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INVESTIGATIONS INTO THE PERFORMANCE OF
A DISTRIBUTED ROUTING
PROTOCOL FOR PACKET SWITCHING NETWORKS

by

Anthony W. Lengerich

December 1982

Thesis Advisor:

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nodes are called "distributed" routing protocols. The relative performance of two distributed, dynamic routing protocols is determined using computer simulations. The protocols are implemented of four theoretical networks and tested under a range of network traffic loads.

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Investigations into the Performance of a Distributed
Routing Protocol for Packet Switching Networks

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Packet switching communication networks employ routing protocols to determine the path traversed by each packet as it passes through the network. Routing protocols which are adaptive and can restructure the packet paths in response to localized network congestion are called "dynamic" routing protocols. Dynamic routing protocols seek to optimize the routing (provide the shortest path) for each packet in the network. Routing protocols which are unaffected by the addition or deletion of any subset of nodes are called "distributed" routing protocols. The relative performance of two distributed, dynamic routing protocols is determined using computer simulations. The protocols are implemented on four theoretical networks and tested under a range of network traffic loads.

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I. INTRODUCTION

A. THE PACKET SWITCHING CONCEPT

The purpose of any communications network is to provide paths for the transmission of information. It is desirable that the process which controls the transmission and reception of messages within the network be transparent to the user. To achieve this result it is required that the communication network impose a tolerable delay in the relay of messages between the originator and the destination. Further, the network should require a minimum number of instructions from the originator to accomplish the task. Ideally, the originator would be required to provide only the destination of the message to the network. The communications network should then be capable of transmitting messages to their destinations in as short a time as possible.

For communications networks which serve many users and have the requirement to exchange large amounts of data, the concept of "packet switching" may provide a method of operation which will satisfy both the speed of service and the transparency requirements of the user. In addition, an increased robustness of the network can be realized without

creating redundant circuitry if an appropriate routing algorithm is employed within the network.

The packet switching concept may be broadly described as the coordinated movement of specified length data streams within a communications network such that the data streams always travel the least congested (ie. quickest) route between the originator and the destination. Packet switching envisions the breakdown of a message into fixed length segments (packets) which are transmitted through the network to the destination by the "shortest path" (called the best path) which is known to exist at the time the packet is released into the network. The implementation of the packet switching concept requires that each station (node) in the network be capable of processing certain data concerning the structure of the network. This is necessary so that the correct routing can be assigned to each packet as it is released by the node into the network. This process can be implemented in the computer software which would control a node's participation in the network. It is important to recognize that the routing of different messages is not independent of each other, since (for example) sending all traffic via one particular link will

introduce congestion (queueing) delays that might be avoided by distributing the traffic over a variety of available links.

Packet switching techniques can be used to transmit both data and digitized voice signals. While the transparency of service to the data user is resolved through use of high bit rate transmission systems and storage buffers at each node, the real time requirement for intelligible voice communications may require the establishment of a dedicated circuit for each conversation. It may also be possible to establish a dedicated voice transmission circuit each time the transmitter is "keyed" rather than maintain a circuit for the duration of the conversation, or to always transmit over the same route (called a "virtual circuit") and to share the channel capacity with other messages during interstices in the conversation. In this way the amount of time a particular set of links remains dedicated to a single transmission is minimized.

B. NETWORK PROTOCOLS

Central to the operation of any communications network is the set of instructions which directs the exchange of network information between nodes. These instructions may

be implemented in hardware or software and are referred to as Network Protocols. The information contained in messages generated by these protocols is used by the communications network to implement the routing of user message traffic within the network. Network Protocols are commonly divided into several hierarchical levels according to their particular function within the network. For instance, the International Standards Organization adopted a "Reference Model of Open System Interconnection" (ISO) which consists of seven layers of protocol. The different layers as described by Tanenbaum [Ref. 1], are: physical layer, data link layer, network layer, transport layer, session layer, presentation layer and application layer. Heritsch, in Reference [2], addresses three levels of protocol which are of concern in studying Distributed Routing Protocols. Five of these layers are incorporated into the three protocol levels discussed by Heritsch. The interrelation of these levels and layers is presented in the following paragraphs. Two layers, the session layer and the application layer, are not considered since they are not present in the test networks used in this study.

The lowest level of protocol is called the Node-to-Node protocol and consists of those instructions necessary to ascertain and verify that a usable communications path exists between any two adjacent nodes. This level is a combination of the physical layer and the data link layer of the ISO and serves to establish the physical exchange of data between nodes. In addition the Node to Node protocol specifies the "handshake" and "acknowledgement" processes which are required whenever messages transit between two neighboring nodes. (The term "neighboring nodes" implies that a direct two way communications path exists between adjacent nodes. Such a path is referred to as a "link".) If the computer software within the node is configured to monitor the transmission and receipt of Node to Node protocol messages, then the continuing function of verifying that a usable link exists can be accomplished without another form of protocol message being entered into the network.

The next level of protocol is the Network Management Protocol which corresponds directly to the network layer of the ISO and exchanges all the information necessary for the nodes to make decisions as to which route each message

originated by or relayed by the node should travel enroute to its destination. There are several different concepts of Network Management protocol. Since if the amount of Network Management traffic is large there is less residual capacity in the network for the transmission of user generated traffic, it is essential to establish an understanding of the portion of total network capacity required to implement a given Network Management Protocol. This study is concerned with developing such an understanding for the Network Management Protocol proposed by Heritsch [Ref. 2].

The final level of protocol is the User Service Protocol. This level is equivalent to the presentation layer of the ISO. As the name implies, this level is concerned with the interface between the user and the communications network. Functions accomplished by this protocol level may include the automatic breakdown of user messages into "packets", attaching accounting numbers to the messages and releasing or receiving messages into and from the network. At this level, tradeoffs made between network transparency and the required user interaction with the network are most apparent.

C. DISTRIBUTED ROUTING PROTOCOLS

The singular feature which distinguishes a packet switching communications network from other communications networks is the repackaging of user messages into smaller fixed length "packets", each of which can be treated separately by the network. An advantage of using fixed length packets is that the network can seek to transmit packets via routes which currently have the fewest number of packets flowing through them. Since all packets are the same length a simple count of the number of packets waiting in queue for a specific link is a measure of the delivery delay a packet traveling that route would experience. The packet switching network attempts to minimize the delay time by routing packets over links which have the fewest number of packets active within them. It is desirable to use Distributed Routing Protocols in packet switching networks to decide which routes are shortest.

Distributed Routing Protocols are sets of instructions utilized by the network to determine on the basis of information exchanged with its neighbors which path each packet should take from its originating node to its destination node. Distributed Routing Protocols may be either synchronous or asynchronous in design.

Synchronous Distributed Routing Protocols cause all nodes within the network to change their routing instructions simultaneously and at periodic intervals. Asynchronous Distributed Routing Protocols permit the nodes to adopt new routing instructions independently whenever the node finds a path to the destination node which is shorter than the path it had previously been using.

This study examines the Distributed Routing Protocol proposed by Heritsch, [Ref. 2], determining its performance in both the synchronous and asynchronous forms and comparing its performance to the centralized routing protocol based upon the Dijkstra shortest distance algorithm [Ref. 3]. The protocols are examined using a computer simulation which uses several different networks and several levels of network message loading to provide an indication of protocol performance under a variety of conditions.

II. A NAVAL APPLICATION

The concept of packet switching offers several advantages to users who require high data rate transmission capability and a robust communications network through which large volumes of message traffic must pass. In particular the requirements of the Navy Tactical Data System (NTDS) might in the future be met utilizing a packet switching network.

NTDS is a computer based tactical information display and decision system. NTDS information is exchanged between units of the fleet via a radio frequency digital communications network. (The term "fleet" is used here in its broadest sense and may include such diverse units as ships, all types of aircraft and troops ashore.) In its present form, the NTDS utilizes a centralized communications network with a net control station (master node) coordinating the exchange of information between units of the fleet. Participating fleet units (nodes) which have direct links with the originating node (ie. are within radio reception range) receive the transmitted message. Nodes which are beyond the radio transmission range must rely on retransmission of the information by a node which is

directly linked to a sending node. Nodes which retransmit messages may be thought of as sub level master nodes and their loss may deprive outlying nodes of information and direction.

