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THESIS

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A MICRO-COMPUTER NETWORK

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A Study of Message Routing within
A Micro-Computer Network

by

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ABSTRACT

The use of microcomputers in a message-switching network is introduced through a discussion of store-and-forward routing techniques. Algorithms that utilize both deterministic and stochastic principles are explained and those parameters which determine the computing machinery necessary are identified. INTEL Corporations MSC-8 microcomputing system is presented as a possible candidate for use in message-switching networks and some applications of these networks are discussed. A modification of a routing algorithm is offered, which makes the microcomputer useable in message-switching networks.

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I. INTRODUCTION

The purpose of this paper is to present various message routing techniques in computer-communications nets denoted as store-and-forward networks. Such nets accept messages from an external source and transmit them over some route to their destination. This transmission takes place over one link at a time with storage taking place at each intermediate switching node in the net. One of the fundamental problems in these nets is the routing of messages in such a manner to ensure their rapid delivery [Ref. 1]. This paper will discuss the various store-and-forward techniques and attempt to define the parameters associated with each technique. Further it will determine which (if any) of these parameters can be varied to allow microcomputers to function in the computer-communication net and, finally, it will determine which, if any, of these routing techniques, using microcomputers, would be suitable for military applications.

A. CHARACTERISTICS OF MODEL NETWORK

In discussing the various routing algorithms, some assumptions must be made about the characteristics of the network itself. The characteristics of the network are:

1. It must operate in a military (possible shipboard) environment.
2. No assumptions are made about the number of computers in the net. Only that there must be a sufficient number to warrant a routing algorithm.
3. Configuration of the network is not considered. It is recognized that there may be an optimum configuration for any given purpose,

but it is not the purpose of this paper to present a complete design for such a system.

4. The network is considered homogeneous. It may use the ARPA network idea of one computer per station whose task is to handle the message traffic, but all computers in the net are the same [Ref. 2]

B. REQUIREMENTS OF MODEL NETWORK

The requirements of the model network are that it must be able to adapt to changes in topology. Degradation must be only gradual: messages must be delivered-possibly delayed and distorted-even after loss of a significant part of the network.

II. ROUTING ALGORITHM CLASSIFICATION

Network routing techniques are of two major classifications: Deterministic and Stochastic techniques. Deterministic routing techniques compute routes through the network based on a given deterministic rule and produce a loop-free routing procedure. Stochastic routing techniques operate as probabilistic decision rules, utilizing topology and either no information about the state of the network or estimates of the present state of the network [Ref. 1]. There is no requirement for stochastic routing techniques to be loop-free and it's possible for messages to be trapped in loops for short periods of time.

A. DETERMINISTIC TECHNIQUES

Deterministic techniques are classified by Kleinrock into four basic groups [Ref. 1].

1. Flooding

a. All

This is essentially a "shotgun" procedure, in that each node that originates or receives a message, transmits a copy of it over all of its outgoing links. The only requirement is that the node must check to see that it is not the destination or that it has not transmitted the message before. This method guarantees successful delivery of messages, but is quite inefficient. If the network has a low volume of message traffic then the inefficiency could probably be tolerated, but in a high volume network a more efficient routing doctrine is necessary.

b. Selective

One method of improving the efficiency is by "selective" flooding. Some scheme of choosing a selected number of "best" outgoing links is used to forward the message. For example only links that are headed in the general direction of the destination might be used. The price of the improved efficiency of the "selective" routing technique is that a table of "best" routes for each destination must be maintained at each node.

2. Fixed Routing

These algorithms specify a unique route that will be followed by a message based on a table stored at each node. Figure 1. is an example of such a table.

If a message is to be forwarded, its destination is used to enter the routing table and the next specific node in the message's path is determined. When a single table such as figure 1. is used, completely reliable nodes and links are required. By expanding the table, however,

Destination Node Number	Next Node Number
1	3
2	1
3	4
4	6
6	9
7	9
8	9
9	10
10	8
11	8

Figure 1.

Node 5 Routing Table

alternate routes could be determined in the event of failure to the "primary next-node". The trade off here is obvious in that large storage areas at each node and more complex "look-up" procedures would be required.

3. Network Routing Control Center (NRCC)

With this technique, one of the nodes is designated as the NRCC. This node collects performance information from all other nodes about the network's performance, computes routing tables and then transmits the appropriate routing table to all nodes in the network. Since this computation is done on a global basis, loop-free paths are maintained between all source-destination node pairs. A fixed routing procedure is used between updates. The disadvantages of this technique are low reliability, cost of extra equipment and the fact that if the period between updates is very long then the routing tables may be out of date with respect to the current state of the network.

4. Ideal Observer Routing

This technique is essentially a scheduling problem. Each time a message enters a source node for routing, its route is computed to minimize the travel time through the network. This computation is based upon the complete present information about the messages already in the network and their known routes. If any future information is known about the network or the routes, then this information could also be used in the computation of the route. From a theoretical standpoint, this method provides a minimum average message delay through the network and may be used as a "standard" to which other routing techniques could be compared.

a. Ideal Routing Table & Shortest Path Problem

An underlying problem in all deterministic routing techniques is the setting up of the routing tables. Boehm and Mobley treat this as

The "Ideal Routing Table and Shortest Path Problem" [Ref. 3]. Figure 2. displays a network that will serve as an example for this problem. Variables X, Y & Z denote arbitrary nodes in the network. The numbers by a link from X to Y represents the transit time, d(X,Y), along a link. Let N4 represent the destination node for messages. Then, the shortest distance from node X to node N4 starting along the link XY, can be represented as a function, R(X,Y), of X and Y alone. Let D(X) be the distance along the shortest path from X to N4, then

$$R(X,Y) = d(X,Y) + D(Y) \qquad (1)$$

Once D(X) has been determined for all nodes X, the ideal routing table entries, Tx(N4,Y), can be computed using equation (1).

b. Dynamic Programming

Dynamic programming is another method of treating the "shortest path" problem. The dynamic programming Principle of Optimality states: An optimal path from X to A has the property that, for any node Y along the path, the remainder of the path is the optimal path from node Y to A [Ref. 3] Let N(X) be the set of neighbors of node X connected to X by links.

