.398321980599	4055.7791486380056	5078.743380875403	6488.218278581928
CI	177.041009653	196.989439727	331.428286871	306.431563149	419.805281774
Median Latency (seconds)	1433.3672855794005	2037.8168517082493	3300.81466062935	4525.420035188899	5899.447345248101
CI	146.606192968	158.184935057	297.786873433	342.321338432	518.330515304
Maximum Latency (seconds)	11641.6987983853	15301.4978343868	17499.3766513072	17610.5715213265	17797.3924119371
CI	1857.1333969	1239.37936954	306.23736005	291.56279411	133.039623168
Average Hop Count	3.0090331853641707	3.3321726409089654	3.6192145214281988	3.840326306230418	4.046228920229243
CI	0.154112509783	0.145804325043	0.167704255208	0.219995317948	0.150992029455
Median Hop Count	2.4	3.0	3.2	3.3	3.5
CI	0.345181786668	0.0	0.281839748613	0.322887995466	0.352299685766
Maximum Hop Count	10.1	10.7	12.6	12.8	13.3
CI	1.01862749493	0.894036376064	1.00636919652	1.29155198187	0.894036376064
Message Replication Overhead Ratio	226.6155879625227	225.14830451577672	192.94304299798577	188.3332427098905	154.00753918738238
CI	25.4909719454	20.9297065216	13.5480473416	9.75086984984	8.0764034809
Network Overhead Ratio	243.87767274540272	243.67545614541817	210.9944983399972	208.8280217069236	171.67493330850465
CI	27.0172692335	22.8779329441	13.6009135853	9.77004032373	8.28090250946
Average Power Consumed per Node (Watts)	0.8229045664983166	0.8236289983164984	0.8257628367003367	0.8274279250841751	0.8281060606060606
CI	0.000507005488158	0.000464051117379	0.000484703264249	0.000392878750909	0.000673176246988

NS-3 Omaha, Epidemic, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.17461538461538462	0.21104895104895105	0.2690909090909091	0.332027972027972	0.39755244755244756
CI	0.0251600139412	0.0244422309496	0.0221330348672	0.0265065054992	0.0315877869177
PDR	0.1751266958240618	0.21108346395700198	0.2693246299605023	0.33293835658982707	0.3988939920420042
CI	0.0253006779857	0.0249089302641	0.0224957696515	0.0270702240233	0.0320497911293
Average Latency (seconds)	1832.2222012406828	2599.667608742816	3720.3927352169567	4649.5294989326	6019.37326395297
CI	178.822720416	218.765198869	353.456766528	348.747951589	321.138368868
Median Latency (seconds)	1318.4926111471998	1927.8979239358	2911.6621686848503	3998.18755400055	5378.74916878385
CI	177.855514236	163.643002582	285.808010857	451.623211879	384.189750489
Maximum Latency (seconds)	10426.3848524297	13840.5237200192	17434.748702711302	17330.6179936161	17792.4254888406
CI	1492.53996514	2062.24977369	333.694168863	423.283368671	85.0322011502
Average Hop Count	3.111658004452343	3.389416186178313	3.704047807402481	3.9731847925627015	4.206063362340454
CI	0.241925374884	0.19818885962	0.202258525615	0.181392683859	0.125658977939
Median Hop Count	2.7	3.1	3.1	3.5	4.0
CI	0.322887995466	0.21137981146	0.21137981146	0.352299685766	0.0
Maximum Hop Count	10.3	11.5	12.4	13.4	14.0
CI	1.33873880591	1.27023458136	0.955765088727	0.902327462708	1.13613234852
Message Replication Overhead Ratio	283.27099705140256	277.42521145740926	258.38365434863664	237.86556123583694	209.47565394182124
CI	33.4317387366	19.4913097852	16.1542178078	19.3136249977	8.82334947659
Network Overhead Ratio	294.1199496530979	289.524738220798	268.6925581437156	248.51912167475479	218.96821285930054
CI	34.3211028611	19.8449734419	15.633281966	19.7491256558	8.94505189134
Average Power Consumed per Node (Watts)	0.8216030092592592	0.8221333122895623	0.8234248737373737	0.8247216961279461	0.8255450336700336
CI	0.000463333544168	0.000430246026856	0.000324938099961	0.000480873653643	0.000450453133975

NS-3 Omaha, Epidemic, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1793006993006993	0.20986013986013985	0.28118881118881117	0.3499300699300699	0.41664335664335667
CI	0.0241277216712	0.0208260309173	0.029117154308	0.0340660656824	0.033484984754
PDR	0.1787823316416198	0.21037974036033863	0.28201376024436675	0.35104444127781004	0.41783131825771774
CI	0.0237917578783	0.0214337894865	0.0292788942497	0.0339604249596	0.0337402568676
Average Latency (seconds)	1834.994077292961	2481.8472071253723	3566.441112900456	4637.898429323631	5953.867081378318
CI	175.634611519	270.901708809	373.414554354	322.293942155	386.169892702
Median Latency (seconds)	1360.2079518706994	1802.6714625303496	2737.75900828455	3965.855164572	5477.69008950015
CI	173.413063128	235.946622433	291.216059078	367.344035149	546.483492207
Maximum Latency (seconds)	9255.6174662993	13490.847265780301	17007.9517044981	17514.3001828945	17563.7370250574
CI	1988.64611194	1763.26787036	779.929821241	507.012558114	331.025927982
Average Hop Count	3.1610151361926073	3.3949143751229984	3.739980709309032	4.009911519404925	4.283137457539878
CI	0.210650534003	0.180854817038	0.167348734058	0.168549602206	0.134508344813
Median Hop Count	2.7	3.1	3.15	3.5	4.0
CI	0.322887995466	0.21137981146	0.225581865677	0.352299685766	0.0
Maximum Hop Count	11.5	11.2	12.9	13.7	14.4
CI	1.34613520919	1.32943543534	1.27802750466	0.836665397189	0.902327462708
Message Replication Overhead Ratio	331.0441887553191	327.15442797732965	290.4267693975298	280.7921177480648	235.04829401612824
CI	28.840823015	29.4604497723	24.8360276738	13.3379823231	11.9557457814
Network Overhead Ratio	341.1681242344283	335.7220371132446	300.09570766380136	289.1500103767772	242.7154962113833
CI	30.5423156478	29.6204791987	25.0235100704	12.679345655	11.4476353857
Average Power Consumed per Node (Watts)	0.8209985269360269	0.8215183080808081	0.8226978114478114	0.8239220328282828	0.8246401515151515
CI	0.000361201590116	0.00036828253547	0.000418245182009	0.000404484004076	0.000484213148026

NS-3 Omaha, Epidemic, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18153846153846154	0.21489510489510488	0.28055944055944054	0.3479020979020979	0.4197202797202797
CI	0.0273729158236	0.0258942366594	0.0261626349162	0.0298230013564	0.0417050697901
PDR	0.18166463880271988	0.21528443075484038	0.28123531625543047	0.34921589260724845	0.4208219608530913
CI	0.0274210947109	0.0260845986281	0.0267193008072	0.0297267586646	0.0416567008303
Average Latency (seconds)	1770.1321124101546	2463.4888633374812	3622.5010464624297	4459.860673004246	5797.753278950449
CI	202.38069487	240.092620067	440.877280957	359.699592545	360.470114895
Median Latency (seconds)	1292.1723273766004	1803.8765166527498	2779.21274026065	3850.912382566199	5120.088147103101
CI	171.118442171	186.751631016	328.864816005	364.968814472	464.134409199
Maximum Latency (seconds)	10065.2100765341	13892.7528468354	16757.5166954196	17482.0289611252	17746.5610643168
CI	1792.43867762	1421.13412041	1206.3836946	407.672268159	195.086080145
Average Hop Count	3.2007428249361167	3.4093950143337057	3.7412696486089727	4.139289043850384	4.293511165324318
CI	0.232235161699	0.211191255046	0.18385009546	0.179676738221	0.185093434143
Median Hop Count	3.0	3.1	3.2	3.8	3.8
CI	0.31510641833	0.21137981146	0.281839748613	0.281839748613	0.281839748613
Maximum Hop Count	11.2	11.7	13.2	14.0	14.4
CI	1.36626887237	1.22243422148	1.32943543534	1.22040191047	1.3442899236
Message Replication Overhead Ratio	356.59129884295015	357.3431951487776	338.10780845453206	312.19097335724786	274.2270848452629
CI	42.0211064925	41.9438390281	25.5495290886	26.1023675384	12.823859208
Network Overhead Ratio	364.62497220916896	367.09055771636497	347.0965010144165	320.21691340126847	281.3881498615239
CI	42.6669269324	42.2757729103	24.6040785703	25.5215030233	12.4048848902
Average Power Consumed per Node (Watts)	0.8206128998316499	0.8209795875420874	0.821947601010101	0.8229140361952862	0.8236952861952862
CI	0.00034583386208	0.000349204026873	0.000299741505875	0.000286015904382	0.000375832156581

NS-3 Omaha, Centroid, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.11776223776223776	0.17321678321678322	0.2922377622377622	0.42524475524475525	0.526993006993007
CI	0.0144566422333	0.0170401580832	0.0294743326966	0.0445303221507	0.0634299253752
PDR	0.11651375476365337	0.1722436579011791	0.29492778246683254	0.42779470709240847	0.5299086182390833
CI	0.0143860951381	0.0162945316464	0.0303225899487	0.0448256086838	0.062871061816
Average Latency (seconds)	3532.7103547897273	5332.569246605127	6946.059508057933	7754.57326558197	7658.698566549003
CI	279.344670038	329.650593489	322.63241649	271.92279241	328.872495979
Median Latency (seconds)	1945.0030507552	3914.7798253599503	6023.7935357118495	7359.3145658372505	7246.47080908325
CI	265.567463541	420.966209342	495.76664892	435.773482162	430.698684077
Maximum Latency (seconds)	17298.993554178698	17718.1753086361	17967.1471324444	17966.9958145209	17946.2905197061
CI	589.753161539	194.812382541	20.1530687246	16.9006695416	48.3753494634
Average Hop Count	6.524759767661758	8.900315737707377	6.567876294663667	4.559213995322583	3.838318893059434
CI	1.22478188002	0.418716806327	0.396839820354	0.176055754438	0.125370534572
Median Hop Count	2.4	4.85	4.4	3.9	3.5
CI	0.645775990933	0.590561887308	0.467378348579	0.21137981146	0.352299685766
Maximum Hop Count	44.5	47.8	30.6	17.5	13.7
CI	4.53632873284	1.36626887237	2.9760462521	2.23370225351	1.18112377462
Message Replication Overhead Ratio	129.1780774396281	153.51040391908435	107.9260619876741	68.50579022087314	43.50457826027612
CI	12.5981443655	13.9094308736	9.094022207	5.32651575139	3.3677993783
Network Overhead Ratio	142.16677906948968	177.69370135794455	131.6171107447099	83.04081611366342	50.94061196442312
CI	13.8681560063	16.0399117764	10.6823819794	5.24860420956	3.6411735438
Average Power Consumed per Node (Watts)	0.8247390572390573	0.8273353324915825	0.82805765993266	0.8278282828282828	0.8268297558922559
CI	0.000579255440282	0.0004934116251	0.00044060731637	0.000595245978465	0.000510252058839

NS-3 Omaha, Centroid, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.11881118881118881	0.17	0.29776223776223776	0.4151748251748252	0.5841958041958042
CI	0.0139789476945	0.0166530735988	0.0309209545476	0.0399011698523	0.0736220951906
PDR	0.1171825844851966	0.16922049640647893	0.29853701491119417	0.41840551432841167	0.5855910218607387
CI	0.0134181286365	0.0169355182985	0.0300460581738	0.0400116408919	0.0733102001258
Average Latency (seconds)	3477.846507710135	5183.744903783727	6837.901961296119	7506.200088314193	7078.271892962328
CI	318.627204574	268.895249697	311.196831878	239.769952667	570.604005684
Median Latency (seconds)	1998.2211275652503	3723.2293240076997	5883.9164368937	6871.319333240799	6587.13584561545
CI	219.048448795	363.821382091	392.201321136	320.063937384	683.200295945
Maximum Latency (seconds)	16856.061462906102	17798.199386882698	17852.0434488812	17956.400004699	17915.387401503598
CI	620.59162475	89.0561123637	128.976371302	28.2224290776	71.2928892847
Average Hop Count	7.077747363209909	11.538402294742571	10.04340123286941	6.260552022903418	4.205444516175243
CI	1.07842921792	0.941711586014	0.413153128346	0.156993200326	0.119004208619
Median Hop Count	2.4	6.1	7.0	5.1	4.0
CI	0.645775990933	1.1978189316	0.545780326338	0.21137981146	0.0
Maximum Hop Count	48.5	49.4	46.5	27.1	14.2
CI	1.34613520919	0.902327462708	1.61443997733	2.71887724719	0.821697008108
Message Replication Overhead Ratio	147.79411600167896	212.8549591717127	173.39027204233523	109.16474858823817	49.3523135699971
CI	13.8841661164	17.5406620671	15.3437781996	7.51052988503	4.59687066964
Network Overhead Ratio	160.91454556648628	237.30222242448616	186.88268889005118	117.52303556975401	54.10349654138344
CI	15.2076075856	19.4770476144	15.4774574379	8.01422745367	4.64551171317
Average Power Consumed per Node (Watts)	0.822678345959596	0.8256192129629629	0.8267171717171717	0.8262621001683502	0.8242624158249159
CI	0.000447938196683	0.000534805945289	0.000334041909174	0.000613364314696	0.000300908209526

NS-3 Omaha, Centroid, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.12153846153846154	0.17272727272727273	0.2834265734265734	0.43482517482517485	0.5921678321678322
CI	0.0131083859898	0.0175164215965	0.0354695221285	0.0544639478252	0.0663016273387
PDR	0.1194552536291457	0.17133093643468633	0.2831206816545908	0.4362052271390311	0.5936356129447142
CI	0.0131169609234	0.0176806883162	0.0346036156552	0.054120359169	0.0660619237226
Average Latency (seconds)	3437.733729983102	5078.518997690099	6697.6347593585415	7145.558696449411	6912.723564562774
CI	288.987215207	246.201352506	352.125522543	417.996158746	743.66552333
Median Latency (seconds)	1880.6879064044997	3813.37213117925	5607.1004506204	6535.384456935851	6436.880435966251
CI	291.864298936	182.937064357	490.191572474	609.703880796	867.398500891
Maximum Latency (seconds)	16797.2861676971	17457.96478041	17853.9753536582	17941.1874350244	17919.3051753977
CI	843.576294341	312.742790581	70.2581424041	20.5797037057	64.4894789572
Average Hop Count	7.214099780099063	12.375155564381064	12.358373659970535	8.268963050329022	4.678675123647639
CI	1.06204536454	0.831406212503	0.695362705179	0.287238051434	0.193874794819
Median Hop Count	2.5	6.25	8.3	6.2	4.1
CI	0.472659627495	1.14970669325	0.894036376064	0.422759622919	0.21137981146
Maximum Hop Count	46.9	49.9	49.5	39.4	16.0
CI	2.12434081399	0.21137981146	0.649608523042	2.40391297546	1.86419471101
Message Replication Overhead Ratio	159.6978199669509	246.96248573708633	239.27193671059163	155.3952466518747	57.18437336587266
CI	17.3093554831	18.3169286658	17.9373019615	9.79272087175	8.05723251821
Network Overhead Ratio	171.17138672751926	275.9570346081615	259.48706929823265	162.82486394440002	61.212620311761505
CI	18.4318030013	21.7768902684	19.1976955275	9.86767292893	8.19221791093
Average Power Consumed per Node (Watts)	0.8212121212121212	0.8236516203703703	0.8250941708754209	0.8250247264309765	0.8225026304713805
CI	0.000246487871157	0.000376128366522	0.000472959069627	0.000442344849952	0.000468606102324

NS-3 Omaha, Centroid, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1197902097902098	0.17636363636363636	0.29734265734265736	0.42818181818181816	0.5993706293706293
CI	0.0135746913237	0.0194021787836	0.0316688074058	0.0362387438411	0.0639343967613
PDR	0.1173431693869274	0.17390979476555335	0.2972932583571744	0.4286197371449868	0.6005497155509761
CI	0.0131342308413	0.0182923284237	0.0314528484432	0.0370179957281	0.0634228100429
Average Latency (seconds)	3490.390591141221	5028.6244346181	6719.474331594753	7164.289873024198	7025.848313441828
CI	135.980971678	386.142847923	270.043398242	349.81319673	501.49386338
Median Latency (seconds)	1930.1998127478998	3567.8764044073	5853.344002948199	6514.9214361533495	6492.7974552285
CI	212.519172687	462.081016521	407.153324995	533.943573674	592.094554476
Maximum Latency (seconds)	16981.385243054	17745.5359084371	17947.6600079255	17933.835464761698	17923.108422016
CI	430.486467758	149.780816822	41.8739282796	63.6040044705	108.414156135
Average Hop Count	7.422124836426512	12.60003666558964	13.660487438776686	9.581948204742607	4.890872919661324
CI	1.16292163176	1.03703709381	0.351530594645	0.491139971386	0.225749403822
Median Hop Count	2.5	6.5	9.15	7.0	4.1
CI	0.568066174258	1.27023458136	0.705479570965	0.445627770393	0.21137981146
Maximum Hop Count	47.6	49.6	49.8	45.4	18.7
CI	1.45085890537	0.645775990933	0.281839748613	3.23195361548	2.69319227098
Message Replication Overhead Ratio	167.02643008266799	259.19528741243886	259.9916219960087	187.17995341051	63.116354891083816
CI	22.8656957037	13.2665295044	20.40506801	11.1881432505	10.0365823361
Network Overhead Ratio	180.09243895003445	293.17145626228285	285.9997310564701	196.21163180116542	66.93412377565977
CI	24.9054066337	12.7474558437	23.2679804597	11.2602827559	10.2035883851
Average Power Consumed per Node (Watts)	0.8206228956228956	0.8227004419191919	0.8243928872053872	0.8241503577441077	0.8217776725589225
CI	0.000163950390516	0.000466856376634	0.00046053188903	0.000358421633413	0.000321340885653

NS-3 Omaha, Centroid, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.12153846153846154	0.17524475524475525	0.29146853146853147	0.44566433566433566	0.6093006993006993
CI	0.0115844259576	0.0163511085949	0.0351378840407	0.0533707777134	0.0647488992587
PDR	0.1196691841410078	0.1736014132932876	0.29116545542901195	0.44729618140430494	0.6105235177410692
CI	0.0112876541479	0.0163175471477	0.0354140768794	0.0528815331974	0.0646790256252
Average Latency (seconds)	3541.899918390984	5010.170255826287	6491.650289734569	7135.9308134906805	6833.550187515043
CI	336.071426005	274.787128626	404.686885898	334.02861451	704.390905576
Median Latency (seconds)	1832.0629497413001	3487.3755251170996	5552.8398807764	6451.2814528326	6302.172119266899
CI	262.870585774	341.441003163	471.268538559	444.253042514	861.190806503
Maximum Latency (seconds)	17324.6468207066	17706.925812616402	17861.6128763291	17942.4326296918	17973.6702289953
CI	271.598844082	132.123937614	92.8986167579	39.8711968549	11.9325577906
Average Hop Count	7.852144429746885	12.848339023071187	14.003469281524008	10.430078490095383	5.1712111024936895
CI	1.10085532593	1.04268376297	0.845042600289	0.588981224586	0.283205095597
Median Hop Count	2.7	6.9	9.4	7.3	4.5
CI	0.708113604662	1.5259091345	1.05454777728	0.775059308685	0.352299685766
Maximum Hop Count	48.4	49.9	49.9	49.0	20.8
CI	1.26827886876	0.21137981146	0.21137981146	0.99645398726	3.25643846255
Message Replication Overhead Ratio	169.6080102533461	264.55290720736105	275.384892352049	205.87591755954037	61.76431993138543
CI	15.8250174642	15.6639668113	19.3451959859	14.3048728021	8.97248313778
Network Overhead Ratio	181.1873186926786	300.3916529233477	306.5575085140669	216.8227157150618	65.35825110449512
CI	16.3070358781	18.4336028425	22.3547055143	16.1847036799	9.04448347153
Average Power Consumed per Node (Watts)	0.8202856691919191	0.8218308080808081	0.8233212331649831	0.8235953282828283	0.8210279882154882
CI	0.000154371345024	0.000318341975403	0.000526145093107	0.000571236159601	0.000274892874627

NS-3 Omaha, GAPR, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.176993006993007	0.2699300699300699	0.35083916083916084	0.4354545454545454	0.5473426573426573
CI	0.0307813910185	0.0533202379579	0.0551836675535	0.0554969018091	0.0589668869136
PDR	0.1800734050210642	0.27710687756451713	0.35677872898603147	0.44223145417940934	0.5524206484049298
CI	0.031282138038	0.0534729766976	0.0560577713258	0.0549708313558	0.0592972944206
Average Latency (seconds)	5403.961481195446	5921.627003153327	6450.901383405652	6670.301545631994	6764.953759296592
CI	282.934110294	372.750110565	347.124099811	164.085517351	405.310752772
Median Latency (seconds)	3538.1621280904	4387.1587989836	5195.08136016725	5721.60066791215	5947.06669386625
CI	508.937346415	580.255822523	447.97620309	289.381908694	489.111737816
Maximum Latency (seconds)	17827.6897762902	17855.3679336322	17878.6696768936	17960.693216717198	17961.400090444702
CI	134.193821776	120.16067948	126.619580569	15.9990359997	22.5463354586
Average Hop Count	1.9236086933085075	2.2855485227924905	2.556559276942404	2.8848001796164864	3.598562937370363
CI	0.0890434677611	0.190768648404	0.196181670184	0.149785387694	0.14400017475
Median Hop Count	2.0	2.1	2.1	2.4	3.3
CI	0.0	0.21137981146	0.21137981146	0.345181786668	0.322887995466
Maximum Hop Count	6.5	8.1	9.2	10.7	11.9
CI	0.721999506982	1.5259091345	1.47124668096	0.894036376064	0.968663986399
Message Replication Overhead Ratio	374.02252154229205	237.6824170567253	163.90762265101597	113.12305869585573	59.17456387985554
CI	74.3550516339	49.9374397785	27.8816997691	14.8641928978	5.68207012603
Network Overhead Ratio	403.46911658220625	255.17307745647045	178.81278731741418	126.82066738990586	70.92911400105949
CI	77.6699423421	50.3724381627	28.7575695751	15.3108333105	6.00825118688
Average Power Consumed per Node (Watts)	0.8345191498316498	0.8361668771043771	0.8349010942760943	0.8331660353535354	0.8293886784511785
CI	0.00087276481049	0.00103249668237	0.000987488884066	0.000977928725555	0.000408719601949

NS-3 Omaha, GAPR, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19552447552447552	0.28881118881118883	0.3960839160839161	0.47041958041958043	0.5883216783216784
CI	0.0298595713248	0.0487480930362	0.0660177469139	0.0714501650133	0.0699523054807
PDR	0.19721397070376015	0.29337893286856886	0.39994007753382516	0.47505599462159326	0.5902598588898997
CI	0.0308263185624	0.0493161849763	0.0663176214502	0.0710297802502	0.0699715807282
Average Latency (seconds)	5474.328316606479	6009.042806229612	6221.160367058363	6231.210610552734	6316.121858701489
CI	335.763647596	361.900227155	316.975128062	285.087894267	516.526325214
Median Latency (seconds)	3748.99569324295	4415.70754957125	4974.8329385166	5124.73928443005	5343.1048513674
CI	519.338137185	578.24853966	418.674175553	402.059795661	563.351317759
Maximum Latency (seconds)	17779.4456698707	17933.8382186275	17844.4674888798	17910.7273595497	17952.0025127047
CI	130.798163355	44.8323192951	138.64320791	45.5377987892	27.2835850075
Average Hop Count	1.9477825095492052	2.3580247427644565	2.7149877083219573	3.102686946753573	3.8938793364616657
CI	0.0751102918334	0.150153748658	0.222407823843	0.193607312914	0.266845404923
Median Hop Count	2.0	2.0	2.3	2.8	3.6
CI	0.0	0.0	0.322887995466	0.281839748613	0.345181786668
Maximum Hop Count	7.7	9.2	9.4	10.9	13.1
CI	1.47965868022	1.29155198187	0.784608654178	1.06625232862	1.06625232862
Message Replication Overhead Ratio	519.7283640819561	347.8447299317713	236.63343597237983	169.7396626367092	87.79853071982188
CI	91.2457298879	69.1033310957	38.4083661968	25.6748252345	12.0880628943
Network Overhead Ratio	561.2634792204904	374.17178937882375	255.32695952689897	185.39599339029945	98.66454402982382
CI	97.9526994372	71.6360309999	40.4436269337	26.1768063445	13.0318996463
Average Power Consumed per Node (Watts)	0.8306428872053873	0.831930765993266	0.8314746422558923	0.8300373526936027	0.8271022727272728
CI	0.000734891661689	0.00101403943286	0.000796986402001	0.000680664638941	0.000462128373231

NS-3 Omaha, GAPR, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.20146853146853147	0.29965034965034965	0.41440559440559444	0.4866433566433567	0.5995804195804196
CI	0.0333539673657	0.0563103996548	0.0663028723207	0.059240623182	0.0641575747882
PDR	0.2016058490173081	0.30142827390413135	0.41680587678625586	0.49037166544264066	0.6018685578781601
CI	0.0335062731736	0.0560941931228	0.0663099019506	0.0603795963325	0.0644180256654
Average Latency (seconds)	5317.799818879142	5821.783933230683	6091.472583175124	6068.629879486674	6181.238143329237
CI	384.345269059	301.688264892	278.383818657	388.918690024	471.711218097
Median Latency (seconds)	3501.23607730425	4178.3756926584	4925.28113421585	4939.53040418165	5226.61273361
CI	508.89571611	481.600182842	406.81650429	455.619054924	483.367594092
Maximum Latency (seconds)	17920.5971578205	17904.7962622309	17948.4295729742	17937.6733023393	17939.5737822147
CI	73.6797890958	73.3093895628	35.4355505852	29.6991382032	42.0061564519
Average Hop Count	1.9328174382772019	2.389943409953796	2.867160712965339	3.2305220948188937	4.05526706410426
CI	0.104308530941	0.168983600315	0.233869881251	0.235947881762	0.267828145717
Median Hop Count	2.0	2.2	2.4	3.1	3.8
CI	0.0	0.281839748613	0.345181786668	0.21137981146	0.422759622919
Maximum Hop Count	7.1	8.6	9.5	11.3	13.0
CI	0.860073141542	0.784608654178	0.787766045825	2.01889545359	1.63734097902
Message Replication Overhead Ratio	798.2139896939613	520.4818495299031	347.5323211355319	259.1913739959073	134.04221929916676
CI	144.849998107	95.3216447036	54.0807175685	30.6468353268	17.8688171459
Network Overhead Ratio	828.9744753807163	542.8285089532197	363.7725738260034	272.74745756445213	143.14953731655706
CI	145.860228109	96.4570545453	55.7064471243	31.624413606	18.3048828758
Average Power Consumed per Node (Watts)	0.8279692760942761	0.828683186026936	0.8283575336700336	0.8276273148148149	0.8253956228956228
CI	0.000503642240246	0.0006469319302	0.000370288108015	0.000392756145704	0.000332692425899

NS-3 Omaha, GAPR, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18895104895104894	0.3048951048951049	0.4090909090909091	0.49944055944055943	0.6146853146853146
CI	0.0251867768687	0.0575596898303	0.0682585847823	0.0672241937391	0.0785781128368
PDR	0.18871155736297304	0.30702152458830706	0.4115920741577057	0.501854308023399	0.6154561597737561
CI	0.0252854831012	0.0581709198276	0.0688221316304	0.0673036169625	0.0788701687719
Average Latency (seconds)	5137.631225548863	5742.488338009239	6010.711678527197	6221.64940574257	6061.144031810498
CI	262.765930082	359.791478803	309.364574816	336.641187838	521.346184112
Median Latency (seconds)	3285.7173723871997	4227.12410776225	4727.062743404101	5050.9067183813	5179.0248137346
CI	352.248184277	537.896170956	488.553303235	437.65190847	556.49284478
Maximum Latency (seconds)	17779.5741838975	17862.9589819411	17917.215799773	17921.9582748045	17927.282740046998
CI	178.538858214	124.53938134	72.5728790477	57.4991051745	47.7248509854
Average Hop Count	1.9666381230498033	2.3542228743176916	2.8897021364407554	3.24147920836858	4.157428232133024
CI	0.0987283534503	0.142825978031	0.23161913601	0.237884993309	0.245111308194
Median Hop Count	2.0	2.0	2.4	3.1	4.1
CI	0.0	0.0	0.345181786668	0.21137981146	0.21137981146
Maximum Hop Count	7.2	8.2	9.5	11.3	12.9
CI	1.29155198187	0.934756697157	0.905074280211	1.26239355223	0.968663986399
Message Replication Overhead Ratio	1024.5227106805044	654.2070120787351	444.9372011869161	319.86298070988636	164.4128852572111
CI	160.280848149	121.299605429	78.2307314158	44.1460843368	28.2513542266
Network Overhead Ratio	1047.4698099839022	671.8786245170427	458.38097099096825	331.9608553063828	173.8914432019983
CI	158.218097795	121.515857126	78.2096444796	44.4121052391	29.0353351334
Average Power Consumed per Node (Watts)	0.8268450126262626	0.8275399831649831	0.8273611111111111	0.8266003787878788	0.8247411616161616
CI	0.000286787379985	0.000479867774611	0.000476338475712	0.000327337928504	0.000533508800857

NS-3 Omaha, GAPR, 54 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1990909090909091	0.3030769230769231	0.4160839160839161	0.5087412587412588	0.5972727272727273
CI	0.0346818444287	0.0578970592828	0.0748120960956	0.0748099055579	0.077852539229
PDR	0.19838501646040915	0.3051094863840811	0.41812179606630934	0.510474374011188	0.5987507627326106
CI	0.0351631887671	0.0580883639368	0.0747470031522	0.0748970849754	0.0782709178281
Average Latency (seconds)	5267.6347293784675	5915.5848621949135	6136.221973075553	6234.638797458388	6110.267780183081
CI	354.587970283	333.950864277	302.954294033	413.20376947	528.764651856
Median Latency (seconds)	3390.5797684342497	4371.7871651564	4829.043235904351	5144.880370124651	5224.7054273413
CI	492.807642525	438.064898909	368.994652473	487.33995481	627.955503295
Maximum Latency (seconds)	17784.6949091768	17929.9764853151	17925.1652160803	17955.6523370026	17928.3484306145
CI	200.924419811	59.5800741124	52.7213019243	30.5816820024	32.3960370066
Average Hop Count	1.9506181366798643	2.3827163718997593	2.9748467167408883	3.299060793107738	4.128174647440409
CI	0.11328732624	0.137748468135	0.254989459928	0.211994573103	0.30778698552
Median Hop Count	2.0	2.1	2.5	3.1	4.0
CI	0.0	0.21137981146	0.352299685766	0.21137981146	0.445627770393
Maximum Hop Count	7.0	8.3	9.4	11.0	12.7
CI	0.771849939584	0.894036376064	0.784608654178	1.37351703396	1.47965868022
Message Replication Overhead Ratio	1202.8843445708121	798.718261768566	532.233131319336	392.14463002388715	196.95348834109728
CI	221.301523236	144.634260793	90.1482678194	51.7398444901	36.1902613105
Network Overhead Ratio	1229.7883179628695	811.4873609829639	543.7429788590242	403.1679707963882	206.52340676535255
CI	231.74484569	142.41412943	90.0720247861	52.1107267603	37.0750229257
Average Power Consumed per Node (Watts)	0.8259022516835017	0.8266219486531987	0.8264593855218856	0.8261116372053873	0.8241619318181819
CI	0.000279474645153	0.000372988103167	0.000266611419057	0.000336598329276	0.000589800549639

NS-3 Omaha, GAPR2, 6 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1823076923076923	0.2483216783216783	0.33398601398601396	0.4115384615384615	0.5137762237762238
CI	0.0244096793618	0.0385962398554	0.0420779484069	0.0513643795712	0.0600739094026
PDR	0.18337991939697537	0.2534075421923584	0.33805770825797354	0.41574316646388026	0.516230584572888
CI	0.0242562440869	0.0381489228845	0.0422245261189	0.051500097432	0.0597718283678
Average Latency (seconds)	5944.186282452966	6384.143710213276	6686.9378134068365	6839.08279701512	7078.890460274057
CI	387.663944487	268.090503606	272.873132653	245.523807482	330.380405736
Median Latency (seconds)	4499.291492091601	5001.7112214134495	5646.62265121475	5937.5174207892	6351.864146666149
CI	578.050751776	450.653868956	429.358685484	340.556883582	446.848213558
Maximum Latency (seconds)	17892.1653846681	17932.933112141698	17926.9901985974	17924.0184166101	17965.6314568229
CI	89.9588641157	45.6130295925	56.3805766197	84.0857462988	12.3338739169
Average Hop Count	1.7143686766317485	1.8816777456700073	2.1831801936376216	2.5473314125391853	3.2470413882653273
CI	0.0861879302161	0.124506827351	0.0949646182348	0.101218166505	0.141455250775
Median Hop Count	1.4	1.9	2.0	2.3	3.0
CI	0.345181786668	0.21137981146	0.0	0.322887995466	0.0
Maximum Hop Count	4.9	6.0	8.3	9.0	11.2
CI	0.735623340478	0.445627770393	1.47965868022	1.83737036704	1.32943543534
Message Replication Overhead Ratio	195.48248639792632	153.42153052255074	110.26441534761013	78.956118712669	45.48259458037945
CI	33.4662082391	28.3872216732	15.1823430034	11.2758515156	5.56840792865
Network Overhead Ratio	229.5778440454475	178.08904483449868	128.5956104499258	93.70229277995996	56.250940803813506
CI	36.6671322121	28.8336579767	15.7281957533	12.2947424486	6.4886674527
Average Power Consumed per Node (Watts)	0.8311011153198653	0.8319486531986532	0.8318365951178451	0.8307959806397306	0.8287531565656565
CI	0.000487625867702	0.00070783266024	0.000733064587812	0.000506981095903	0.000541498598978

NS-3 Omaha, GAPR2, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19013986013986015	0.27013986013986013	0.3569230769230769	0.43615384615384617	0.5473426573426573
CI	0.0270663151186	0.0456776909035	0.0560060290968	0.0534739386391	0.0500111910362
PDR	0.1899083624724594	0.2722169850961134	0.35900937932747995	0.4377549901895231	0.5500208267108047
CI	0.0270341596026	0.0457934623138	0.0559923729474	0.0530497240649	0.0505727252825
Average Latency (seconds)	5841.189314745772	6299.926468702053	6367.801337621924	6684.471602146361	6983.2283778758865
CI	327.967987598	360.757985409	377.989681706	346.969043787	384.216025287
Median Latency (seconds)	4330.6672636701005	4928.248282777201	5289.37889826995	5780.931549022051	6310.97345732455
CI	519.103702387	526.282519134	529.11177022	489.02913197	469.980818657
Maximum Latency (seconds)	17886.9015689223	17965.9767341325	17919.0549736107	17942.3736856345	17963.2017284369
CI	71.1918223483	25.3097090804	28.9535473295	32.6983959619	27.2282874235
Average Hop Count	1.7893985789757656	2.022366593222587	2.351205062817541	2.6896611117068803	3.5058826320291603
CI	0.102250273904	0.122566981689	0.142267829849	0.135777724463	0.199513232421
Median Hop Count	1.6	1.9	2.0	2.4	3.2
CI	0.345181786668	0.21137981146	0.0	0.345181786668	0.281839748613
Maximum Hop Count	5.4	7.7	8.1	9.5	11.0
CI	0.784608654178	1.6082779702	1.1978189316	1.0568990573	1.44399901396
Message Replication Overhead Ratio	319.50369021081144	244.1792122614651	174.29350186697306	127.60992969463587	69.53422715794979
CI	50.9851960186	46.5744496671	26.4486373656	17.2897311723	8.9780321935
Network Overhead Ratio	344.446773504399	265.29101653701844	190.62475770117098	141.3090648654179	78.74594783313451
CI	52.2523897211	47.8938518566	28.0203705788	18.062387901	9.37837162132
Average Power Consumed per Node (Watts)	0.8291714015151515	0.829821127946128	0.8294097222222222	0.8288825757575757	0.8269881102693603
CI	0.00054838548343	0.000503249214058	0.000452667190613	0.000436157050755	0.000443332809178

NS-3 Omaha, GAPR2, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18727272727272726	0.2706993006993007	0.3630769230769231	0.4571328671328671	0.5708391608391609
CI	0.0261756231828	0.0380482435508	0.0468447193627	0.0538737929817	0.074283877153
PDR	0.1854695327143781	0.27146831964981893	0.364717359611527	0.4577499113951339	0.5726086734115979
CI	0.0256532667472	0.0381346622192	0.0468832896721	0.0540484491214	0.0743789011508
Average Latency (seconds)	5529.752932566087	6178.219847738366	6329.863878372056	6629.503913119724	6742.366827580499
CI	264.550631101	311.123508819	269.319380998	335.109972185	409.710830429
Median Latency (seconds)	3895.4308779007	4636.3778179049505	5143.1627401298	5653.2363817020505	5976.1449388435
CI	332.645315675	398.095559135	319.364838312	449.274937911	518.477403176
Maximum Latency (seconds)	17895.357424561502	17923.2349198991	17938.560870586603	17926.883441043	17897.8552694758
CI	55.7189982389	50.7799274429	37.8076574287	41.0608758673	58.8856502111
Average Hop Count	1.8343071577798797	2.1180139023767475	2.422217377497904	2.8406635532257805	3.718602219773996
CI	0.0768624509578	0.160773510236	0.141545281016	0.182596059024	0.272944924616
Median Hop Count	1.7	2.0	2.0	2.6	3.5
CI	0.322887995466	0.0	0.0	0.345181786668	0.352299685766
Maximum Hop Count	5.8	7.7	8.6	9.9	11.7
CI	0.821697008108	1.41095914193	1.38072714667	1.1978189316	1.09383237345
Message Replication Overhead Ratio	479.36382692752665	378.4499692073207	276.08382036628814	195.39442243714592	94.28320610804548
CI	78.2718666202	60.9419240019	34.3249079479	23.7237389161	13.9449780229
Network Overhead Ratio	504.7881826060724	396.9771436232786	289.7762673723303	207.29923158737736	103.06304614672429
CI	76.8401752026	61.2978813698	34.4780809137	24.8742707008	14.3130346602
Average Power Consumed per Node (Watts)	0.827500526094276	0.8280424031986532	0.8277919823232324	0.827198547979798	0.8251352062289562
CI	0.000438798713494	0.000361588839105	0.000376066256691	0.000404106748332	0.000409093443559