In contrast, the packet switching concept offers a distributed communications network to support the information and coordination requirements of a widely dispersed fleet. By employing a Distributed Routing Protocol, a packet switching network can achieve increased network robustness by decentralizing the control of the network and seeking to optimize the routing of each message entered into the network. An NTDS participant would enter information into the communication network addressed to other NTDS participants as required. Upon entry the information would be reformatted into "packets" and transmitted along the best path to the destination nodes. Since all nodes are constantly "updating" their status and the status of their connecting links to other nodes in the network, the best path between any two nodes can be autonomously and continuously determined by each individual node using the network's Distributed Routing Protocol. The loss of nodes or degradation of links within the network

becomes known to all nodes and best paths can be reevaluated such that the network can continue to pass messages as long as possible. This feature of a packet switching network derives not from the physical addition of links between nodes but from considering of all nodes and links within the network as potential transmission paths to any other node in the network.

An important result of the packet switching concept is its ability to automatically relay messages to nodes which are beyond the radio reception range of the sending node. Since the sending node provides the destination addresses at the time of message transmission, the network can assume responsibility for delivery of the message rather than the conventional method of broadcasting a message and maintaining the receiving nodes within direct radio reception range. This capability would allow widely dispersed nodes to enjoy the information and coordination advantages of the NFDS without the burden of additional radio circuits. Additionally, the packet switching concept is adaptable to a variety of Anti-Jan (AJ) and Low Probability of Intercept (LPI) communications schemes which are under study or development by the Department of Defense.

In particular, packet switching is ideally suited for use with several spread spectrum communication schemes.

Conceptually, the most difficult problem to be overcome in the deployment of packet switching networks afloat is the mutual interference which two nodes transmitting simultaneously in the same frequency band might cause at the receiving node. This difficulty could be overcome using a "carrier sense" or a "listen before transmit" approach in the transmitter/receiver design and employing a signalling scheme which permits the receiver to "lock up" on the first signal received to the exclusion of all other signals. Conceivably, units could operate at slightly different carrier frequencies and the receivers would automatically shift their intermediate frequency sections to "lock up" on the sending unit's carrier. Mutual interference effects can also be ameliorated by use of wide-band pseudo-noise transmissions using uncorrelated keystreams.

It is with the possibility in mind, that the packet switching concept could improve the usability and survivability of NTDS, that this study was undertaken. To this end a set of generalized network configurations were developed so that several performance characteristics of the

packet switching concept could be determined. The specifics of the networks are outlined in Chapter III.

III. PARAMETERS OF A PACKET SWITCHING NETWORK

A. QUANTIFYING PROTOCOL PERFORMANCE

Critical to determining the relative performance of different routing protocols operating within a packet switching network, is the determination of an expression (mathematical or otherwise) which provides an unbiased and meaningful basis for comparison. In this study the average delay time in delivering a packet (T_p) is used as one measurement of protocol performance. Another measure of performance used is the utilization factor of the network (ρ). A mathematical derivation of the inter-relation of these terms, based upon queueing theory, is presented in Appendix A.

The average time delay per packet, (T_p) has the advantage of relating network congestion to network loading in terms of delay time, which is ultimately the most meaningful statistic to the network users. The utilization factor provides a measure of the fraction of the capacity of the network which is required to transmit user messages (packets) or network management messages (updates) given a specified network and traffic loading for the network. Both of these measures are affected by several physical

parameters of the network. For instance the processing time within a node for a packet adds delay time to the packet which is proportional only to the number of nodes traversed by the message route, hence independent of the routing protocol in use. On the other hand, if a packet must wait in a queue for an update to be transmitted on a link then the incurred delay is of interest because it represents interference by network management traffic with the transmission of user message traffic. A discussion of the various network parameters and their impact on the comparison measures, average delay per packet and update utilization factor, is presented in the next section.

B. NETWORK CONFIGURATIONS

In order to ensure that the performance measures " T_p " and " p " obtained from the simulation of the network are accurate, it is necessary to determine which physical characteristics of the network effect the measures of protocol performance. By fixing these characteristics as constants for all the networks under consideration, it is possible to obtain measures of performance which are representative of the protocol's performance in networks of varying complexity and traffic loading conditions. The

network characteristics which were deemed to be significant and the values assigned to them are listed in Table I and are discussed in the paragraphs that follow.

TABLE I
Significant Network Characteristics

<u>Parameter</u>	<u>Value</u>
packet transmission time for any link	0.05 sec.
packet processing time in any node	0.0001 sec.
update transmission time for any node	0.02 sec.
update processing time in any node	0.00001 sec.
update cycle time	0.2 sec.
update channel value calculation window	0.5 sec.
number of nodes in the network	variable
number of links in the network	variable
average number of packets per user message	variable
average number of user messages per sec.	variable
simulation run time	30 sec.

The packet transmission time is related to the length of the packet and the data transmission capacity of the link over which it is to travel. For this study only two types of messages (updates and user messages) are allowed to enter the links. User messages are subdivided into packets which are fixed in size to be 2.5 times longer than an update

message. In this way the length of an update is made to be small compared to the length of the packet. This action appears reasonable in view of the significantly smaller information content in an update versus a packet. The relative length of the the updates is also important to the performance of the distributed routing algorithm when computing channel values which are discussed in section C of this chapter. The time of 0.05 seconds selected for the transmission time of a packet, is equivalent to a packet length of 800 bits transmitted over a link with a capacity of 16,000 bits per second. Alternatively, it equates to a 120 bit packet transmitted over a link with a capacity of 2,400 bits per second.

The time required to process a packet within a node was arbitrarily chosen to be 0.0001 second and the processing time for an update was set to be one tenth of the packet processing time. This assignment also appears reasonable since in processing a packet each node must read the complete address section of each packet to determine onward routing if required and prepare a new address section for each packet which is retransmitted. On the other hand, an update message contains only a relatively small amount of

information which is either discarded or stored and relayed as required.

The update cycle time represents the frequency with which the network establishes a new best path for routing packets. An asynchronously operating protocol does not implement best paths simultaneously throughout the network but rather each node implements a new best path immediately upon determining that a new best path exists. However, if a distributed routing algorithm is implemented synchronously, it is necessary for the update message to have reached all the destinations before a new routing scheme is established in the network. An update cycle consists of two equal length time periods. During the first period nodes generate the required update messages, which receive transmission priority over packets. During the second period nodes receive and relay update messages as required. Nodes are restricted from generating update messages during the second half of the update cycle in order to allow the updates to suffuse throughout the network. If the nodes were an average of 16.4 kilometers (10 miles) apart and a maximum of 5 relays were required for each update to reach the destination node most distant from it, then the maximum time

required for an update to reach its destination can be computed as

$$\text{time required} = \text{travel time} + \text{processing time} \\ + \text{transmission time}$$

which becomes

$$t = 5 * \frac{15.4 \text{ km}}{3 * 10^{**5} \text{ km / sec}} + 5 * 0.00001 + 5 * 0.002$$

or

$$t = .025 \text{ sec.}$$

which is well within the available 0.1 seconds. Note that this result implies that for applications where the nodes are close (in relation to signal travel time) then the propagation time is insignificant compared to the time required to process an update through a node. By choosing an update cycle time of 0.2 second the network configurations used in the simulation could be considered representative of real world networks which have longer link lengths and/or a greater number of relays required for the delivery of an update message.

It is the complexity of the network which has the most potential for impacting on the performance of a Distributed

Routing Protocol, and it is therefore important to consider how the topology of the network interacts with the protocol. The number of nodes in a network determines the number of update messages which must be generated during each update cycle, which translates into an increasing requirement for network capacity to pass updates as the number of nodes increases. This results in less network capacity available for the transmission of user messages. The number of links in a network is also important since it determines the capacity of the network both for message and update traffic.

Traffic loading is another network parameter which may affect the performance of a Distributed Routing Protocol. For a packet switching network the traffic loading is controlled by three factors, the number of user messages entering the network per unit time and the length of the messages and the distribution of the originator and destination addresses of each message. Since messages are decomposed into fixed length packets, this last factor is the same as the number of packets in a user message.

In a real world network each of these parameters is random and it is common in queuing theory to assign a distribution to the frequency with which messages are

entered into the network and the number of packets into which a message is decomposed in terms of a probability distribution. It is often assumed that generation of messages into a network can be represented by an exponential distribution and that the number of packets in a message can be represented as a uniform distribution. Two mean values of packet distribution were used in this study (5.5 and 10.5 packets per message) so that the effects, if any, of the length of the messages on the performance of the protocols could be determined.