Then $$D(X) = \min_{Y \in N(X)} (d(X,Y) + D(Y)). \qquad (2)$$

This relationship allows an iterative scheme for computing D(X) for all X, from the starting condition D(N4) = 0. Let U be the set of "unconsidered nodes", then using figure 2. as an example, the flowchart of figure 3. gives this scheme. The numbers next to the nodes in figure 2. represent minimum distances to N4. The crossed-out numbers are intermediate results. Boehm and Mobley point out that the method of dynamic programming to update routing tables would work well for small networks, where the requirements

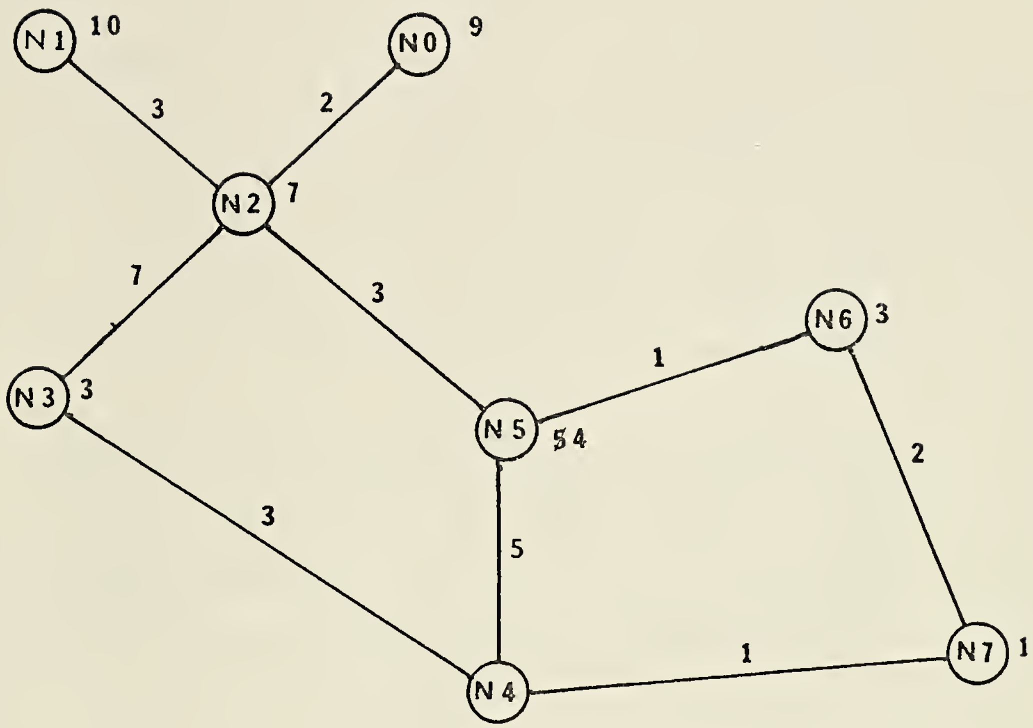


Figure 2.

Example Network

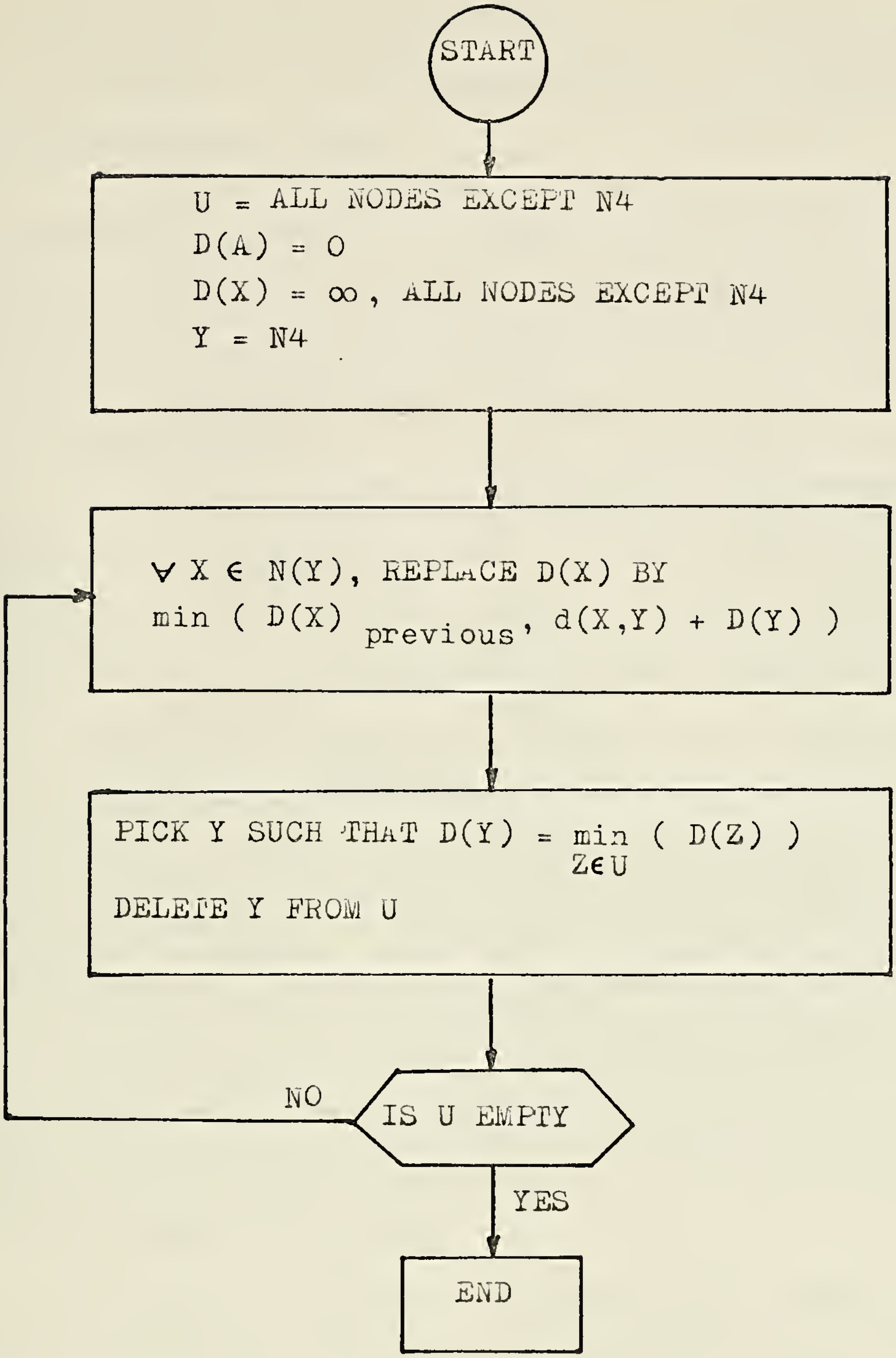


Figure 3.

Dynamic Programming Flow Chart

on computer storage and speed are low [Ref. 3]. It's rather obvious that as the number of nodes and links increases, then these requirements become more difficult to meet.

B. STOCHASTIC TECHNIQUES

Kleinrock, Boehm, and Mobley all classify stochastic routing techniques into three basic categories [Refs. 1, 3].