NS-3 Omaha, GAPR2, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19202797202797203	0.28188811188811186	0.37664335664335663	0.4404895104895105	0.5781818181818181
CI	0.030332289467	0.0467906071681	0.0714335643969	0.0587757025948	0.067188791782
PDR	0.19049333727944695	0.28232232440707816	0.37827920215428573	0.4421843200444303	0.5789924256541231
CI	0.030216203508	0.04692400678	0.0708864621403	0.058728332572	0.0673642742624
Average Latency (seconds)	5561.889443246762	6138.698348028026	6377.9840360463	6546.3170962321965	6562.539646464276
CI	379.806507744	423.491428826	410.604117613	319.219525922	457.853448776
Median Latency (seconds)	3909.7349329225	4786.6120020045	5240.9709407033	5509.2839254124	5756.273297314049
CI	478.403875931	568.480271001	557.163282504	411.192084339	503.137470991
Maximum Latency (seconds)	17826.0210533373	17888.6419373386	17901.2432784244	17922.9341969846	17922.1414731363
CI	126.224406188	78.7749793309	50.273328944	34.3200244628	81.5767586186
Average Hop Count	1.8579204428726883	2.164225729839183	2.5274284693937648	2.8874849937354345	3.834205345336728
CI	0.0798809076815	0.155231442484	0.167731513465	0.189310875678	0.27636572352
Median Hop Count	1.8	2.0	2.2	2.7	3.7
CI	0.281839748613	0.0	0.281839748613	0.322887995466	0.322887995466
Maximum Hop Count	6.1	7.7	9.2	10.4	12.2
CI	0.493219560073	0.708113604662	1.03554536	1.41622720932	1.60054210058
Message Replication Overhead Ratio	569.6297529561382	459.439159760967	341.48004862761195	259.6291558550363	115.96101074096875
CI	90.8919688582	84.6173793677	62.5113647544	37.6023579034	25.3150445369
Network Overhead Ratio	594.600090247916	477.696007818434	354.0517227975355	270.59450567010794	124.62562875081598
CI	91.3442001137	84.3249418267	61.830942541	38.2697802969	26.1552777896
Average Power Consumed per Node (Watts)	0.8264499158249158	0.8271191077441077	0.827087015993266	0.8266109006734007	0.8242618897306397
CI	0.000540716469252	0.000494591965673	0.000482492823868	0.000352677002754	0.000705604969659

NS-3 Omaha, GAPR2, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18832167832167832	0.2783916083916084	0.36832167832167834	0.4646153846153846	0.5888811188811189
CI	0.0232335723546	0.0428096827437	0.0500296347661	0.0653349835426	0.0792470964435
PDR	0.18656110812716717	0.2791455202475821	0.3689954217774319	0.46621048862386594	0.5897967386101641
CI	0.0231872050578	0.0426190948546	0.0498362082413	0.065046753872	0.0794447517038
Average Latency (seconds)	5609.459168951571	6150.851427349713	6317.561880358931	6506.755561455498	6621.778809896038
CI	306.006884591	254.515491062	336.364228913	314.713702483	439.279199829
Median Latency (seconds)	3931.384644331251	4832.857964452251	5216.8925942037995	5533.3739137846	5857.47550477295
CI	383.983149383	417.825010218	526.015107894	445.789362003	563.359144763
Maximum Latency (seconds)	17843.3384123853	17797.088745426	17915.7862013708	17922.2588277983	17957.7949977964
CI	103.929559112	214.774143359	37.5393372315	63.3171208412	36.5747313454
Average Hop Count	1.8462051142066265	2.1746644003071043	2.4954216631181723	2.9309210384460864	3.8308087277437335
CI	0.0733391051226	0.160783861808	0.145369742182	0.217732975542	0.264177108155
Median Hop Count	1.9	1.9	2.1	2.6	3.7
CI	0.21137981146	0.21137981146	0.21137981146	0.345181786668	0.322887995466
Maximum Hop Count	6.0	8.2	9.0	10.4	13.1
CI	0.704599371532	1.2525232401	0.833693219421	0.845519245839	1.97915930757
Message Replication Overhead Ratio	655.1195708721103	540.6527372579487	420.4868899411297	299.64279357172825	127.06161231085471
CI	95.3863825128	103.8285828	66.8572985142	51.444345653	27.9608441309
Network Overhead Ratio	681.4394630865606	557.019518683198	434.3732315446147	310.63363548966294	135.74452798394123
CI	95.2635392143	101.693124616	65.4349538845	51.5678882093	28.32198259
Average Power Consumed per Node (Watts)	0.8254008838383838	0.8262289562289562	0.8262436868686869	0.8257907196969697	0.8233964646464647
CI	0.000419457687214	0.000593708893315	0.000378281801746	0.000432731851766	0.000664077605456

NS-3 Omaha, GAPR2a, 6 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18874125874125874	0.2832867132867133	0.35244755244755244	0.4302097902097902	0.5408391608391608
CI	0.0321123727665	0.0458005162883	0.0564648612419	0.0602279903655	0.0623758698808
PDR	0.18923149437130737	0.2878019416340564	0.3597649870107093	0.4357358953841432	0.5442629719350938
CI	0.0315210219694	0.0465013433142	0.0567921269363	0.060467794162	0.0622833077096
Average Latency (seconds)	5654.976722484028	6095.354723083718	6498.568146483578	6808.676607654654	7021.582574546858
CI	275.65807984	305.852889349	296.667005582	269.454926274	342.932714644
Median Latency (seconds)	4061.89818580375	4541.6908971341	5439.942931549549	5871.9782439334995	6237.93122874615
CI	415.982617199	508.057575971	398.27657918	477.548451493	483.106435546
Maximum Latency (seconds)	17782.7706835934	17899.5111967309	17944.5084049994	17957.1989796337	17922.8752699285
CI	167.462859389	87.3454602614	29.360201257	24.6787633062	71.4092914127
Average Hop Count	1.8449061863315341	2.2306106320436303	2.4355633582626526	2.769601046551197	3.421066206652157
CI	0.140556515151	0.194672375624	0.132780936327	0.158232179214	0.134598270523
Median Hop Count	1.6	2.0	2.0	2.6	3.2
CI	0.345181786668	0.31510641833	0.0	0.345181786668	0.281839748613
Maximum Hop Count	6.3	6.8	7.6	8.7	10.4
CI	0.708113604662	0.527273888642	0.845519245839	0.708113604662	0.645775990933
Message Replication Overhead Ratio	205.1663811382042	143.98138504695552	127.95576879074883	98.11470910179678	56.1126642450389
CI	39.3727503913	24.218795099	20.9983298529	12.6812337613	5.83140241646
Network Overhead Ratio	233.50611075986208	168.46060048350034	147.3213585310132	113.65814877784436	68.6507188458518
CI	40.9243815186	25.9258138316	23.5432503574	13.7611700919	6.42441312781
Average Power Consumed per Node (Watts)	0.8277535774410775	0.8302156986531987	0.8319628577441077	0.831500946969697	0.8287405303030303
CI	0.000455380098409	0.000445493271434	0.000674567002212	0.000628895459161	0.000505088337098

NS-3 Omaha, GAPR2a, 12 Mbps

Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19398601398601398	0.3058741258741259	0.3904195804195804	0.48405594405594404	0.5962237762237762
CI	0.0280752273318	0.0541951137588	0.0600496564031	0.067569289034	0.0652773613347
PDR	0.19383438014958693	0.30794666900510437	0.3931560505248696	0.4871879190462097	0.5991579797359757
CI	0.0288323061762	0.054326475273	0.0602795502949	0.0672284761067	0.0649645577879
Average Latency (seconds)	5606.81140277091	6126.869423313574	6453.97023425401	6502.938269360648	6586.2435321164485
CI	213.574844321	313.188865073	335.366570995	330.42364541	416.593593617
Median Latency (seconds)	3862.54491054075	4626.3637788176	5323.2470260295	5434.3398274699	5773.512037088651
CI	365.472510229	487.077189577	522.214715858	501.654226971	505.614143847
Maximum Latency (seconds)	17902.6712085732	17886.4993200816	17936.3479710584	17911.1694081663	17940.452742880698
CI	69.5004921586	114.957066581	35.2396564478	62.0337751324	34.905784283
Average Hop Count	1.8501015822434308	2.2957286900414884	2.6113004069325765	2.9703277605641474	3.7928437135618074
CI	0.127023186868	0.208539410306	0.194233477936	0.181531248984	0.240860143347
Median Hop Count	1.7	2.2	2.2	2.8	3.7
CI	0.322887995466	0.281839748613	0.281839748613	0.281839748613	0.322887995466
Maximum Hop Count	5.1	7.0	7.9	8.7	11.8
CI	0.493219560073	0.704599371532	0.664717717669	0.451163731354	1.12735899445
Message Replication Overhead Ratio	300.8079972020251	222.1381151176559	183.70520844018577	143.74660584569247	86.08903698072042
CI	40.6931072261	40.6357717726	29.1680653273	21.4104673241	11.7629284582
Network Overhead Ratio	324.47692403181736	240.7540454647474	201.75921932841084	159.00463196713324	96.18777395813005
CI	43.6804746648	40.5848672227	30.6350400701	22.3831317311	12.4762875496
Average Power Consumed per Node (Watts)	0.8257139099326599	0.8278561658249158	0.8288247053872054	0.8287315867003366	0.8268392255892256
CI	0.000292362936479	0.000326260063766	0.000475602894082	0.000465865212428	0.000232033849483

NS-3 Omaha, GAPR2a, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1974125874125874	0.31314685314685314	0.4053146853146853	0.4804895104895105	0.5906993006993007
CI	0.0318143227386	0.0617851943582	0.0805011303694	0.0688332331929	0.0689553731251
PDR	0.1968237439118409	0.3147451285592666	0.4078794389211033	0.4830088751018499	0.592768198708744
CI	0.0325130588159	0.0622606100018	0.0807105373135	0.0689121629501	0.0682738585764
Average Latency (seconds)	5606.768287603919	6064.336386466897	6227.281249549222	6369.409023135787	6351.644284122811
CI	307.781094148	355.303377719	388.305646083	391.340885307	415.762784401
Median Latency (seconds)	3835.2536433844	4606.485926374499	5037.20420885385	5337.853590274651	5425.5397006018
CI	482.124141156	573.472107866	604.52144024	546.686782836	502.642934405
Maximum Latency (seconds)	17817.6779319328	17913.507712004	17931.585134325902	17924.7692965796	17927.0197152481
CI	133.168496732	56.9561299559	26.2678617891	42.8214695043	51.2065092086
Average Hop Count	1.851785532464273	2.3143226909034835	2.692135859793457	3.0496881621119725	3.952336626504214
CI	0.144428651669	0.180733985265	0.258897033869	0.23743477816	0.261808206058
Median Hop Count	1.7	2.2	2.3	2.8	3.9
CI	0.322887995466	0.281839748613	0.322887995466	0.281839748613	0.37943837387
Maximum Hop Count	5.9	7.3	7.8	10.0	11.4
CI	0.735623340478	0.550309701315	0.690363573336	0.99645398726	1.00636919652
Message Replication Overhead Ratio	422.4998820075469	332.0861214443847	290.95437816862676	229.99208902540875	129.7318026457129
CI	68.4446404822	60.5652608517	52.5525045976	28.6516233906	19.9777966423
Network Overhead Ratio	445.85723770702737	346.75603442214003	303.80543068080476	242.33753461501774	138.6066483215594
CI	72.3775351059	60.4767931269	52.8940079805	28.8896059636	20.2810519126
Average Power Consumed per Node (Watts)	0.8239756944444445	0.8263126052188552	0.8272979797979798	0.8271827651515151	0.8254124579124579
CI	0.000345068565096	0.000310913387375	0.000232492933966	0.000367444522003	0.000416889423346

NS-3 Omaha, GAPR2a, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19839160839160838	0.306013986013986	0.4230769230769231	0.4925174825174825	0.6261538461538462
CI	0.0265314527179	0.0580620402371	0.0718533592039	0.060901933536	0.0726992353001
PDR	0.1968632050481024	0.30695959252723004	0.424067822001045	0.49420085718357104	0.627159857793757
CI	0.0264484555937	0.0580353874336	0.0715458108853	0.0608826493845	0.0726850128336
Average Latency (seconds)	5494.659582391594	6146.761632724968	6290.7518810559895	6290.495640864913	6157.877240965191
CI	347.406844821	306.108256262	278.41000911	302.738506285	451.872385538
Median Latency (seconds)	3895.3895481603504	4714.6393487594505	5049.94016964245	5221.4103012779	5244.8721759672
CI	494.371480316	508.033459881	441.409083908	374.765943687	530.994333583
Maximum Latency (seconds)	17893.1334620036	17903.9712040584	17922.791892088702	17876.5834707325	17902.5492767589
CI	70.6956024747	73.976351549	45.4581334197	66.2441536371	70.5051195541
Average Hop Count	1.9053063497451348	2.338325641133688	2.782563556085663	3.1758389019889264	4.070608540294405
CI	0.139227584361	0.157080006483	0.21994520666	0.19095887557	0.271276769686
Median Hop Count	1.85	2.2	2.4	3.0	3.8
CI	0.225581865677	0.281839748613	0.345181786668	0.0	0.281839748613
Maximum Hop Count	6.0	7.2	8.4	9.7	13.0
CI	0.545780326338	0.527273888642	0.902327462708	0.634139434379	1.17902025776
Message Replication Overhead Ratio	471.0502604509042	390.4222674455729	339.1188611074187	278.13869001886644	148.69026368072065
CI	63.5822224617	61.5879751617	56.5790866029	37.7798231686	30.23527628
Network Overhead Ratio	494.9060447003544	406.23164237077117	351.846464336653	288.95795702901455	157.86383490341436
CI	62.8948736726	61.5170793281	56.4862712227	38.2633735414	30.7568932053
Average Power Consumed per Node (Watts)	0.8230871212121212	0.825301452020202	0.8265277777777778	0.8264325547138047	0.8245512415824916
CI	0.000294746180848	0.000346891508985	0.000247429300836	0.000306111206602	0.000605210784076

NS-3 Omaha, GAPR2a, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.20573426573426573	0.3193006993006993	0.4156643356643357	0.49804195804195805	0.6037762237762238
CI	0.0353294416594	0.056991350926	0.0853792529726	0.0692058648789	0.0747975562155
PDR	0.20385093190396328	0.320942353856778	0.41662775360174215	0.5006264455381513	0.6055665778791101
CI	0.0348421070222	0.0571106003335	0.085486494163	0.0696777746457	0.0745540288974
Average Latency (seconds)	5568.6295312339425	5959.3722154775205	6209.717933406882	6276.521660756015	6224.97808313679
CI	408.533612726	364.533528713	327.680140726	318.046486638	477.600342701
Median Latency (seconds)	3923.7379617461006	4421.20739756115	5002.9143211715	5163.53452148355	5279.65932477955
CI	658.508182243	551.569323457	496.077875293	491.381852752	583.705239321
Maximum Latency (seconds)	17861.3863226711	17906.1245986419	17910.900938608702	17888.0881646877	17942.1956204976
CI	100.191496362	117.161765735	41.0162579669	110.185998926	42.272529624
Average Hop Count	1.8896290600111958	2.364282458095343	2.82062246407748	3.1736627777491693	4.076862658346277
CI	0.130506412824	0.167234254742	0.229787674021	0.218071379778	0.265220426337
Median Hop Count	1.8	2.3	2.4	2.9	4.0
CI	0.281839748613	0.322887995466	0.345181786668	0.21137981146	0.31510641833
Maximum Hop Count	5.9	7.2	8.2	8.9	12.2
CI	0.735623340478	0.821697008108	0.614255491238	0.664717717669	1.08242609332
Message Replication Overhead Ratio	511.86247217892196	418.13660078718544	404.3112818838806	335.3145953323823	168.76451118770342
CI	88.8492008425	75.6363373357	82.5001968833	47.3696551929	33.1797786576
Network Overhead Ratio	537.2081272989128	432.3752428788088	418.17021501035344	345.71501263473317	177.90508324350046
CI	90.664401805	74.2259607651	83.1661483942	47.3357333015	33.785020726
Average Power Consumed per Node (Watts)	0.822192760942761	0.8241577230639731	0.8256407828282829	0.8255787037037037	0.8236795033670034
CI	0.000171369083876	0.000229672322527	0.000265752432404	0.000246532464169	0.000545129835482

NS-3 Omaha, Vector, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18286713286713285	0.2423776223776224	0.3455244755244755	0.43580419580419577	0.5297202797202797
CI	0.0316829484063	0.0370471603936	0.0421403597912	0.0614115559537	0.0652699411038
PDR	0.1824840054514829	0.2420021776701122	0.3471260965994	0.4391635335255237	0.5311273462020484
CI	0.0316217314857	0.0362015700875	0.0417672592063	0.0612535214348	0.0643519921219
Average Latency (seconds)	5403.95643139104	6022.35893531423	6874.43487630873	7421.764224696436	7526.6292015408335
CI	397.667477346	319.917421313	267.374978552	346.868060564	413.083273812
Median Latency (seconds)	3738.7050245858	4571.6740800296	5781.5718423504995	6795.89843888245	7086.11486814815
CI	486.194056098	520.556100024	504.075152841	593.562776351	594.651882187
Maximum Latency (seconds)	17820.9085929537	17925.2208365819	17967.759163149	17958.4350217393	17949.0755155257
CI	211.660912594	35.0050258351	14.1588148368	35.7882017633	36.3665101222
Average Hop Count	5.97801592747561	6.3610046109535405	5.109863339318719	3.9906244226724996	3.7418548808971366
CI	0.333120346858	0.376299022297	0.250594949876	0.0819523939709	0.150139401769
Median Hop Count	2.5	3.0	3.4	3.15	3.3
CI	0.352299685766	0.0	0.345181786668	0.225581865677	0.322887995466
Maximum Hop Count	48.4	46.3	28.1	15.8	12.7
CI	0.955765088727	2.25141275675	3.41494536483	1.2525232401	0.634139434379
Message Replication Overhead Ratio	131.49858337435322	114.45038937024941	77.29865713249768	54.597673456608575	38.0983888624256
CI	20.9433933645	15.0948190565	9.00015583295	8.01574175096	3.61238922028
Network Overhead Ratio	150.88377061426633	134.97701913839128	90.97415782437994	63.68034698994288	43.95662338673032
CI	24.8167574615	15.854738613	10.0271341865	8.68419494025	3.72617016746
Average Power Consumed per Node (Watts)	0.8282817760942761	0.8293623737373738	0.8292319023569024	0.828410143097643	0.8270070496632996
CI	0.000987317437871	0.00068415726822	0.00077587659828	0.000708866590384	0.000538580294116

NS-3 Omaha, Vector, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.18314685314685314	0.24986013986013986	0.3583916083916084	0.4577622377622378	0.567972027972028
CI	0.0271102315644	0.0374051069298	0.0442342753149	0.0495381392889	0.0588447878163
PDR	0.18306733604445954	0.25004658606364205	0.3593332894876264	0.4597059779967627	0.5688969516272238
CI	0.0273520091707	0.0379148646659	0.0447512744133	0.0491688080742	0.057975535778
Average Latency (seconds)	5178.7494474824725	5782.466336067038	6889.898184251887	7382.904667639635	7200.043306311822
CI	411.874449181	363.563507543	332.255393447	284.775591794	525.456048436
Median Latency (seconds)	3423.08646224325	4275.6996520535995	5824.9208355863	6757.5063851116	6707.25235591775
CI	479.268104962	497.172377027	575.5995504	388.628719842	634.897422666
Maximum Latency (seconds)	17723.623431855798	17843.1688917731	17937.7749734345	17935.5715145746	17964.0986346618
CI	242.194819858	173.188288658	34.0179917777	52.8089591862	32.8458745445
Average Hop Count	6.8795336846759705	7.49115035946054	6.692929421146086	5.195956507740697	4.060986499161227
CI	0.518605995357	0.462329070641	0.423270879513	0.313787664329	0.0906873692366
Median Hop Count	2.65	3.4	3.8	4.1	3.8
CI	0.317069717189	0.345181786668	0.281839748613	0.21137981146	0.281839748613
Maximum Hop Count	48.9	49.3	44.0	25.5	14.4
CI	0.664717717669	0.550309701315	2.72890163169	3.38281086141	0.955765088727
Message Replication Overhead Ratio	179.57657074259984	162.63059352345556	116.88030775148435	74.58058680677074	41.592713778448534
CI	16.8768490829	18.5259526715	10.9453653957	6.50937545872	3.83075673113
Network Overhead Ratio	196.60395833836714	178.71750947746384	126.03643839061411	80.59237501463367	45.61533456950061
CI	17.7741862799	21.3132390387	11.4999454853	6.93374730438	3.92275733739
Average Power Consumed per Node (Watts)	0.8262284301346802	0.8275931186868687	0.8278109217171717	0.8265283038720539	0.8240877525252525
CI	0.00103403138759	0.00107326594319	0.000795643926814	0.000950938867278	0.000373018126355

NS-3 Omaha, Vector, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.19244755244755246	0.2700699300699301	0.37503496503496503	0.47790209790209787	0.5972027972027972
CI	0.0260389232666	0.0414006666384	0.0511710753395	0.0637517693555	0.0566918570055
PDR	0.19100962047886821	0.27030037963074605	0.37490819805105835	0.4791064244922119	0.5976301395389624
CI	0.0259433380987	0.0416742955208	0.0516076879565	0.0639227371856	0.0568808268399
Average Latency (seconds)	5223.617397214027	5868.74442385859	6729.610563329532	7129.155767606024	6959.2720902461915
CI	407.393967251	431.645836334	311.090763479	391.300138464	601.397350486
Median Latency (seconds)	3747.8025218675493	4464.0203714538	5673.2862031217	6332.731534373701	6330.058678834501
CI	634.469401522	598.087876613	420.24145661	495.290718122	707.644622901
Maximum Latency (seconds)	17741.7750190388	17873.6382203613	17904.1064549027	17934.188011986	17951.6246099335
CI	141.974480883	80.6572435701	62.7638519277	42.6056850497	26.4461639007
Average Hop Count	7.656708062916317	8.445379118156673	8.518475033252184	6.1550546606718095	4.459028650950266
CI	0.511577531472	0.704147293968	0.586687442637	0.550744891479	0.202402917253
Median Hop Count	2.9	3.4	4.55	4.35	4.0
CI	0.37943837387	0.345181786668	0.332358858835	0.317069717189	0.0
Maximum Hop Count	49.5	48.8	49.1	35.4	14.9
CI	0.568066174258	1.2525232401	0.735623340478	4.81195461287	1.01862749493
Message Replication Overhead Ratio	227.63075848841515	201.17163720685122	164.31582777999708	102.67146698652098	46.6411903087273
CI	25.2151314457	21.5076406319	17.9543444174	17.449047502	5.141842294
Network Overhead Ratio	244.5520644452115	218.41118637556383	176.1176004079313	107.93464026699519	50.3317523291574
CI	26.384633539	23.2322500061	19.7226094948	18.1866690862	5.3949343936
Average Power Consumed per Node (Watts)	0.8243644781144781	0.8254887415824915	0.826328388047138	0.8249989478114478	0.8223305976430977
CI	0.00100361781446	0.000806556964438	0.000900093646375	0.00100687379009	0.000391547283963

NS-3 Omaha, Vector, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1867832167832168	0.26706293706293704	0.369020979020979	0.48713286713286713	0.6076923076923076
CI	0.0266614393853	0.0438468470186	0.0536475445949	0.0646671635553	0.0706502242177
PDR	0.18552379177673767	0.26715298863300047	0.368337553482628	0.4875332039884978	0.6085811529228644
CI	0.0265879933637	0.043922035228	0.0546709311116	0.0644960980391	0.0705944183265
Average Latency (seconds)	5152.881294171853	5914.993729508698	6667.756409281281	6976.146634177944	6838.617541349194
CI	481.606839726	367.233919923	309.620516111	341.455096892	714.79752918
Median Latency (seconds)	3538.60252987435	4413.588451972899	5627.052488939	6257.36523437065	6272.4232419489
CI	564.68347189	608.092087035	361.720491331	471.876810674	845.995094716
Maximum Latency (seconds)	17820.6208903107	17893.0205968128	17927.4311696379	17907.4621249664	17882.8119933849
CI	186.177145941	64.7695598254	50.0449705488	53.383764397	133.788357869
Average Hop Count	7.790629706141135	8.7053025475236	8.656949486504006	6.91798883994008	4.685842573475304
CI	0.487426769755	0.532009003031	0.508465594508	0.564828835423	0.245153813022
Median Hop Count	2.8	3.45	4.2	4.7	4.1
CI	0.392304327089	0.332358858835	0.422759622919	0.322887995466	0.21137981146
Maximum Hop Count	49.5	49.8	48.6	41.2	17.6
CI	0.649608523042	0.422759622919	0.902327462708	5.24252236893	2.36224754923
Message Replication Overhead Ratio	245.1108135706244	219.23855317463924	181.05789671757728	118.81189744078756	49.7875961324009
CI	25.7316730255	23.930211023	17.9661229434	16.8892813131	8.62572212286
Network Overhead Ratio	264.37256869661223	236.22171437545362	194.87472759434058	124.89448044026057	53.26837852932344
CI	27.3866862944	26.4861376812	22.2973020892	18.3634991952	8.84652928003
Average Power Consumed per Node (Watts)	0.8231134259259258	0.8241645622895623	0.8249573863636364	0.8242066498316498	0.8215419823232324
CI	0.000873833172587	0.000807502524	0.000698052347629	0.000774550046498	0.000401098538819

NS-3 Omaha, Vector, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1962937062937063	0.2646853146853147	0.3711888111888112	0.49615384615384617	0.6248951048951049
CI	0.0322230164082	0.0451221844453	0.056855125636	0.0544717258215	0.0621836880684
PDR	0.1948987346859734	0.2634321323263436	0.3702921585606916	0.4962484516984731	0.6251595801042797
CI	0.0318200453629	0.0451375881851	0.0572844124444	0.054121059517	0.062215793896
Average Latency (seconds)	5030.467380127583	5668.180794898701	6706.063011358467	6994.6003902186585	6892.079259461815
CI	484.067023479	463.54947249	347.221963852	371.189746549	631.436386424
Median Latency (seconds)	3426.28084980395	4211.684948938901	5635.4712964035	6256.376761369001	6309.5714983026
CI	600.120567863	570.094472526	532.980395761	508.270433304	749.571188961
Maximum Latency (seconds)	17762.097967058202	17849.1679685513	17924.2867445067	17928.2774841317	17930.8955110703
CI	222.403257355	75.9382667212	68.3228526675	46.0820519284	47.6642470392
Average Hop Count	8.161112385774222	9.023470639902923	8.859686098632006	7.327455342409269	4.641416013124711
CI	0.674952028292	0.543248939019	0.48190112898	0.547521311551	0.196466446586
Median Hop Count	3.0	3.6	4.6	4.8	4.1
CI	0.31510641833	0.345181786668	0.345181786668	0.281839748613	0.21137981146
Maximum Hop Count	49.4	49.6	49.9	44.9	16.7
CI	0.645775990933	0.345181786668	0.21137981146	2.56864887563	2.09136678207
Message Replication Overhead Ratio	249.60012050779036	235.31528227105704	196.41914186173804	136.87259101580867	49.273839169797
CI	27.400753546	18.9814064156	19.3803980748	20.70098471	7.11747038822
Network Overhead Ratio	268.36886779061484	254.71677620678634	210.11063362547273	142.82441531760253	52.59912958397134
CI	31.0525013461	22.7977801342	22.0386859367	22.0202198525	7.342510664
Average Power Consumed per Node (Watts)	0.8220554503367004	0.8230566077441077	0.8238157617845118	0.8233564814814814	0.8209248737373738
CI	0.000452847009266	0.000776591753416	0.000874331897249	0.000703848488907	0.000318436921184

NS-3 Omaha, Vector No Limit, 6 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.1911888111888112	0.2674125874125874	0.3713986013986014	0.47601398601398603	0.57
CI	0.0276921247523	0.0418569632271	0.0633752638792	0.0779935528474	0.0724829307827
PDR	0.19107685056286927	0.2688468944451143	0.3725259146397162	0.4784909403808	0.5718585464417382
CI	0.027775344779	0.0423477328147	0.0639966678138	0.0782740078184	0.0721531753369
Average Latency (seconds)	5213.074995981055	5825.860012988948	6614.141255555578	7104.636930687874	7149.218356529081
CI	417.795748473	434.478843939	285.247686076	320.323128549	522.867809346
Median Latency (seconds)	3570.9166848783	4364.954883556299	5359.1507525822	6311.74118010735	6698.98078956675
CI	506.961070818	576.639202325	465.091127736	480.448284455	628.34750075
Maximum Latency (seconds)	17829.4262209126	17863.1369114203	17922.1027286879	17912.97389075	17909.3089327445
CI	166.656566109	106.338622785	62.9682119397	50.716965446	73.7852400942
Average Hop Count	6.138498930801852	6.1749677692371225	5.437969945893366	4.543679213705406	4.102164009158981
CI	0.597258144215	0.30844653029	0.253539398143	0.126830498481	0.140004396299
Median Hop Count	3.3	3.35	4.0	4.0	3.7
CI	0.451163731354	0.317069717189	0.0	0.0	0.322887995466
Maximum Hop Count	47.0	48.2	31.1	17.3	13.6
CI	1.66738643884	1.60054210058	2.84382451452	1.47965868022	0.645775990933
Message Replication Overhead Ratio	176.3698850406548	124.19223195843824	89.47201991542829	59.788094711441545	42.667139061868404
CI	19.3833800037	16.4546765406	13.1585427131	6.68639653901	2.971143311
Network Overhead Ratio	213.1141202474351	152.96526925566218	109.47251331550434	71.43403595839642	50.387439708681946
CI	21.4414524272	19.9205410697	14.0899071662	6.8889076477	2.54660797444
Average Power Consumed per Node (Watts)	0.8280239898989898	0.8291719276094276	0.8296864478114478	0.8285953282828282	0.827103324915825
CI	0.000510287065875	0.000453544212472	0.000519755809307	0.000577421239083	0.000528496413525

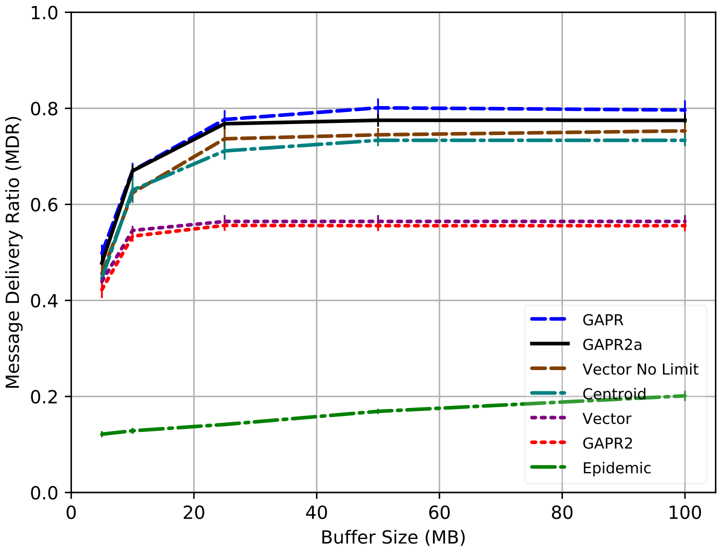
NS-3 Omaha, Vector No Limit, 12 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.20244755244755244	0.27776223776223774	0.3832167832167832	0.49790209790209794	0.6361538461538462
CI	0.038168523681	0.0499133984481	0.0566284413582	0.0542429362259	0.0769484256134
PDR	0.2022450828866552	0.2783301727886235	0.3843008619335226	0.49883242536181843	0.6374312627198223
CI	0.0381854485936	0.0498123011788	0.0564059584993	0.054426499566	0.0763947084897
Average Latency (seconds)	5185.019242861702	5644.170622782161	6480.749683786849	7013.789213363494	6554.002230496304
CI	481.62504052	429.555286289	374.131478655	384.705837316	636.477984318
Median Latency (seconds)	3585.3899729763	4083.03695780575	5357.085218229	6196.526846852599	5905.5328566415
CI	610.626455185	619.591783092	536.739575131	611.135487554	830.893976519
Maximum Latency (seconds)	17859.8364951596	17850.4715531698	17924.7097022989	17909.1925300163	17861.5458360499
CI	88.4228351572	63.6206374959	36.1225241796	62.7745360891	115.605462126
Average Hop Count	7.696506334386313	7.495840225601239	7.228824984493057	5.68036510629489	4.690355708888465
CI	0.52797806646	0.480081280156	0.437989836425	0.320051512203	0.158909936548
Median Hop Count	3.6	3.75	4.5	4.55	4.4
CI	0.345181786668	0.284033087129	0.352299685766	0.332358858835	0.345181786668
Maximum Hop Count	49.5	48.8	45.7	26.4	15.8
CI	0.568066174258	0.986439120145	2.13831689113	2.60225251317	1.08242609332
Message Replication Overhead Ratio	267.88282094199724	194.42626531847722	141.30901557617005	88.37876257614407	49.03109960482197
CI	35.7161926946	25.8497653865	16.2200369341	7.37421150457	3.85469747538
Network Overhead Ratio	295.79921695890994	218.3509684492888	157.67203566361061	96.32002743038193	53.948381071052786
CI	41.0032634265	28.3691263373	16.9921913498	7.97552948528	4.20712376662
Average Power Consumed per Node (Watts)	0.826478324915825	0.8276525673400673	0.8282097011784512	0.8271790824915825	0.8247685185185185
CI	0.000612910611765	0.000649057422877	0.000584082218814	0.000689986990732	0.000495588892891

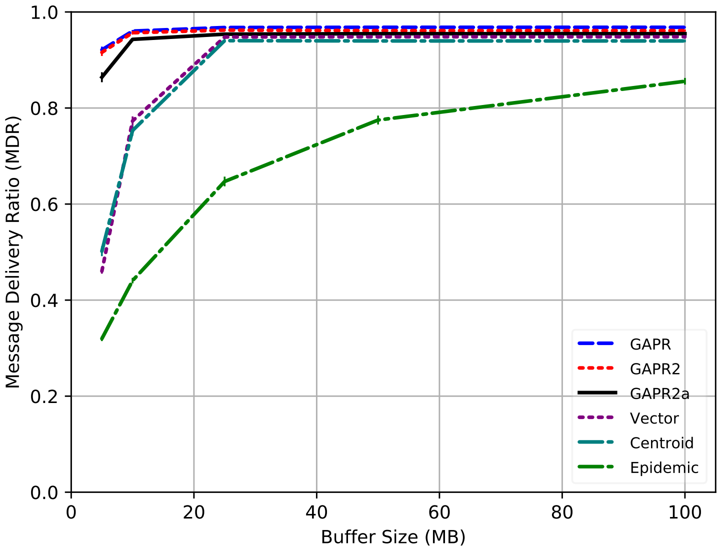
NS-3 Omaha, Vector No Limit, 24 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.20734265734265733	0.2765734265734266	0.3934965034965035	0.496993006993007	0.6141958041958042
CI	0.0288985442849	0.0476063119661	0.0719512952014	0.0671624991793	0.0803138843574
PDR	0.20761545122713174	0.2765551524186388	0.3941422135505157	0.4981190191715354	0.6151503359677295
CI	0.0290045004559	0.0473138422116	0.0724204745941	0.0681059192384	0.0794499427869
Average Latency (seconds)	5220.309780712573	5524.191454159543	6140.055653261538	6557.70779131623	6406.837113227402
CI	490.26119253	576.897358192	392.125993573	405.282336639	536.970672032
Median Latency (seconds)	3705.6099900556	4043.6208411531998	4780.16484498945	5721.667114035549	5717.9438454163
CI	581.686972133	850.649735753	540.650523273	567.693984274	679.397666733
Maximum Latency (seconds)	17900.1989836347	17950.6758120788	17907.7486615206	17955.8529762367	17900.556763803597
CI	61.6653570565	63.7947025482	68.3981592809	24.5069436066	41.7835106476
Average Hop Count	8.483802862777987	8.32599865945532	8.337353564024925	6.716365252457776	4.833477232097133
CI	0.382581992536	0.514488134387	0.487468095967	0.38037088466	0.200802691673
Median Hop Count	3.8	3.9	4.5	5.0	4.2
CI	0.527273888642	0.37943837387	0.352299685766	0.0	0.281839748613
Maximum Hop Count	49.6	49.8	49.0	42.9	18.6
CI	0.645775990933	0.281839748613	1.04508975863	3.38574478292	3.04204199743
Message Replication Overhead Ratio	346.62652338189656	264.95716934394244	196.12387310708039	129.0566123920442	55.071908898748184
CI	30.7505185546	28.9590376987	18.6890578052	15.209654062	5.92407832143
Network Overhead Ratio	371.1324805682526	289.13145702346594	210.91199823411526	135.9948348867427	59.19170780212422
CI	34.2757113028	34.3012985006	20.7153126794	16.1199282694	6.025466936
Average Power Consumed per Node (Watts)	0.8248469065656566	0.8258264941077441	0.8264194023569024	0.8257233796296297	0.822700968013468
CI	0.000565735962938	0.000653817381449	0.000707403514304	0.000627881280982	0.000496815644502