A final factor which may affect the performance of a Distributed Routing Protocol is the simulation run time. If the complete network is considered to be a system and the first message into the system is viewed as an impulse input into the system then it is clear that the system will undergo some period of transition between the dormant condition (ie. no inputs) and its equilibrium operating state. The length of this transition phase can be determined mathematically for the probabilistic case of a communications network only with difficulty. However, by observing the results of the network simulation after several different simulation run times it was determined

that a run time of 30 seconds allowed the transition phase to be completed and provided a period of steady state operation long enough so that meaningful data could be taken.

A total of four networks were generated for use in this study. A diagram of each network is provided in Appendix B. The number of nodes in each network varied between 5 and 20 and the number of links varied between 10 and 40. To reduce distortion of the simulation results which could be caused by different network topologies, a base network of 5 nodes and 10 links was adopted. By expanding the base network in a consistent manner, valid comparisons between the performance of a protocol and network complexity could be drawn. More complex networks were created by expanding the link/node structure of the base network. The chosen base network is illustrated in Figure 3.1 and consists of five nodes and ten links.

To provide a convenient method of referencing the networks the notation "5/10" has been adopted to denote a 5 node and 10 link network. The 5/10 network was expanded into a 10/20 network by adding an additional 5 nodes and 10 links. Similarly, a 15/30 and 20/40 network were derived.

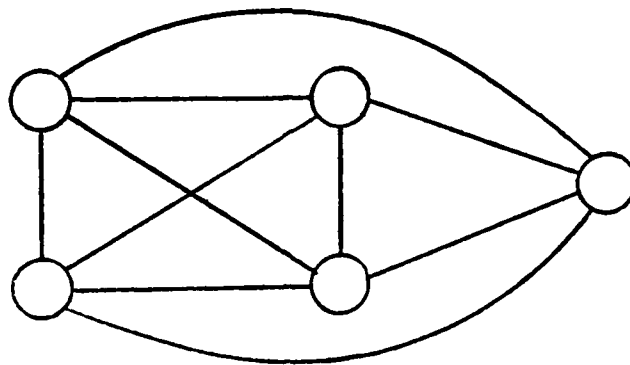


Fig. 3.1. The 5/10 Network.

Note that each succeeding network contains the preceding network.

C. CHANNEL VALUES

As described in section B of this chapter, the channel values ("link distances" in some literature) are computed during the update window time and represent the current demand for a particular link's services as a relay path. The channel value also represents a prediction of the demand on a particular link during the upcoming update cycle. By using these channel values it is possible to determine a path between any two nodes which will have the lowest cumulative channel value (ie. the best path during the next update cycle). It is the function of the distributed

routing protocol to generate, transmit and evaluate the channel values and establish best paths within the network. To accomplish this task the protocol generates update messages which contain channel value information. The exact content, method of relay and method of evaluating the update message is unique to each protocol.

The method of generating channel values for both the Heritsch and Dijkstra algorithms as implemented in this study is identical, and a complete description can be found in Heritsch [Ref. 2]. In short, the channel value represents the average number of packets waiting in the queue to be transmitted over the link during the preceding 0.5 second of simulation time.

IV. TWO DISTRIBUTED ROUTING PROTOCOLS

A. THE HERITSCH ALGORITHM

Heritsch proposed in Reference [2], a Distributed Routing Protocol which seeks to minimize the number of update messages required to be circulated throughout a network during a single update cycle. Update messages in the Heritsch algorithm contain three items of information: the node which just relayed the update, the node which originated the update and the cumulative channel value from the node which just received the update to the node which originated the update, through the node which relayed the update. Thus each node receiving an update can compare the cumulative channel value through the relaying node to the cumulative channel value of the path over which it is currently passing packets to the node which originated the update. If the new channel value in the most recent update is less, a new best path to the node which originated the update is adopted through the node which relayed the update. In any event, the node which just received the update now generates an update message to all of its neighbor nodes (less the node which relayed the update that started it all), and informs all the neighboring nodes of the new

cummulative channel value. These nodes in turn repeat the process of evaluting the information contained in the update, establishing new best paths if the minimum cummulative channel value changes.

If no new best path is adopted and the channel value through the current best path has not changed, the node discards the update without relaying the information it contained. Since nodes which are "upstream" from the node which received the update do not change their best paths unless the best path "downstream" changes, there is no reason to relay the update further through the network. Note that even if a new best path is not adopted but the channel value changes over the current best path, this information must be relayed "upstream" since it may affect the best path decisions of "upstream" nodes. What is significant is that the algorithm purges update messages from the network at the first opportunity and thus releases channel capacity to the network for the relay of packets.

The disadvantage of the algorithm is that it does not guarantee optimum routing for each packet released into the network. It is possible for a packet to loop through several nodes before being delivered to its final

destination. This looping is the result of a packet following a best path which is changed more than once during the transit of the packet through the network.

The basic algorithm as stated above is substantially identical to the routing procedure originally used in the ARPANET. The major innovation proposed by Heritsch is that the number of update messages required in a given network could be reduced if the network was subdivided into nodal colonies which are called groups and families. A group can be defined as a collection of nodes and a family is a collection of groups. By treating the groups and families of nodes as "super nodes" it may be possible to significantly reduce the number of update messages required to implement the protocol. This reduction is accomplished by restricting the propagation of the update message to the basic group of the node which originates the update. Nodes which are connected to other groups or families originate updates which reflect the cumulative channel values from that node into the neighboring family or group. The result is that all nodes within a basic group can determine the best path to any other group or family and are not required to determine best paths to all other nodes in the network.

Thus a packet generated in one group would travel the best path to the destination group and once it reaches the destination group receive onward routing to the destination node.

The Heritsch algorithm may be implemented either synchronously or asynchronously in a packet switching network. Since the algorithm allows each node to autonomously determine new best paths it is possible to implement new best paths whenever an update is received rather than adopting best paths in synchronism with all the other nodes in the network. The only constraints to the algorithm are that update message generation be restrained to a fixed time interval so that update messages are able to reach their "final" destinations before a new update generation cycle starts.

A comparison of the algorithm's performance when implemented both synchronously and asynchronously in identical networks was accomplished as part of this study. No significant difference was found to exist in the performance of the protocol under the two implementations.

From the viewpoint of network robustness, it is desirable to implement the algorithm asynchronously.

However, for purposes of comparison with the Dijkstra algorithm, (which can only be implemented synchronously), the Heritsch algorithm was restricted to the its synchronous implementation.

B. THE DJIKSTRA ALGORITHM

The algorithm proposed by E. Dijkstra in Reference [3] is used in the current ARPANET routing protocol, which requires that each node within the network receive the channel value for each link in the network before a new best path is determined. The protocol causes each node to generate an update which contains the channel value from the originating node to each of the originating node's neighbors. The data is forwarded to each node in the network and each node enters the received channel values into a matrix which is manipulated in such a way that a best path is produced from each node to each other node in the network. The Dijkstra algorithm may also be adapted to utilize the group and family scheme proposed by Heritsch. An examination of the Dijkstra algorithm's performance using a group and/or family configured network was not conducted as a part of this study.

The significant differences between the two protocols are the number of update messages required to implement each protocol and the "quality" of the best path which is determined by each algorithm. The Djikstra algorithm provides an optimum quasi-static best path for each packet released into the network. That is to say, each node in turn routes the message to the next relay node along the best path in accordance with the Djikstra algorithm which is guaranteed to produce a minimum distance route. Similarly, in the Heritsch algorithm each packet is addressed to the next node along its estimated best path, but there is no guarantee that this esitnated path is indeed the optimum path. With regard to the number of update messages required by each algorithm, at first glance it would appear that the Djikstra network requires an inordinate amount of network capacity to pass updates through the network. The situation is not this bad however, since update messages which would travel along the same best path to their destination can be combined to reduce the total number of update messages required.

The matrix manipulation required by the Djikstra algorithm to determine the best paths is accomplished in the

following manner. If the 5/7 network illustrated in Figure 4.1 is considered as an example then the channel values between adjoining nodes may be represented by the symbols \rightarrow or \leftarrow , where the arrowhead indicates the direction of the channel value and the number indicates some relative measure of the channel values as they might appear at the start of any update cycle.