1. Random Routing

This method of routing is very similar to the "flooding" technique discussed under deterministic methods. The main difference being that the decision of where to route the message is based on some probability distribution over the set of neighboring nodes. Prosser has investigated various random routing techniques and compared their results [Refs. 4, 5]. He demonstrated that although these techniques were highly inefficient, they were also very stable. Given enough time, a message is sure to get through to its destination. Under normal operating conditions, the degree of ineffeciency would probably not be tolerated, but in an extremely hostile environment, where reliability becomes the dominating factor, a network using random routing techniques will continue to operate in the presence of serious network degradation.

a. Network Assumptions

An accurate analysis of a communications system operating under a random routing procedure is very difficult to achieve. However, by introducing some broad assumptions designed to simplify the analysis some "rough" estimates of the operating characteristics of such a system can be examined [Ref. 4].

For the purpose of this analysis the following assumptions are made:

1) The network is a connected graph consisting of a fixed number of nodes, n, and each node is connected to approximately k neighbors.

2) Messages originate at each node of the network with a Poisson distribution in time of mean λ and with an exponential distribution in length of $1/\mu$. Both λ and μ are the same for all nodes.

3) Each message is addressed to a node in the network chosen at random.

4) Each node has a finite queue of messages to be relayed which operates First-in, First-out.

Using these broad assumptions some information about the network can be computed.

b. Number of Messages in Network

Frist, the average total number, $N(t)$, of messages in the network at the end of a given cycle, t, can be estimated. This is determined by:

1) The average total number of messages in the network at the end of the last cycle i.e., $N(t-1)$

2) The average total number of messages added to the network during a given cycle i.e., λ n

3) The average total number of messages dropped from the network during a given cycle by either being delivered or being dropped due to insufficient storage. (Assume that the storage is sufficient.) This is just the fraction, f, of $N(t)$ handled during a cycle, times the probability, p, that one of these messages will be delivered to its destination, divided by the expected number of cycles $1/\mu$ required to deliver a message. i.e., $\mu pfN(t-1)$. Therefore

$$N(t) = N(t-1) + \lambda n - \mu pfN(t-1) \qquad (4)$$

By assuming that the system is empty at $t = 0$ i.e. $N(0) = 0$, then the behavior of $N(t)$ as $t \to \infty$ can be investigated. The behavior depends only on the assumptions made about f and p. The particular routing procedure that is used will determine p, and if the messages are assumed to be independently randomly distributed throughout the network, then Prosser [Refs. 4, 5] demonstrates that by using the methods of Riordan, the expected value of f is given by:

$$f(N) = \frac{n}{n + N-1} \tag{5}$$

Notice that

$$f(N) \sim \begin{matrix} n/N & \text{if } N>>n \\ 1 & \text{if } N<<n \end{matrix} \tag{6}$$

If N>>n, then equation (4) becomes the first-order difference equation:

$$N(t) = N(t-1) + (\lambda - \mu p)n \tag{7}$$

whose solution is

$$N(t) = (\lambda - \mu p)nt \quad \text{[Refs. 4, 5]} \tag{8}$$

Notice that as $t \to \infty$, $N(t) \to \infty$. This implies that if N>>n then the network has no steady-state. If N<<n, then equation (1) becomes

$$N(t) = N(t-1) + \lambda n-\mu pN(t-1) \tag{9}$$

whose solution is

$$N(t) = n/\mu p(1-(1-\mu p)^t) \tag{10}$$

As $t \to \infty$ in this case then equation (10) becomes

$$N(t) = n/\mu p \tag{11}$$

which is a steady state solution.

c. Traverse Time of Messages

The next step is to estimate the average number of cycles required to relay a message from sender to receiver. If p is independent of time, then the probability that a message will still be in the system after s relays is $(1-p)^s$. This gives a distribution over s whose mean, m, and variance, σ^2, are

$$m = \frac{1-p}{p} \sim 1/p \tag{12}$$

$$\sigma^2 = \frac{1-p}{p^2} \sim m^2 \tag{13}$$

The average number of cycles, Z, required for the average relay depends on: 1) The average service time in cycles, 1/u, and 2) the average time in cycles, spent waiting in storage i.e. $1/\mu \cdot \frac{a}{1-a}$ (average number of messages waiting in storage) [Ref. 4]. Where $a = n\lambda/\mu$.

Therefore,

$$Z = 1/\mu \ (1 + \frac{a}{1-a}) = 1/\mu \ . \ \frac{1}{1-a} \tag{14}$$

Thus the mean traverse time in cycles from (12) and (14) is

$$m' + \frac{(1-p)}{\mu p} \cdot \frac{1}{1-a} \tag{15}$$

and when the network is lightly loaded i.e. a is sufficiently small then (15) becomes

$$m' = \frac{1-p}{\mu p} \tag{16}$$

Thus far, the probability of a message being relayed to its destination in a single relay, p, has been assumed to be a constant. It is dependent on the routing procedure used and varies depending on how much each node knows about the network. With this in mind the value of p has the following form: It is given by

1) The probability that the message is located at a neighbor of its destination.

Multiplied by

2) The probability that this neighbor will relay the message to its destination.

Various cases can now be examined.

1) Pure Random:

Each node knows only its own identity. Thus each node relays every message to one of its k neighbors selected at random. In this case the "destination" of the message consists of the addressee, and there are k neighbors of this destination. The probability that the message is located at such a neighbor is k/n. Thus

$$p = k/n \cdot 1/k = 1/n \tag{17}$$

2) First Order Neighbors:

Each node knows the identity of itself and the identity of each of its neighbors. Messages are still relayed at random unless addressed to a neighbor, in which case they are relayed to that neighbor. The "destination" now consists of k + 1 nodes (addressee plus k neighbors). The number of neighbors of this destination depend somewhat on the details of the network graph. If the neighbors of each node are located somewhat randomly throughout the network, then they are relatively independent of each other and there are approximately k(k-1) neighbors of the destination. The probability that a message is located at one of these neighbors is then

$$p = \frac{k(k-1)}{n} \cdot 1/k = \frac{k-1}{n} \tag{18}$$

3) Second Order Neighbors:

Each node knows the identity of itself, its neighbors, and their neighbors. This is an extension of (a) and (b) and the probability that a message is located at a "destination" is

$$p = \frac{k(k-1)^2}{n} \cdot 1/k = \frac{(k-1)^2}{n} \tag{19}$$

This proceedure can be continued for as many "destinations" as necessary. However it is eveident that the more information each node has about the net, the higher the probability becomes that the message will be delivered in a certain period of time. The results can be summarized as follows: [Refs. 4, 5]. If the " destination" of a message is defined as the set of nodes which know the location of the addressee node and can assure a deterministic path to the addressee node, and if there are h neighbors of this destiantion, each of them connected to the destination in j different ways, then

$$p = h/n \cdot j/k \tag{20}$$

2. Isolated Techniques:

This class of routing algorithms operate by forming a "delay table" at each node. The entries of the delay table, $T_j(D,L_N)$, are the estimated delays of going from the present node, (say j), to some destination node, D, using various output lines, L_N. A "routing table" is then formed by choosing the output line, $OL_N(i)$, with the minimum delay time entry for each destination, i. Formally:

$$OL_N(i) = \min_{\{L_N\}} T_j\ (i,L_N) \tag{21}$$

Where $\{L_N\}$ is the set of output line numbers. Figure 4 is an example of a delay table and a routing table for an arbitrary node J. The manner in which these delay tables are formed, and how their entries are determined is basically a function of the specific algorithm used. Some problems arise using these techniques. For example, if two messages, each headed for the same destination, arrive at an intermediate node at approximately the same time. Both need the same outgoing link. One solution is to store one of the messages until the best outgoing link is available, but this could require an extremely large storage capacity at some intermediate nodes, especially if they are on the main artery of traffic flow. An alternate solution to this problem is to include in the "routing table" at each node not only the best outgoing link, but the next best link etc. An incoming message is then routed out on the best link available at the time. Two algorithms using isolated techniques are discussed here.