NS-3 Omaha, Vector No Limit, 36 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.2095104895104895	0.2872727272727273	0.3905594405594406	0.49041958041958045	0.6198601398601399
CI	0.0412922725263	0.0502792908084	0.0613361791202	0.0598552786297	0.065163454353
PDR	0.20893776467278313	0.2863926675362732	0.38971708557585855	0.4912863965040356	0.6208769506772335
CI	0.0411877271602	0.0509786256571	0.0618447705343	0.0599349553159	0.0649888652143
Average Latency (seconds)	5055.73163464852	5477.707703546534	6203.359025874235	6674.830370776324	6389.630827168629
CI	494.387764309	401.041037036	337.074748245	440.943351927	564.754076393
Median Latency (seconds)	3601.23889631965	3881.76462755815	4816.7069740005	5900.9387630357505	5720.90580032055
CI	605.645267762	515.784086786	568.182131521	643.378609415	700.616553707
Maximum Latency (seconds)	17853.5178821111	17842.1899874082	17904.1146324195	17901.9987505486	17901.8931981465
CI	99.9029216315	93.7360496061	53.52984146	75.0109183552	51.1808792895
Average Hop Count	8.752800240918129	8.533528442931885	9.15030029825613	7.311578928745523	5.059858566052593
CI	0.58219917916	0.743452451627	0.618594493038	0.47051418406	0.185353854923
Median Hop Count	3.9	3.9	4.9	5.2	4.3
CI	0.735623340478	0.37943837387	0.21137981146	0.281839748613	0.322887995466
Maximum Hop Count	49.5	49.7	49.9	43.7	18.7
CI	0.472659627495	0.451163731354	0.21137981146	4.21642531358	1.91801215664
Message Replication Overhead Ratio	410.8956888541876	306.5797907493908	225.18379766030395	144.8976043151374	56.872821965790536
CI	43.2426865088	34.7093806855	22.6949553598	11.8049235676	5.68704823651
Network Overhead Ratio	435.8064995286351	332.3753623221449	241.33921482722565	151.87170197088537	60.7301517856268
CI	47.839572239	39.9691827493	25.887657318	13.1626111938	5.85767451301
Average Power Consumed per Node (Watts)	0.8240093644781145	0.8248290193602694	0.8255034722222222	0.8246054292929293	0.8217713594276095
CI	0.000806264908484	0.000751176522938	0.000577692102335	0.000614245325589	0.000333246440976

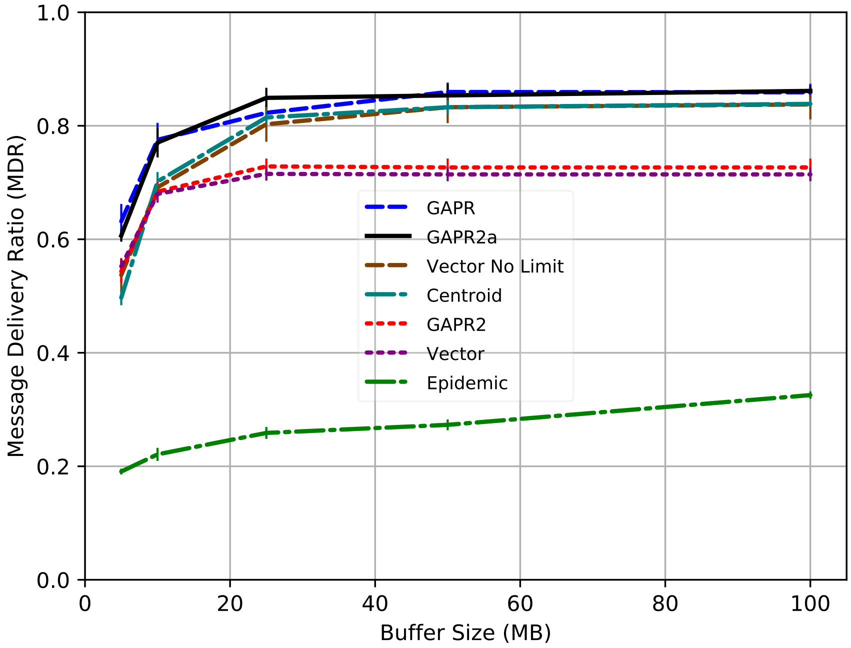
NS-3 Omaha, Vector No Limit, 54 Mbps					
Buffer Size (MB)	**5.0**	**10.0**	**25.0**	**50.0**	**100.0**
MDR	0.21433566433566434	0.27678321678321677	0.39853146853146854	0.5125874125874126	0.6352447552447552
CI	0.0391345786436	0.0494373730371	0.066653557486	0.0652612924016	0.05921141633
PDR	0.21330461439527637	0.27620000219228535	0.3979447324863804	0.5133528446729293	0.6358760189559607
CI	0.0386069512435	0.0501240265703	0.0664706257066	0.0650577266243	0.0594347462179
Average Latency (seconds)	5031.645185921528	5333.923900558096	6396.369119699955	6509.090585111876	6313.107522130482
CI	424.93223519	476.380011759	362.115323572	474.354414846	696.455690937
Median Latency (seconds)	3483.1894237873503	3700.36196176	5151.01561083825	5619.99876869375	5576.26535560535
CI	557.059300182	709.347428696	572.417562883	617.425715983	841.428777855
Maximum Latency (seconds)	17799.5571893249	17856.3453580194	17934.664663862	17910.6999295281	17886.2937793978
CI	92.5878255908	74.4128727208	45.3222031622	105.483689431	118.222100989
Average Hop Count	8.930562770765398	8.800967109918751	9.38344860679655	7.9776645582015355	5.216006565435869
CI	0.708916109053	0.436041118918	0.504162626974	0.583442749946	0.209377675342
Median Hop Count	4.15	3.95	5.0	5.2	4.6
CI	0.669369402956	0.332358858835	0.31510641833	0.281839748613	0.345181786668
Maximum Hop Count	49.4	50.0	49.7	47.6	20.1
CI	0.718553188942	0.0	0.322887995466	2.40391297546	3.1894311439
Message Replication Overhead Ratio	441.63612864220823	327.5299977081245	251.07419639704102	165.9460945763772	59.69357885010607
CI	30.7458572895	28.4141277903	12.0824335098	14.1835670392	5.8524356252
Network Overhead Ratio	466.72010198153305	357.8089177134875	270.30070151965225	174.5515675772707	63.54651490144901
CI	30.6844254138	34.1819742334	14.2971030471	16.1066976955	6.03139280793
Average Power Consumed per Node (Watts)	0.8231791877104377	0.8238315446127946	0.8246254208754209	0.8241203703703703	0.8211763468013468
CI	0.000752439828306	0.000757143932645	0.000730688739295	0.000905629688846	0.000293089344795

APPENDIX G:
Helsinki Figures

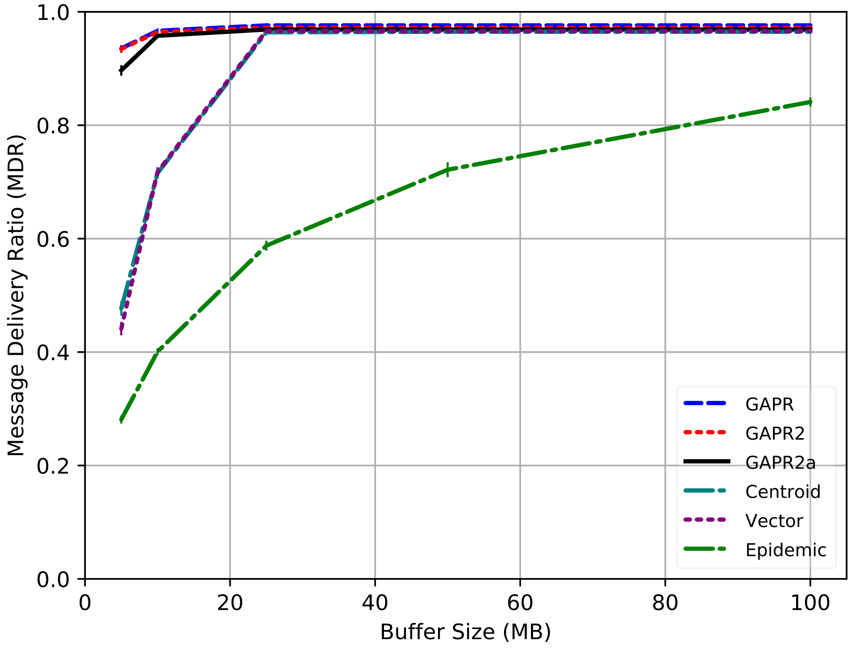

NS3 Helsinki MDR for 6 Mbps Base Radio


ONE Helsinki MDR for 6 Mbps Base Radio

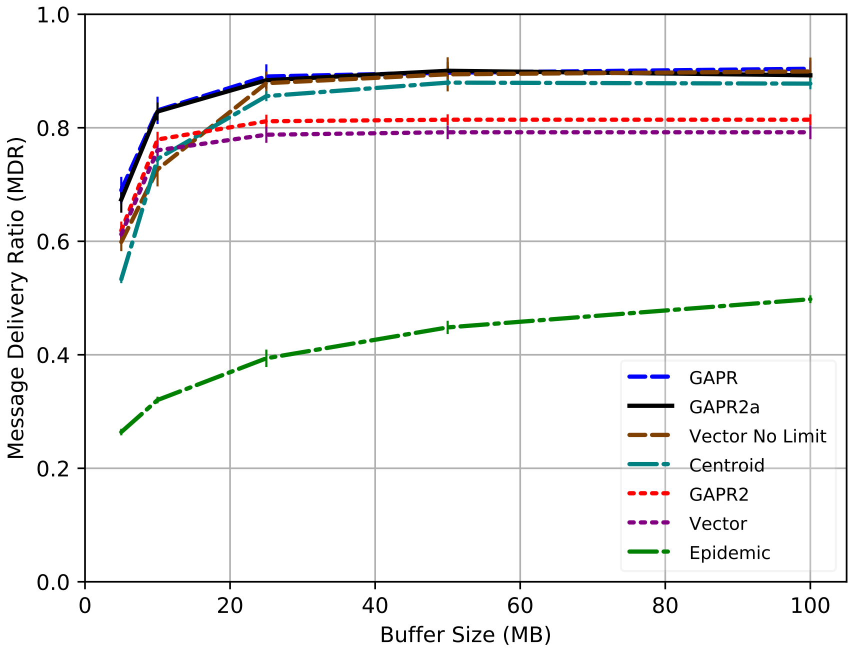
NS3 Helsinki MDR for 12 Mbps Base Radio



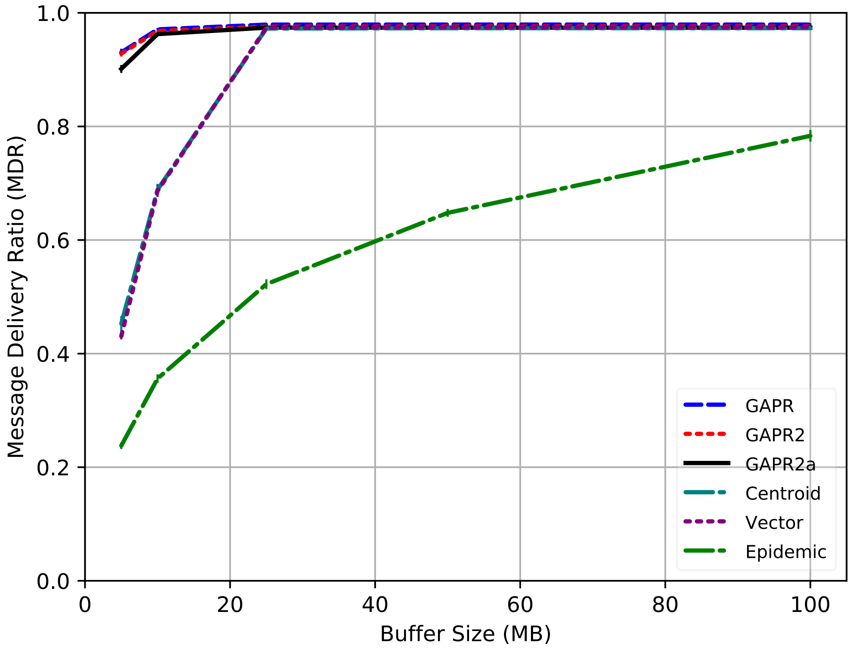
ONE Helsinki MDR for 12 Mbps Base Radio



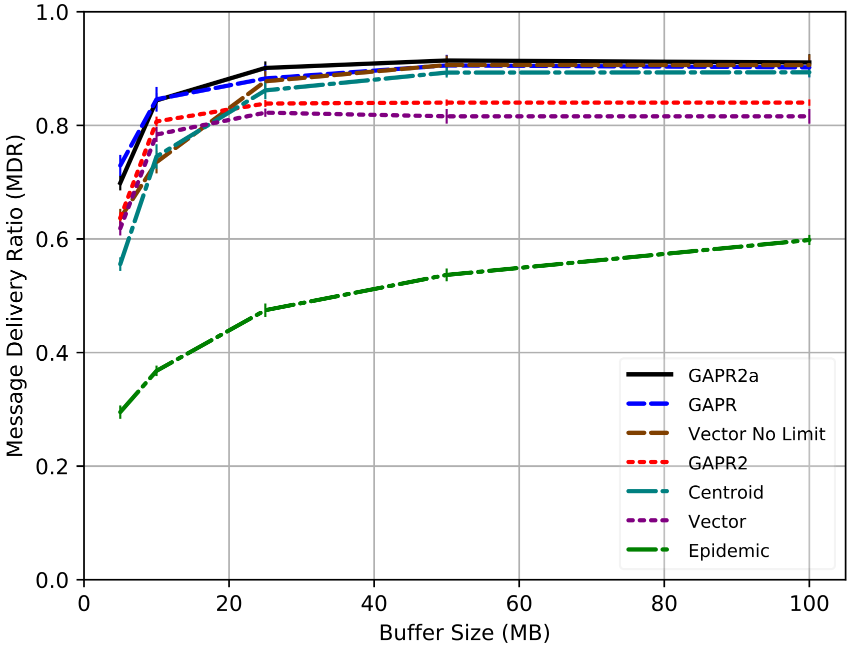
NS3 Helsinki MDR for 24 Mbps Base Radio



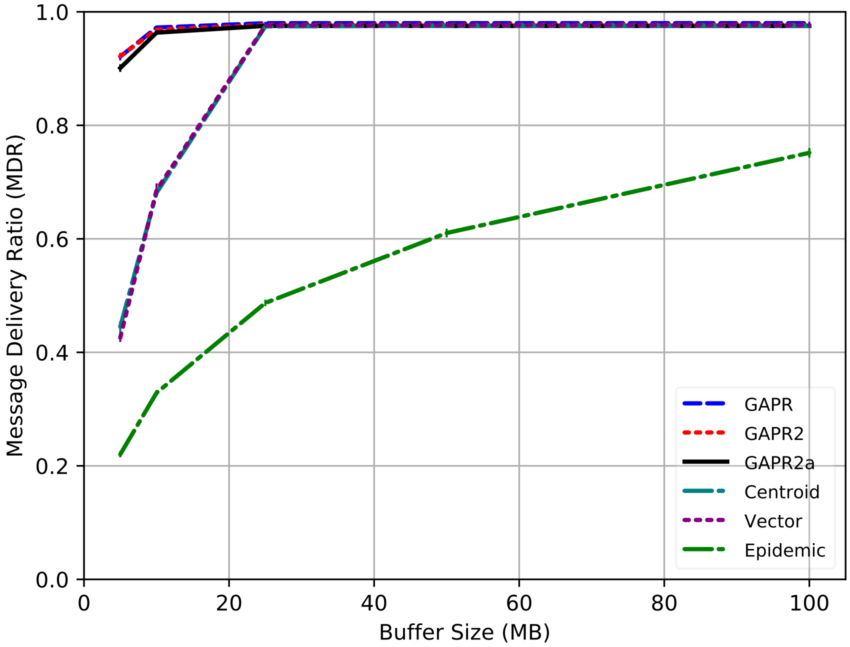
ONE Helsinki MDR for 24 Mbps Base Radio



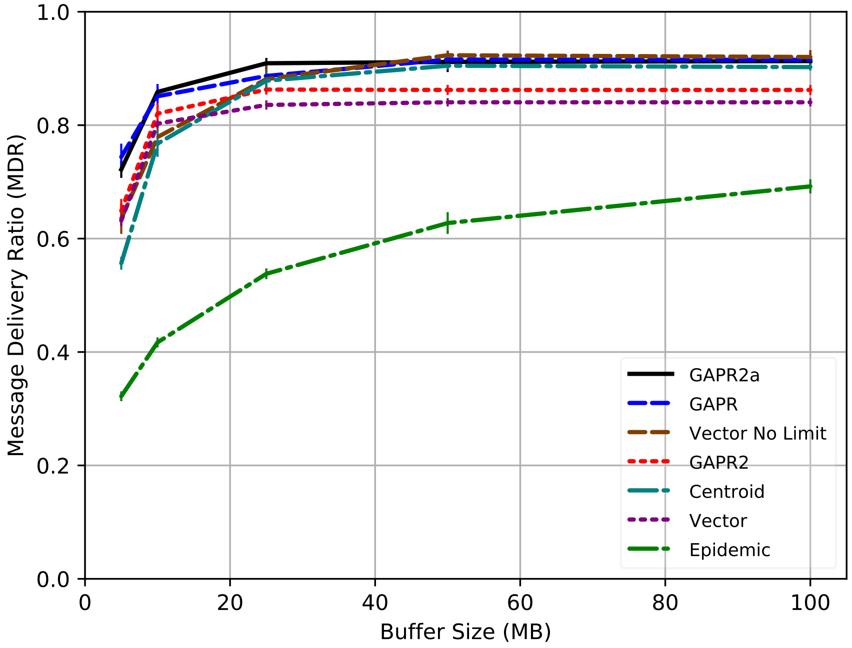
NS3 Helsinki MDR for 36 Mbps Base Radio



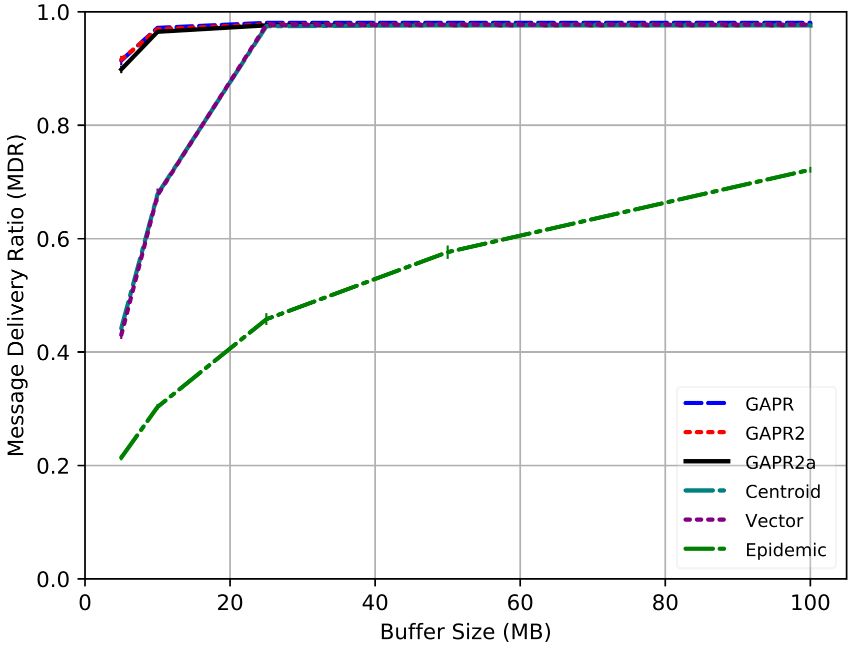
ONE Helsinki MDR for 36 Mbps Base Radio



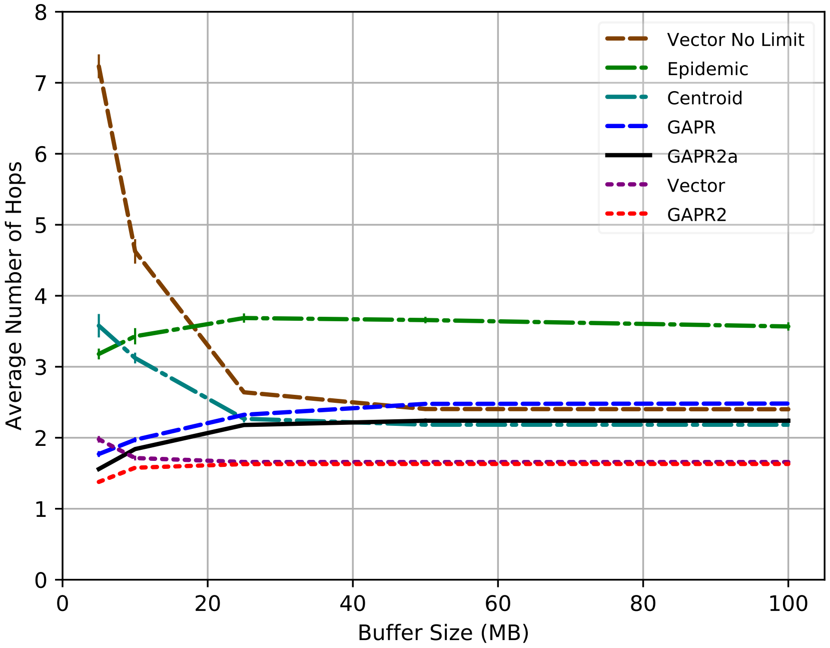
NS3 Helsinki MDR for 54 Mbps Base Radio



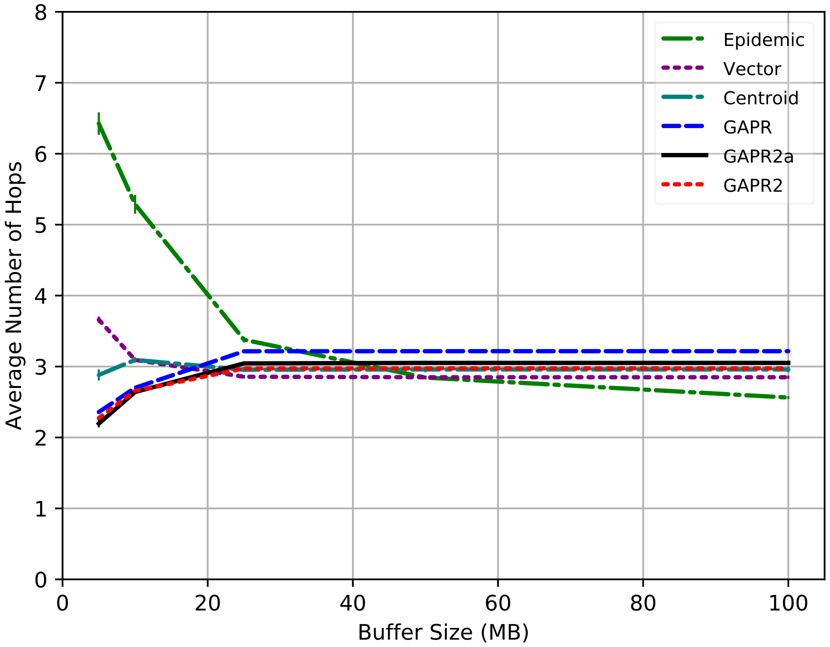
ONE Helsinki MDR for 54 Mbps Base Radio



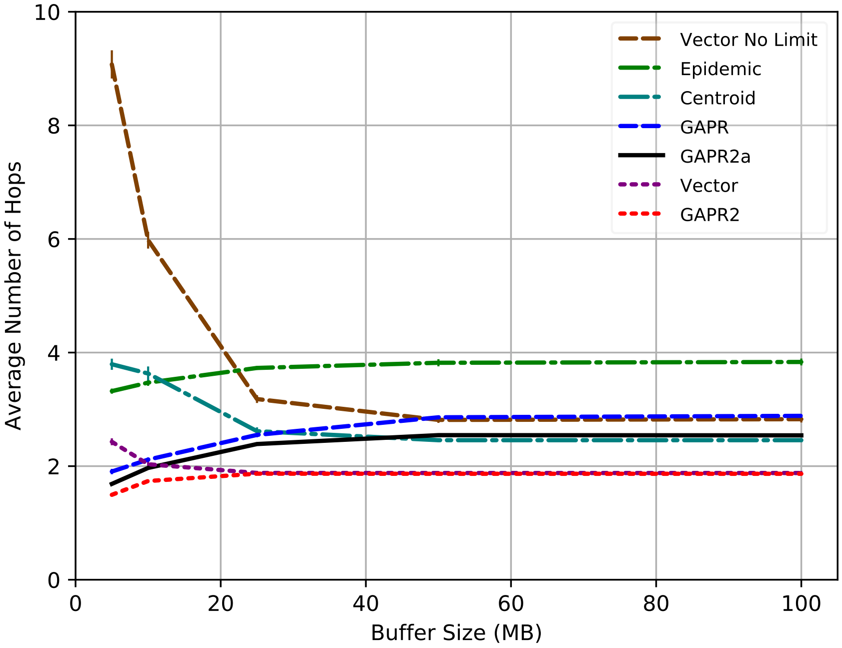
NS3 Helsinki Average Hop Count for 6 Mbps Base Radio



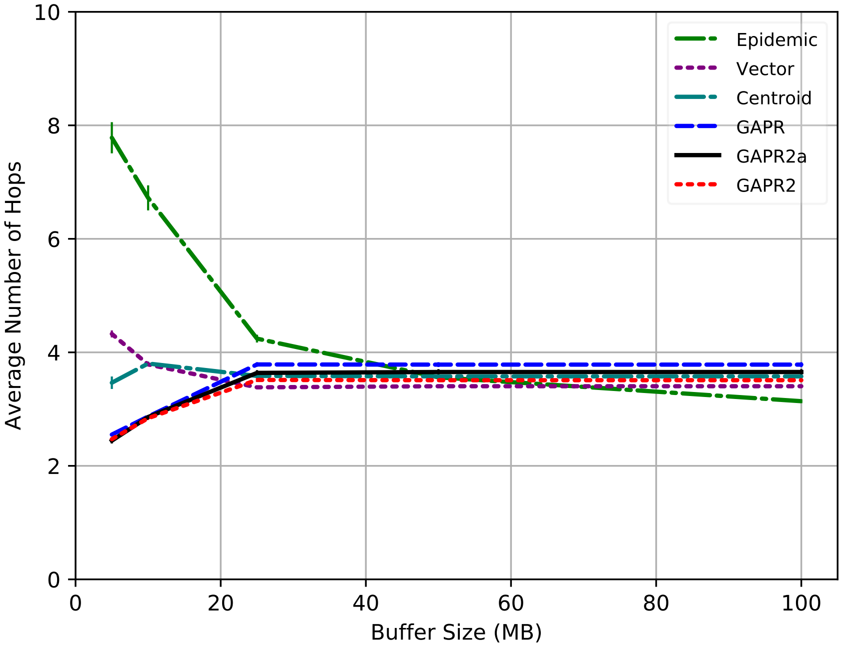
ONE Helsinki Average Hop Count for 6 Mbps Base Radio



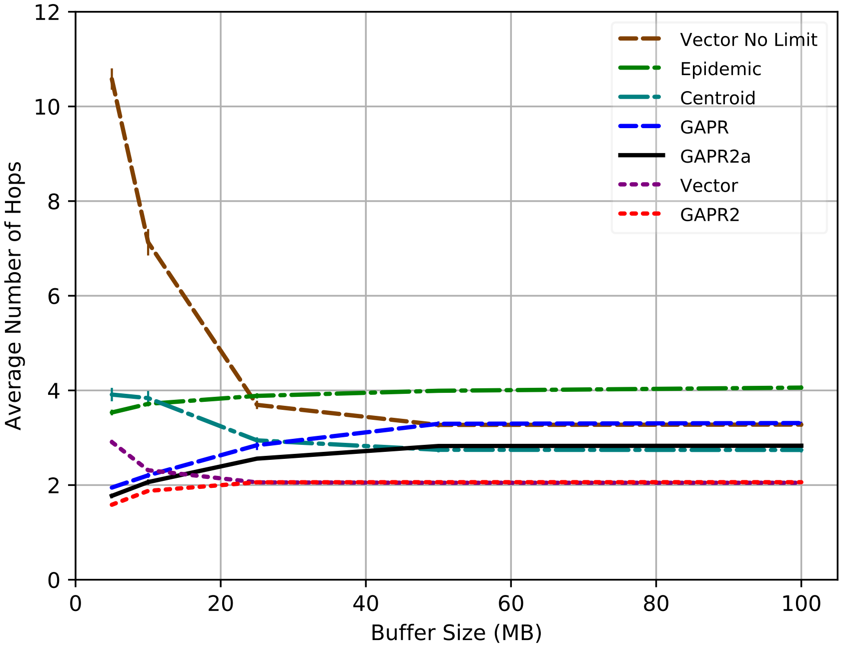
NS3 Helsinki Average Hop Count for 12 Mbps Base Radio



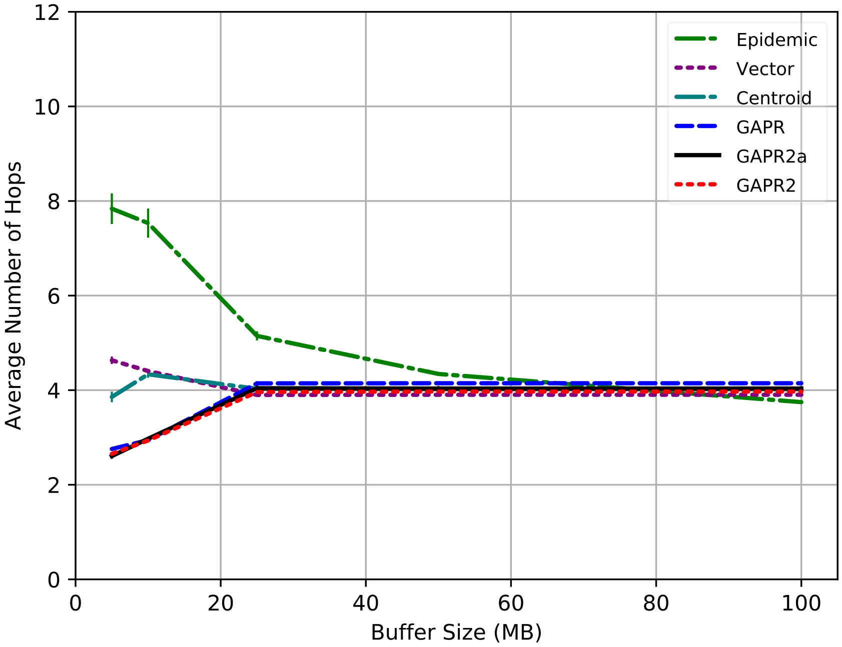
ONE Helsinki Average Hop Count for 12 Mbps Base Radio



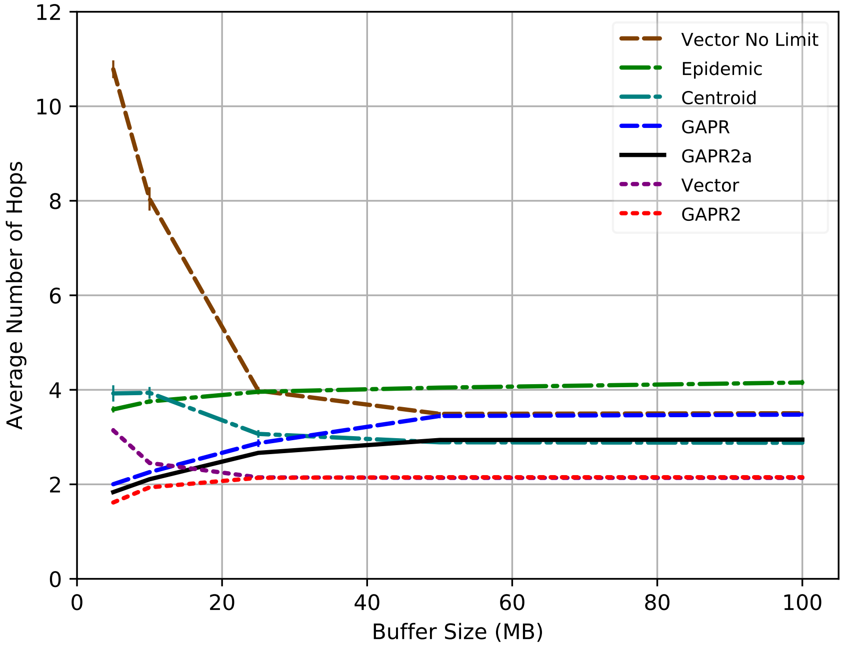
NS3 Helsinki Average Hop Count for 24 Mbps Base Radio



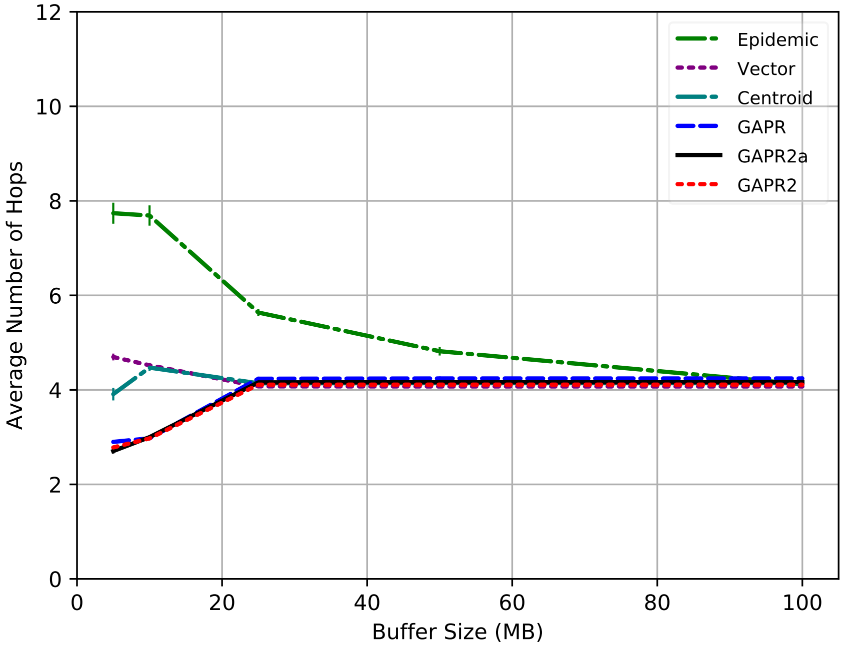
ONE Helsinki Average Hop Count for 24 Mbps Base Radio



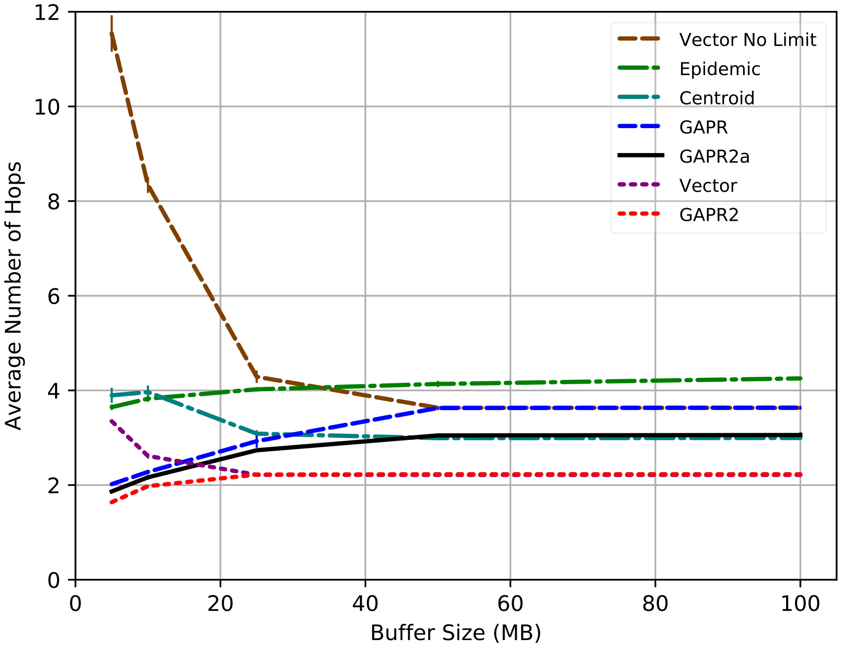
NS3 Helsinki Average Hop Count for 36 Mbps Base Radio



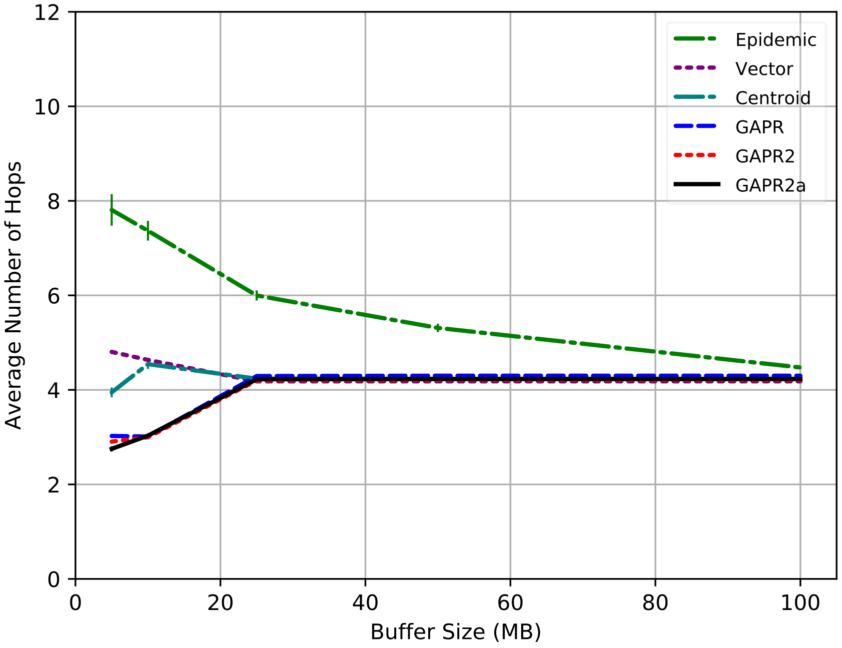
ONE Helsinki Average Hop Count for 36 Mbps Base Radio