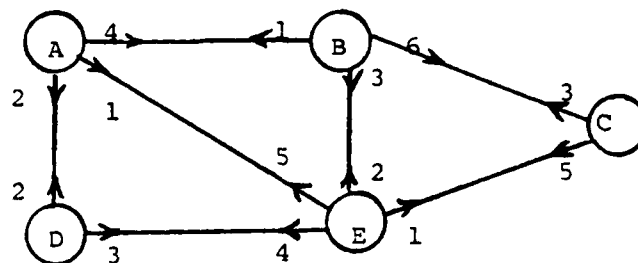


Fig. 4.1. A 5/7 Network

From this network the matrix in Figure 4.2 is constructed. Note that nodes which have no direct link between them are initially represented at the start of every cycle as having an infinite channel value between them.

Beginning with node A, observe that a direct link exists with node B and that the channel value from node A to node B

		To				
		A	B	C	D	E
From	A	-	4		2	1
	B	1	-	6	∞	3
	C	∞	3	-	∞	5
	D	2	∞	∞	-	3
	E	5	2	1	4	-

Figure 4.2. Initial Channel Value Matrix For The Dijkstra Algorithm.

is 4 (the notation A/B/4 will be used as a convenient description of the path and its channel value). Next every other path in the network from node A to node B is considered in turn to determine if a cumulative channel value less than 4 can be found. First the A/C/ ∞ + C/B/3 path is considered which represents a path from node A through node C to node B. Clearly the result of this path, A/C/B/ ∞ , is greater than the A/B/4 path and so a new best path through node C is rejected. Next the A/D/2 + D/B/ ∞ = A/D/B/ ∞ path is considered and also rejected as a new best path. Finally, the path A/E/1 + E/B/2 = A/E/B/3 is considered and adopted as the tentative new best path from node A to node B since the resultant cumulative channel value of 3 is less than the previous value of 4.

Similarly the channel values from node B to each other node are considered and tentative best paths established. When all paths between nodes of the network are evaluated and tentative best paths established (ie. the matrix is run through completely one time) the entire process is repeated until a run through the matrix is completed with no new tentative best path adopted. When this occurs the best paths within the matrix are adopted simultaneously by all nodes of the network for the duration of the next update cycle and represent the optimum paths between nodes.

Fm	To				
	A	B	C	D	E
A	-	3	2	2	1
B	1	-	3	3	2
C	4	3	-	6	5
D	2	5	4	-	3
E	3	2	1	4	-

Fig. 4.3. The Completed Best Path Matrix

The final result of the matrix manipulation for the update cycle considered in this example is shown in Figure 4.3.

V. SIMULATION OF THE PROTOCOLS

A. PROGRAMMING SCHEME

The simulation programs used in the study were written in the SIMSCRIPT II.5 programming language [Ref. 4]. This language provides an excellent vehicle for simulation work in which many events may occur almost simultaneously. In addition, the ability to control the flow of the simulation by utilizing a language generated simulation clock, provides the user with a means of obtaining data from the simulation at various times without regard for the events being processed.

Three simulation programs were developed from the program presented by Heritsch in Reference [2]. The three programs are listed at the end of this study and represent an asynchronous implementation of the Heritsch algorithm, a synchronous implementation of the Heritsch algorithm and a synchronous implementation of the Dijkstra algorithm. The program listing for the synchronous implementation of the Heritsch algorithm is provided in Appendix C. Each simulation is constructed in modules which correspond to the different functions which the network and the routing protocol must perform. For example, each simulation

contains individual subroutines for the generation of updates, arrival of packets within a node and the computation of channel values. A listing of all the arrays used within the programs is provided in Appendix D to assist in tracing the functional composition of the programs. The parameters of the network under consideration are externally input into the simulation as a data set which is read by the source code during the execution of the simulation. A sample of an input data set is listed in Appendix E.

The results of the simulations can be output in several formats. The most extensive output available is a complete listing of every event occurring during the simulation. It is possible to limit the output to only the desired data by specifying the desired results in the "Special Output" subroutine of each program. The simulation programs also feature the ability to make any number of simulation runs with various input parameters during a single job submission. In addition, the results of the simulation can be diverted to either mass storage peripheral devices or the normal printer output or both. A sample of the output format used for this study is provided in Appendix E.

The implementation of the packet switching network is identical in all the simulation programs. Each link within the network is "configured" to have two input queues (a packet queue and an update queue). No queues are constructed for the input side of each node. Nodes are required to give priority to the transmission of updates over packets as would be required in a real world network. Update messages are generated only during the first half of the update cycle. The precise time at which each node generates its update message is uniformly distributed throughout the first half of the update cycle. User messages are generated into the network at time intervals which are exponentially distributed. The originating node and destination node of the message and the number of packets in the message are determined using uniformly distributed random variables. The destination node of a user message can be constrained to be outside the originating node's group and/or family in order to ensure that a specified percentage of the user messages are destined for other groups and/or families.

B. ARTIFICIALITIES OF THE SIMULATION PROGRAM

Several artificialities were introduced into the simulation programs in order to reduce computer run time and program complexity. The most significant of these is the assumption that each node has a processor dedicated to each link entering the node. This implies that the node can simultaneously receive and process inputs on all of its links. While the capability of parallel processing is desirable in a packet switching network, it is not a requirement and may be replaced by employing a "listen-before-transmit" and "receiver-lock-up" node design, in which each node can communicate with only one other node at a time. In either case the maximum throughput of any node is considered to be determined by the output capacity of the node and not its input capacity. Thus the absence of input queues in the simulation is considered reasonable.

The simulation also does not consider the network capacity which is required to implement the Node to Node Protocol, which is vital to the operation of a packet switching network. The capacity required to carry the Node to Node protocol messages is relatively insignificant compared to that required for update and packet

transmissions. Since this study is concerned only with the performance of the routing protocol, the network capacity required by the Node to Node Protocol is disregarded.

C. LIMITATIONS OF THE SIMULATION PROGRAM

The detailed results of the simulations depend substantially on the "seed" numbers which are used to initialize the random number streams generated internal to the SIMSCRIPT language. Since the random number streams are used to determine the origination node, destination node, time of message origination and the number of packets in a message, the simulation will provide somewhat different results for the same input parameters if different "seed" numbers are used. The variability of a particular result from the average result computed from several different runs of the simulation using the same inputs but different "seeds", was empirically determined to be on the order of 5 percent of the average result. Thus, although the graphical results of the simulations (Appendix F) appear to be discontinuous in nature as the input parameters are changed, it is expected that these perturbations are due to the "randomness" of the simulation. If a sufficient number of simulation runs were made for each data point, the average

of these points would be expected to result in a "smoother" curve.

D. GENERATION OF DATA

A total of twelve different simulation runs were required to produce the results presented in this study. The physical parameters of the networks and the network loadings were selected to represent the most critical and interesting aspects of the interaction between the network and the routing protocol in use. The Heritsch algorithm was synchronously implemented on four networks (5/10, 10/20, 15/30 and 20/40) and asynchronously on two networks (10/20 and 15/30). The algorithm was also synchronously implemented on the 10/20 and 15/30 networks, with the networks divided into 2 groups of 5 nodes and 3 groups of 5 nodes respectively, to investigate the capacity required to implement the algorithm in a multiple group/family network. Lastly, the Dijkstra algorithm was implemented on the 5/10, 10/20, 15/30 and 20/40 networks.

The graphs of the data contained in Appendix H were derived from the data obtained from these twelve simulation runs and are presented in two forms. The first group of twelve graphs illustrates for each network and each

algorithm, the average delivery delay per packet versus the loading of the network. The second group of twelve graphs shows the packet and update utilization factors versus the network loading for each algorithm and each network. The interpretation of the data presented in the graphs is provided in Chapter VI.

VI. RESULTS AND CONCLUSIONS

A. RESULTS

1. Comparison of Average Delivery Delay

The average delivery delay for a packet (T_p), was computed using Equation (A-12) from Appendix A. This equation uses the measured utilization factors for updates and packets (p_u and p_p) and a specified network loading (g) to compute T_p . Although the equation does not provide an absolute measure of the protocol's performance it is useful in comparing the relative performance of the Dijkstra algorithm to the Heritsch algorithm. Theoretically, T_p should increase dramatically as the network loading begins to approach the network capacity. Figure 6.1 illustrates the general form of the expected T_p versus g results. This expected result reflects the obvious conclusion that the delivery delay experienced by a packet must increase without bound when more packets are entering the network per second, on the average, than can be delivered by the network in a second.