a. Shortest Queue Plus Zero Bias

This algorithm is also referred to by Baran as "Hot-Potato Routing" [Ref. 6]. With this algorithm, a message's route is selected by placing it in the shortest output queue. Since the route is chosen independent of the messages destination, the delay table, figure 4, is reduced to a single row, where the row entries would reflect the output queue lengths. It is now obvious that much bookkeeping is necessary at all the nodes. Methods must be devised to keep the routing table current and the "best" queue lengths for each outgoing link must be determined. Further, some method for "dropping" messages from the network (when all queues are full) must be considered.

b. Local Delay Estimate or Backward Learning

This method uses the delay table and the routing table of

Output Lines

Destination Node

	L_1	L_2	L_3	L_4
1	0.2	0.1	0.5	0.7
i	0.1	0.9	1.0	0.2
N	0.5	0.8	0.6	0.2

Delay Table

$T_i \; (D=i, \; L_N = L_4)$

$$OL_N(i) = \min_{(L_N)} T_i(i, L_N)$$

L_2	1
L_1	i
L_4	N

Routing Table

Figure 4.

Node J Delay and Routing Table

figure 4 to handle its messages. Each time a message is received (say at node j) the delay table is updated as follows [Ref. 1].

$$T_j(D{=}S,\ L_N^{(R)})_{new} = K_1 \cdot T_j(D{=}S,\ L_N^{(R)})_{old} + K_2 \cdot T_{IN}(S,J) \qquad (22)$$

Where

$T_{IN}(S,J)$ = The time the message has spent in the network traveling from its source node, S, to the current node J.

$L_N^{(R)}$ = The reverse (outgoing) line corresponding to the forward (incoming) line (if a duplex pair is used) or its the same line that the message entered node J on, used as an outgoing line.

K_1 and K_2 are constants determined by the network characteristic [Ref. 5].

This "backward" learning technique assumes that the time that it takes a message to go from X to S via some link in the network is approximately the same time that it would take the message to go from S to X using the same link. The constants K_1 and K_2 are used to bias the update so that the new table entry, $T_j(D,L_N^{(R)})$, is a certain fraction of the difference between the old table entry and the new table entry. Once the delay table has been updated by equation (22), then the routing table is updated by equation (21). Boehm [Ref. 3] points out that a distinct disadvantage of using this technique occurs when certain nodes are removed from the network due to damage. The result is a "ping-ponging" effect or looping that could delay delivery indefinitely. The solution offered is kind of a negative-reinforcement technique that "penalizes" a node for returning the message to a node that it has already

been to. The "penalty" is in the form of a constant added to the delay table entry, which will then cause all messages bound for a certain destination to try a different route. Again, another disadvantage occurs in the form of the delay tables having very large entries. This will happen since "looping" for short periods of time cannot be avoided using stochastic routing techniques. Eventually entries in the delay table would have to be re-initialized. A good synthesis of the backward learning technique and the negative reinforcement is what Boehm calls the bi-adaptive technique. It uses the backward learning technique to decrease the delay table entries to correct overcompensations of negative reinforcements. This is satisfactorily accomplished by setting K_2, in equation (22), to zero for the particular calculation. It is now necessary for the node to recognize messages that have been there before, but this could be accomplished by setting a flag bit on the message itself.

3. <u>Distributed Techniques</u>

This class of algorithms use the same basic techniques to compute and update the delay tables as the isolated techniques, but the instants at which these tables are updated and the route selection procedures differ depending upon the particular structure of the algorithm. There are basically two mechanisms for updating the entries in the delay table:

(1) As messages are taken off or put on an output queue, all delay table entries corresponding to that output line must be decreased or increased respectively to reflect the change in expected delay. These methods were discussed in the previous section.

(2) Delay information from neighboring nodes is utilized to update the delay table estimates.

It is method (2) that will be discussed here. Referring to figure 5., suppose, by some method, a decision has been made at node J to inform its neighbors (N_1, N_2, N_3) of its current estimated delays to reach all nodes in the network. Node J forms a "minimum delay" vector say V_J = (T(1), T(2), ...), where the k^{th} entry in the vector, $T(K) = \min_{\{L_N\}} T_j (K,L_N)$, and transmits V_J to its neighbors (N1, N2, N3). Upon receipt of the minimum delay vector, a node (say N1) adds its current output line queue length (line L_1 for this example) plus a constant, Dp, to all entries in the vector V_J and replaces column 1 (corresponding to line L_1) in the delay table with these new values. The updated table entries for node M are:

$$T_M(D,L_N) = Q(M,L_N) + Dp + T(D) \tag{23}$$

Where

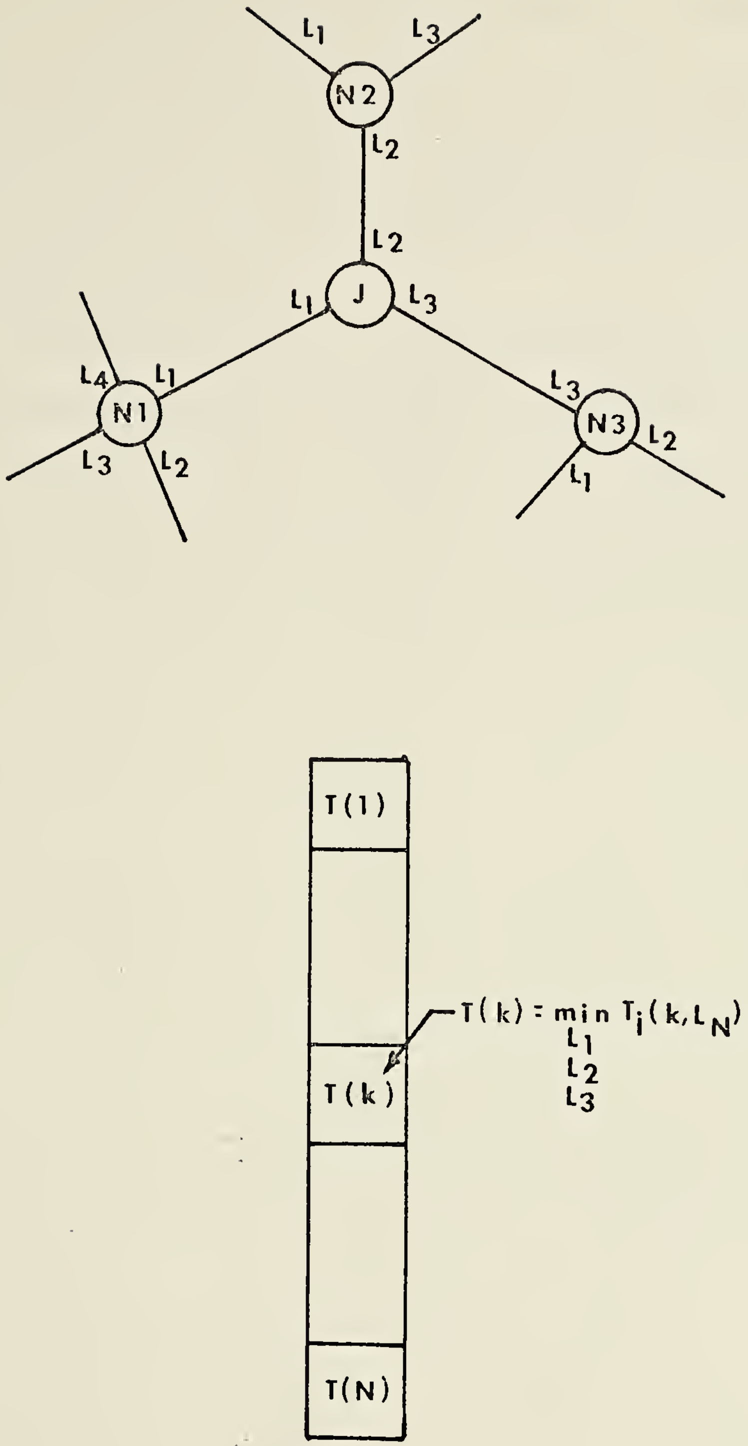
$Q(M,L_N)$ is the queue length at line number N at node M. The constant Dp is used to control the degree of alternate routing and the sensitivity of the algorithm to small variations in queue length. That is, if Dp is large compared to the average queueing delay in a node, then the path chosen for a message would tend to be one of the paths that would encounter the smallest number of lines enroute to its destination [Ref. 1]. There are basically two methods which can be used to cause the delay vector, V_J, to be transmitted.

a. Periodic Update

The periodic updating algorithm forces these transmissions at fixed periods of time.

b. Asynchronous Update

This algorithm can cause an update to be transmitted, after



Vector V_J

Figure 5.

Minimum Delay Vector and Example Network Segment

a message has been transmitted in accordance with equation (21), on the same line that the message has been transmitted on, provided that the delay vectors can percolate through the network in a short time period. If the threshold values are very large, then updating ceases and the asynchronous routing scheme reduces to the "shortest queue plus zero bias" algorithm discussed earlier.

The choice of routes is now determined as follows: If the update mechanism is periodic, then equation (21) is used to determine the set of routes and this set of routes is held fixed until the next update occurs. If the update mechanism is asynchronous then equation (21) is used to determine the route of each message as it arrives.

III. USE OF MICRO-COMPUTERS IN THE COMMUNICATIONS NETWORK

In the preceeding sections, no restriction was placed on the size of the computer that would handle the message routing at each of the nodes. These computers could have been Micro, Mini, or large-scale. Further, no consideration was given to the amount of memory necessary at each node to be able to handle the more sophisticated algorithms. In this section, I would like to examine the feasibility of using micro-computers at each of the nodes and discuss which, if any, of the algorithms are still usable with this new restriction on the network. The micro-computer that will be considered as a candidate for use in the network will be INTEL Corporation's MCS-8 [Ref. 11]. Before discussing the characteristics of the MCS-8, some possible network applications should be mentioned.

A. MILITARY APPLICATIONS

Generally speaking, communication networks that are in use today are very large scale, such as the ARPA network which is used to pass data between computers across the United States, and the Bell Telephone System that routes communication traffic throughout the United States and Overseas.

In this paper, the networks under consideration will be restricted to a somewhat smaller scale, and will be used for military purposes. For example, a possible network might be set-up aboard a large ship or at a shore station to monitor and route all incoming communication traffic, whether it be Broadcast or Tactical. A network of this sort would require one or more micro-computers at each station to screen the messages that are received from other stations and either forward them to their destination or to drive a teletype if the message is for their station.

A more abmitious application might be the replacement of the present NTDS system by an NTDS network aboard our large combatants. For this application, the computing that is presently being done by large "centralized" computers could be distributed throughout the ship. For example, radar information received in CIC concerning a target, must currently be sent to the NTDS computer for processing where the target's course, speed, and CPA are computed and then that information is passed to a weapon system of some sort to engage the target. In the proposed network, microcomputers in CIC would receive target data from the radars and compute the target's course, speed and CPA. A second micro-computer that could communicate with each of the "radar" micro-computers would have the task of designating targets according to some priority scheme. Another microcomputer, somewhere else, might have the task of selecting a weapon, and another micro-computer at the weapon station might have the task of training the guns or aiming the missiles. By distributing the tasks normally done by a "centralized" computer, a remarkable increase in the reliability of the entire system can be realized. For example, loss of any part of the network would not cause the network to fail, whereas failure to the "centralized" computer does cause the system to fail. What is needed to make the network operational is a means of communication for the micro computers: Some method of routing messages from station to station. It is worthwhile to mention here, with the cost of micro-computers being what they are today, that a network of approximately one-thousand micro-computers could be implemented for the same hardware cost as our present NTDS system.

B. THE MCS-8 MICROCOMPUTER SET

The MCS-8 microcomputer set is made up of a model 8008 single-chip MOS 8-bit parallel processor interfaced with any type or speed standard

semi-conductor memory of up to 16k 8-bit words [Ref. 11]. The processor communicates over an 8-bit data and address bus and uses two input leads (READY and INTERRUPT) and four output leads for control. Time multiplexing of the data bus allows control information, 14-bit addresses, and data to be transmitted between the CPU and external memory. The CPU contains six 8-bit data registers, an 8-bit accumulator, two 8-bit temporary registers, four flag bits, and an 8-bit parallel, binary, arithmetic unit which implements addition, subtraction, and logical operations. A memory stack containing a 14-bit program counter and seven 14-bit words is used internally to store program and subrouting addresses. The 14-bit address permits the direct accessing of 16k words of memory which may be any mix of RAMs, ROMs, or shift-registers. The control portion of the CPU contains logic to implement a variety of register transfer, arithmetic control, and logical instructions. Most instructions are coded in one byte (8-bits); data intermediate instructions use two bytes, and jump instructions use three bytes. Presently operating with a 500 KHz clock, the CPU executes non-memory referencing instructions in 20 microseconds. The instruction set for the 8008 consists of 48 instructions including data manipulation, binary arithmetic, and jump-to-subroutine. The normal program flow of the 8008 may be interupted through the use of the INTERRUPT control line. This allows servicing of slow I/O peripherals while also executing the main program. The READY command line synchronizes the CPU to the memory cycle allowing any type or speed of semiconductor memory to be used. Figure 6 is a block diagram of the 8008 central Processing Unit [Ref. 11].