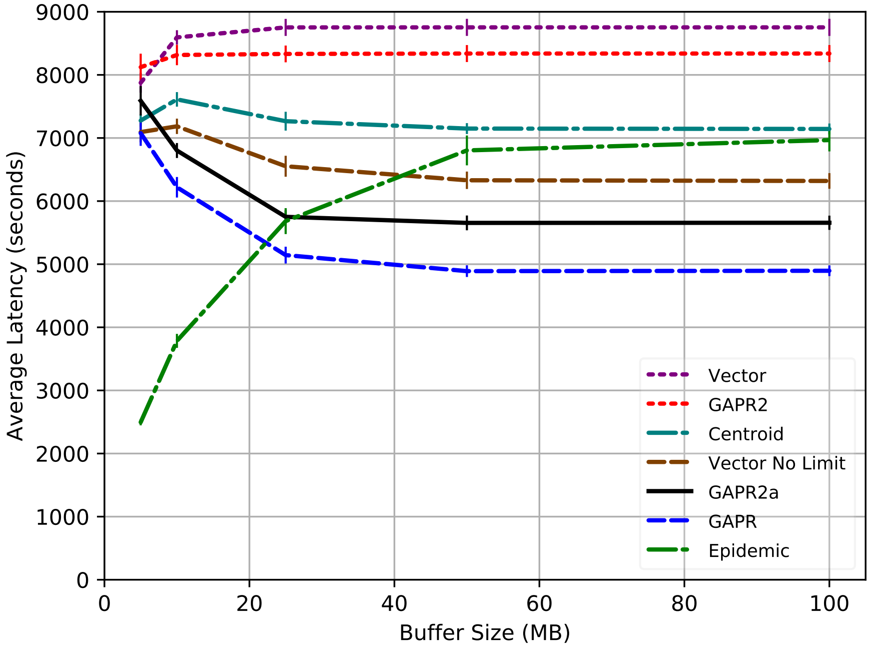
NS3 Helsinki Average Hop Count for 54 Mbps Base Radio



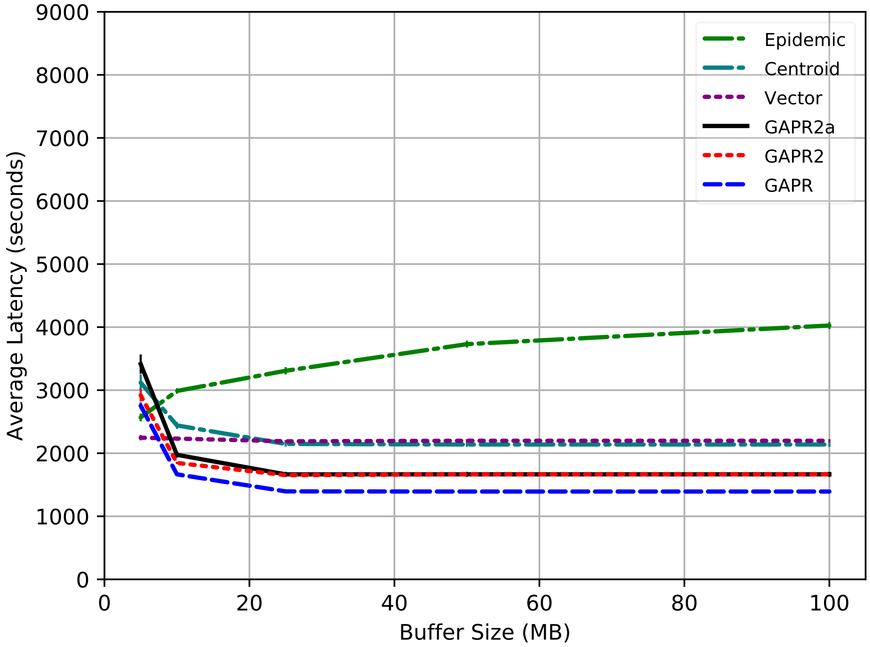
ONE Helsinki Average Hop Count for 54 Mbps Base Radio

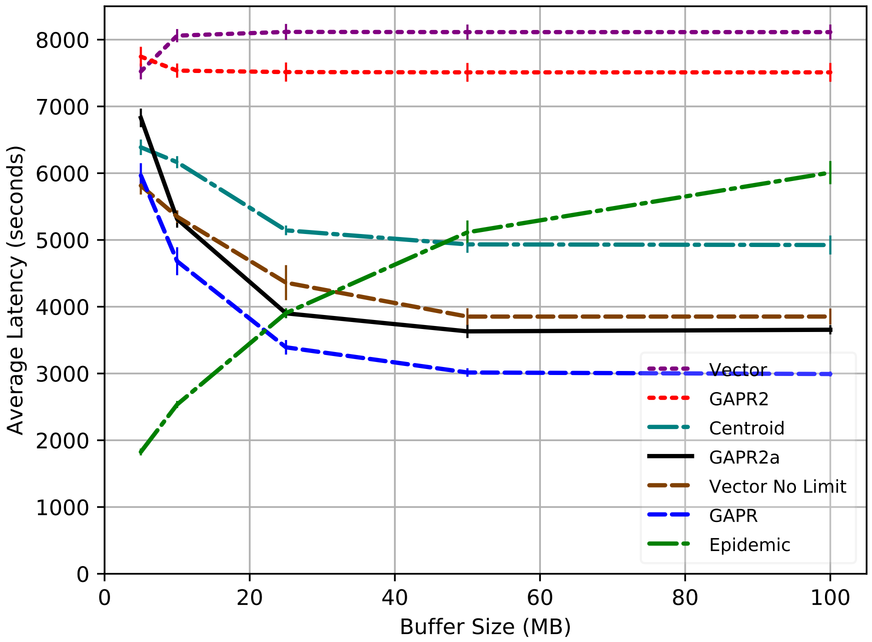


NS3 Helsinki Average Latency for 6 Mbps Base Radio

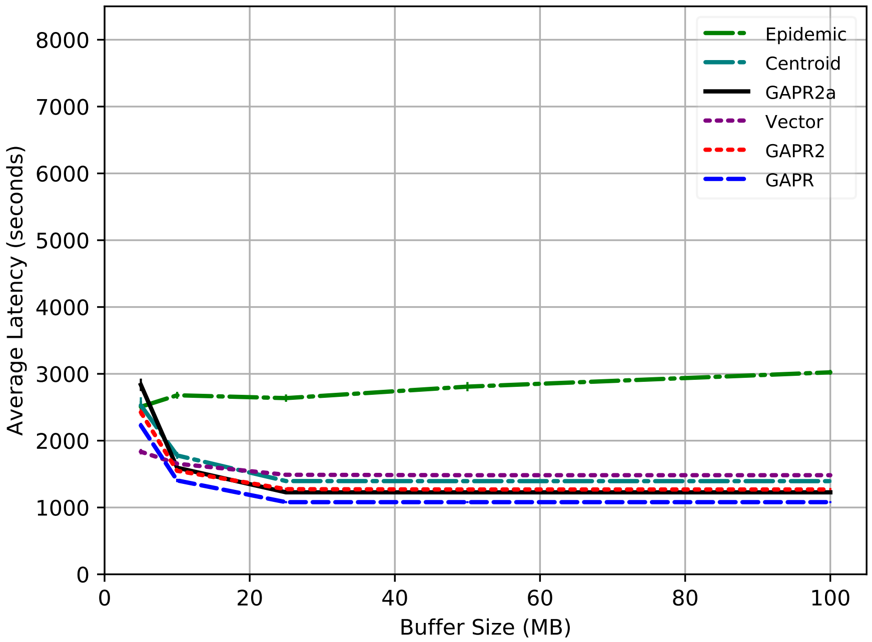


ONE Helsinki Average Latency for 6 Mbps Base Radio



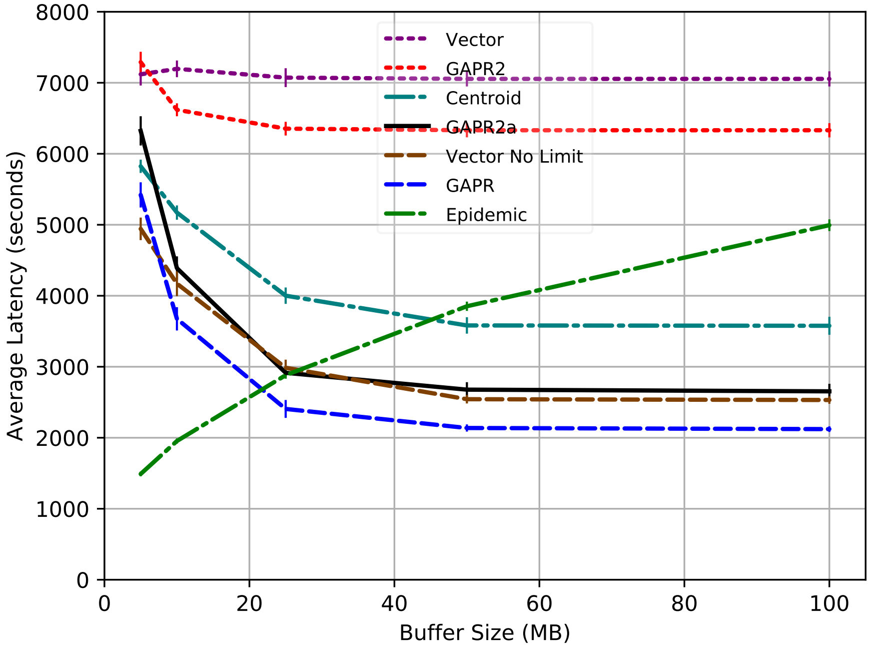


NS3 Helsinki Average Latency for 12 Mbps Base Radio

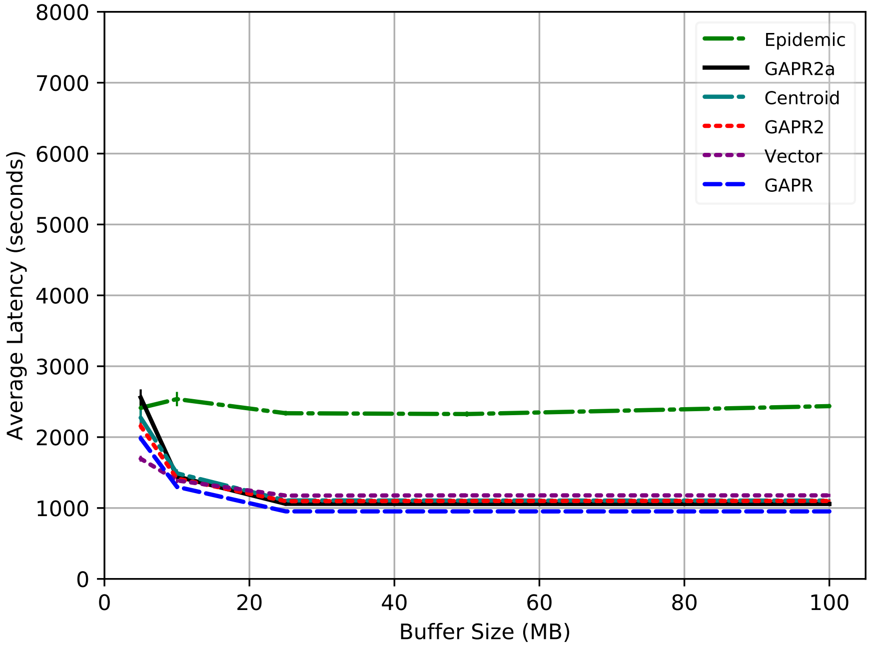


ONE Helsinki Average Latency for 12 Mbps Base Radio

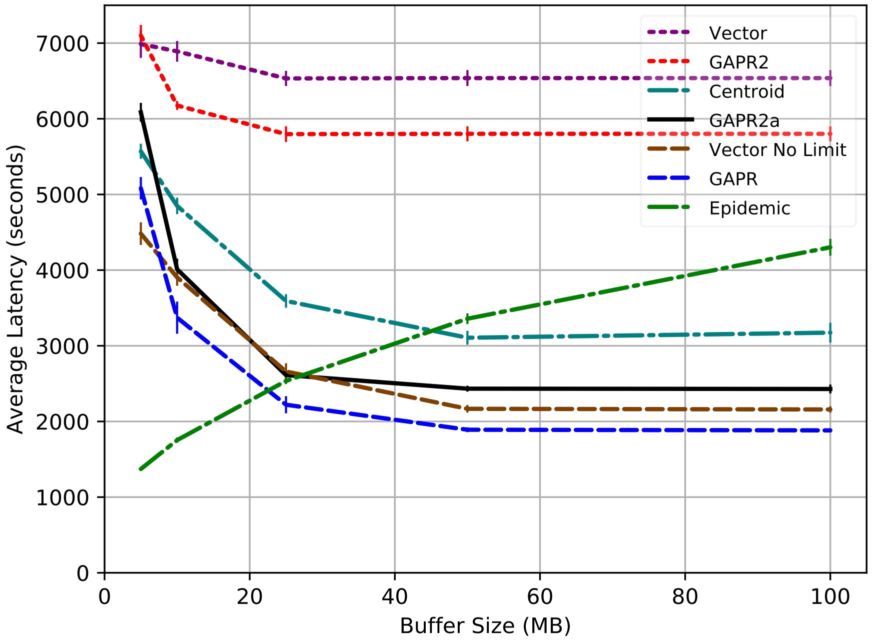
NS3 Helsinki Average Latency for 24 Mbps Base Radio



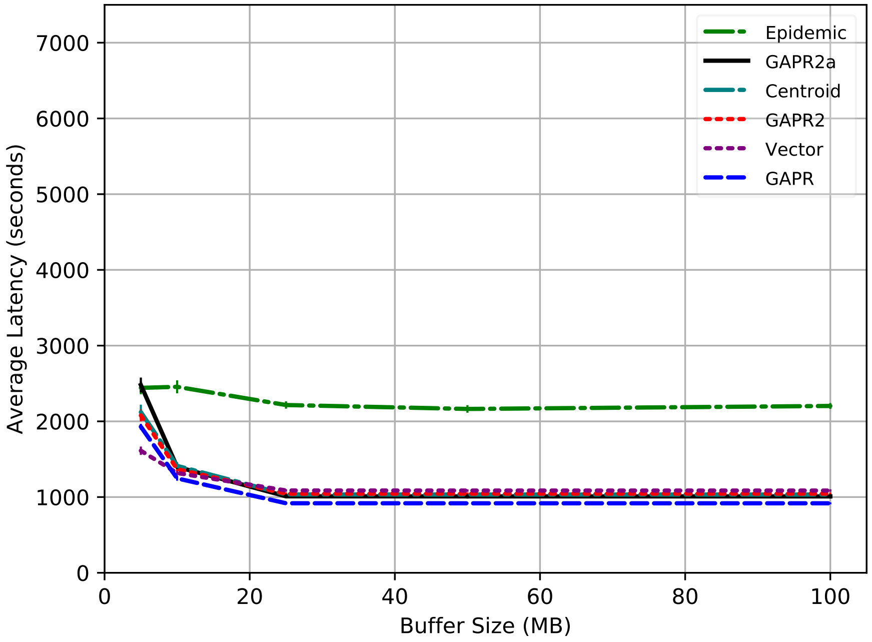
ONE Helsinki Average Latency for 24 Mbps Base Radio



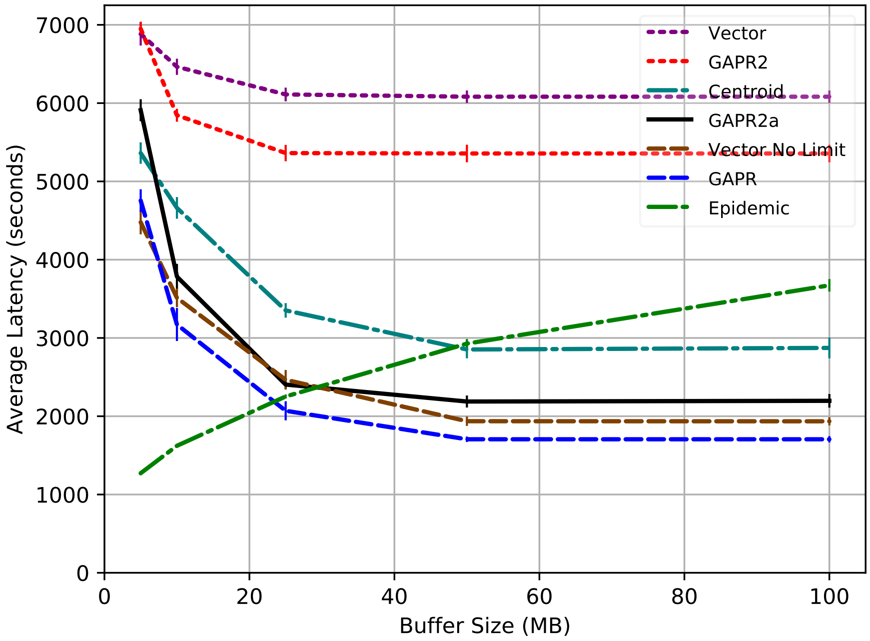
NS3 Helsinki Average Latency for 36 Mbps Base Radio



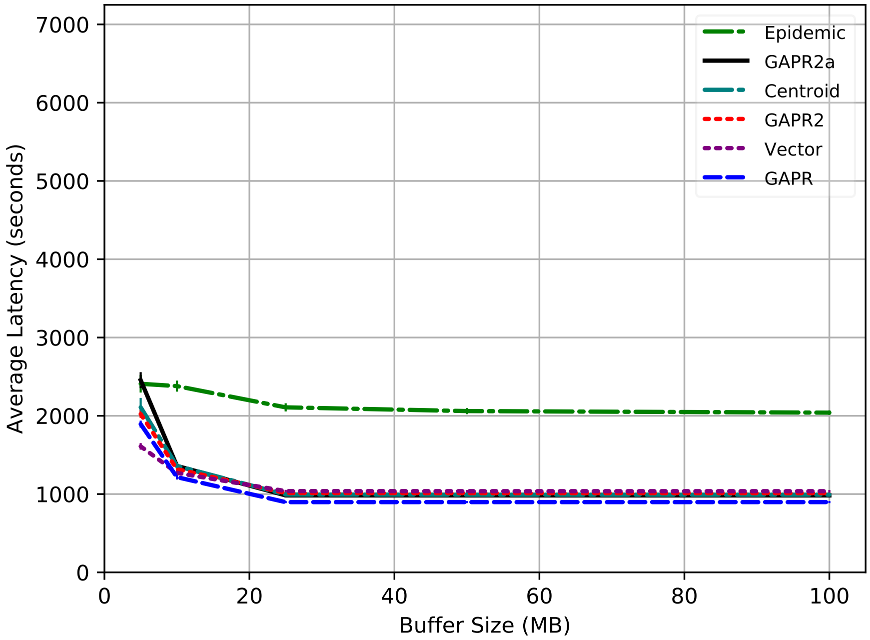
ONE Helsinki Average Latency for 36 Mbps Base Radio



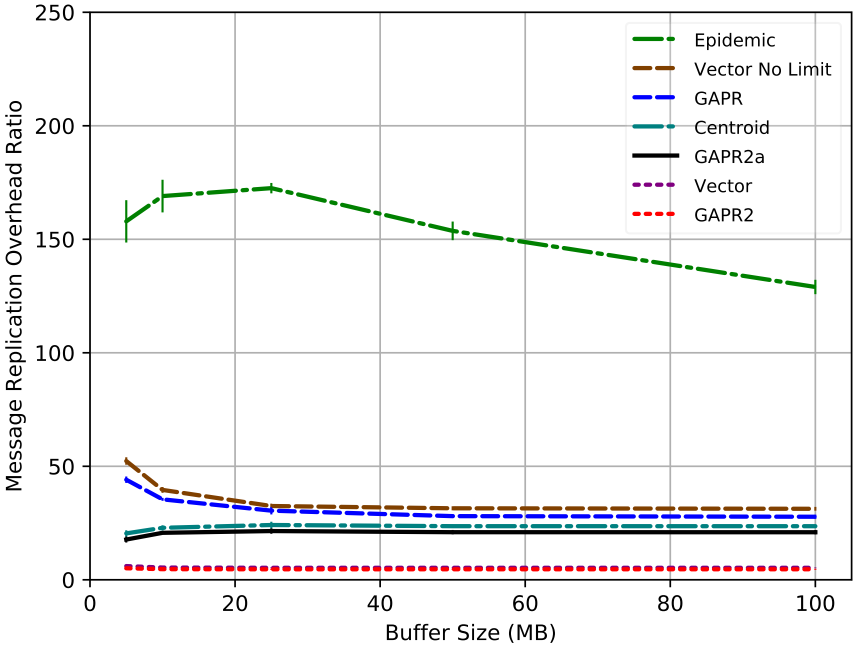
NS3 Helsinki Average Latency for 54 Mbps Base Radio



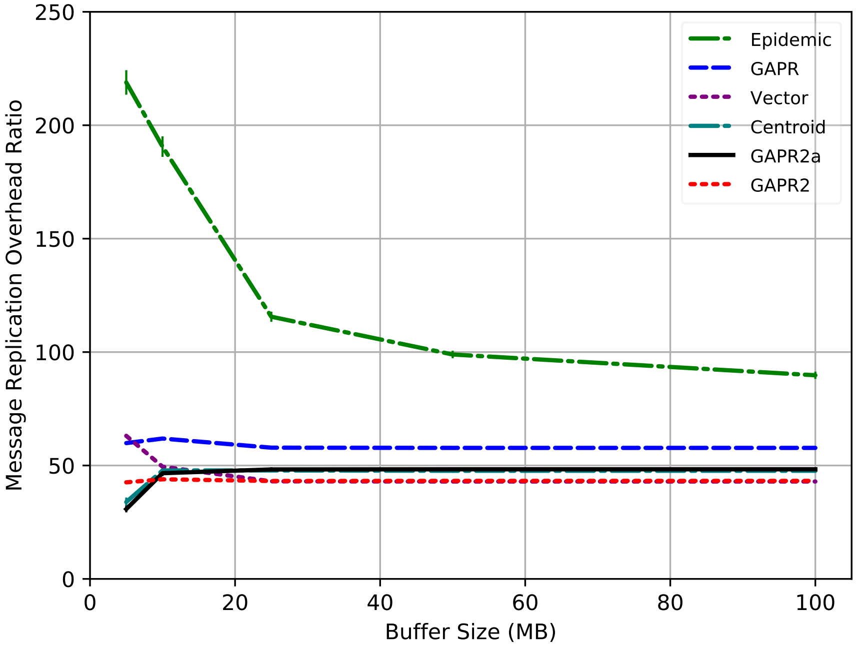
ONE Helsinki Average Latency for 54 Mbps Base Radio



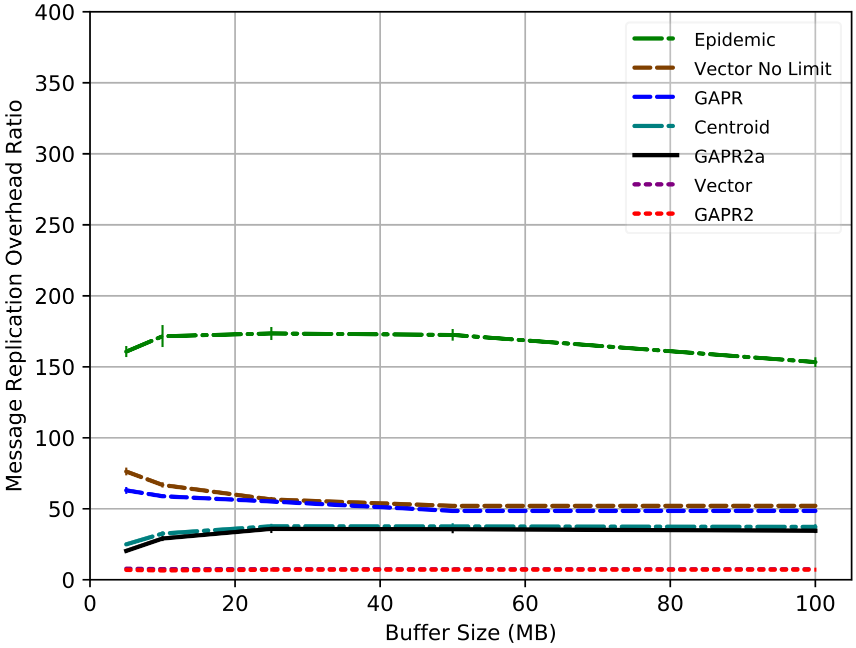
NS3 Helsinki Message Replication Overhead for 6 Mbps Base Radio



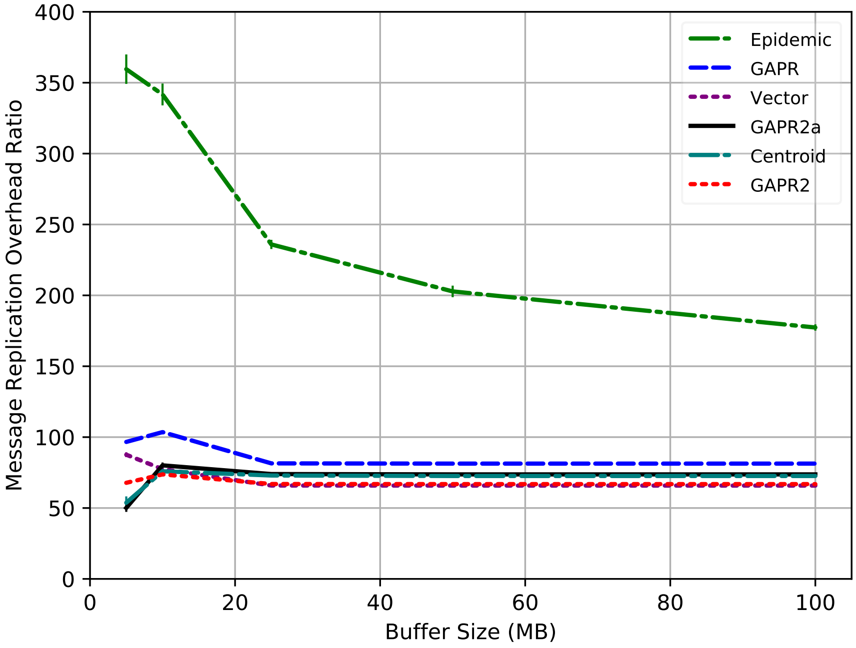
ONE Helsinki Message Replication Overhead for 6 Mbps Base Radio



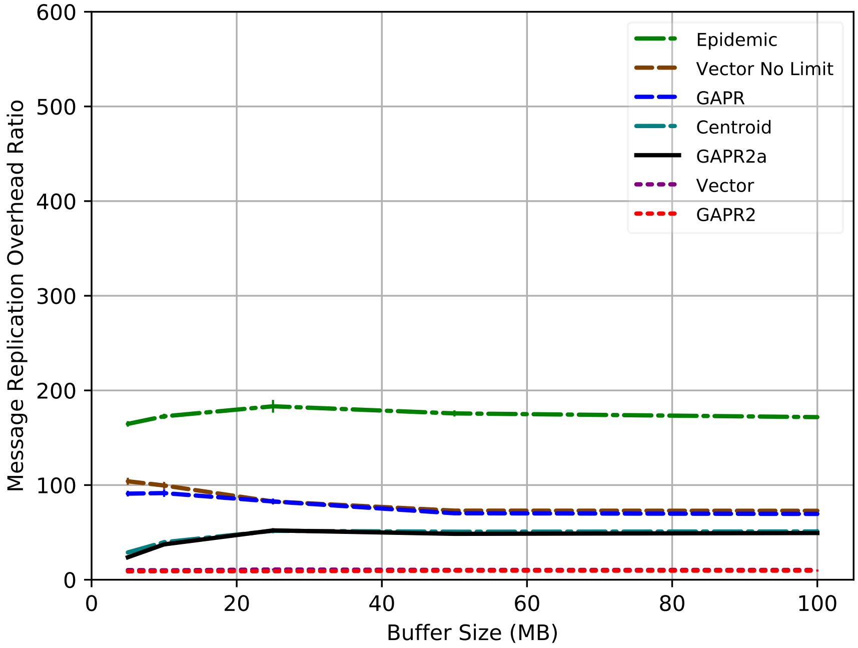
NS3 Helsinki Message Replication Overhead for 12 Mbps Base Radio



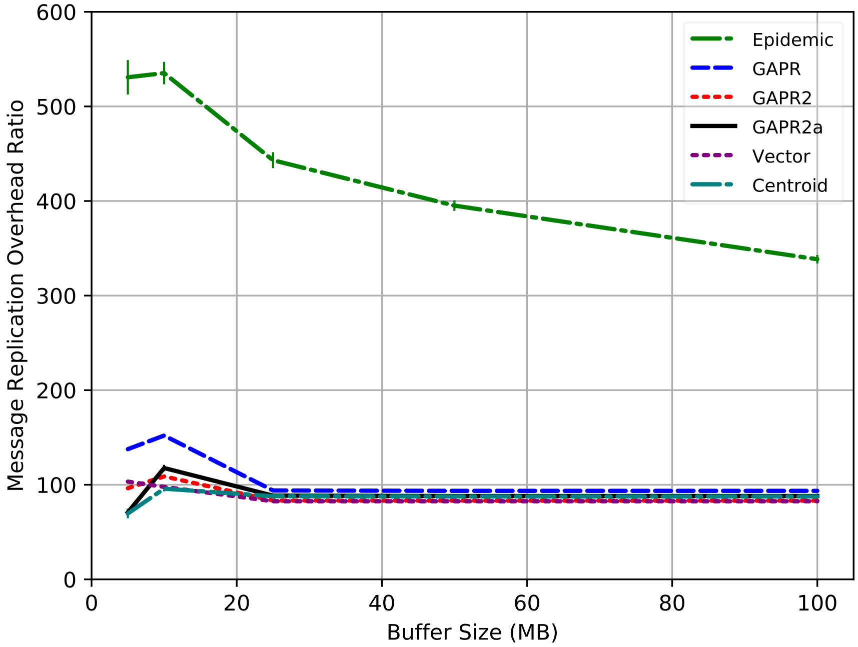
ONE Helsinki Message Replication Overhead for 12 Mbps Base Radio



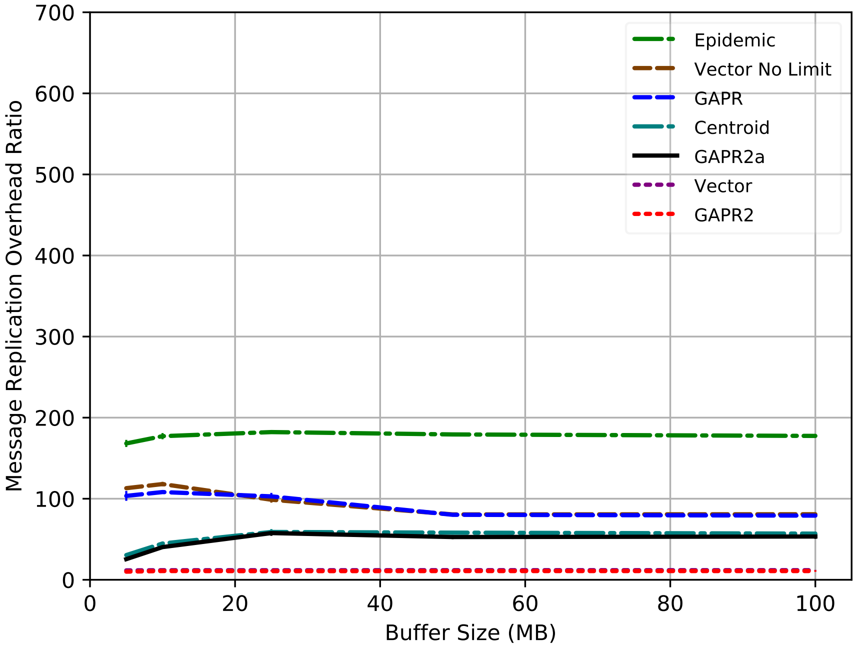
NS3 Helsinki Message Replication Overhead for 24 Mbps Base Radio



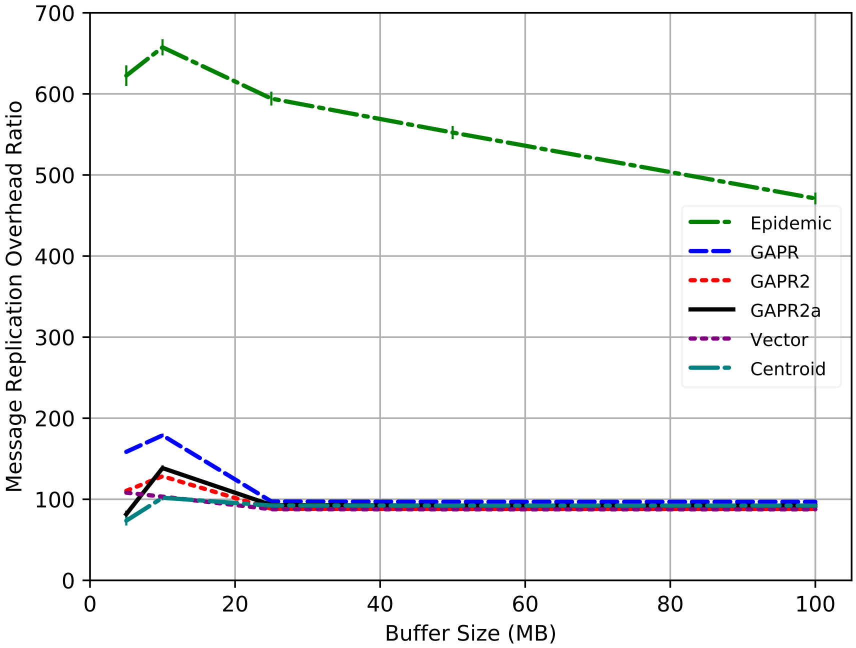
ONE Helsinki Message Replication Overhead for 24 Mbps Base Radio



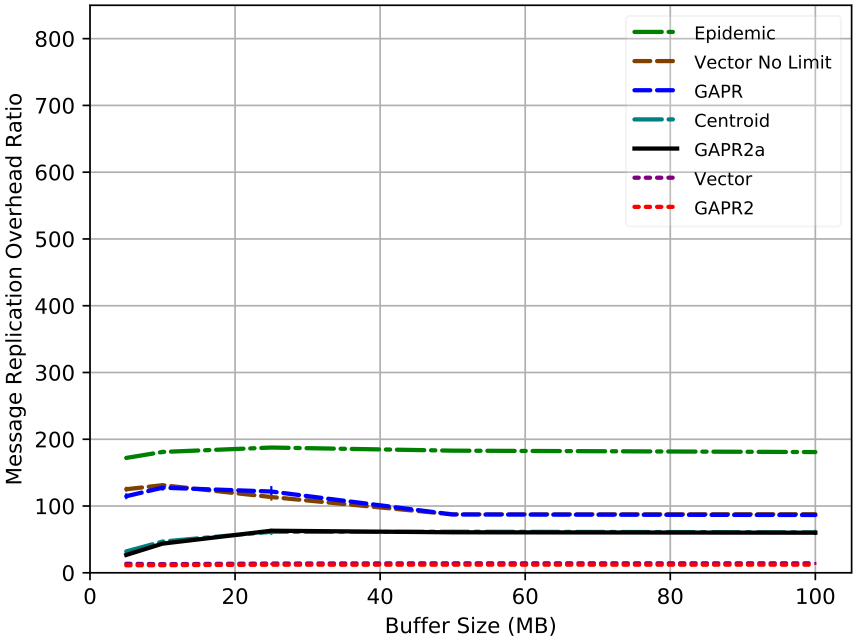
NS3 Helsinki Message Replication Overhead for 36 Mbps Base Radio



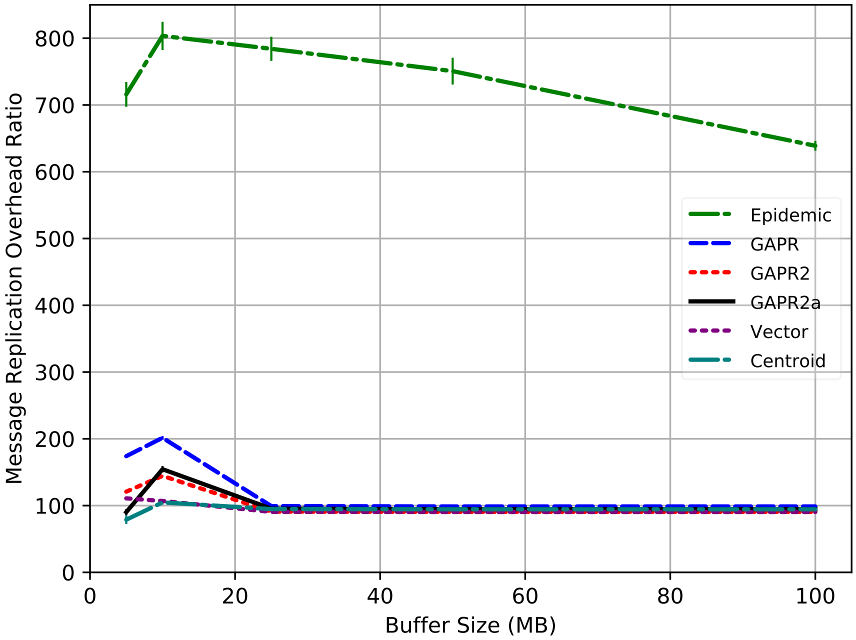
ONE Helsinki Message Replication Overhead for 36 Mbps Base Radio