From the simulation results contained in Appendix F, it is concluded that a packet switching network employing the Dijkstra algorithm has less average delay per packet

than an identical network under identical loading which employs the Heritsch algorithm. Further, a network which employs the Dijkstra algorithm is capable of accepting a wider range of network loading conditions before the average delivery delay per packet increases dramatically.

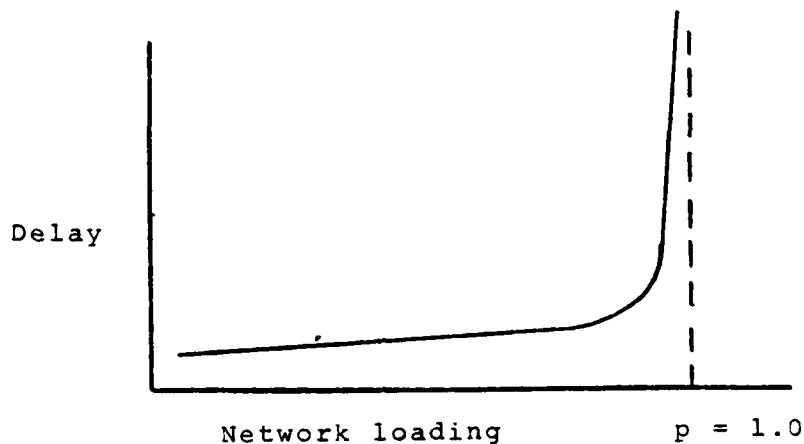


Fig. 6.1. Expected Average Delay Per Packet

The simulation results contained in the first twelve graphs of Appendix F present two measures of the average delay per packet. One curve on each graph represents the results of Equation (A-12) and the other represents the average actual delay per packet which was computed using measured data from the simulation as follows.

$$M_p = \frac{t_t}{k} \quad (6-1)$$

where

M_p = the average delay per packet (measured)

t_t = the sum time required to transit the network of all packets which reach their final destination

k = the total number of packets originated during the simulation which reach their final destination.

Equation (6-1) provides a much different result for the average delay per packet than does Equation (A-12), and both of these methods of predicting the protocol performance are subject to considerable inaccuracy as discussed in the following paragraphs.

As noted in Appendix A, Equation (A-12) was derived from queuing theory results which apply to networks with a fixed routing and an exponential service time distribution. Since the networks under study have a dynamic routing scheme and a fixed service time, the direct transfer of mathematical analysis from one application to the other has questionable validity. Adding to this uncertainty is the priority handling of update messages and their shorter service time, which was factored into the derivation

presented in Appendix A. Finally, some error in the results of the equation is expected due to the method of measuring the utilization factors. Since it was desirable to avoid including the transient effects of initial network start-up, the measurement of the utilization factor for each link was limited to the last half of the simulation. To accomplish this restriction, it was necessary to structure the simulation program so that any link which was busy at the instant of "half time" was identified and the fixed value of 0.05 seconds (packet transmission time) was added to the busy time of the link for the first half of the simulation. This busy time was then subtracted from the total time the link was busy throughout the simulation. The end result was a measured utilization factor for any one link which could be on the order of 0.003 percent smaller than the actual value. Despite these probable inaccuracies, the results of Equation (A-12) agree with the intuitive notion that the average delay per packet should exhibit a dramatic increase as the network loading approaches the network capacity.

In a network with fixed routing the "break point" for the rise in delay time can occur at moderate network loads if a critical subset of links is saturated ($\rho = 1.0$)

and a portion of the nodes are effectively "cut-off" from the network. The rationale for employing a dynamic routing scheme is that saturated links are bypassed (wherever possible) until their utilization factors return to a more normal level. The effect is to postpone the dramatic rise in network delay until greater network loading conditions are experienced by the network. Thus a whole subset of the network (vice only a few links) must have a utilization factor nearly equal to unity before the characteristic delay curve exhibits its predicted rise.

The actual measurement of the average delay per packet was accomplished by accumulating the transit time of all messages which reached their destination and dividing by the number of messages which reached their destination. This measure does not include a method of determining the delay near the "break point", since near that point the number of messages which are delivered in a finite time period becomes relatively constant regardless of the network loading. Thus the result from this method of computing delay does not exhibit the strong non-linearity of Equation (A-12) in regions near utilization factors equal to unity. Most packets are not delivered under these circumstances, but

accumulate in the queues instead. If a correct expression of the average delay per packet is to be measured, it must account for the future delay which queued messages will incur as they ultimately work their way out of the network. The formulation of an expression which accurately describes the shape of the delay curve in its entirety (including the "break point") proved an elusive goal. However, it can be intuitively argued that the performance of the protocol in regions near $p = 1.0$ must be such that the average delay per packet is increasing very dramatically as the network loading approaches close to the network capacity. This intuitive argument was verified by running the simulation for a duration of greater than 180 seconds at network loadings which produced average network utilization factors in excess of 0.996 percent. Under these conditions it was found that the average delay per packet did exhibit the expected dramatic increase. (Note that this delay was evident only after relatively long simulation run times.)

In summary, the theoretical delay curve predicted by Equation (A-12) does not accurately predict the performance of the Distributed Routing Protocol due to the adaptive nature of the protocol and the finite duration of the

measurement period. Further, a successful mathematical model for predicting the measured performance of the protocols was not found.

Lastly, the average delivery delay which resulting when the Heritsch algorithm was implemented in a test network which had the nodes divided into groups was investigated. Although the average delay per packet was significantly decreased using the group/family routing feature of the Heritsch algorithm, for the small networks studied here it was not as low as the average delay per packet experienced in a single group network of the same size which employed the Djikstra algorithm. It is believed that more significant and favorable results will be achieved if larger networks are used in comparing the performance of the Heritsch algorithm in single group versus multiple group/family networks.

2. Updating Requirements Versus Network Complexity

The inherent disadvantage in using Distributed Routing Protocols is the requirement to utilize a portion of the network's capacity to support the updating requirements of the protocol. Naturally, the protocol which provides the most optimum routing and requires the least network capacity

to operate is the most desirable. The amount of network capacity required by the protocol is determined by the frequency at which update messages are generated and the number of nodes by which each update must be received.

It was determined, during the course of this study that the network capacity required by each of the protocols under consideration is a nearly constant value for a given network and did not depend, to any great extent, on the traffic loading of the network. Table II contains the average update utilization factor for the Heritsch algorithm (for single and multiple group networks) and the Dijkstra algorithm (for single group networks only). No data was obtained for the Heritsch network implemented on a 5/10 or 20/40 multiple group network.

TABLE II

Update Utilization Factors

Network	Heritsch (single group)	Heritsch (multiple groups)	Dijkstra (single group)
5/10	.044	****	.009
10/20	.085	.023 (2)	.019
15/30	.139	.041 (3)	.023
20/40	.201	****	.028

The numbers in parenthesis in Table II indicate the number of groups into which the network under consideration was divided and the values shown are derived from a simulation using a mean of 5.5 packets per message (values obtained for a mean of 10.5 packets per message are identical). The data in Table II indicates that it is very desirable to divide a network into groups and families whenever the Heritsch algorithm is employed since the same order of routing optimization is achieved with a significant reduction in the network capacity required to support the protocol.

A significant result is that for small networks the Dijkstra algorithm requires less network capacity than does the Heritsch algorithm regardless of how the network is structured for the Heritsch algorithm. While this result may appear startling given that the Heritsch algorithm purges updates from the network which are not required to be retransmitted, it must be remembered that the Heritsch algorithm also requires all "upstream" nodes to be notified whenever a new best path is adopted or a channel value is changed. This requirement causes the generation of many additional update messages the aggregate of which is

potentially larger than the total number of update messages per cycle generated by the Dijkstra algorithm. Despite the lesser channel capacity required to implement the Dijkstra algorithm it must be remembered that the algorithm can only be implemented synchronously which may preclude its consideration in some applications. Also for large enough networks, the Dijkstra algorithm will require more channel utilization than would the Heritsch algorithm for a network which is partitioned into an appropriate hierarchy of groups and families.

