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Effects of GPS Error on Geographic Routing

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***Abstract*—A number of geolocation-based DTN (Delay Tolerant Networking) routing protocols have been shown to perform well in selected simulation and mobility scenarios. However, the suitability of these mechanisms for widely-available inexpensive GPS hardware has not been evaluated. In this brief paper we evaluate the effect of GPS positional error on our own and previously existing geographic routing protocols.**

I. INTRODUCTION

Research published by the Delay- and Disruption-Tolerant Networking (DTN) community over the last decade shows significant benefits to incorporating geolocation information into routing algorithms. This is unsurprising, given that DTN routing protocols are required to make local forwarding decisions, without the benefit of consistent global routing information.

Much of this work is evaluated only in simulation and emulation environments (and we include our own prior work in making this generalization [1], [2]), in which the positional measurements are assumed to be highly accurate. In practice DTN nodes are often (and perhaps increasingly so) constructed from very inexpensive hardware without high-quality antennas or complex GPS chipsets, and expected to function in urban canyons or other environments with partially obstructed GPS signals.

Under such conditions, the advertised ± 20 m civilian GPS accuracy bounds quickly decay to nearly 200 m, with the more eccentric error typically occurring orthogonally to the direction of travel, without resembling a normal error distribution [3]. The implication for the consumer of such position data is that the location delta between updates due to error may be an order of magnitude larger than the actual distance travelled in the same time. Simply taking additional samples cannot resolve this error due to the high degree of self-similarity between consecutive GPS location readings. This explains the all-too-common scenario of "my GPS thinks I'm driving in a field/lake/building/offramp/etc". Commercial GPS-based mapping devices are relatively successful at hiding such inaccuracies by by taking hints from the map database and making sophisticated assumptions (learned through decades of development on this single application) such as smoothed travel trajectories and snapping the position to nearby roads. The DTN routing research community doesn't typically have the luxury of such assumptions, and so must find other mechanisms for accommodating errors in positional data. Please note that we don't mean to imply that advances in technology won't decrease these errors; technology trickle-down, availability of GLONASS, and planned improvements in future GPS satellites will all have that effect in the coming decades, however the current general assumption of zero error will continue to be unwarranted for the foreseeable future.

II. SIMULATIONS & ANALYSIS

We perform our analysis using The ONE Simulator [4], as it is specifically suited to DTN routing analysis. In previous work we have used a number of mobility scenarios with the ONE, however in this case evaluating the protocols on multiple scenarios did not yield any additional insights, so for clarity we present a single evaluation scenario in this work. We choose the Helsinki map-based model, which has become well-known in DTN routing literature due to its inclusion as the default mobility model for the ONE simulator.

Each data point in the plots that follow represents the average of 4 simulation runs with varying random seeds, and the error bars on all the plots in this paper represent 95% confidence intervals.

A. *Positional Sample Error*

As discussed earlier, we are concerned with the effect of errors in the positional (e.g. GPS) sample data provided to the routing protocol. To perform a preliminary evaluation of these effects, we employ three DTN routing protocols: 1) Vector Routing [5], a simple protocols that uses inferred direction-of-travel information from GPS to maximize message spreading while minimizing overhead. 2) Centroid Routing, a protocol we have designed explicitly to use a routing primitive that minimizes the effects of GPS error instead of raw direction-of-travel, but is otherwise similar to Vector. 3) CenterMass Routing, a protocol that extends Centroid Routing to route messages towards the geographic centroid of the destination. Due to space constraints we cannot present the full specification of the Centroid and CenterMass routers in this paper.