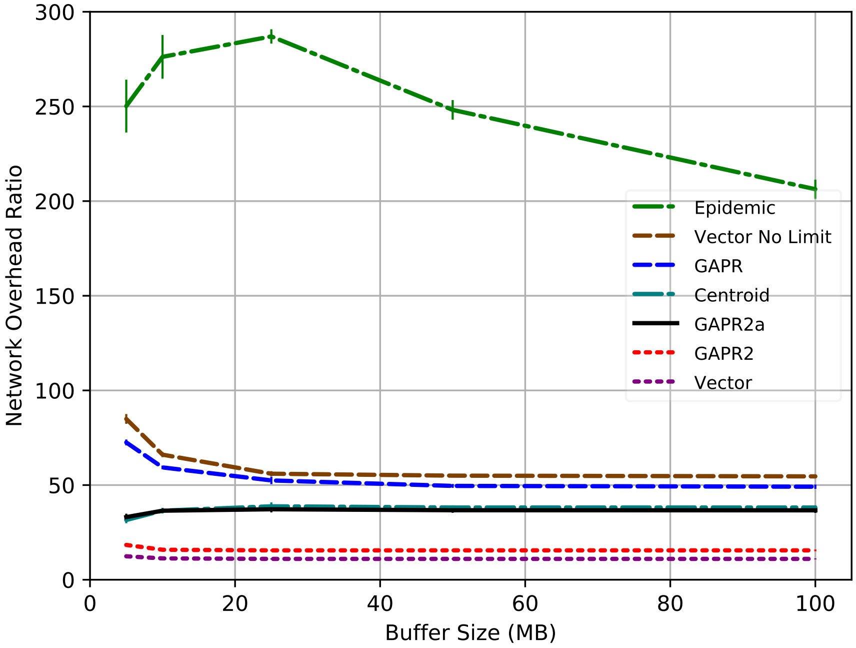
NS3 Helsinki Message Replication Overhead for 54 Mbps Base Radio



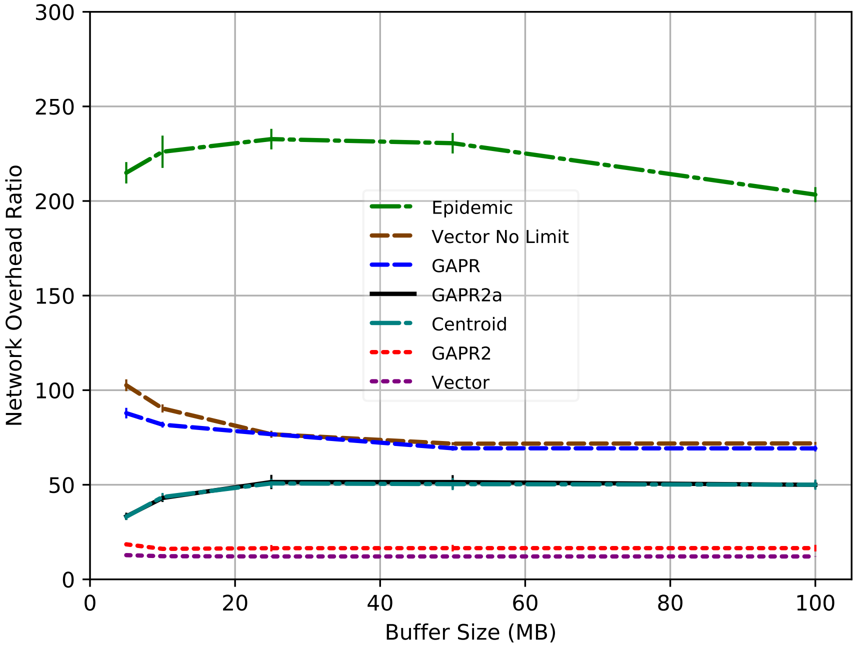
ONE Helsinki Message Replication Overhead for 54 Mbps Base Radio



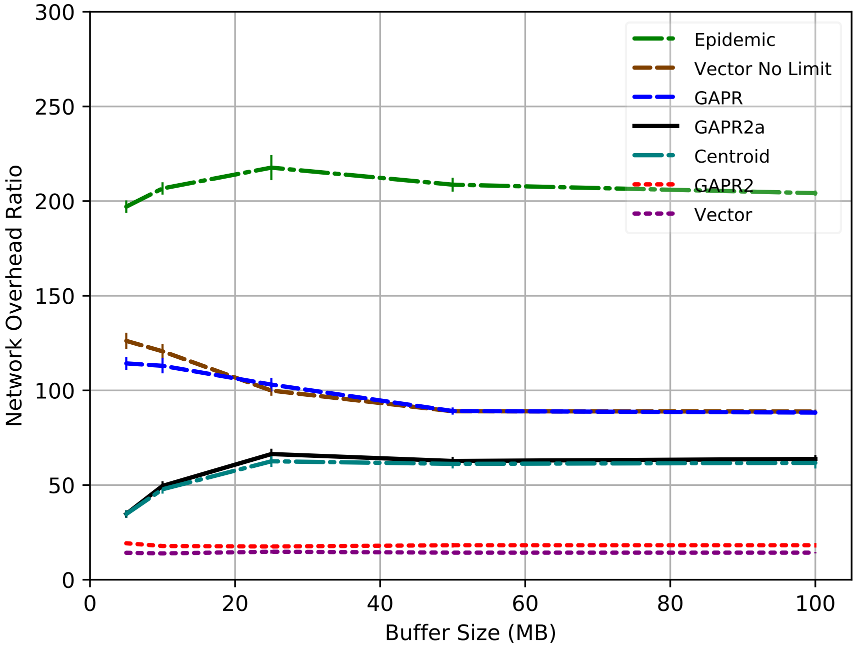
NS3 Helsinki Network Overhead for 6 Mbps Base Radio



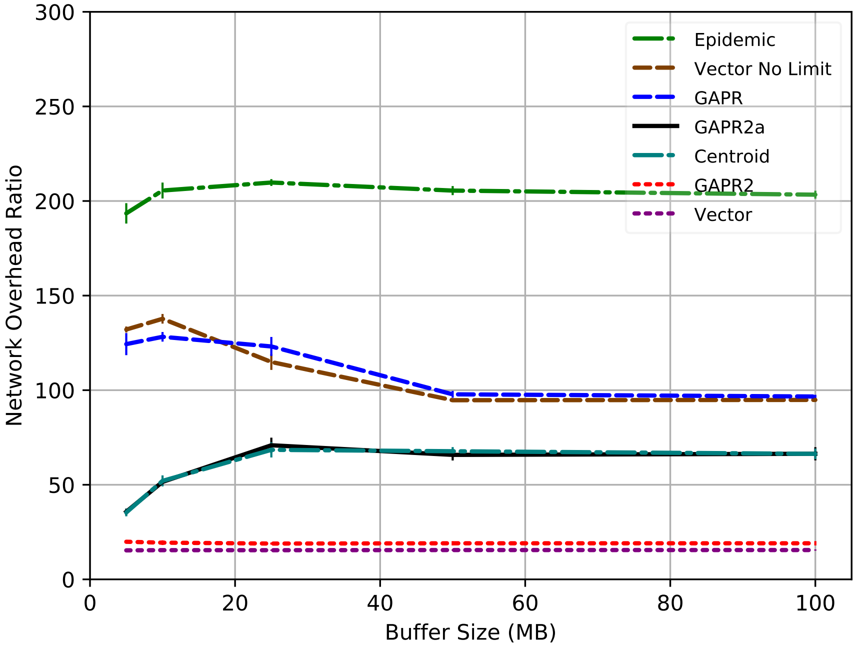
NS3 Helsinki Network Overhead for 12 Mbps Base Radio



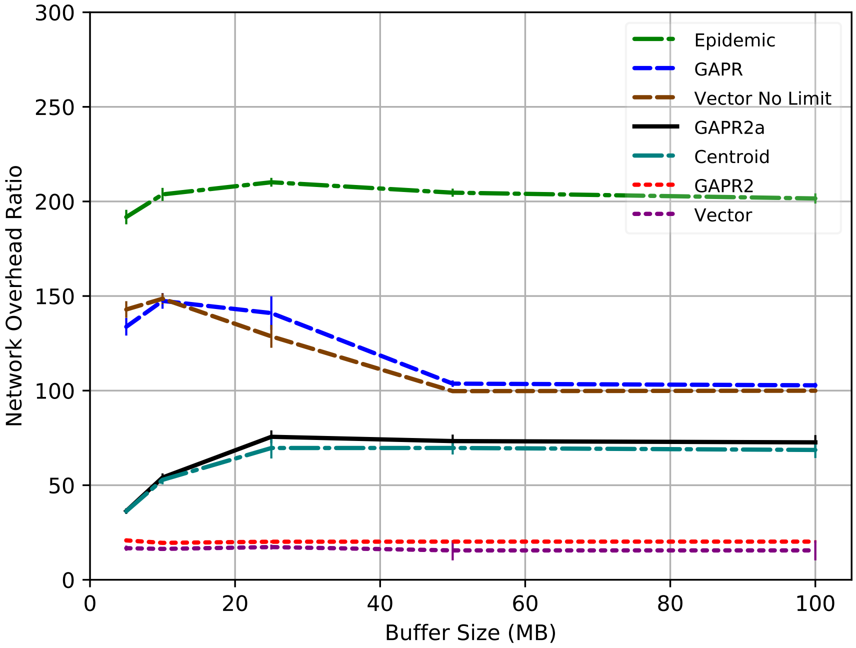
NS3 Helsinki Network Overhead for 24 Mbps Base Radio



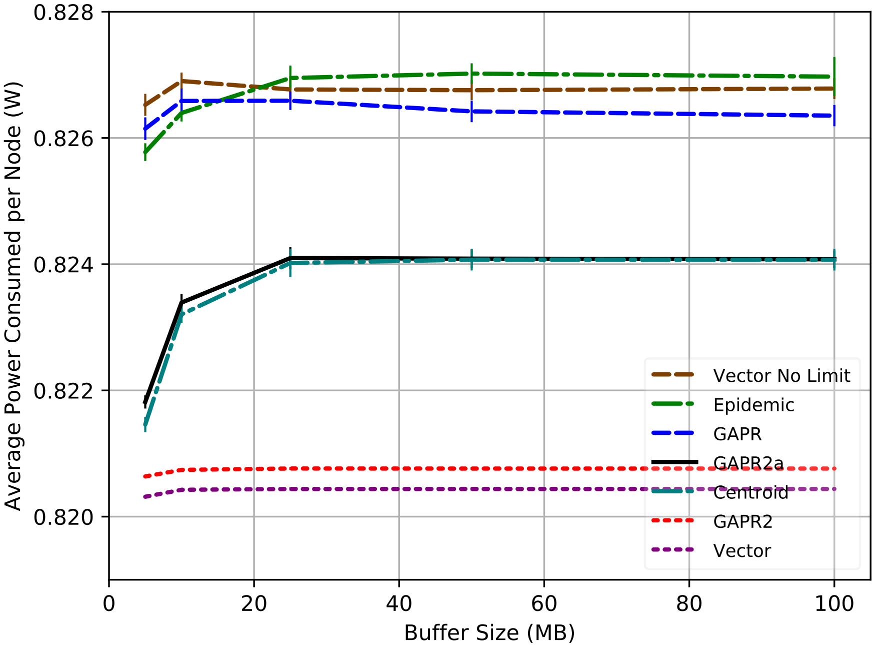
NS3 Helsinki Network Overhead for 36 Mbps Base Radio



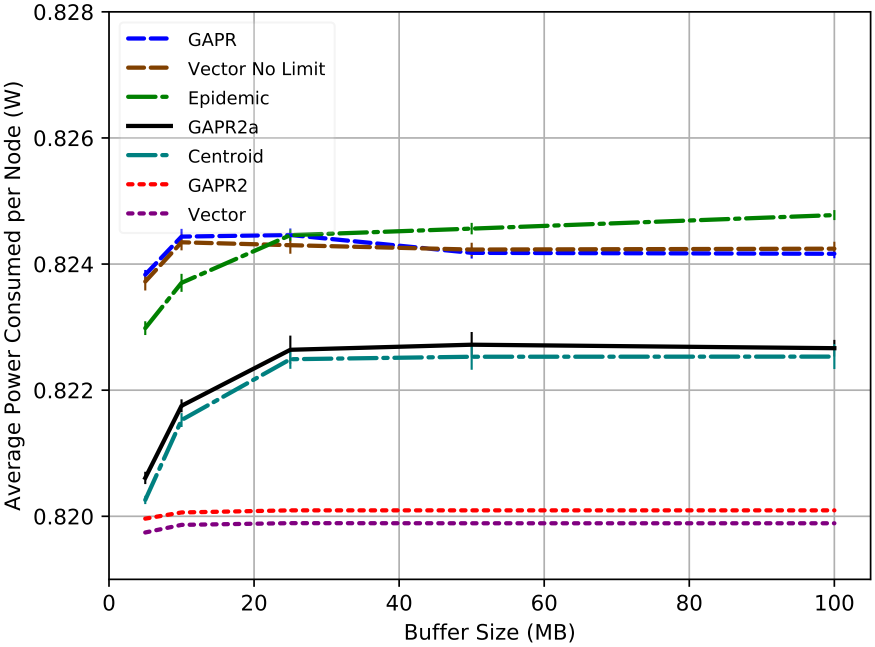
NS3 Helsinki Network Overhead for 54 Mbps Base Radio



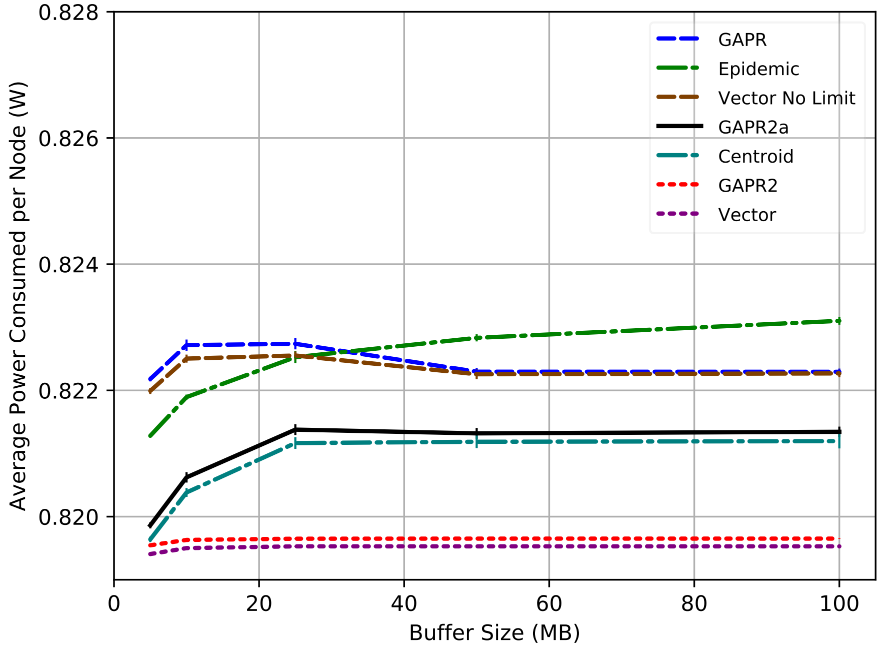
NS3 Helsinki Average Power Consumed per Node for 6 Mbps Base Radio



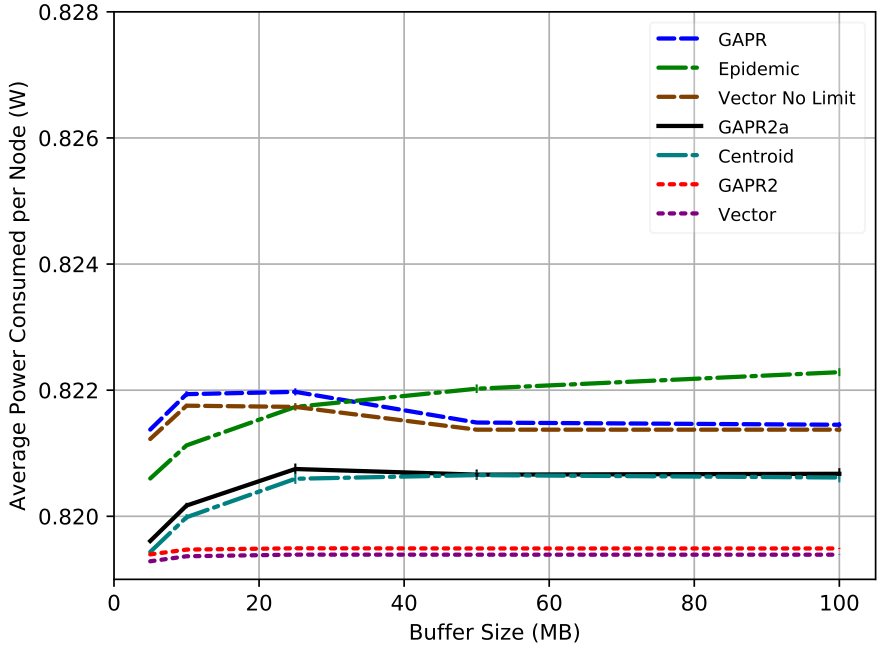
NS3 Helsinki Average Power Consumed per Node for 12 Mbps Base Radio



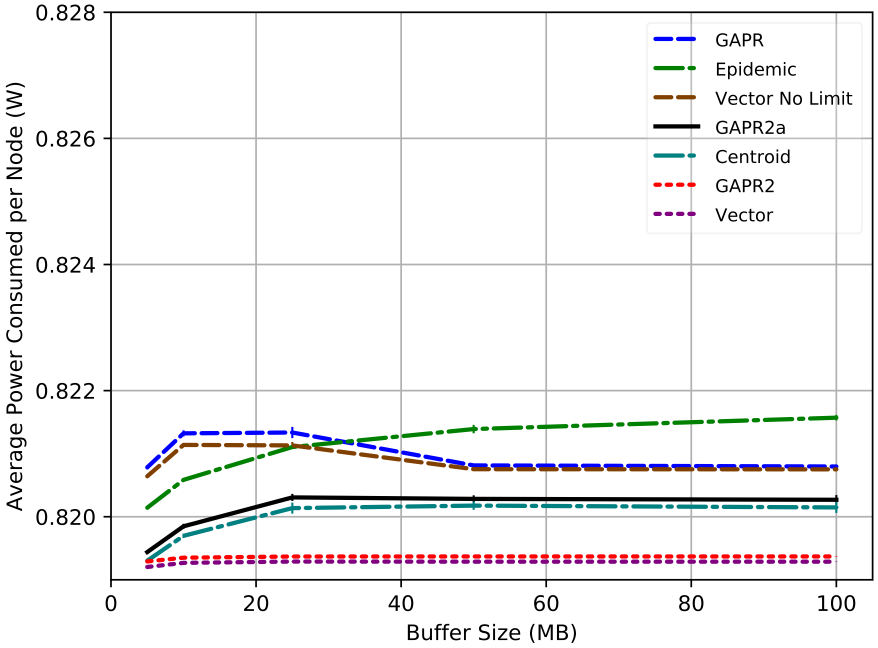
NS3 Helsinki Average Power Consumed per Node for 24 Mbps Base Radio



NS3 Helsinki Average Power Consumed per Node for 36 Mbps Base Radio

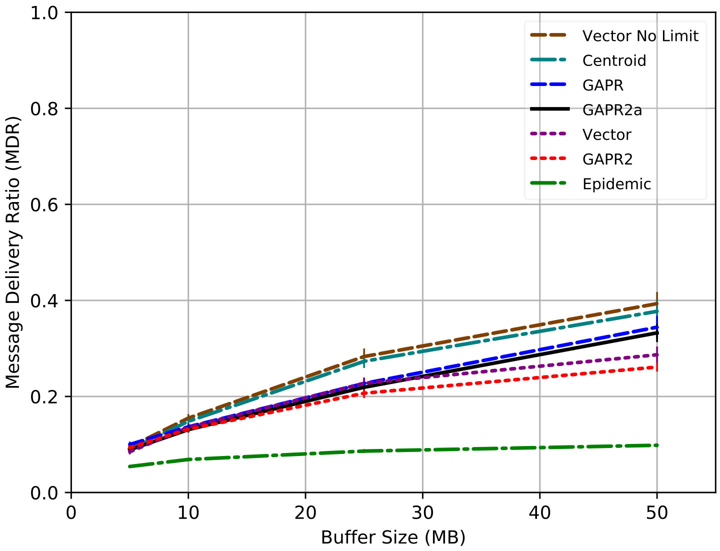


NS3 Helsinki Average Power Consumed per Node for 54 Mbps Base Radio

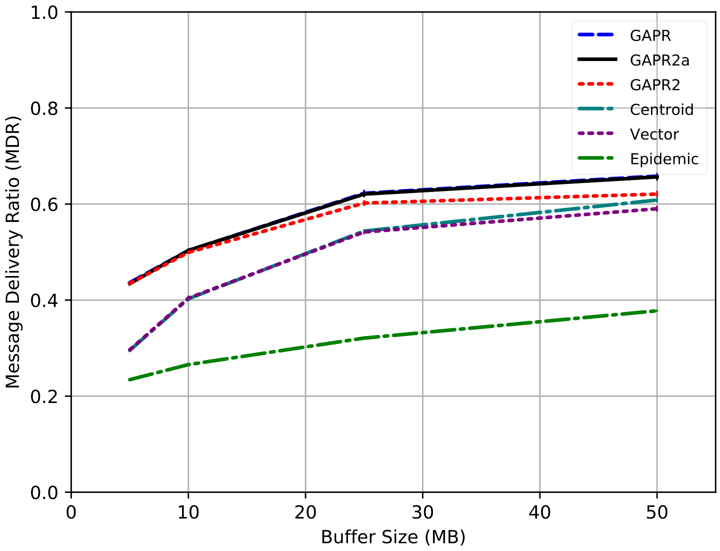


APPENDIX H:
Bold Alligator Figures

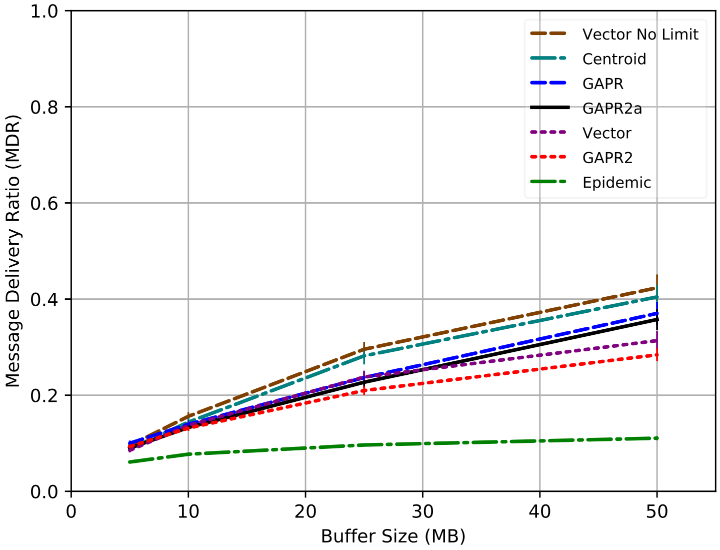
NS3 Bold Alligator MDR for 12 Mbps Base Radio



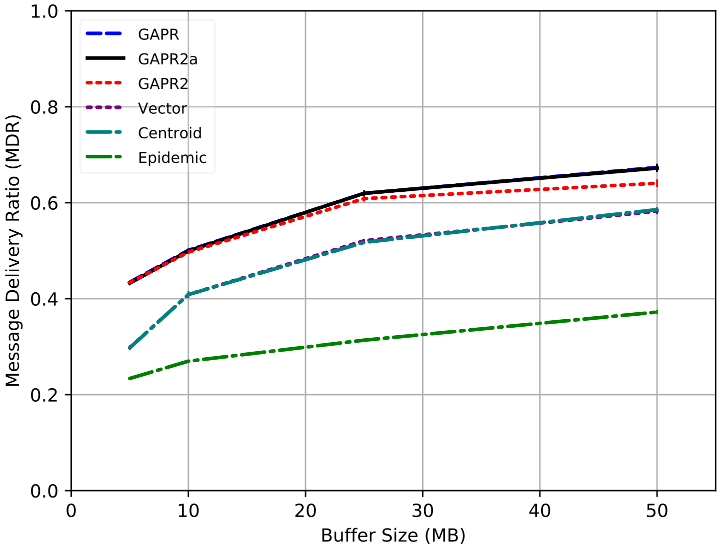
ONE Bold Alligator MDR for 12 Mbps Base Radio



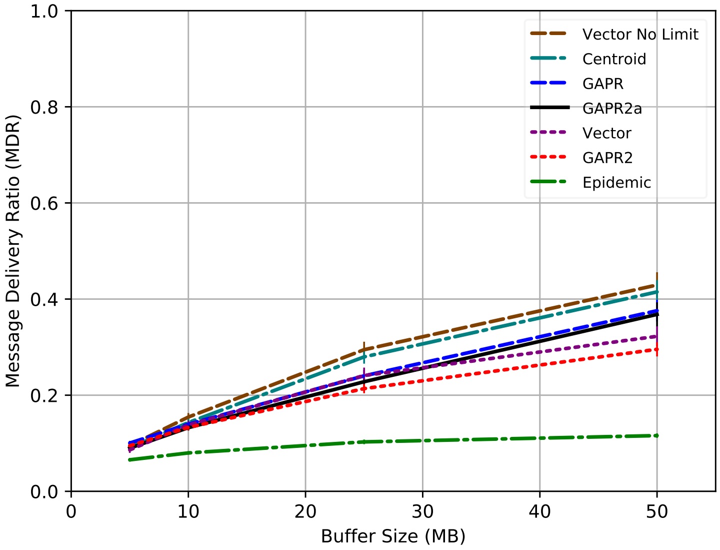
NS3 Bold Alligator MDR for 24 Mbps Base Radio



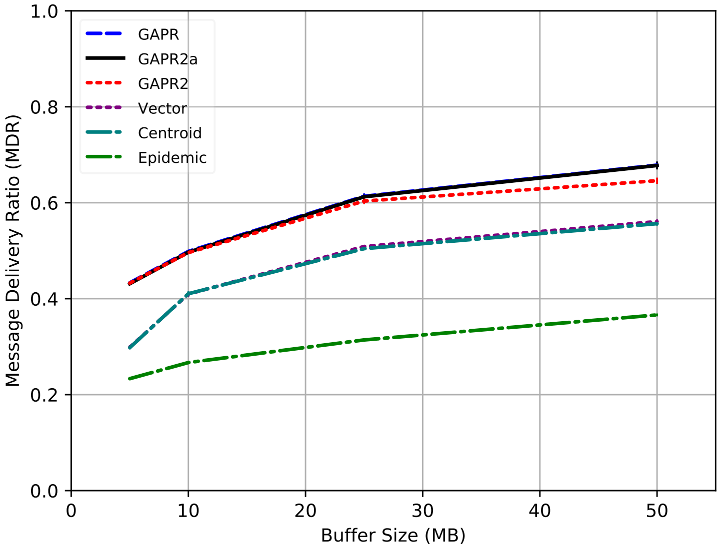
ONE Bold Alligator MDR for 24 Mbps Base Radio



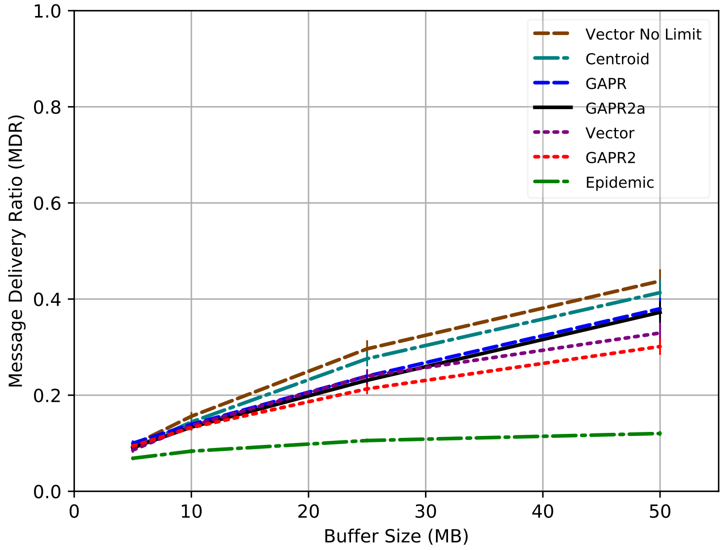
NS3 Bold Alligator MDR for 36 Mbps Base Radio



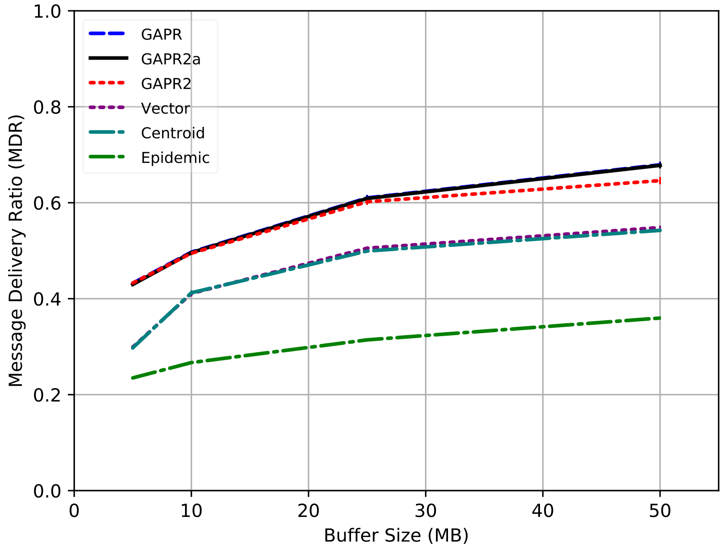
ONE Bold Alligator MDR for 36 Mbps Base Radio



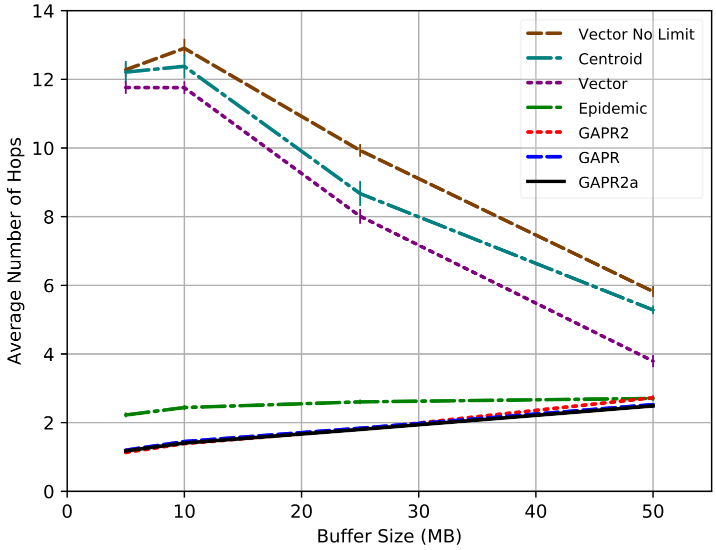
NS3 Bold Alligator MDR for 54 Mbps Base Radio



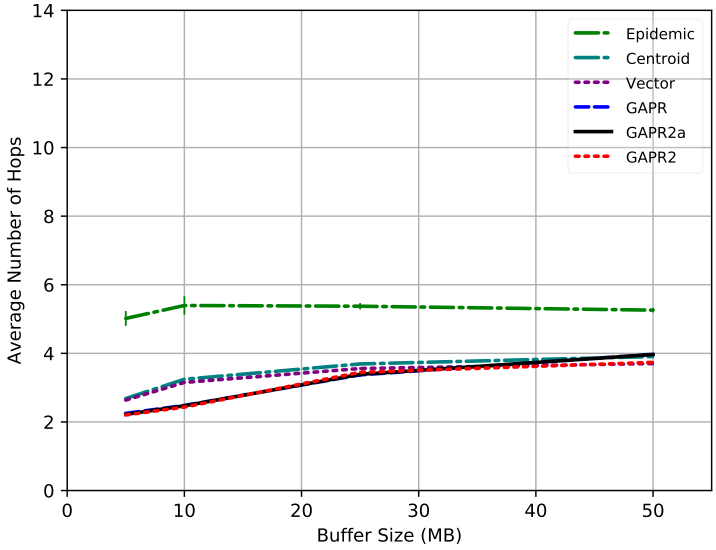
ONE Bold Alligator MDR for 54 Mbps Base Radio



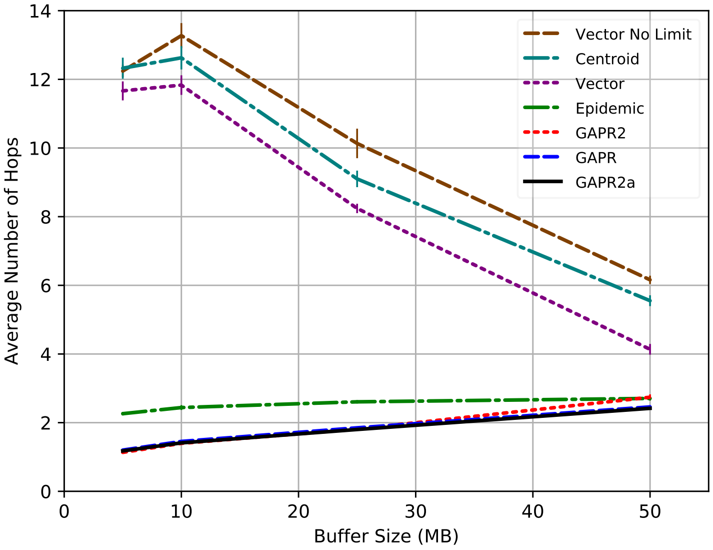
NS3 Bold Alligator Average Hop Count for 12 Mbps Base Radio



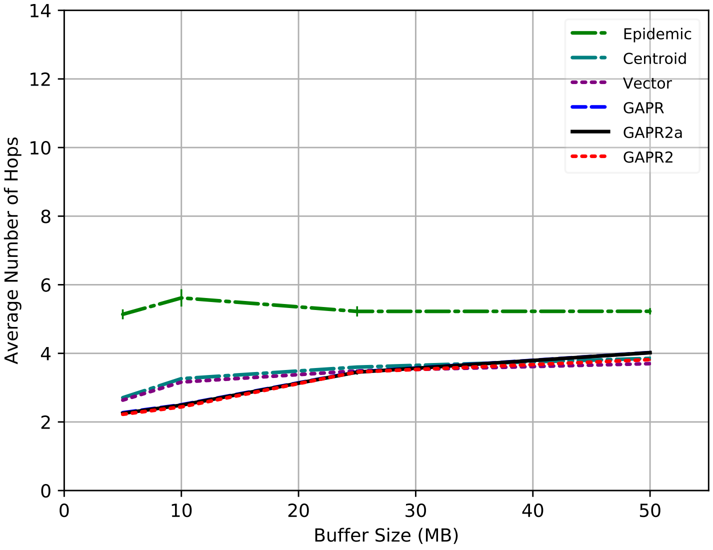
ONE Bold Alligator Average Hop Count for 12 Mbps Base Radio



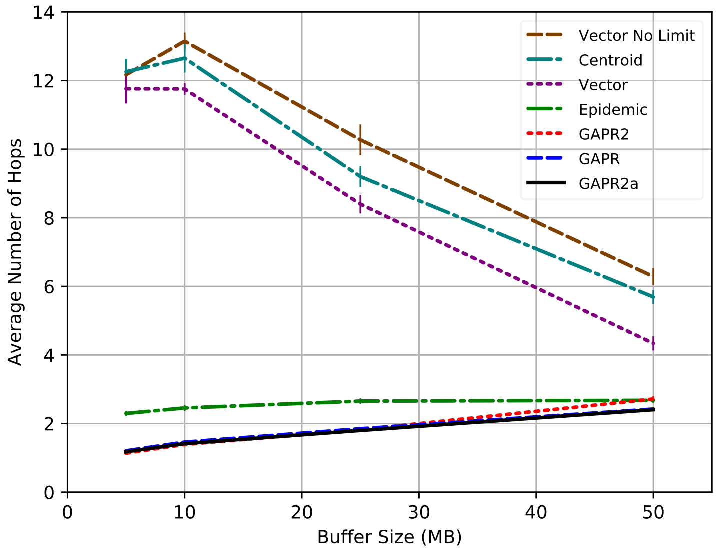
NS3 Bold Alligator Average Hop Count for 24 Mbps Base Radio



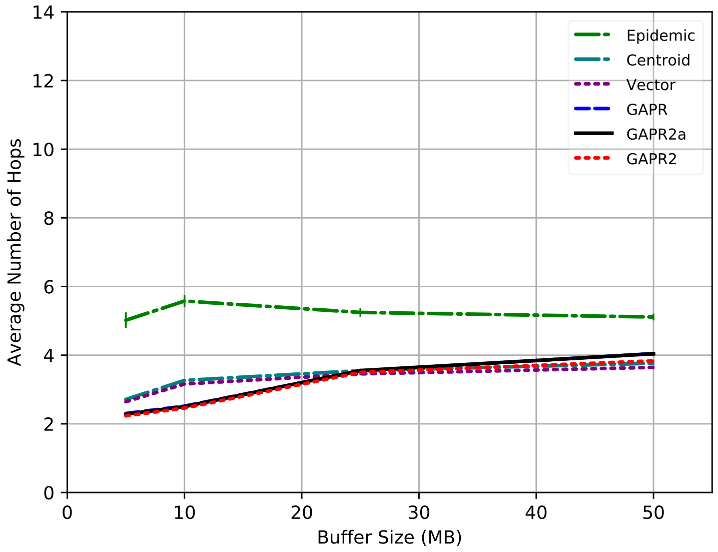
ONE Bold Alligator Average Hop Count for 24 Mbps Base Radio