3. Synchronous Versus Asynchronous Updating Performance

When the utilization versus network loading curves for the asynchronous implementation of the Heritsch algorithm are compared with the curves obtained for the synchronous implementation of the algorithm, it is found that there is very little difference in the shape and corresponding numerical values of the respective 10/20 and 15/30 curves. While only the results for these two networks are presented here, they are typical of results obtained when a variety of different network topologies were tested under different network loadings using the two implementations of the Heritsch algorithm. The conclusion

drawn from these results is that for a given network and specified updating cycle time there is no significant advantage in implementing the Heritsch algorithm synchronously as opposed to asynchronously (or vice versa). This conclusion has considerable impact on the physical design of a packet switching network, since it is not required to precisely synchronize the adoption of new best paths throughout the network in order to obtain the full benefits of the Heritsch algorithm. This translates to a reduced complexity in the design of the packet network terminal equipment.

4. Effects Of User Message Lengths

One of the initial objectives of this study was to determine how the distribution of the lengths of user messages impacts the performance of a Distributed Routing Protocol. Since the simulation programs are constructed to operate on a predetermined packet length, the length of a user message is related to the number of packets which make up the message. In the simulations, the number of packets in each message is based upon a uniformly distributed random variable with the maximum and minimum values of the variable specified at the beginning of the simulation. The mean

value of the resulting distribution is used to control the interval between the generation of user messages. In this way the average number of packets per second entering the network is maintained as a constant for each run of the simulation, and the mean number of packets that are contained in each message can be increased arbitrarily.

The results of this investigation are plotted on each of the graphs presented in Appendix F. The graphs contain the results found when the mean number of packets in a message was 5.5 and 10.5, corresponding to maximum message lengths of 10 and 20 packet, respectively. No significant difference in the performance of either the Djikstra or the Heritsch protocols was found as a result of increasing the length of the user messages. Mean packet values of 1, 3.5 and 7.5 were also investigated but are not presented here since the results obtained do not differ substantially from those mentioned above.

B. SYNOPSIS OF RESULTS

It is not possible to conclude that a particular Distributed Routing Protocol (Djikstra or Heritsch) exhibits better overall performance characteristics than the other. Each algorithm has advantages and disadvantages which must

be considered on the basis of the network in which the protocol is to be implemented. Certainly, if optimal routing is a priority of the network, then the Dijkstra algorithm is superior. However, if non-optimal routing is acceptable and complexity of terminal equipment is a consideration then the Heritsch algorithm has distinct advantages if implemented asynchronously.

The final conclusion of this study is that the length of user messages does not degrade the performance of either protocol much when the average number of packets entering the network per unit of time is relatively constant. Thus the interspersion of long and short user messages is not a factor in the design of a packet switching network.

Lastly, it appears in the context of the NTDS communications network that the Dijkstra algorithm is the protocol of choice should the NTDS be converted to a packet switching network. While the asynchronous advantages of the Heritsch algorithm appear desirable for this application, the increasing amount of information the NTDS is being required to throughput, points to the adoption of a protocol which requires a minimum of network capacity to operate. Additionally, since units of the fleet are not constrained

by the size and complexity of the terminal equipment which is required to maintain a synchronized network (as compared to a man-pack version of a packet switching network) the choice of the Djikstra algorithm for NTDS applications is reasonable.

APPENDIX A

AVERAGE DELAY PER PACKET

The unit of measure used in this study to compare the relative performance of routing protocols in a given network is the average delay per packet (T_p). The derivation of the relation of this measure to the link utilization factors of the network is provided here and is based upon material presented in Gross and Harris [Ref. 5]. and Kleinrock [Ref. 6].

One of the basic parameters in queuing theory is the utilization factor (ρ) which is defined as the average arrival rate of customer (eg. packets and updates) at a service center (eg. link) multiplied by the average time required to service (eg. transmit) the customer. In general this is expressed as

$$\rho = \lambda x \quad (A-1)$$

where

- λ = the average arrival rate of the customers
- x = the average time required to service a customer

For this derivation the subscripts p and u are used to indicate that a particular variable is referred to packets

or updates respectively. Thus the utilization factor for packets over the i-th link is expressed as

$$p_{pi} = l_{pi} x_{pi} \quad (a-2)$$

where

l_{pi} = the average number of packets per second arriving for transmission over a link.

For an M/M/1 queue, the term x_{pi} can be replaced by the term $1 / uC_i$, where u represents the percentage of a packet which is represented by 1 bit (ie. $1 / u$ represents the length of a packet in bits) and C_i is the number of bits per second which can be serviced by the i-th link. Equation (A-2) can then be rewritten as

$$p_{pi} = \frac{l_{pi}}{uC_i} \quad (A-3)$$

Moreover, for M/M/1 systems (ie. a system with customers arriving at an exponentially distributed rate and the service time per customer is exponentially distributed) the expected time a packet spends in the i-th link's queue before servicing begins can be expressed as

$$W_{qpi} = \frac{1/p_i / uC_i}{uC_i - 1/p_i} \quad (A-4)$$

and the expected delay for the delivery of a packet over a link is

$$W_{pi} = W_{qpi} + \frac{1}{uC_i} \quad (A-5)$$

which is to say that the expected delivery delay for a packet is the sum of the expected time the packet spent in the service queue plus the time required to service the packet.

The assumption is made for the remainder of the derivation that Equation (A-4) will provide a fair representation of the expected delay time for a packet when the service time per packet is fixed instead of probabilistic in its nature. However, since two types of messages (updates and packets) with different fixed service times are allowed to enter a link, the time available for the link to service packets is reduced by the amount of time the link is busy servicing updates. Thus Equation (A-4) must still be modified to reflect the system perturbation due to the loss of available packet service time.

Consider the case where x_{ui} is the time required to service an update message and t_{ui} is the interval between the arrival of update messages at the i -th link. The arrival rate of updates at the link (l_{ui}) is equal to $(1 / t_{ui})$. Using Equation (A-2), modified to reflect its application to update message, the utilization factor for updates becomes

$$p_{ui} = \frac{x_{ui}}{t_{ui}} \quad (A-6)$$

The fundamental interpretation of the term u_i in Equation (A-4) is the maximum average number of packets which can be transmitted per second over the i -th link. Only a fraction $((t_{ui} - x_{ui}) / t_{ui})$ of the time is available for packets, however, when updates must also be transmitted. Accordingly, we must reduce u_i by the factor

$$1 - \frac{x_{ui}}{t_{ui}} = 1 - p_{ui} \quad (A-7)$$

which is equivalent to reducing u to u' , where

$$u' = u (1 - p_{ui}) \quad (A-8)$$

Replacing u with u' in Equation (A-4), a new expression for W_{pi} (Equation (A-5)) is obtained

$$W_{pi} = \left[\frac{1_{pi} / (uC_i (1 - p_{ui}))}{uC_i (1 - p_{ui}) - 1_{pi}} + \frac{1}{uC_i} \right] \quad (A-9)$$

From Kleinrock, [Ref. 6], the average packet delay (T_p) for a network of service centers is expressed as

$$T_p = \sum_{i=1}^k \frac{1_{pi}}{g} W_{pi} \quad (A-10)$$

where

g = average total number of packets per second entering the network

k = number of links in the network

Substituting Equation (A-5) into equation (A-10) the expression for average delay time for a packet in the network becomes

$$E_{tp} = \frac{1}{g} \sum_{i=1}^k \left[\frac{1_{pi} 1_{pi} / (uC_i (1 - p_{ui}))}{uC_i (1 - p_{ui}) - 1_{pi}} + \frac{1_{pi}}{uC_i} \right] \quad (A-11)$$

After some simplification this becomes

$$T_p = \frac{1}{g} \sum_{i=1}^k \left[\frac{p_{pi}^2 / (1 - p_{ui})}{1 - p_{ui} - p_{pi}} + p_{pi} \right] \quad (A-12)$$

Equation (A-12) represents a method of relating the network capacity which is utilized by a routing protocol and the traffic loading level of the network to the average packet delay. For the simulation work presented in this study the utilization factors (p_{ui} and p_{pi}) were measured directly and the network loading (g) was an input parameter to the simulation.