The One Simulator provides exact positional coordinates, so we create alternate versions of each of the three protocols, which add noise to the position provided by the simulator before using it in calculating their respective routing primitives (labeled VectorNoise, CentroidNoise, and CenterMassNoise respectively). This noise is random and uniform, in the range ± 20 m. Note that this roughly the *advertised* error for civilian

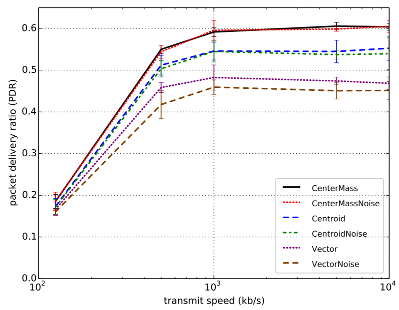

Fig. 1. Effect of GPS errors on delivery probability vs. radio bandwidth

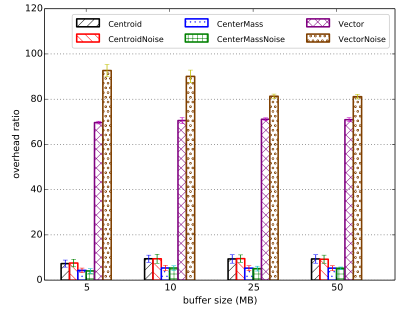

Fig. 2. Effect of GPS errors on overhead ratio vs. buffer size

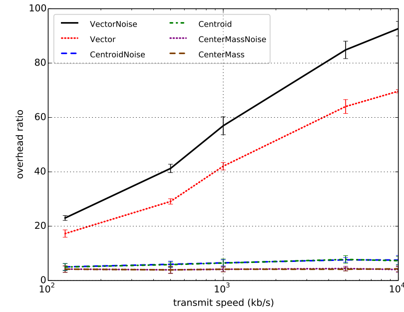

Fig. 3. Effect of GPS errors on overhead ratio vs. radio bandwidth

GPS, and is far from a worst-case scenario that could be ± 200 m with strong self-similarity properties between samples.

Figure 1 shows how this measurement error affects the Packet Delivery Ratio (PDR) of the three protocols. All the protocols are bunched together at low (125 Kb/s) radio data rates. With higher transmission rates (500 Kb/s – 10 Mb/s) the protocols become distinguishable. The Vector protocol is most significantly affected, with the positional errors noticeably reducing the packet delivery ratio. That being said, the reduction is only about 10% at its worst. We believe that since the Vector protocol only relies on the trajectory to enable efficient spreading of messages, it may be less affected than a protocol that uses trajectory in a more specific manner (e.g. identifying trajectory in the direction of the message destination). Unfortunately we do not have such a protocol implemented in the ONE at this time to test our hypothesis. Both of the Centroid-based protocols show negligible effects from the noise, as expected. While the traces with noise do trend lower than those without, they are within the 95% confidence intervals of each other at almost every data point. Not only is the Centroid routing protocol less affected by noise, it outperforms the Vector protocol by about 20% in the presence of positional errors. The CenterMass protocol achieves an additional 10% performance improvement over Centroid.

Lastly we look at the effect on overhead. The overhead ratio reported the the ONE simulator is: $\frac{\text{(forwarded messages} - \text{delivered messages)}}{\text{delivered messages}}$. From Figure 2 we can now explain the reduced latency achieved by the Vector protocol, since there are literally $10\times$ more copies of every packet forwarded in the Vector routing simulations that there are in the Centroid routing simulations, and the positional errors make the Vector overhead approximately 30% worse. Increasing the buffer size reduces the impact of positional errors on Vector's overhead, and has almost no effect on Centroid or CenterMass. We do note that in addition to the improved delivery probability of CenterMass over Centroid, CenterMass has significantly lower overhead than Centroid. For a view of the effects of increasing transmission speed we look to Figure 3. Here we see that not only does the effect of positional errors on Vector increase as more bandwidth is made available, but the absolute overhead appears to run-away, quadrupling between 125 Kb/s and 10 Mb/s. Centroid also has increased overhead as the bandwidth increases, but only slightly, and there appears to be almost no effect on the overhead of CenterMass.

From these plots we see that the negative impact of positional errors on some protocols is real, and that these two Centroid-based routing protocols have a significant advantage in terms of overhead, relative to Vector, a protocol of comparable complexity and message delivery performance.

III. Conclusion

We demonstrate the negative effect that positional errors can have on DTN routing protocols that rely on geolocation inputs, depending on how that input is used. We also demonstrate Centroid Routing and CenterMass Routing, both of which are immune to random error in positional data inputs.

Acknowledgment

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