The four basic functional blocks of the CPU (figure 6.) are the instruction register, memory, arithmetic logic unit (ALU), and I/O buffers. They communicate with each other over the internal data bus.

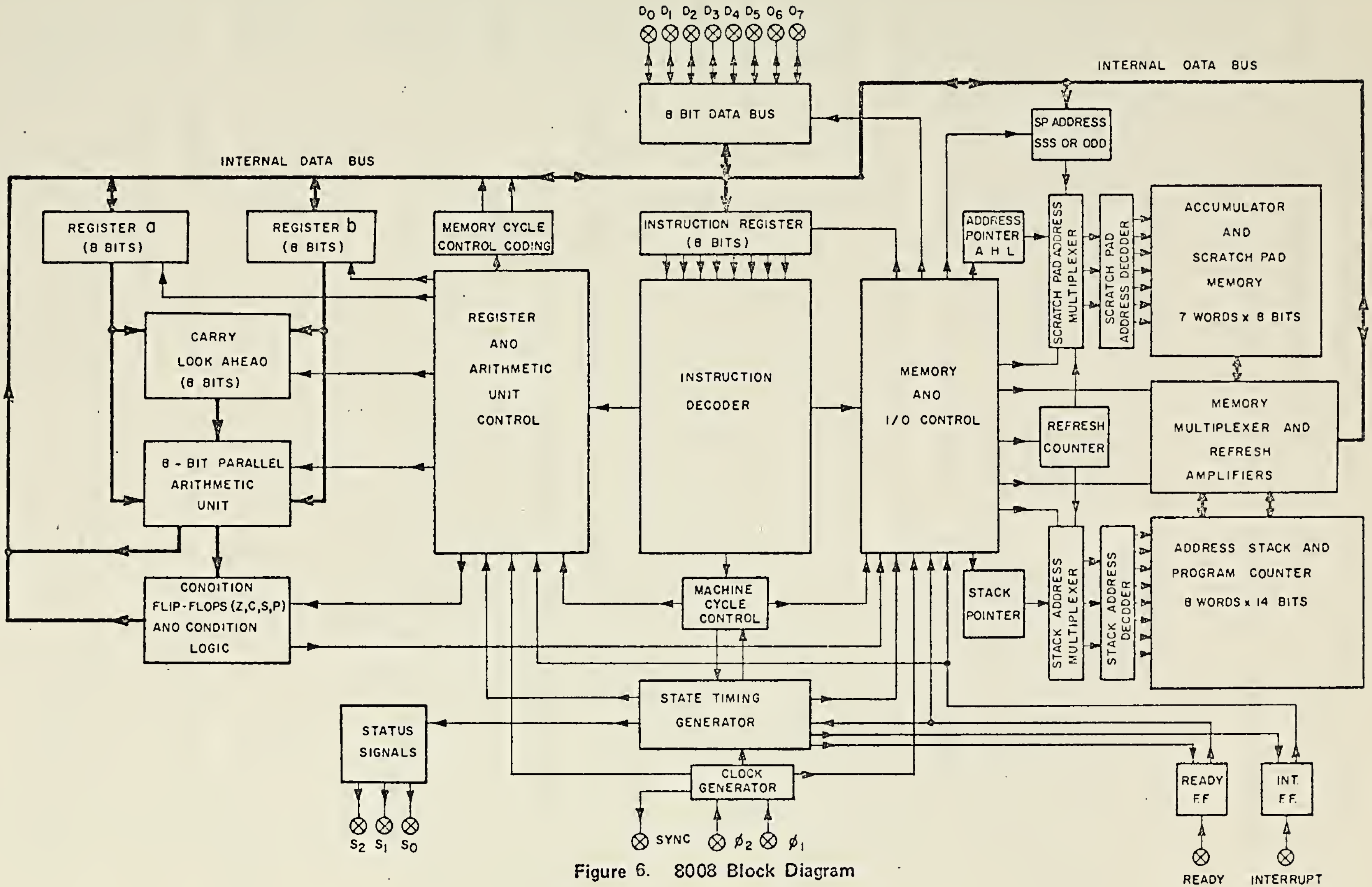


Figure 6. 8008 Block Diagram

The instruction register is the heart of all processor control. Instructions are fetched from memory, stored in the instruction register, and decoded for control of both the memories and the arithmetic logic unit.

Two separate dynamic memories are used in the 8008; the push down address stack and a scratch pad. The address stack contains eight 14-bit registers, providing storage for eight lower and six higher order address bits in each register. One of these registers is used as the program counter and the other seven permit address storage for the nesting of subroutines. The stack automatically stores the content of the program counter upon execution of a CALL instruction and restores the program counter upon execution of a RETURN. A three-bit address pointer is used to designate the present location of the program counter. When the capacity of the stack is exceeded the address pointer recycles and the content of the lowest level register is destroyed. The 14-bit program counter provides direct addressing of 16k bytes of memory. Through the use of an I/O instruction for bank-switching, memory may be indefinitely expanded. The scratch pad contains the accumulator and six other 8-bit registers. These registers are independent and may be used for temporary storage. Two of these registers may be used for indirect addressing.

All arithmetic and logical operations are carried out in the 8-bit parallel arithmetic unit which includes carry-look-ahead logic. Two temporary registers are used to store the accumulator and the operand for all ALU operations, or they may be used for temporary address and data storage during intra-processor transfers. Four control bits are set as a result of each arithmetic and logical operation. These bits provide conditional branching capability through CALL, JUMP, or RETURN-ON-CONDITION instructions and also the ability to do multiple precision binary arithmetic.

The I/O buffer is the only link between the processor and the rest of the system. Each of the eight buffers is bi-directional and is under control of the instruction register and state timing. Each buffer is low power transistor-to-transistor logic (TTL) compatible on the output and the input.

1. Example Program

To provide some insight into how the MCS-8 would have to be programmed, the following subroutine is presented. This subroutine might be used at each node to check an incoming message and determine the next node in its path. This program resides on ROM at locations 100-115. Memory locations 0-199 are reserved for the message buffer with the source and destination occupying bytes 0 and 1 respectively. The "Routing table" is located at bytes 200-219 and is similar to figure 1. The subroutine returns with the next node number in the accumulator (A-register). Although this subroutine is not very complex, it does provide a sample of the programming language used with the MCS-8 and approximately how much time is required to do a simple table look-up. This subroutine executes in approximately 300 micro-seconds. Figure 7 is a flowchart for the example program.