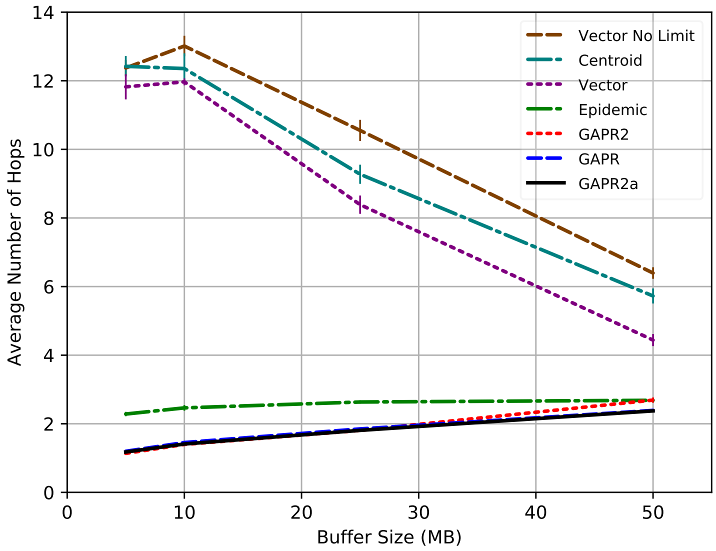
NS3 Bold Alligator Average Hop Count for 36 Mbps Base Radio



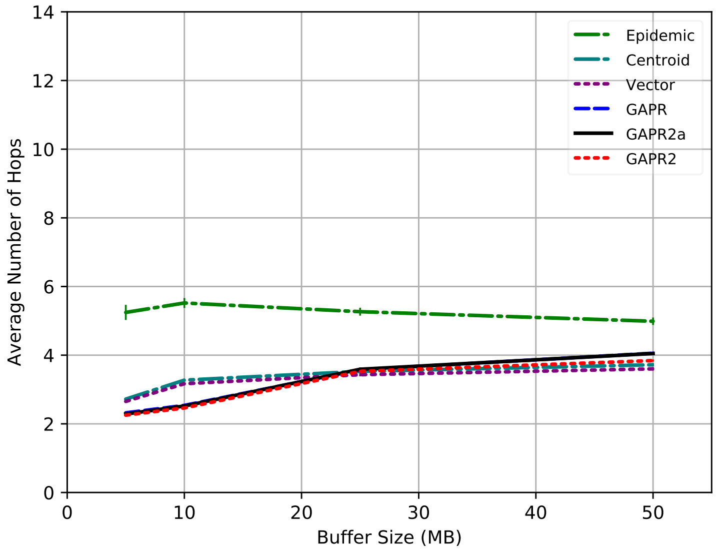
ONE Bold Alligator Average Hop Count for 36 Mbps Base Radio



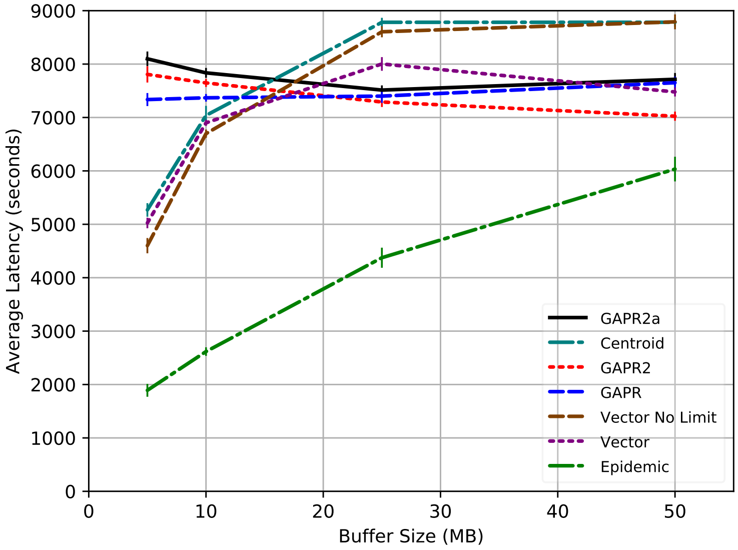
NS3 Bold Alligator Average Hop Count for 54 Mbps Base Radio



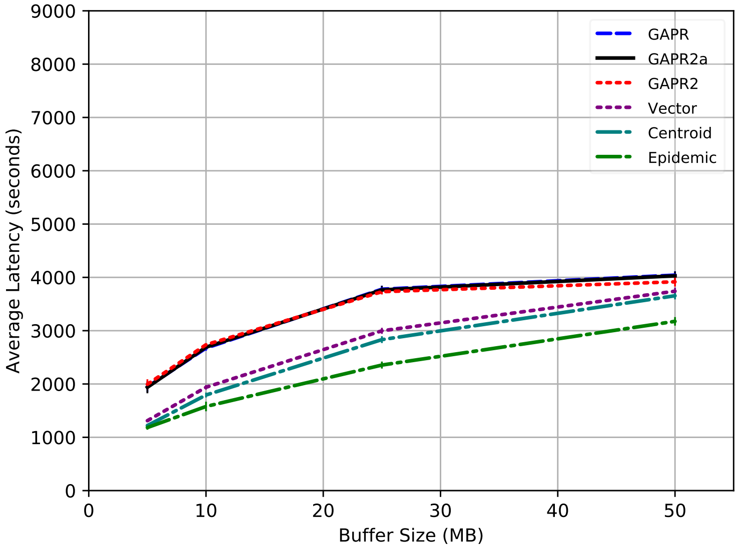
ONE Bold Alligator Average Hop Count for 54 Mbps Base Radio



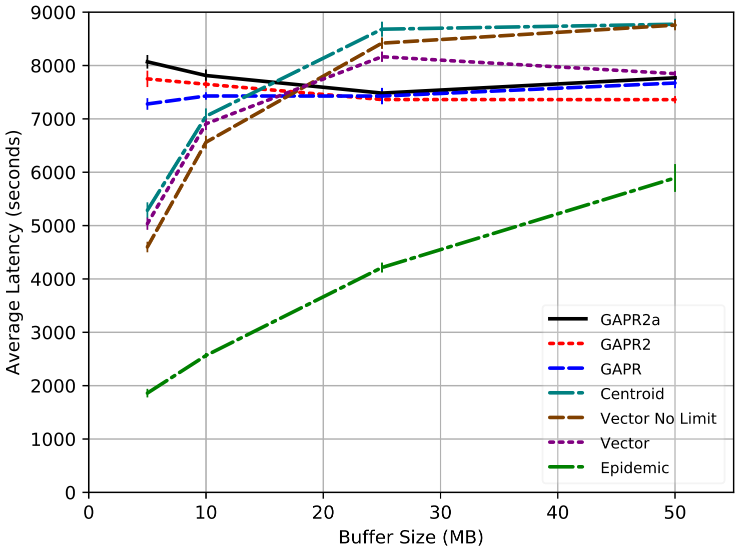
NS3 Bold Alligator Average Latency for 12 Mbps Base Radio



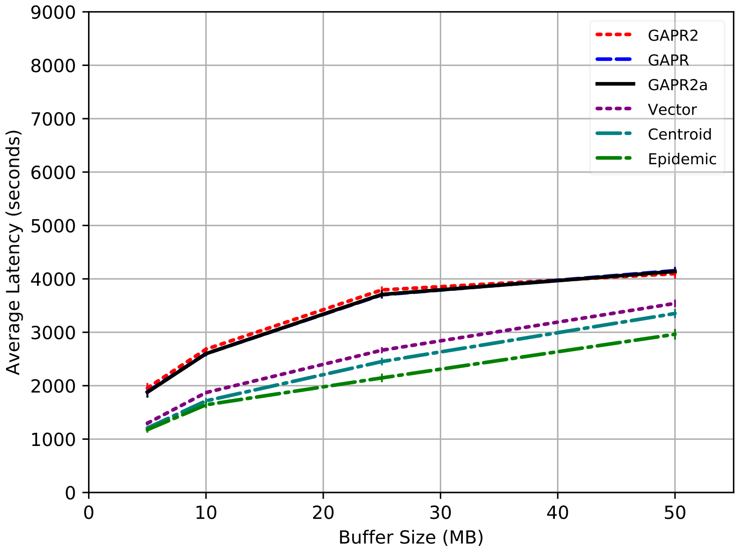
ONE Bold Alligator Average Latency for 12 Mbps Base Radio



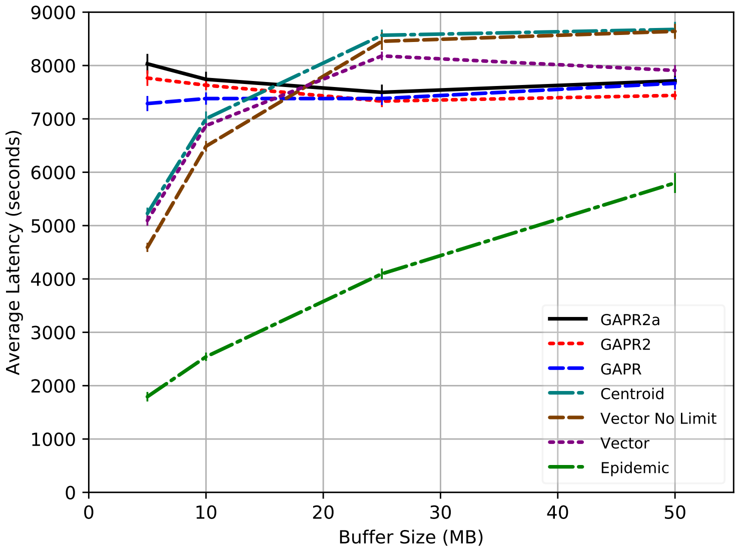
NS3 Bold Alligator Average Latency for 24 Mbps Base Radio



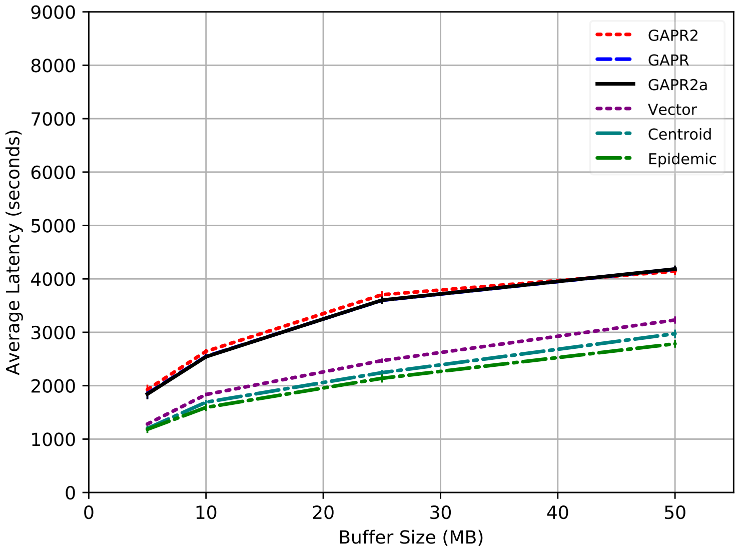
ONE Bold Alligator Average Latency for 24 Mbps Base Radio



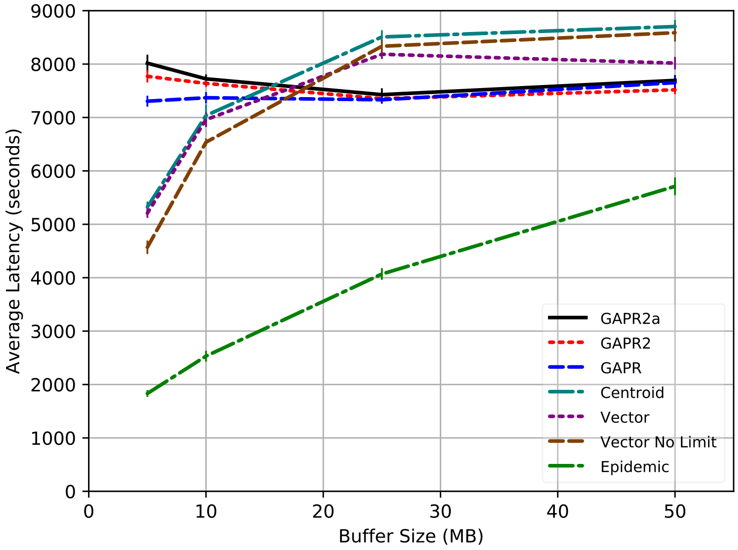
NS3 Bold Alligator Average Latency for 36 Mbps Base Radio



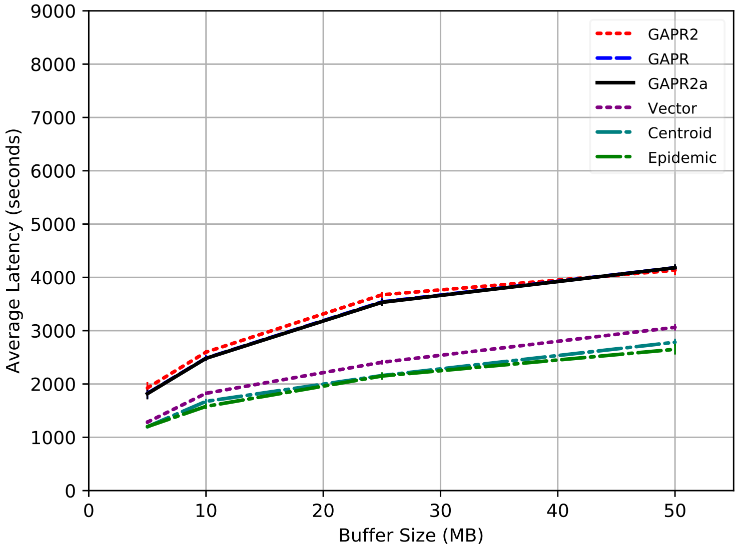
ONE Bold Alligator Average Latency for 36 Mbps Base Radio



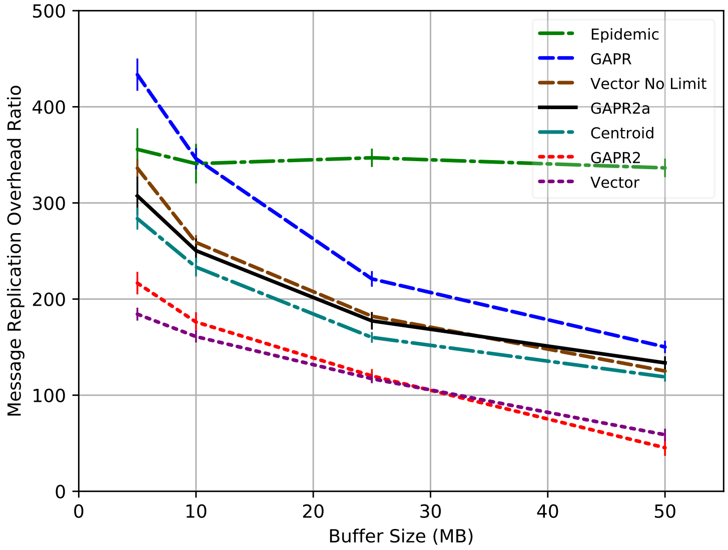
NS3 Bold Alligator Average Latency for 54 Mbps Base Radio



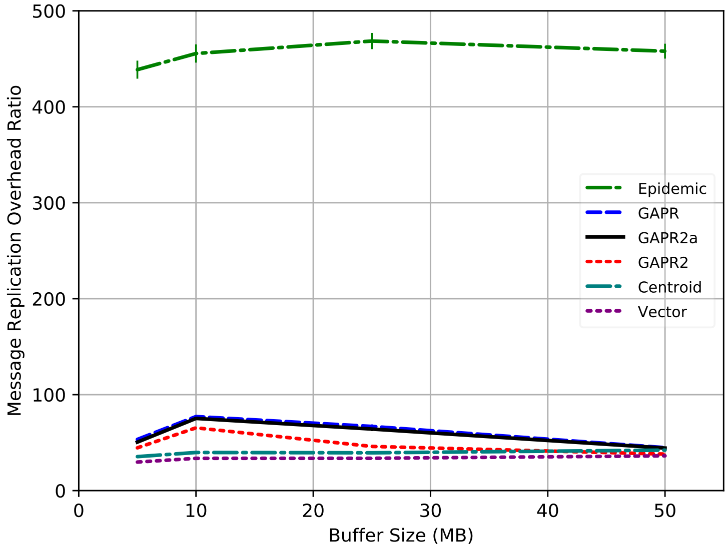
ONE Bold Alligator Average Latency for 54 Mbps Base Radio



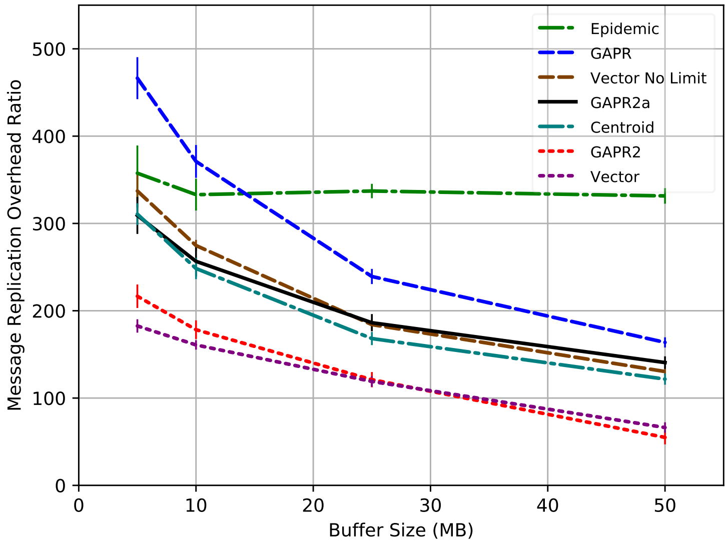
NS3 Bold Alligator Message Replication Overhead for 12 Mbps Base Radio



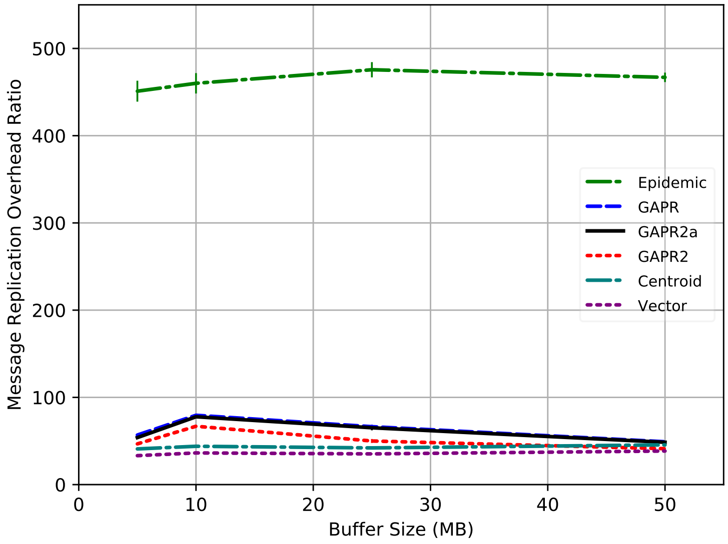
ONE Bold Alligator Message Replication Overhead for 12 Mbps Base Radio



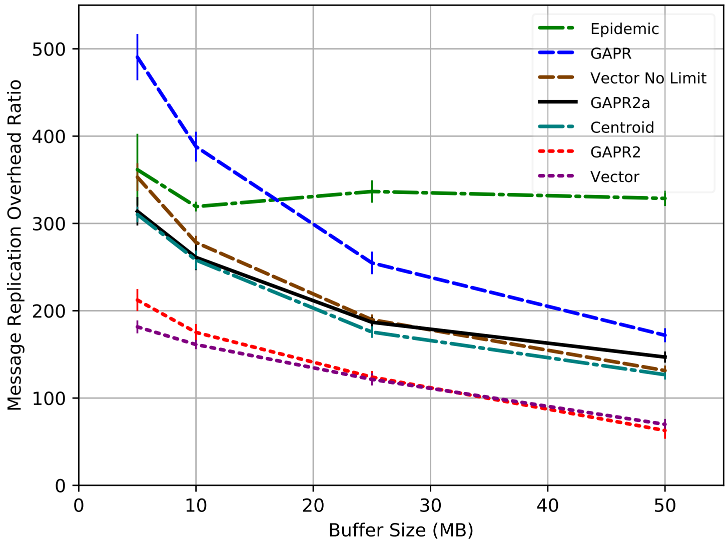
NS3 Bold Alligator Message Replication Overhead for 24 Mbps Base Radio



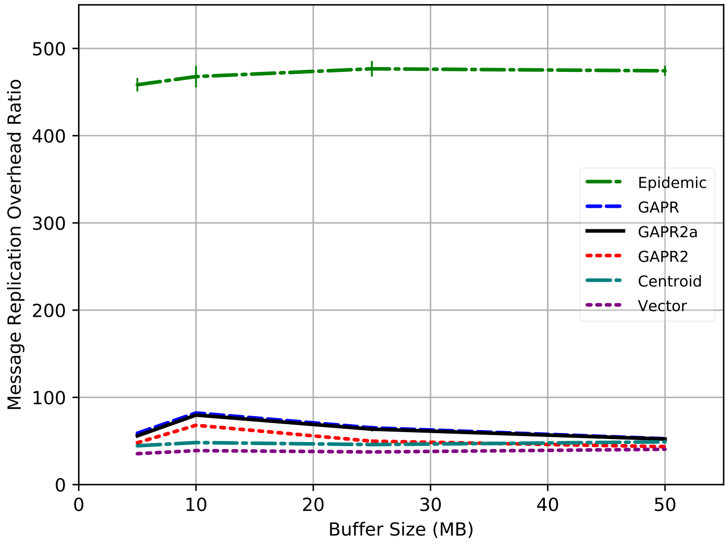
ONE Bold Alligator Message Replication Overhead for 24 Mbps Base Radio



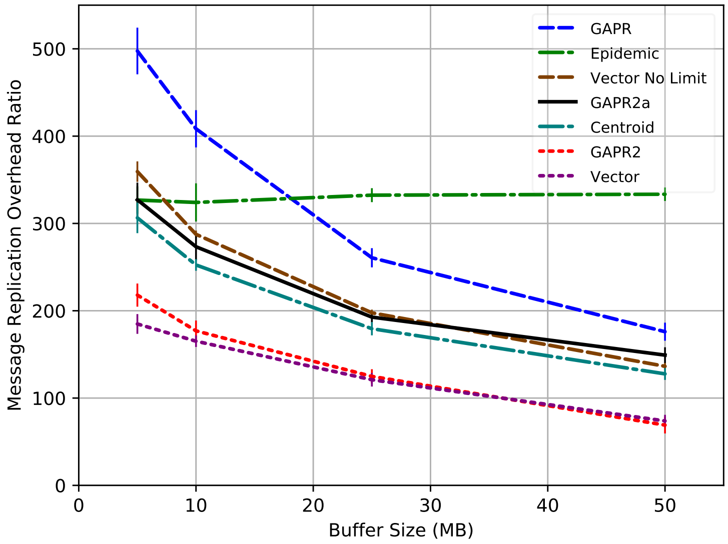
NS3 Bold Alligator Message Replication Overhead for 36 Mbps Base Radio



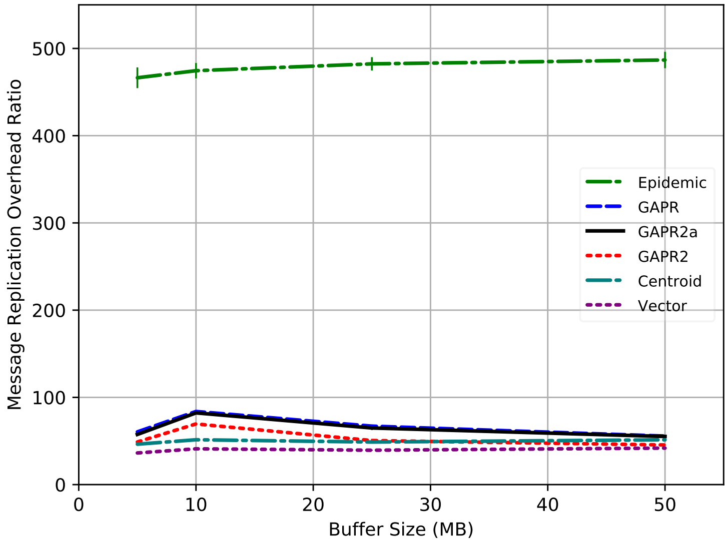
ONE Bold Alligator Message Replication Overhead for 36 Mbps Base Radio



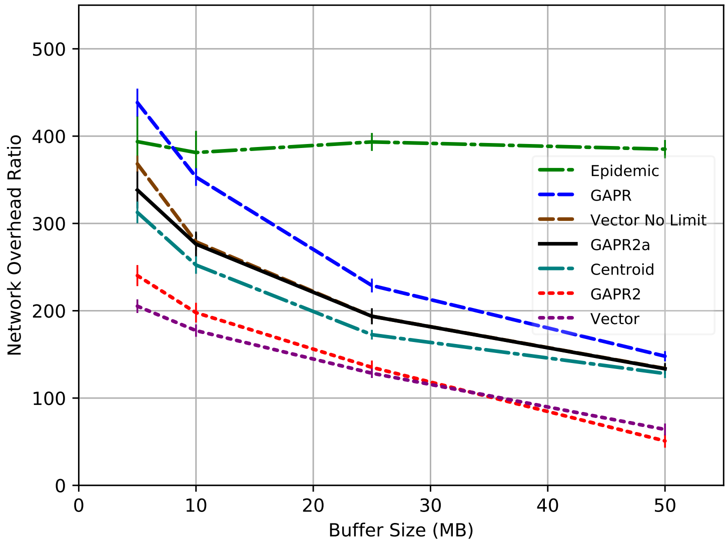
NS3 Bold Alligator Message Replication Overhead for 54 Mbps Base Radio



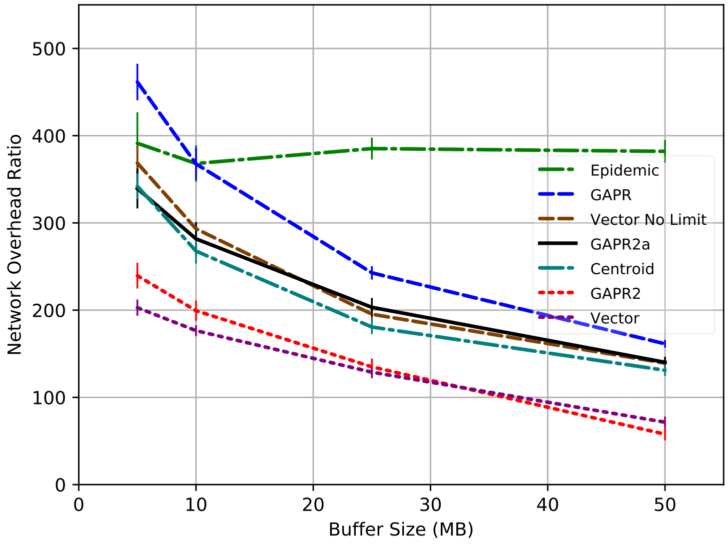
ONE Bold Alligator Message Replication Overhead for 54 Mbps Base Radio



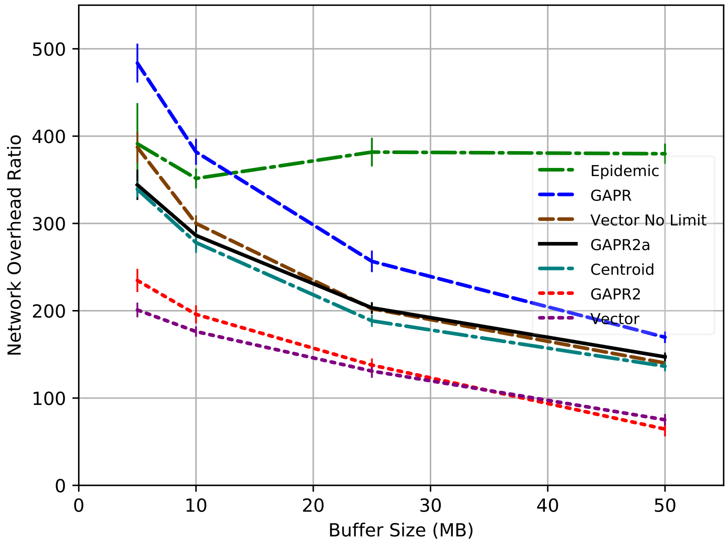
NS3 Bold Alligator Network Overhead for 12 Mbps Base Radio



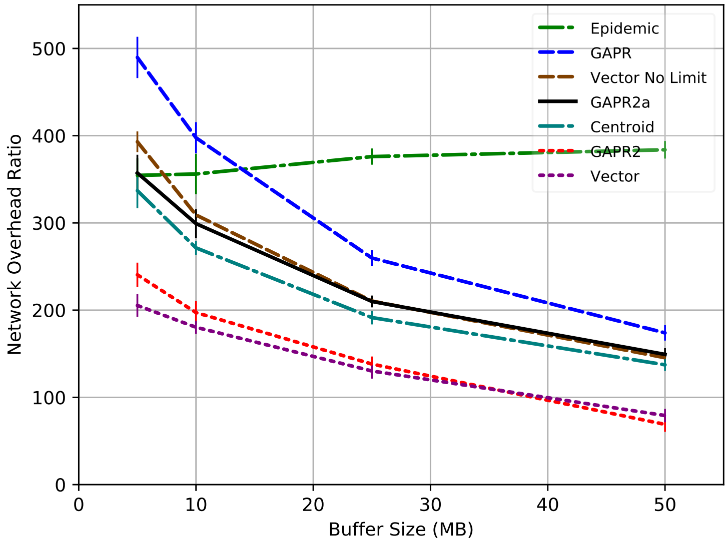
NS3 Bold Alligator Network Overhead for 24 Mbps Base Radio



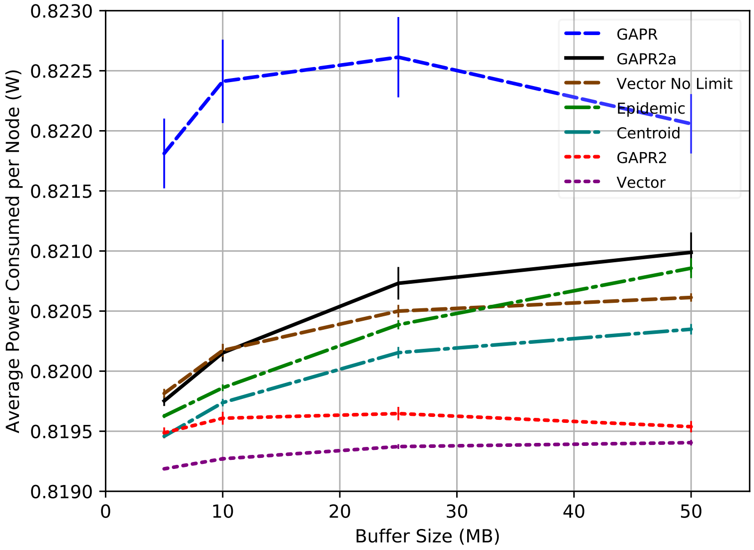
NS3 Bold Alligator Network Overhead for 36 Mbps Base Radio



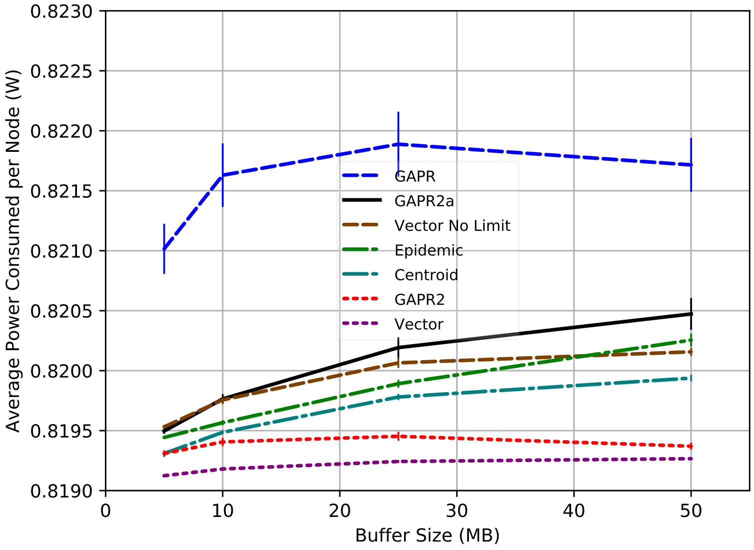
NS3 Bold Alligator Network Overhead for 54 Mbps Base Radio



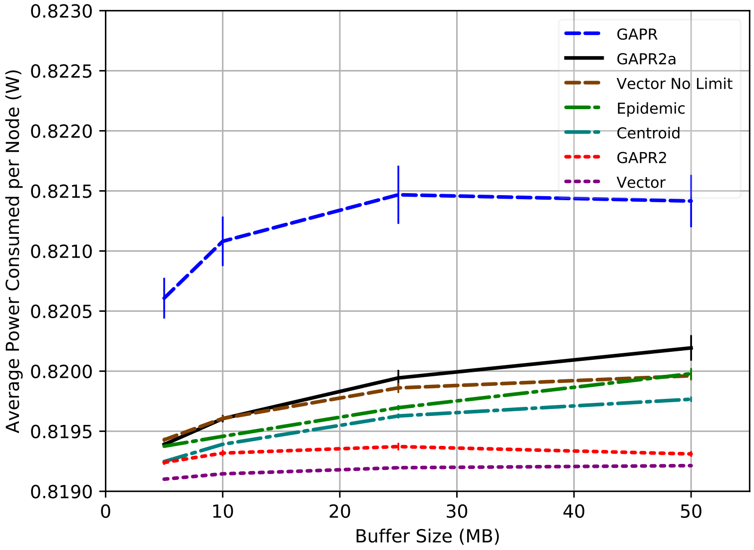
NS3 Bold Alligator Average Power Consumed per Node for 12 Mbps Base Radio



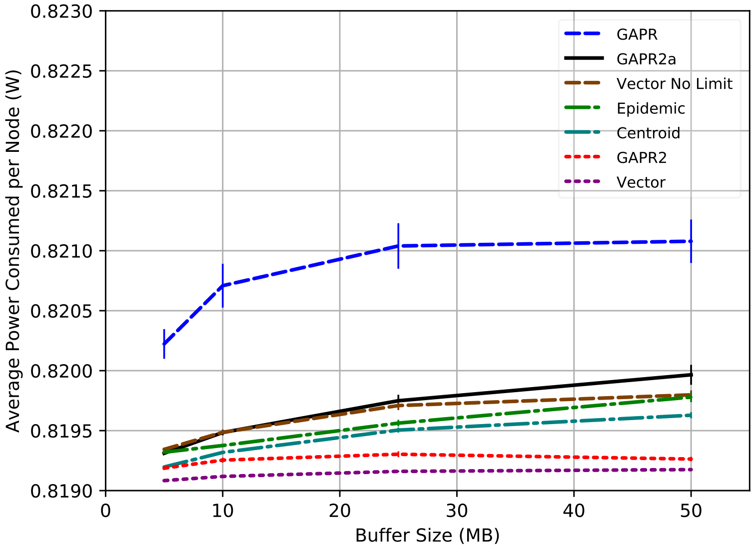
NS3 Bold Alligator Average Power Consumed per Node for 24 Mbps Base Radio