The reader should note that Equation (A-12) is valid only for comparing the performance of protocols and not for calculation of the actual performance of a protocol.

APPENDIX B
NETWORK CONFIGURATIONS

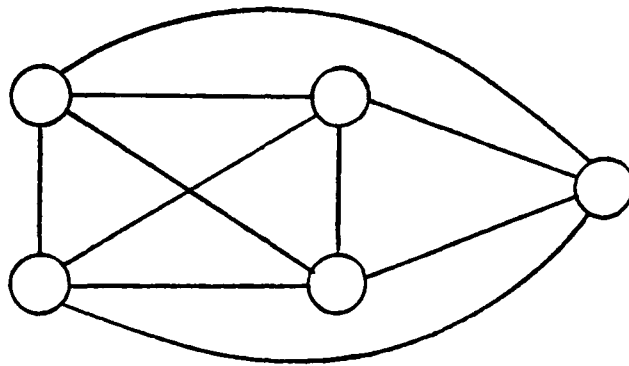


Fig. B.1. The 5/10 Network

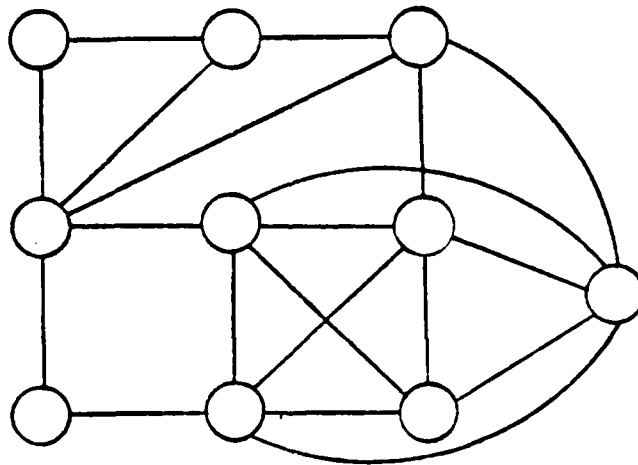


Fig. B.2. The 10/20 Network

APPENDIX C

HERITSCH ALGORITHM (SYNCHRONOUS): PROGRAM LISTING

```

//LENGERIC JCB (1611,0140),LENGERIC 1101,CLASS=C
//*MAIN ORG=NPGVM1.1611P,LINES=(50)
//*FORMAT PR,DCNAME=DEST=LCCAL
// EXEC SIM25CLG,REGICN.GO=3072K,PARM.GO=*MAP,SIZE=760K*
//SYSPRINT CD SYSCUT=A
//SIM,SYSIN CD *
//PREAMBLE
..
.. THIS PROGRAM SIMULATES THE HERITSH DISTRIBUTED ROUTING
.. PROTOCCL (SYNCHRONOUS).
..
.. NORMALLY MOCE IS INTEGER
.. GENERATE LIST ROUTINES
..
.. PERMANENT ENTITIES
.. EVERY NODE HAS A TRANSMIT PERCENT, A RECEIVE PERCENT, A GROUP, UPDATES
.. A FAMILY, A U.TOTAL, A AVE.NUMBER,UPDATES, A ALT.AVE.NUMBER,UPDATES
.. AND A PKTS.RELAYED, OWNS AN UPDATE.OUT.QUEUE, A PACKET.OUT.QUEUE ,
.. A TIME.QUEUE AND A LNK.FLAG
.. DEFINE TRANSMIT PERCENT, RECEIVE PERCENT, AVE.NUMBER,UPDATES,
.. AND ALT.AVE.NUMBER,UPDATES AS REAL VARIABLES
.. DEFINE UPDATE.OUT.QUEUE AND PACKET.OUT.QUEUE AS FIFO SETS
..
.. TEMPORARY ENTITIES
.. EVERY MESSAGE HAS A TYPE, A RELAYER, A NEXT.STOP, A DESTINATION,
.. AN INFO1, AN INFO2, AN INFO3, AN INFO4, AN INFOS, AN INFOE.ENTRY.TIME,
.. AN ORIG.TIME, A LNK.ENTRY.TIME AND A TOT.QUEUE.TIME
.. AND MAY BELONG TO A UPDATE.OUT.QUEUE, A PACKET.OUT.QUEUE,
.. AND A LNK.FLAG
.. DEFINE ORIG.TIME AS A REAL VARIABLE
.. DEFINE LNK.TIME AND TOT.QUEUE.TIME AS REAL VARIABLES
.. DEFINE LNK.ENTRY.TIME AS A REAL VARIABLE
.. EVERY PACK HAS A NUMBER, AN ENTRY.TIME, A PAC.NEIGHBOR AND MAY
.. BELONG TO A TIME.QUEUE
.. DEFINE TIME.QUEUE AS A LIFO SET
.. DEFINE ENTRY.TIME AS A REAL VARIABLE
..
.. EVENT NOTICES INCLUDE REPORT.RESULTS, QU.SAMPLER, SAMPLE,
.. COMPUTE.CV,ADAPT.NEW.BEST.PATH,
.. NEW.UPDATE.MESSAGES HAS A SENDING.NODE, AND A TYPE.MESSAGE
.. UPDATE.ARRIVES HAS AN ID.MESSAGE.NUMBER
.. CONT.UPDATE.MESSAGES HAS A LAST.NODE, A NEXT.NODE, A NET.CV,
.. A SOURCE,DATE.MILES, A HOP,CNT, A GR.DUP
.. PACKET.ARRIVES, HAS AN ID.NUMBER
.. CON.PACKET.MESSAGE HAS AN IDENT.MESSAGE
.. NEW.PACKET.MESSAGE HAS A T.MESSAGE
.. COMPLETED.TRIP HAS A MES.NUM
..

```

DEFINE UP.DATE.PERIOD, PROCESSING.TIME, PKT.XMN.TIME AND TIME.LIMIT

```

AS REAL VARIABLE AND RCV.PCNT AS REAL VARIABLES
DEFINE LINKS AS A VARIABLE
DEFINE MSG.HLT AS A VARIABLE
DEFINE NEIGHBOR.LIST AS A 3-DIMENSIONAL INTEGER ARRAY
DEFINE BEST.PATH AS A 3-DIMENSIONAL INTEGER ARRAY
DEFINE CHANNEL.VALUE TO MEAN INFO1
DEFINE FAMILLY TO MEAN INFO2
DEFINE GRPS TO MEAN INFO5
DEFINE GRPS, FMLY AND NGFS AS VARIABLES
DEFINE LINK.ABLE AS A 2-DIMENSIONAL ARRAY
DEFINE LINK.MONITCR AS A 3-DIMENSIONAL ARRAY
DEFINE TRACER AS A 2-DIMENSIONAL ARRAY
DEFINE CLOCK.DATA AS A 2-DIMENSIONAL REAL ARRAY
DEFINE HOP.CCNT AS A 2-DIMENSIONAL ARRAY
DEFINE PKT.SMP.SET AS A 2-DIMENSIONAL ARRAY
DEFINE PKT.QU.DISTR AS A 2-DIMENSIONAL ARRAY
DEFINE UP.QU.DISTR AS A 1-DIMENSIONAL ARRAY
DEFINE FAM.CF.GRP AS A 1-DIMENSIONAL ARRAY
DEFINE TOL TO MEAN 0
DEFINE BUSY TO MEAN 1
DEFINE MSG.GENERATION.INTERVAL, MIN.PKTS.PER.MSG,
DE MAX.PKTS.PER.MSG AS REAL VARIABLES
DEFINE TRACKS.NUMBER TO MEAN INFO1
DEFINE NODES.HOPPED TO MEAN INFO2
DEFINE RELEASE.TIME TO MEAN INFO3
DEFINE FM.GP TO MEAN INFO4
DEFINE YES TO MEAN 1
DEFINE NO TO MEAN 0
DEFINE UPDATE TO MEAN 1
DEFINE TRAF.LIMIT AS A VARIABLE
DEFINE WIND.CW AS A REAL VARIABLE
DEFINE UP.PAC.RATIO AS A REAL VARIABLE
DEFINE PRNT AS A VARIABLE
DEFINE IN.GROUP, IN.FAMILY, SELECTOR AS REAL VARIABLES
DEFINE NET.U.LINKS, UP.STARTS, MAX.U.HOPS AS VARIABLES
DEFINE TT.MER AS A REAL VARIABLE
DEFINE SMP.LINKS, NO.OF.SAMPLES, SMP.CNTR AS VARIABLES
DEFINE EARLIEST.UPDATE AND LATEST.UPDATE AS REAL VARIABLES
DEFINE U.XMN AS A REAL VARIABLE
DEFINE TOTAL.NUMBER.CYCLES AND NUMBER.CYCLES.COMPLETED AS
REAL VARIABLES