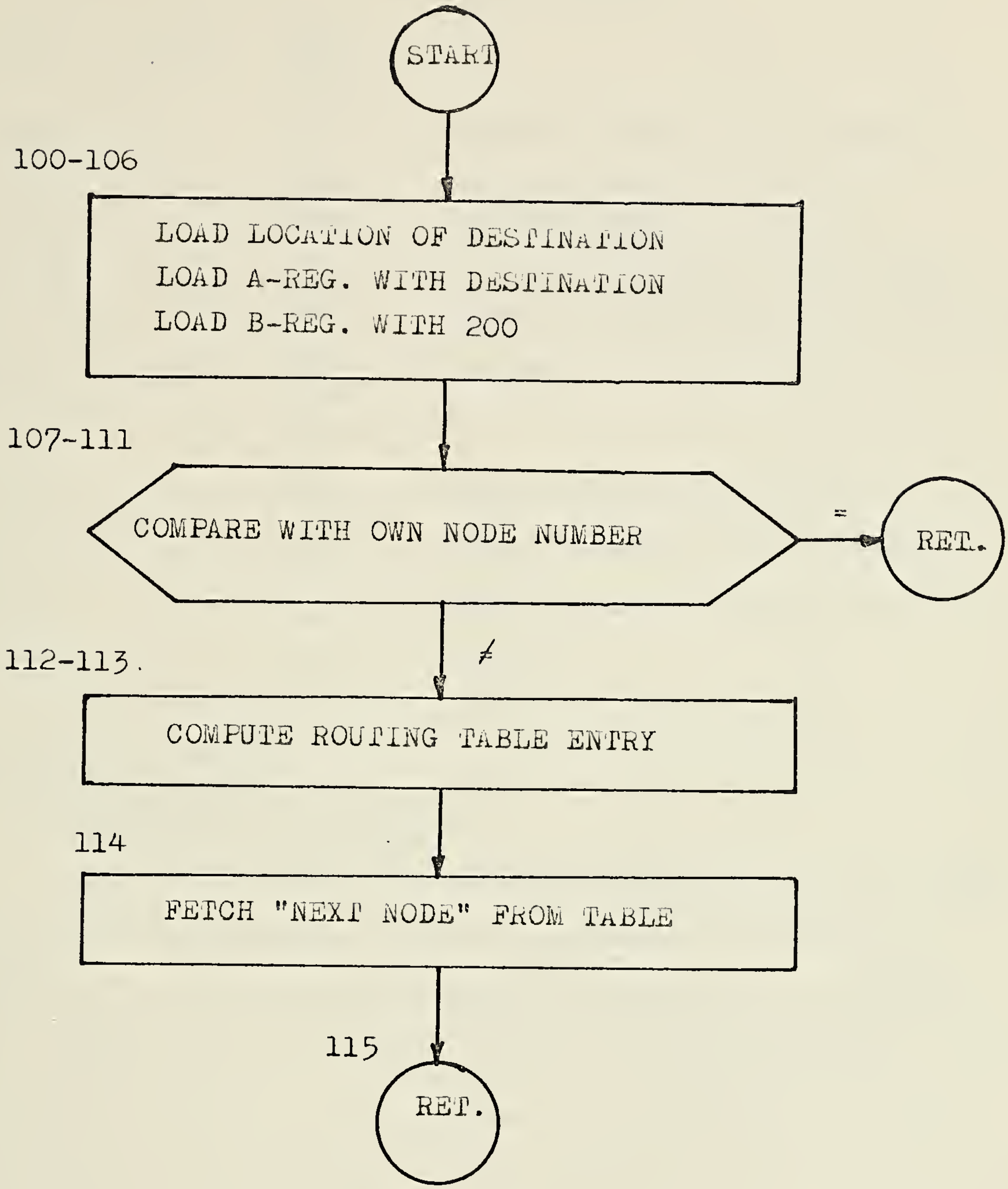


Figure 7.

Subroutine to Determine Next Node

MNEMONIC	OPERAND	LOCATION	COMMENT
LLI	001	100	Load L & H registers with address of the destination
LLH	000	102 103	
LAM		104	Load Accumulator with Destination
LBI	200	105 106	Load B register with start of Routing Table
CPI	004	107 108	Compare Destination, with own Node number, (4), if own Node is Destination,
JTZ	115	109 110 111	return
ADB		112	Compute Routing Table entry
LLA		113	Load this address into L & H Reg.
LAM		114	Fetch Contents of Routing Table
RET		115	Return

C. ROUTING ALGORITHMS

1. Efficiency vs. Reliability

The central problem in choosing an algorithm to route messages through the system appears to be one of efficiency vs. reliability [Refs. 4, 5]. In an entirely favorable environment, the reliability of a communications system is limited only by the characteristics of the components themselves, and the system should be organized for maximum efficiency. In an extremely hostile environment, the system must be organized for maximum reliability and the efficiency is limited by this organization. Thus in a civilian system, messages should get through quickly and accurately but if disaster strikes a central office then failure is liable to be absolute. In a military system, however, such

a loss cannot be tolerated. Degradation must be gradual and messages must get through even after a loss of a large part of the system.

Any large-scale civilian communications system should probably be essentially a directory system: Every operating station in the system should either have a directory of its own or have access to one which contains complete information on how to reach every other station in the network. In many cases there could also be a "central" station whose task it is to handle, or assist in handling, the routing of messages through the network. This type of organization has the advantage that very efficient routing procedures can be obtained by all stations from the directory, but it has the obvious disadvantage that it depends heavily upon this directory. This system will work fine when failures in the system are few, but in a hostile environment the disadvantages are likely to outweigh the advantages because any change in the system requires a revision of the directory of every station in the network.

In contrast to the above, any military communications system operating in a hostile environment should probably operate as a random system. There are no directories to maintain and each station will send messages to whatever station it can, based on whatever information it has, and hopes for the best. This type of operation is likely to be extremely inefficient, but has the advantage that it will continue to operate in the presence of serious degradation. In a favorable environment the disadvantages surely outweigh the advantages of such an organization and such a degree of inefficiency would not be tolerable unless conditions were indeed desperate.

This problem can be restated in terms of the information available to each station about the rest of the network. The directory system supposes that each station has complete and accurate information about every other

station in the network and routes messages based on this information. Such a system can be made efficient but has the problem of devising optimum routing procedures from this information and keeping this information up to date. On the other hand, stochastic techniques suppose that no station has complete information about the system and routes messages based on random choices or by some other method depending on what information is available to each station. Such a system can be made reliable, but it must be determined how to make this system efficient. It is likely that a military system operating under a variety of conditions will necessarily incorporate elements of both the directory and stochastic techniques, the proportion being determined by the particular use of the network and the computing machinery available.