NS3 Bold Alligator Average Power Consumed per Node for 36 Mbps Base Radio

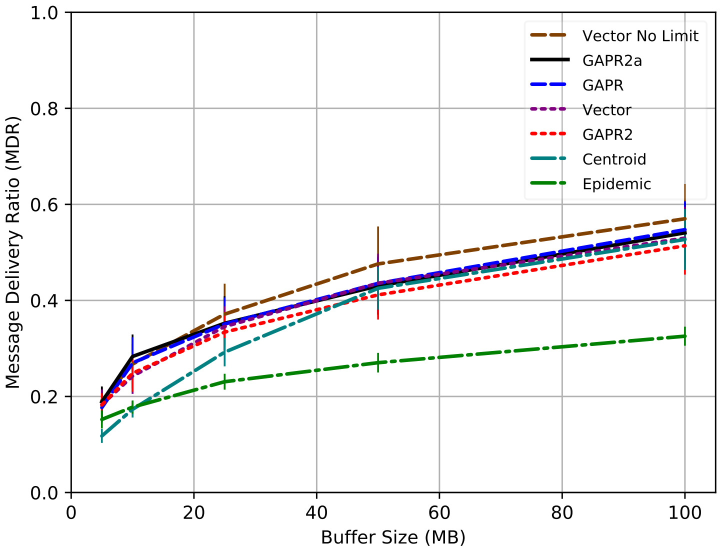


NS3 Bold Alligator Average Power Consumed per Node for 54 Mbps Base Radio

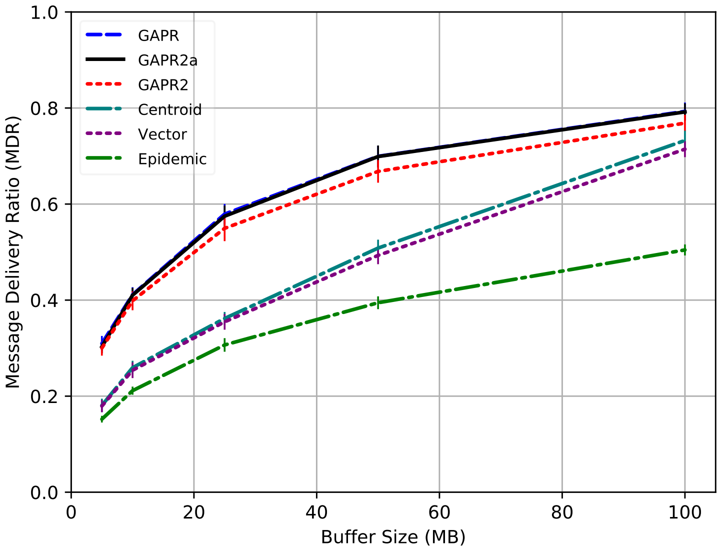


APPENDIX I:
Omaha Figures

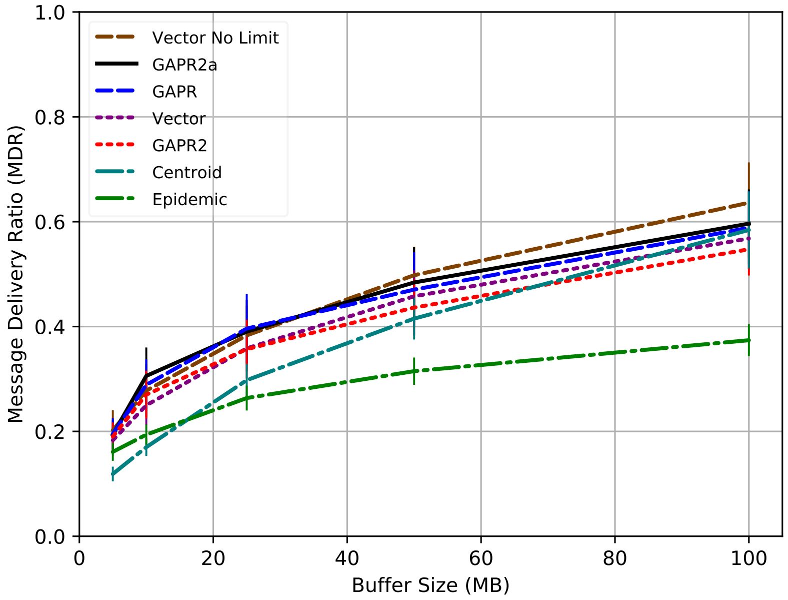
NS3 Omaha MDR for 6 Mbps Base Radio



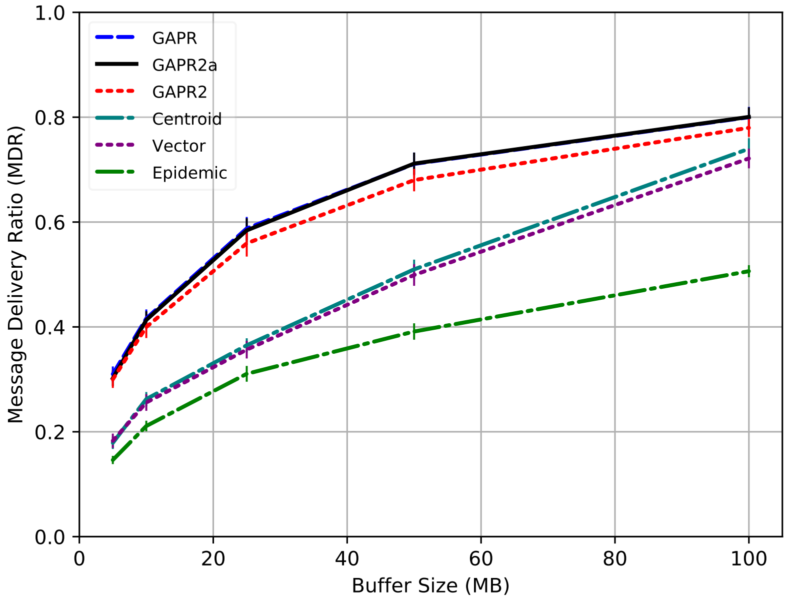
ONE Omaha MDR for 6 Mbps Base Radio



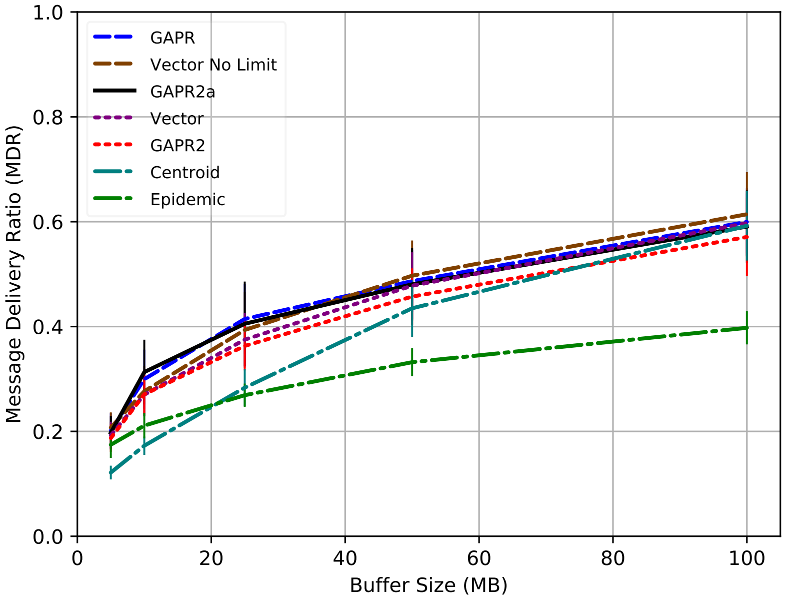
NS3 Omaha MDR for 12 Mbps Base Radio



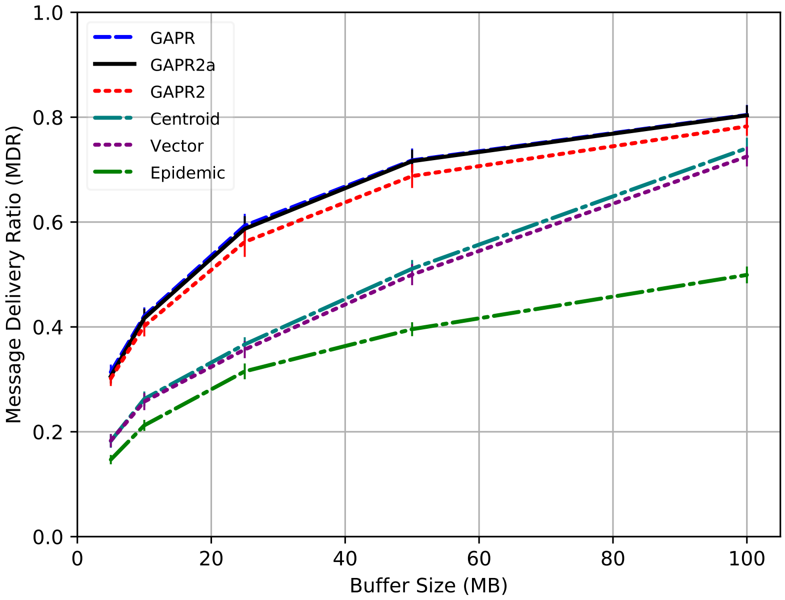
ONE Omaha MDR for 12 Mbps Base Radio



NS3 Omaha MDR for 24 Mbps Base Radio



ONE Omaha MDR for 24 Mbps Base Radio



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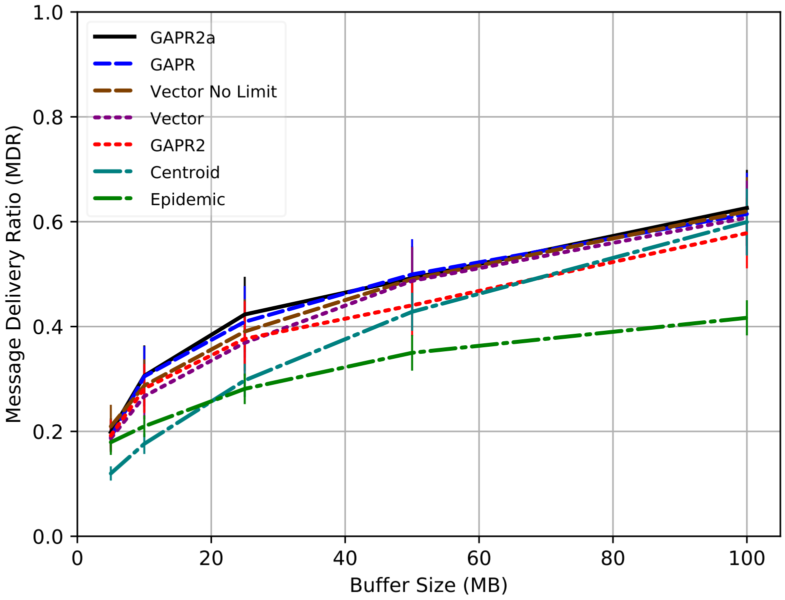

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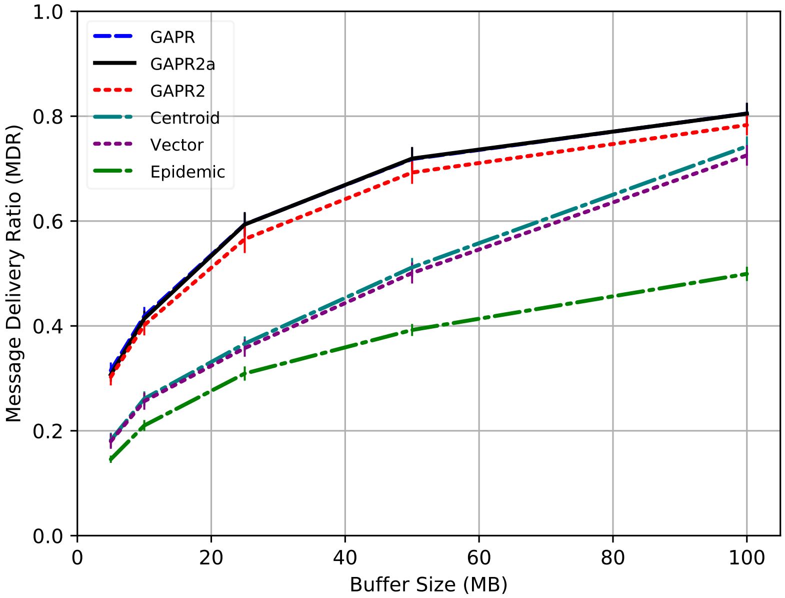

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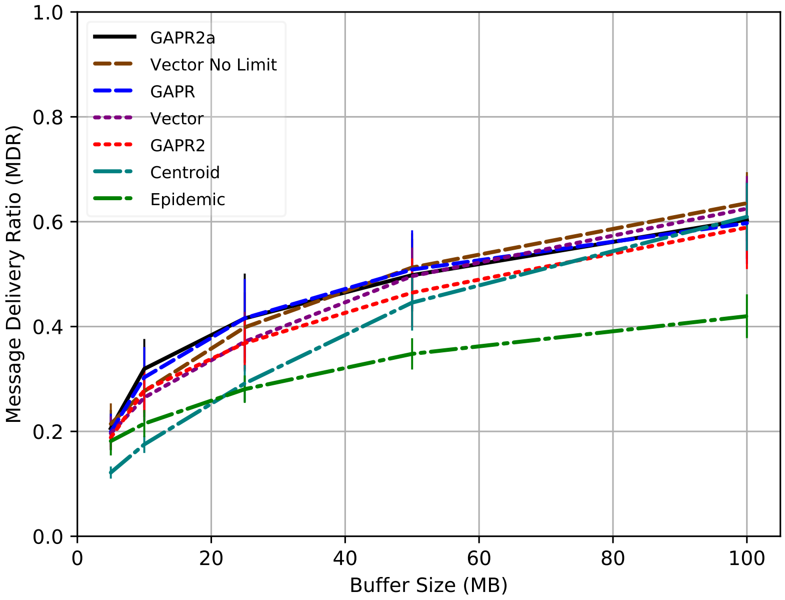

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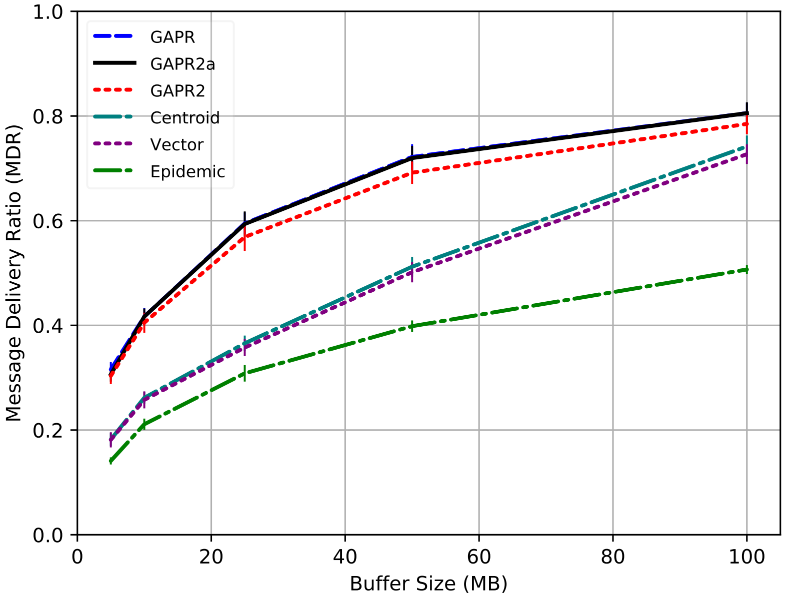

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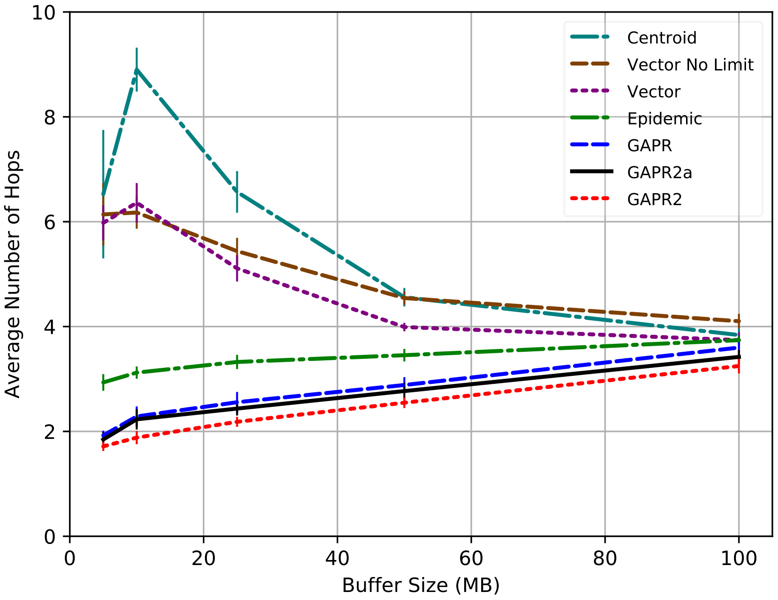

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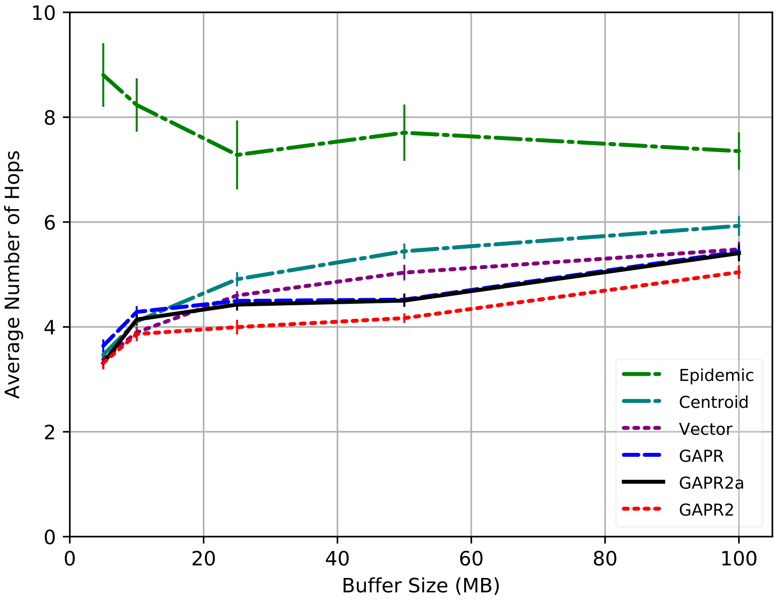

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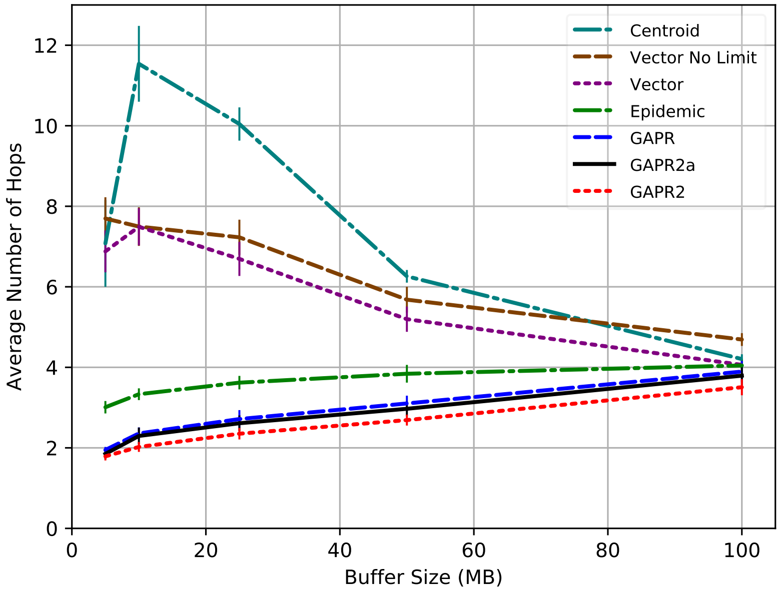

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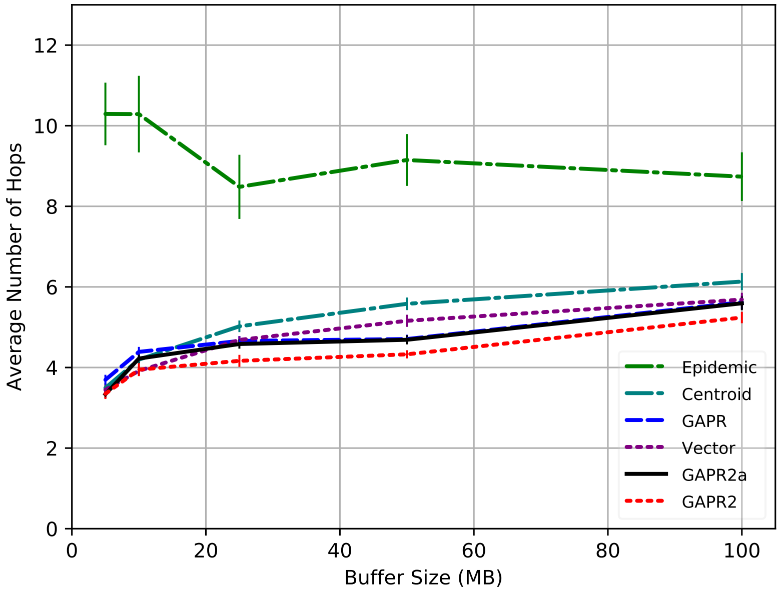

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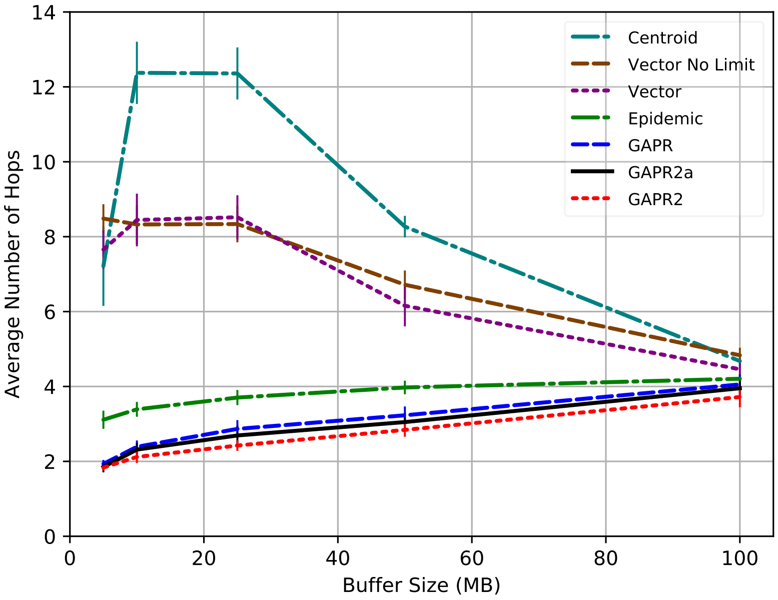

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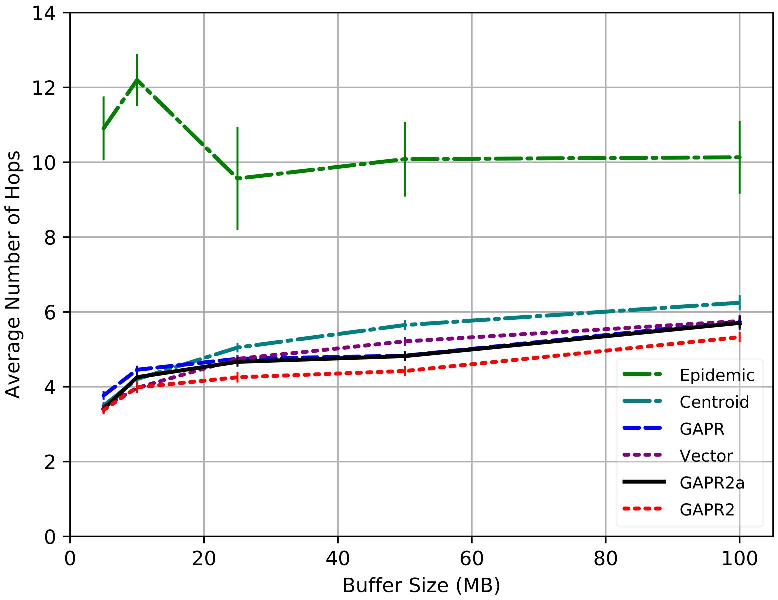

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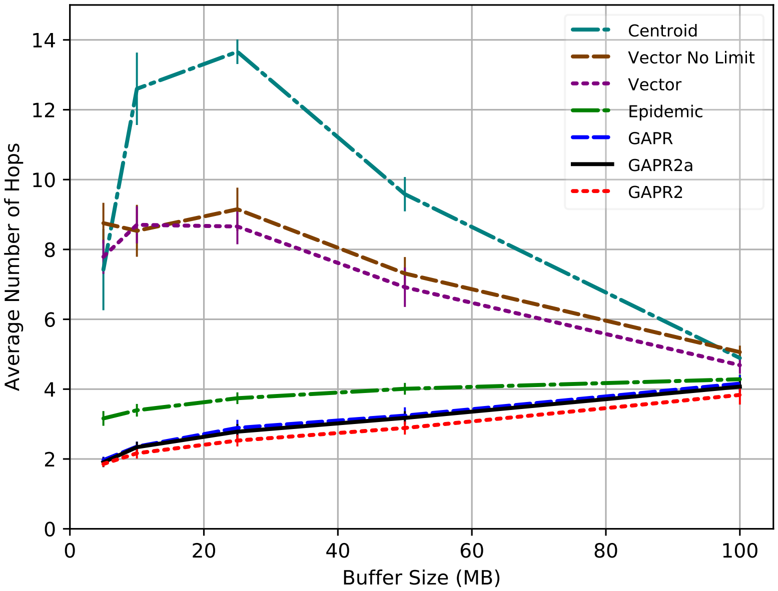

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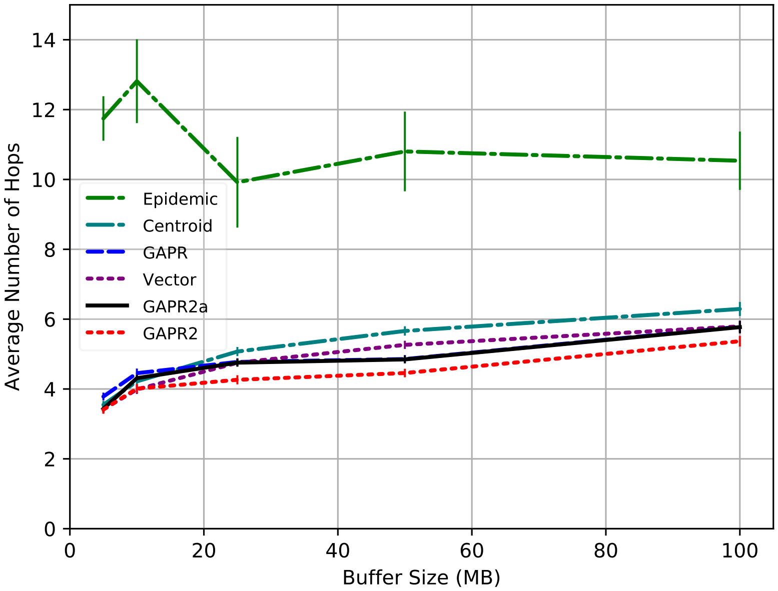

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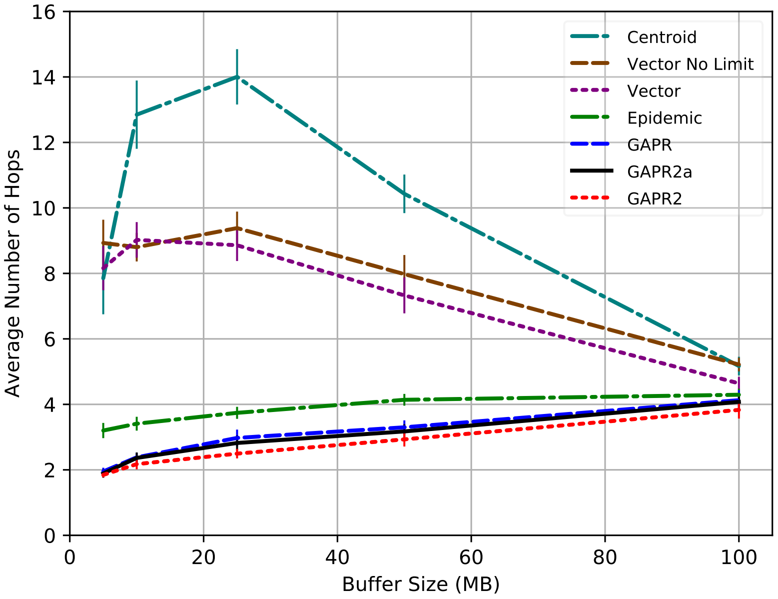

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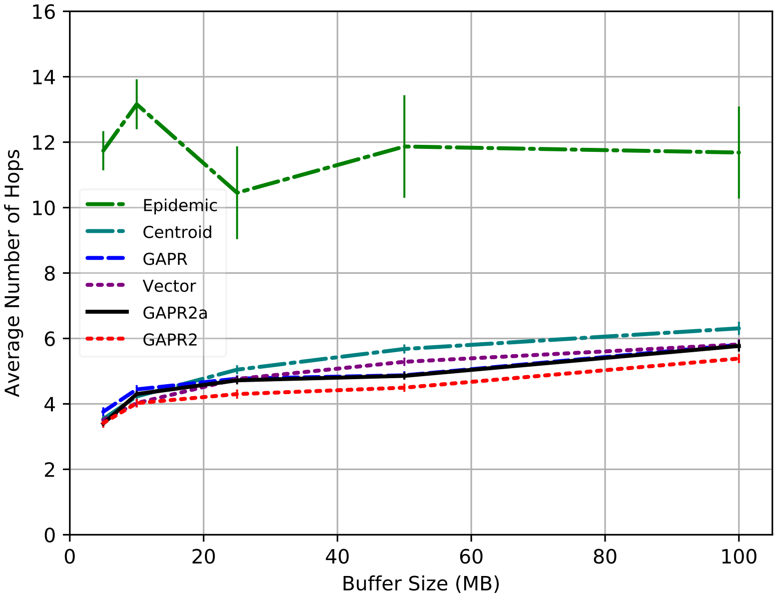

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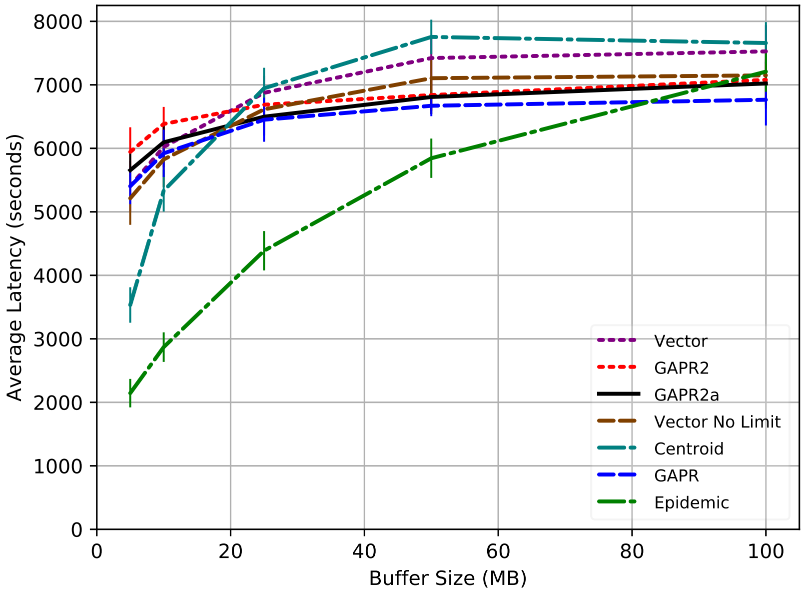

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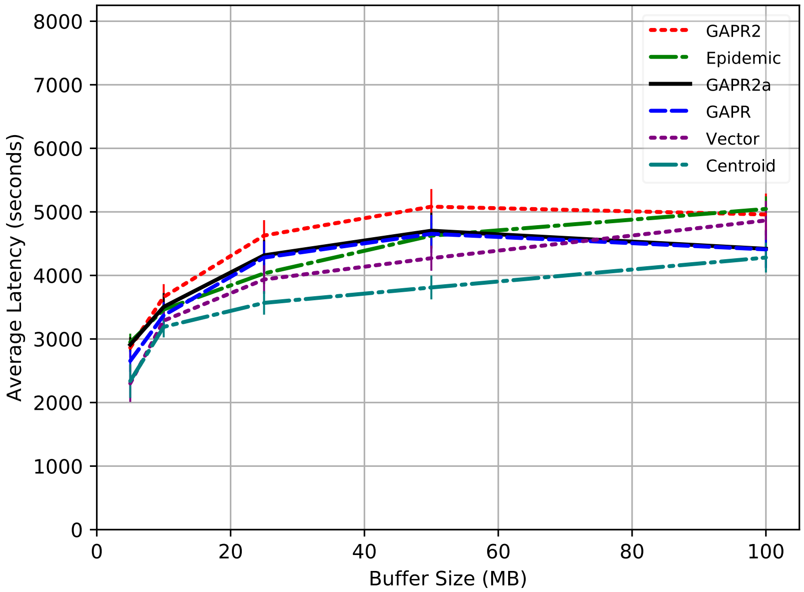

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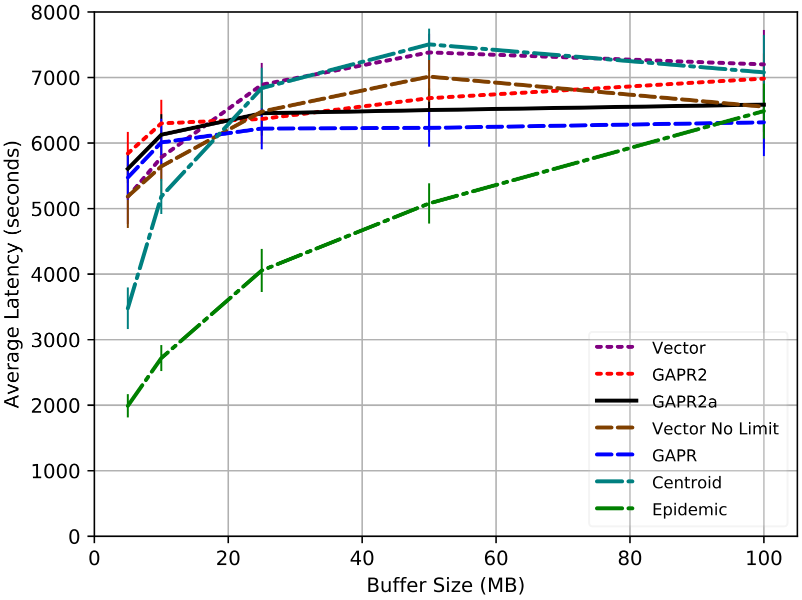

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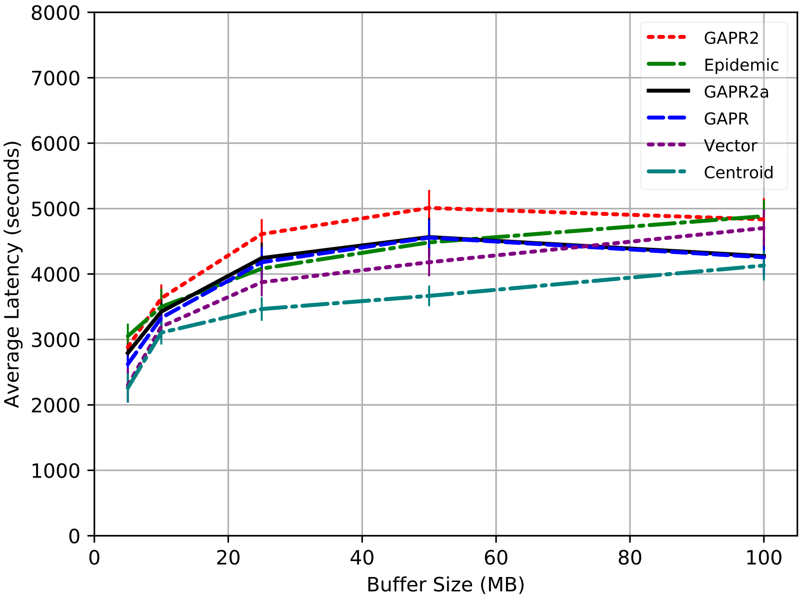

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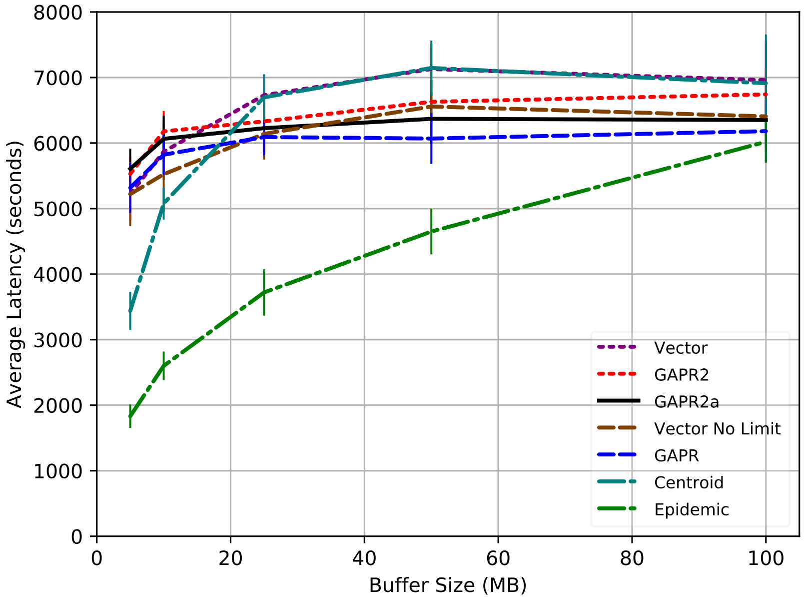

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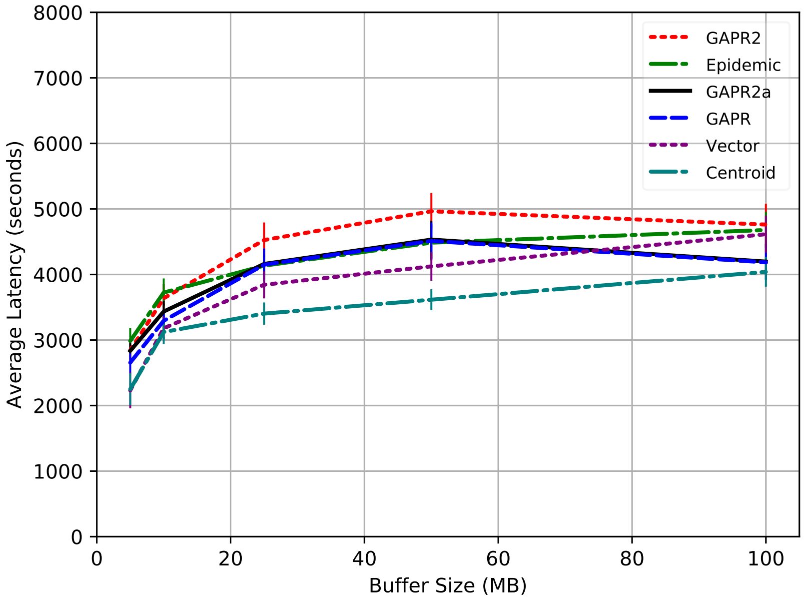

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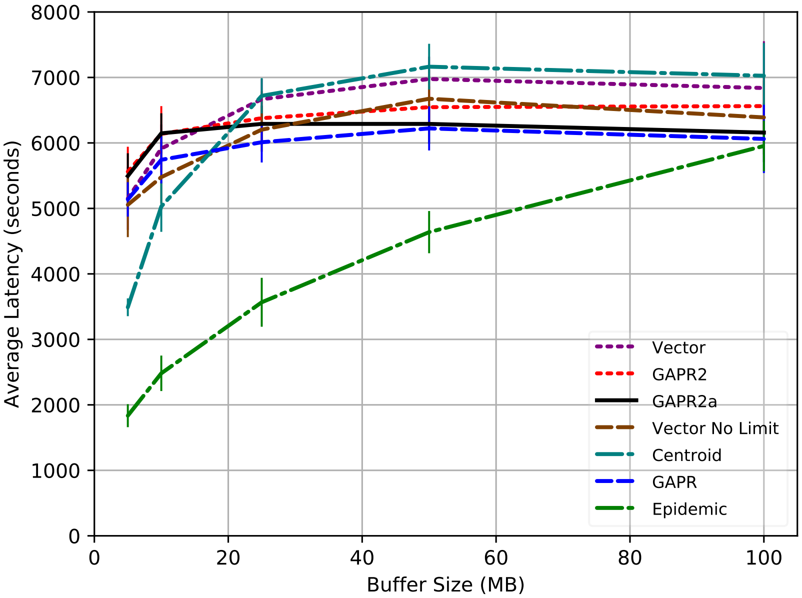

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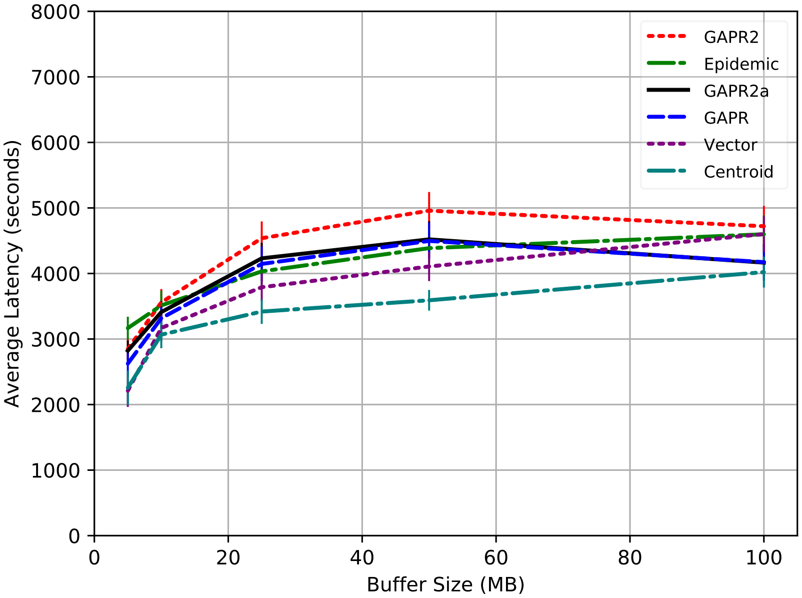

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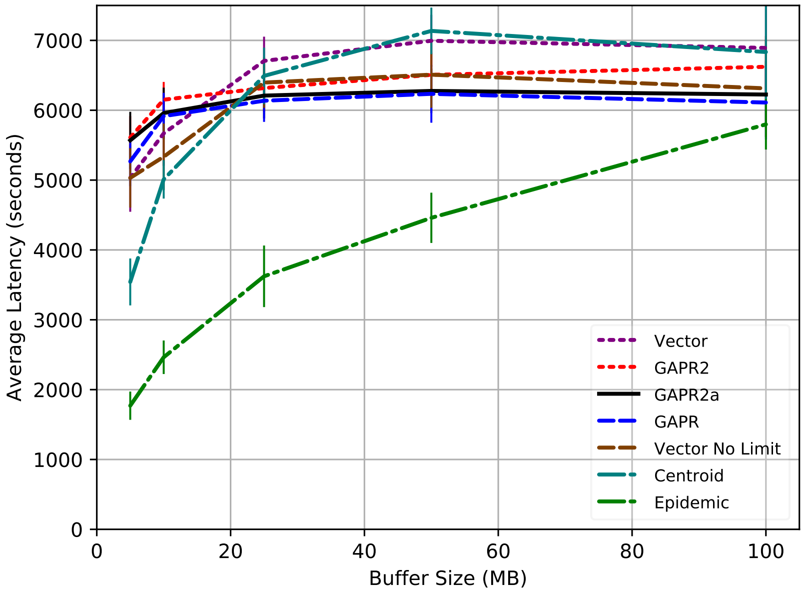

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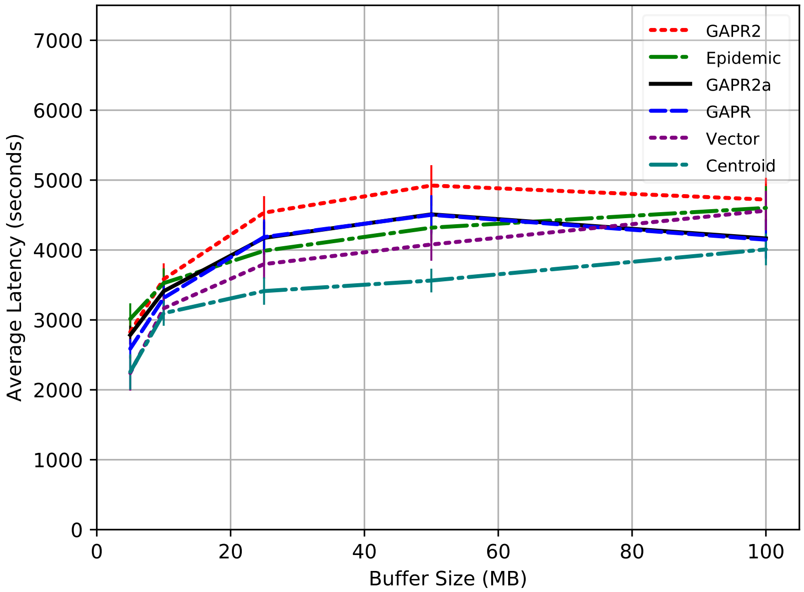
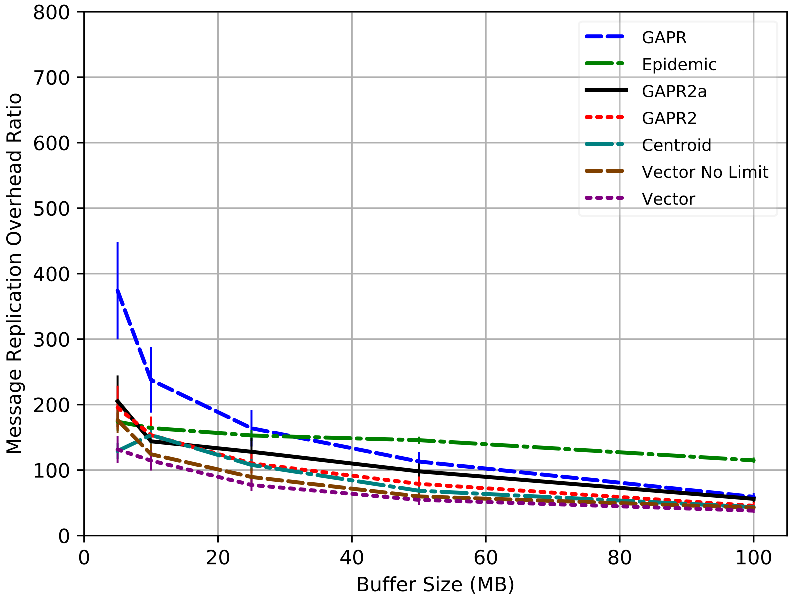


NS3 Omaha Message Replication Overhead for 6 Mbps Base Radio



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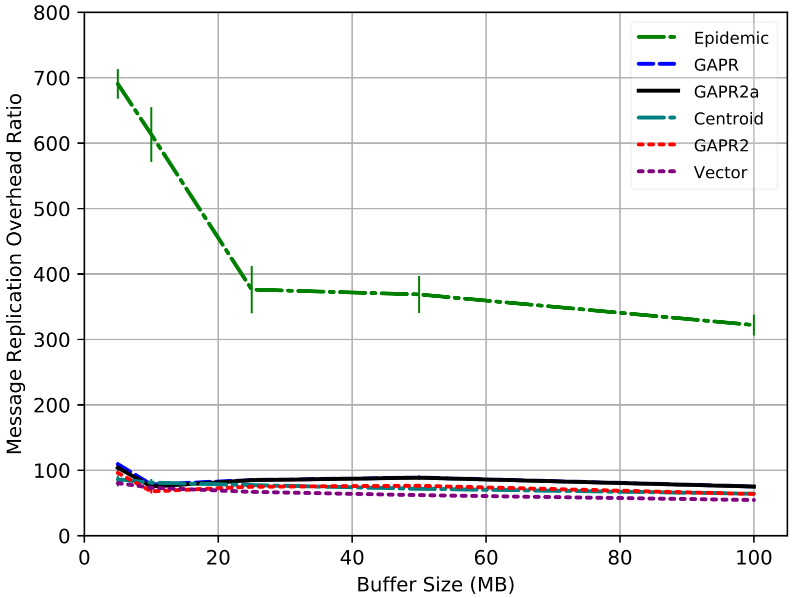

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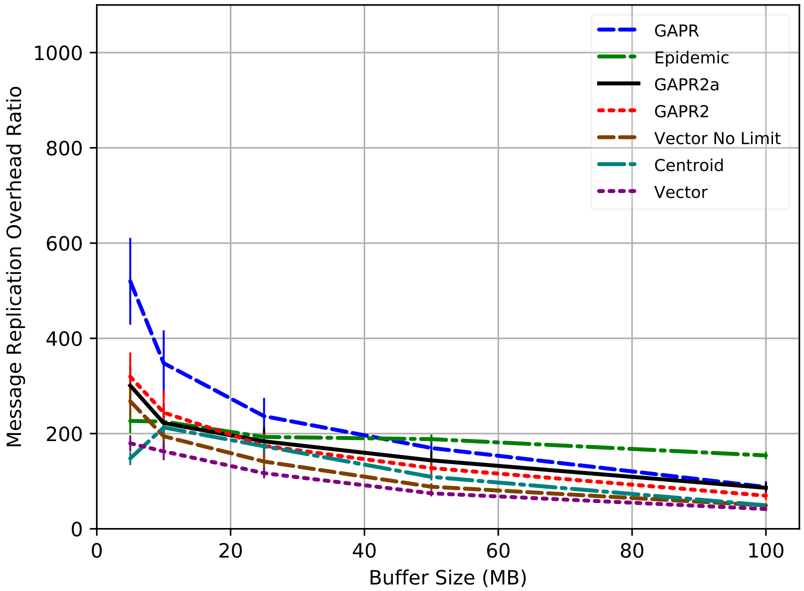

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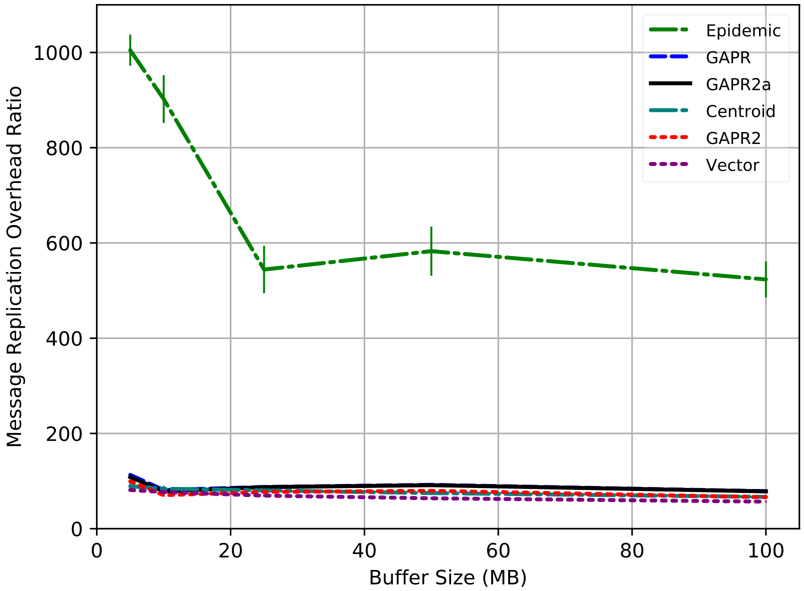

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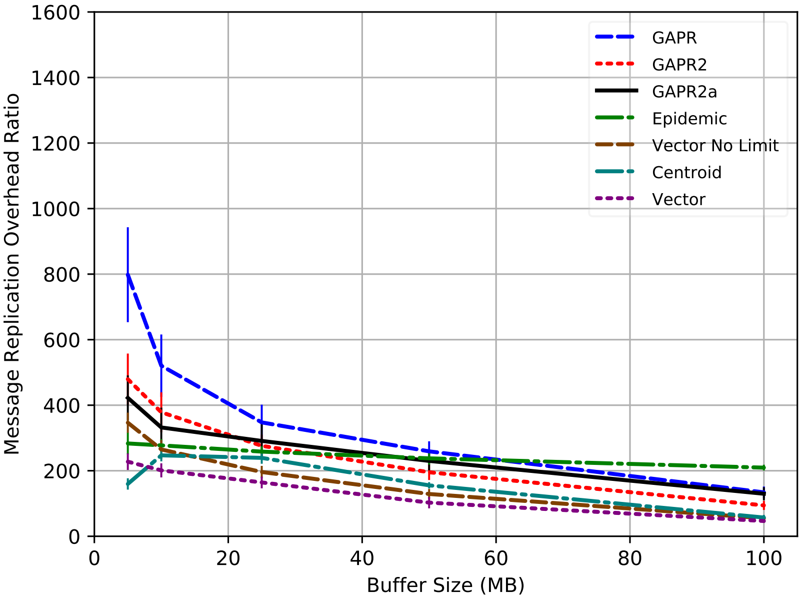

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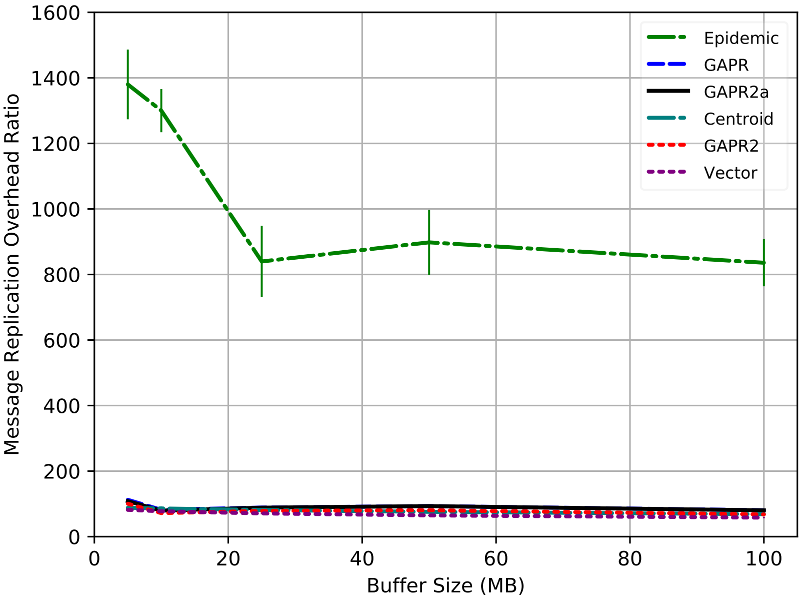

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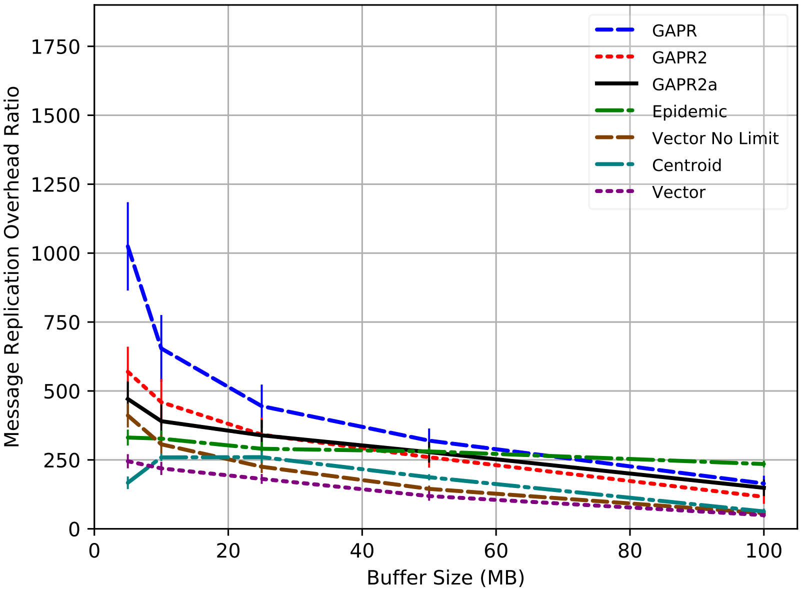

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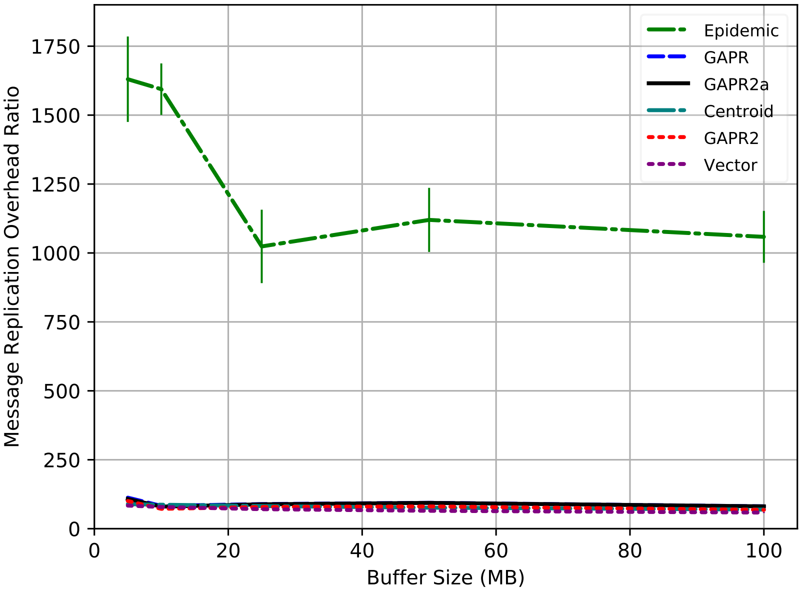

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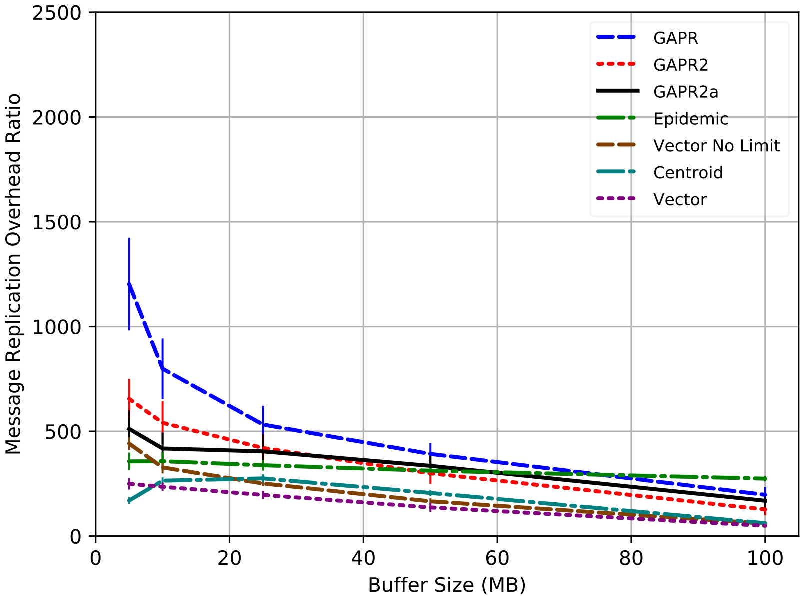

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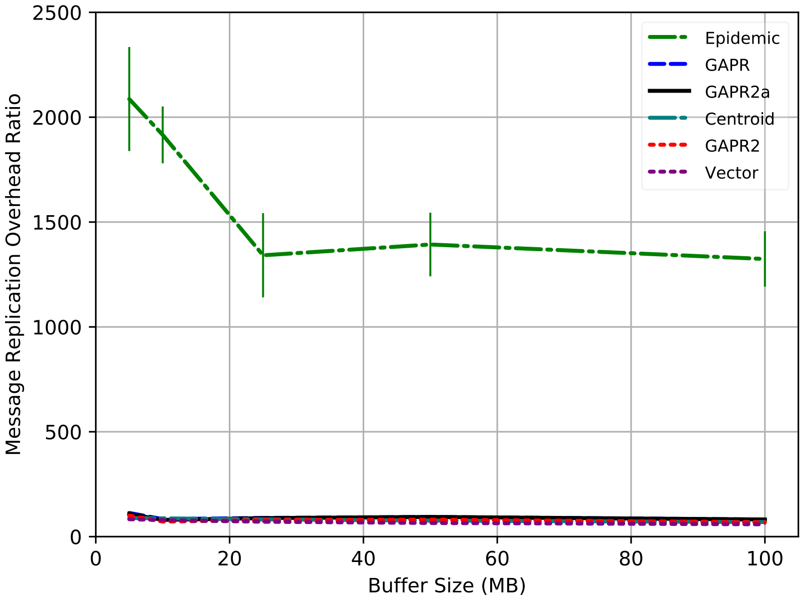
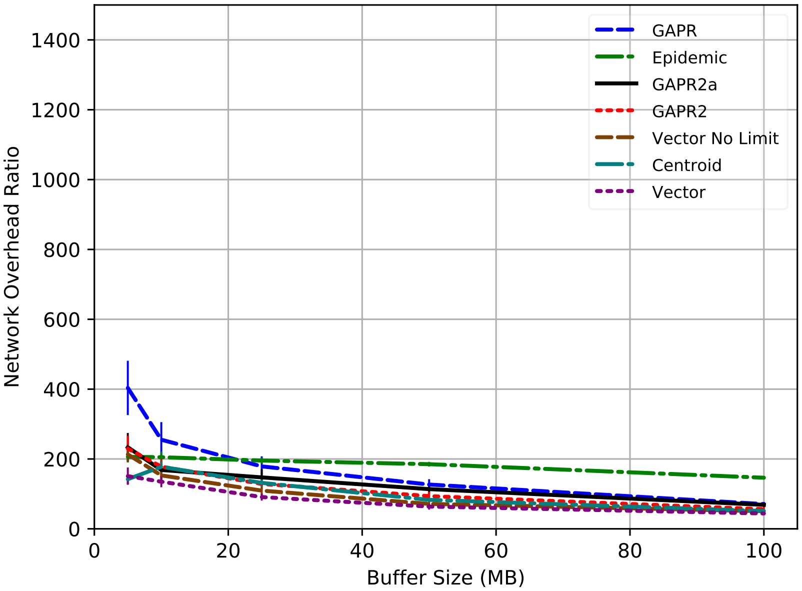


NS3 Omaha Network Overhead for 6 Mbps Base Radio



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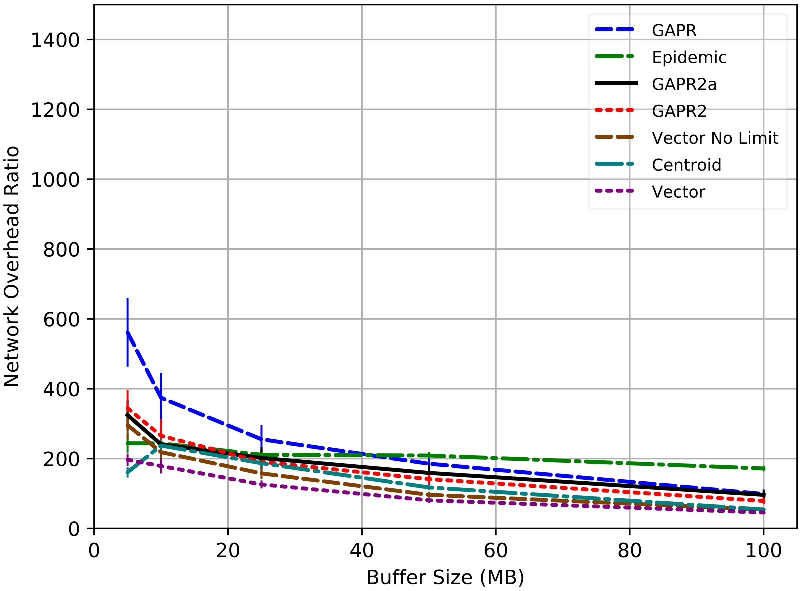

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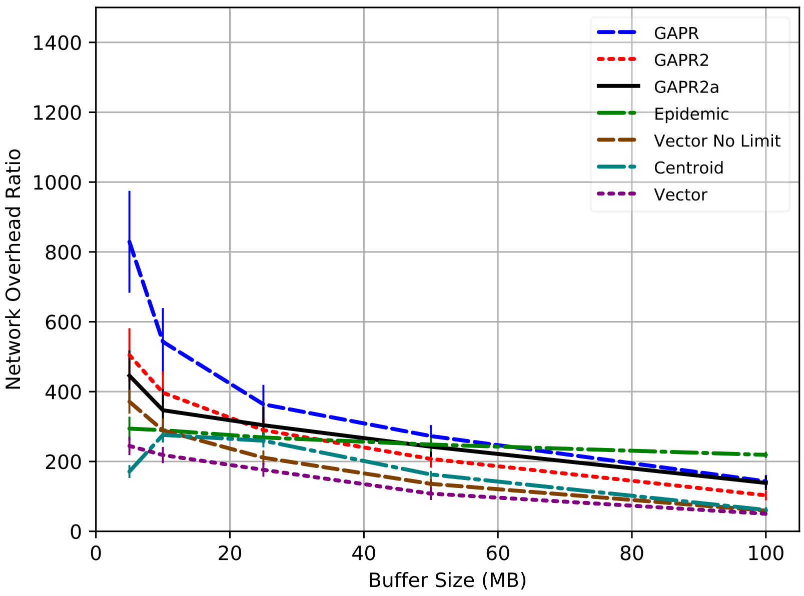

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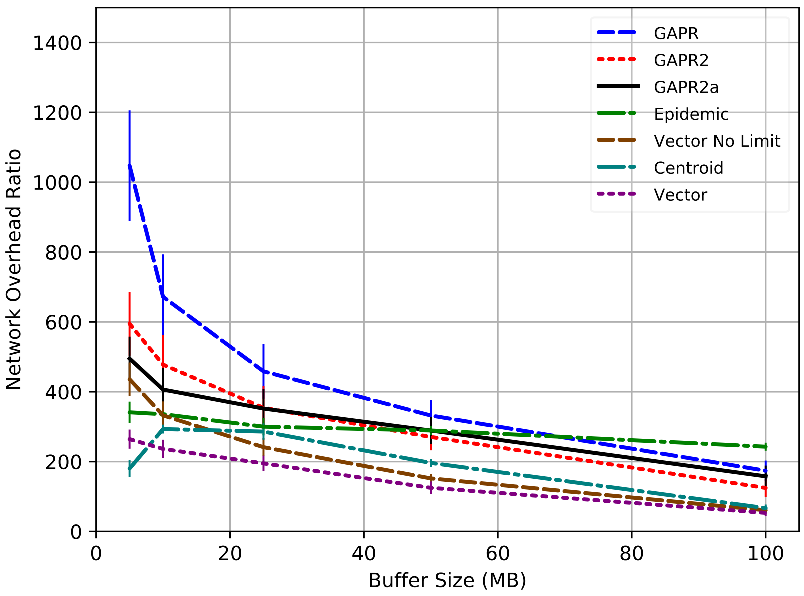

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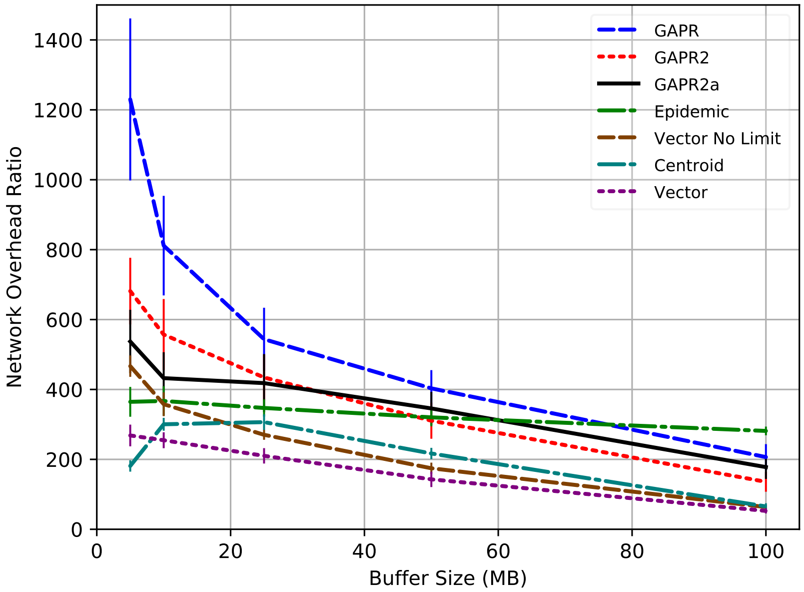
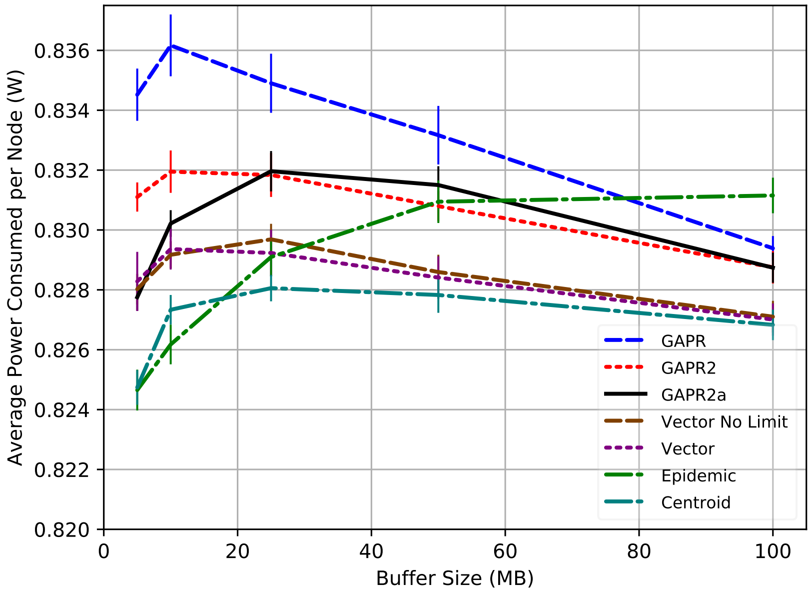


NS3 Omaha Average Power Consumed per Node for 6 Mbps Base Radio



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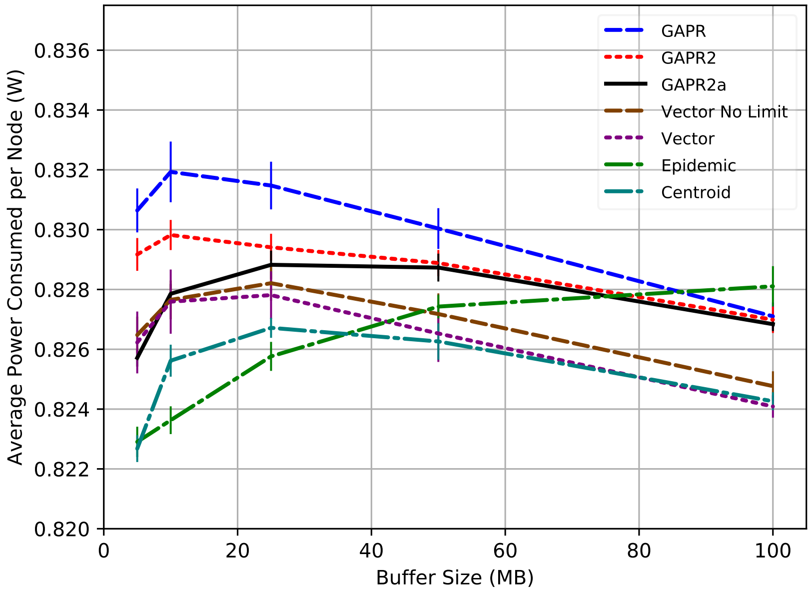

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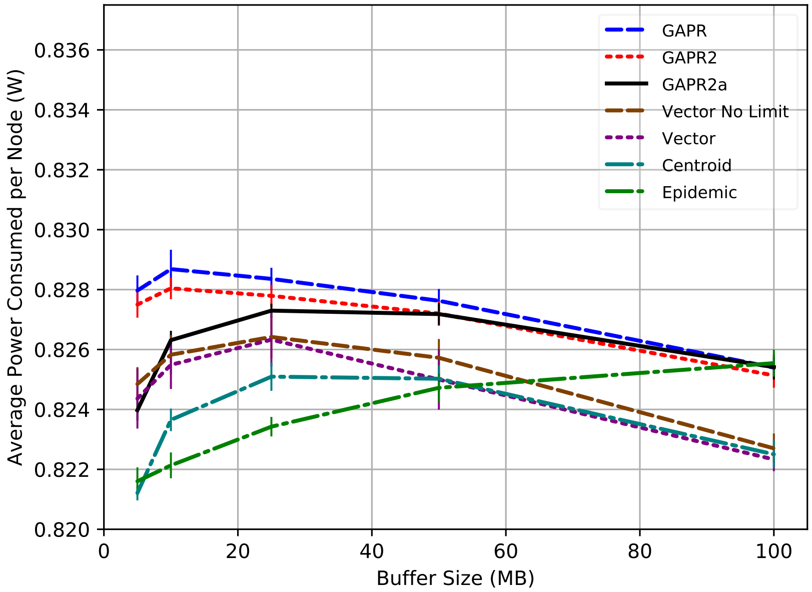
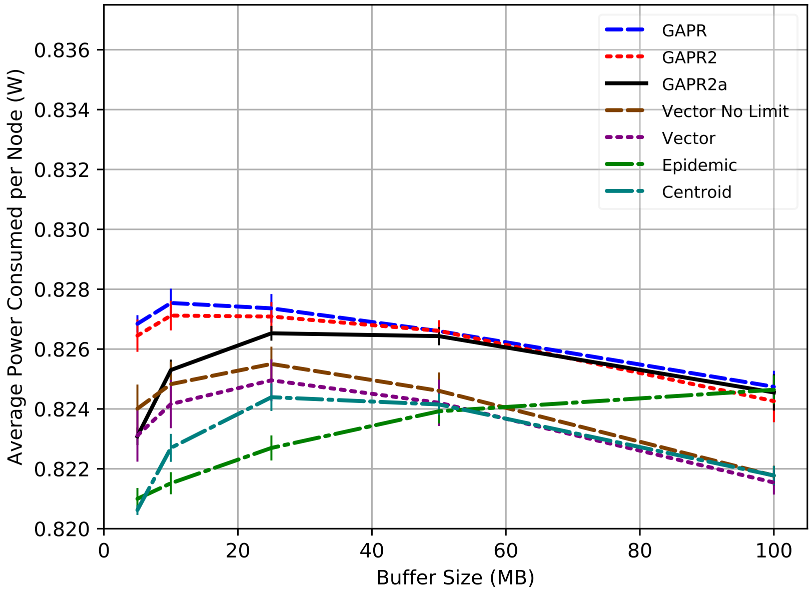
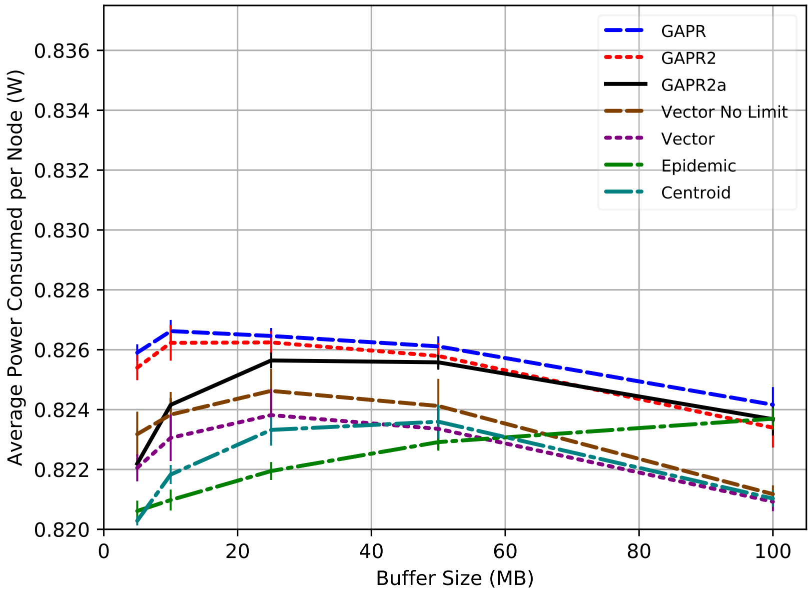


NS3 Omaha Average Power Consumed per Node for 36 Mbps Base Radio



NS3 Omaha Average Power Consumed per Node for 54 Mbps Base Radio



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Initial Distribution List

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California