2. Deterministic Techniques

A communications network using micro-computers at each node should be able to operate quite effectively using deterministic techniques as routing algorithms. The "flooding" or "selective flooding" algorithms are compatible with the MCS-8 microcomputer with only a slight increase in message transit time realized. This is due to the relatively slow (20 microsecond) instruction cycle of the MCS-8 as compared to the faster times of most large-scale or even minicomputers. For certain applications, where low-volume message traffic is the rule, a very reliable network could be had. The inherent inefficiency of this type of algorithm could be reduced somewhat by including a table of "best" routes, hence selective flooding, but the small increase in the efficiency of the network would have to be weighed against the further increase in message transit time.

On the opposite end of the scale of highly reliable flooding techniques are the very efficient "Network routing Control Center, (NRCC)" and the "Ideal Observer" methods of handling messages within this network. The MCS-8 is quite capable of functioning as an NRCC providing that the time requirement for updating routing tables is not too critical, and the network is small enough to allow the MCS-8 to monitor and control all nodes. If this method were to be used for large networks, then a small group of MCS-8's could be used, each monitoring their own segment of the network and communicating with each other concerning the status of net. The unacceptable level of reliability of this configuration tends to override the high efficiency and makes this method impractical for military applications. As stated earlier, the "Ideal Observer" method has doubtful application in any type of network with any type computer, and should be used only as a theoretical aid.

The use of "Fixed Routing" techniques seems to be a suitable compromise of the other methods that can easily be handled by the MCS-8 network. This method, with its fixed routing table at each node, would require a table look-up each time a message arrived at a node. This table look-up would cause some increase in the message transit time, but even with the slow processing time of the MCS-8, this increase would be tolerable. The problem of increasing the reliability, predominant in nets using deterministic techniques, seems to be more easily overcome using fixed routing tables than in the nets using a NRCC; this method allows a higher volume of traffic than could be allowed using flooding techniques. To accomplish this compromise, a modification of the routing table in figure 1. is necessary. The new routing table, figure 8., although fixed, now offers alternate routes should the primary "next node" be "down" for

Destination Node Number	Primary Next Node	1st Alternate Node		nth Alternate Node
1	3	2	. . .	7
2	1	7		4
3	4	6		9
4	6	10		11
6	9	11	. . .	4
7	9	11		4
8	10	6		5
9	8	7		5
10	8	4		9
11	7	4	. . .	6

Figure 8.

Modified Routing Table

any reason. The number of alternate routes included in the table increases with the amount of reliability required and would vary depending on the application of the network. The possibility exists that these tables might become quite large in a large network, but with the low cost of the MCS-8, several of these micro-computers could be placed at each node to accomodate the large tables and still do the necessary tasks assigned to the node. Some problems that would have to be solved when using this method are:

1) How to determine when the primary "next node" is down.

2) Once it has been determined that the primary node is down, how should the routing table be modified, and

3) How can a previously down node, that is now operational, be recognized as operational.

3. Stochastic Techniques

In contrast to the deterministic techniques, the stochastic algorithms are not as easily adapted to an MCS-8 micro-computer network. In general, attempts to increase the efficiency of a network using these techniques result in very long delay times at each node and tend to raise the overall transit time to an unacceptable level. The possible exception being the "Random" routing technique which is very similar to the "Flooding" technique discussed previously. In a low volume network, where efficiency is of minor concern, either of these methods could be used very effectively. All other stochastic techniques use a delay table and attempt to bring the efficiency of the network up to an acceptable level by keeping this delay table as current as possible. The requirement is that longer messages or additional messages must be introduced into the network; and, for some algorithms, a queue must be set-up at each node ("Hot-Potato"

routing). In all cases, though, comples algorithms must be used at each node to keep the delay tables current.

IV. CONCLUSIONS

The MCS-8 is capable of meeting the requirements for large storage areas and/or complex algorithms by having a group of computers at each node and assigning each a specific portion of the tasks to be accomplished. The problem however, is that messages may be delayed for an abnormal length of time while the table is being updated and some loss in node reliability would be realized, since a loss of any one of the computers at the node would cause the node to fail.

A. ALGORITHM SELECTION

The most adaptive of the stochastic techniques is the "Backwards Learning" technique. Although this method does require a more complex algorithm to reduce the "ping-ponging" effect in the network, it does not introduce new messages into the network, as is the case with the "Delay Vector" techniques, and the tables required at each node are similar in size to the routing tables described under Deterministic Techniques. This technique does require that the estimated delay time be added to a message at each node and the delay table be updated each time a message is received or transmitted.

In summarizing the above observations, it is apparent that there is no single "best" algorithm that can be utilized in the MCS-8 micro-computer network, but the choice of algorithm depends on the requirements imposed on a particular application. It does appear, though, that the "modified" fixed routing table, figure 8., offers a degree of efficiency and reliability that is acceptable for most applications. If a stochastic

algorithm must be used, as would be the case when "best" routes were continually changing, then the "Backward Learning" technique seems most compatible with the MCS-8 network. Although this method requires a more complex algorithm, it does offer good efficiency and reliability and should not be too difficult to implement.

B. FUTURE STUDIES

During the research and writing of this paper, some additional problems were uncovered concerning micro-computer networks. These problems are presented here for possible future study.

1. Topology Studies

For a given application, determine the configuration of the network required to provide the optimum message delivery rate. This study would probably require simulating various network configurations. For networks that are very small, it is possible that the best method may be to connect each computer in the network to every other computer, hence eliminating the need for routing algorithms altogether. As the network grows, however, a point is reached when routing algorithms become necessary for efficient operation.

2. Programming Algorithms

The routing algorithms proposed as acceptable should be written and studied to determine what the actual delay time would be at each node.

3. Message Construction

The length of the message is important because it determines the buffer size necessary at each node. The physical construction may vary depending on the specific network application but the optimum size should be determined. The construction will also be affected if the message must be transmitted in parts.

4. Message Handling

The problem of what to do when two or more messages arrive at a node at approximately the same time must be considered. Multiple buffers for nodes that are on a high traffic path may be necessary, but too many buffers would increase the delay time at each node. A priority scheme should probably be introduced in a multiple-buffered node to ensure that priority traffic is handled first. The method of handling multiple destination messages should also be considered.

5. Applications

Microcomputer network applications other than those mentioned herein, should be studied.

6. Node Improvements

The affect of faster, larger storage micro-computers on network performance should be studied. For example, INTEL Corporation has plans of manufacturing a 2 microsecond, processor, the 8080, that is capable of handling 65K of memory. This machine may allow the use of more complex algorithms than are presently feasible with the MCS-8 system.

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ABSTRACT

The use of microcomputers in a message-switching network is introduced through discussion of store-and-forward routing techniques. Algorithms that utilize oth deterministic and stochastic principles are explained and those parameters hich determine the computing machinery necessary are identified. INTEL Corporations SC-8 micro-computing system is presented as a possible candidate for use in essage-switching networks and some applications of these networks are discussed. modification of a routing algorithm is offered, which makes the microcomputer seable in message-switching networks.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stochastic						
Deterministic						
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