```

```

DEFINE MAX.LINKS.FER.NODE AS VARIABLE
DEFINE TIME.ELAPSEC AND CYCLE.TIME AS REAL VARIABLES
DEFINE P.FLOW1, P.PATH AS REAL VARIABLES
DEFINE LONGEST.PATH AS 4-DIMENSIONAL REAL ARRAY
DEFINE LINK.NODE.RATIO AS REAL VARIABLE
DEFINE P.FLOW.TOTAL, U.FLOW.TOTAL, AVE.P.FLOW, AVE.U.FLOW AND
PCNT.U.FLOW AS REAL VARIABLES
DEFINE AVE.NETWORK.FLOW AS VARIABLE
DEFINE SPECIFY.OUTPUT AS VARIABLE
DEFINE PERUN AS VARIABLE AS REAL VARIABLE
DEFINE PERSEC.AVE AS REAL VARIABLE
DEFINE NODE.FACTOR AS 1-DIMENSIONAL ARRAY
DEFINE HISTOGRAM AS A 1-DIMENSIONAL ARRAY
DEFINE PI.DELAY, P2.DELAY, U1.DELAY, U2.DELAY,
TOTAL.DELAY, LPK1 AS REAL VARIABLES
DEFINE AVE.DELAY.PKTS AS REAL VARIABLE
DEFINE RATIO.STRANDED PKTS.END AS VARIABLE
DEFINE PKTS.HALF AND GEN.COUNT AS VARIABLES
DEFINE STRANDED.WAIT AND TRANSIT.TIME AS REAL VARIABLES
DEFINE T.IN.LINK AND Q.IN.LINK AS REAL VARIABLES
END ** OF PREAMBLE **
**
** MAIN **
**
LEFT LINES.V = 79
SKIP 2 OUTPUT LINES
**
PRINT 4 LINES AS FOLLOWS
##### HERITZSCH UPDATE ALGORITHM: SYNCHRONOUS VERSION #####
##### FIXED #####
##### INCREMENT FOR PKTS PER MSG: HARMONIC #####
##### NORMALIZE: AVE.PKTS.PER.MSG.PER.NODE #####
**
SKIP 2 OUTPUT LINES
**
** THE "MAIN" ROUTINE "CALLS" THE SUBROUTINE "INITIALIZATION".
** "INITIALIZATION" SETS THE VALUE OF INPUT VARIABLES
** WHICH WILL REMAIN CONSTANT FOR ALL RUNS OF THIS
** SIMULATION. THIS ALLOWS THE "MAIN" ROUTINE TO ACT AS A
** "DRIVER" ROUTINE FOR SIMULATION. THE "MAIN" CAN BE
** STRUCTURED TO CHANGE CERTAIN CONDITIONS OF THE SIMULATION
** AND RERUN THE SIMULATION AGAIN.
**
DEFINE INC.PKTS.PER.MSG, LIMIT.PKTS.PER.MSG, AVE.PKTS.PER.MSG,
PKTS.PER.SEC.MIN, PKTS.PER.SEC.INC, PKTS.PER.SEC.MAX

```

```

.. AS REAL VARIABLES
..
.. SET THE MAXIMUM, INCREMENT AND MINIMUM VALUES OF THE
.. VARIABLES WHICH ARE TO BE ITERATED.
..
.. BY MULTIPLYING PKTS.PER.SEC.( ) * NCDE.FACTOR THE RESULTS
.. OF THE SIMULATION CAN BE NORMALIZED SO THAT NETWORKS
.. WITH DIFFERENT NUMBERS OF NODES CAN BE COMPARED USING
.. WAVE.PKT.PER.SEC.NODE" AS A CONSTANT MEASURE OF
.. NETWORK LOADING. (E.G. IF A 5 NODE NETWORK IS THE
.. COMPARISON BASE THEN A 10 NODE NETWORK HAS A NODE.FACTOR
.. = 2. ## NOTE: NODE.FACTORS GREATER THAN 4 REQUIRE IN
.. EXCESS OF 3072K CF CORE TO RUN THE SIMULATION.
..
.. READ NCDE.FACTOR
..
.. LET MIN.PKTS.PER.MSG = 10.
.. LET INC.PKTS.PER.MSG = 10.
.. LET LIMIT.PKTS.PER.MSG = 21.
..
.. LET PKTS.PER.SEC.MIN = 50. * NODE.FACTOR
.. LET PKTS.PER.SEC.INC = 50. * NODE.FACTOR
.. LET PKTS.PER.SEC.MAX = 500. * NODE.FACTOR
..
.. LET PKTS.PER.SEC.AVE = PKTS.PER.SEC.MIN
..
.. THE FOLLOWING ARRAYS WILL CONTAIN THE 'X' AND 'Y' VALUES OF
.. DATA TO BE GRAPHED.
..
.. "ITERATE" IS THE NUMBER OF TIMES THE VALUE OF "MAX.PKTS.PER.MSG"
.. IS CHANGED AND THE SIMULATION REINITIATED.
.. "POINTS" IS THE NUMBER OF TIMES THE VALUE OF "PKTS.PER.SEC.AVE"
.. IS CHANGED AND THE SIMULATION RERUN. THE
.. TOTAL NUMBER OF TIMES THE SIMULATION RUNS IS
.. ( ITERATE * POINTS ).
..
.. ITERATE = 2
.. POINTS = 10
..
.. LET AVE.PKTS.PER.MSG = (1.0 + MIN.PKTS.PER.MSG) / 2.
.. LET MSG.GENERATION.INTERVAL = AVE.PKTS.PER.MSG / PKTS.PER.SEC.AVE
..
.. THE VALUE OF "MAX.PKTS.PER.MSG" WILL BE INCREMENTED USING A
.. HARMONIC SERIES.
..
.. LET MAX.PKTS.PER.MSG = MIN.PKTS.PER.MSG
..
.. "RERUN" CONTROLS THE PRINTING OF THE NEIGHBOR AND CV

```

```

.. LISTING. THE LISTING IS PRINTED ONLY FOR INITIAL
.. EXECUTION OF THE PROGRAM.
..
LET RERUN = 0
PERFORM INITIALIZATION
RELEASE INITIALIZATION
LFT EST.MAX.NR.MSGS = 2 * INT.F( TIME.LIMIT / ( 1.0 /
RESERVE TRACER ( *, * ) AS EST.MAX.NR.MSGS BY 2
LET RERUN = 1
.. THESE STATEMENTS CAUSE THE VALUES OF "ITERATE" AND
.. "POINTS" TO BE WRITTEN TO THE MASS STORAGE SYSTEM
.. FOR LATER RETRIEVAL BY A PLOTTING ROUTINE.
..
USE UNIT 8 FOR OUTPUT
WRITE ITERATE AS I 4
WRITE POINTS AS / I 4
USE UNIT 6 FOR OUTPUT
.. SCHEDULE INITIAL EVENTS
..
SCHEDULE THE FIRST UPDATE FOR EACH NODE (NEW.UPDATE.MESSAGE)
COMPUTE CHANNEL VALUES FOR THIS UPDATE (COMPUTE.CV)
SCHEDULE THE FIRST REPORT ( REPORT.RESULTS )
SCHEDULE THE FIRST MESSAGE GENERATION (NEW.PACKET.MESSAGE)
SCHEDULE A TEST FOR MAX QUEUES HALF WAY THRU RUN (QU.SAMPLER)
..
"TOTAL.POINTS" COUNTS THE NUMBER OF TIMES THE SIMULATION IS
.. RUN.
..
LET TOTAL.PCINTS = 0
.. DO.IT.AGAIN.
..
LET TOTAL.PCINTS = TOTAL.POINTS + 1
..
FOR EACH NODE, DO
SCHEDULE A NEW.UPDATE.MESSAGE GIVEN NODE, UPDATE IN ( UNIFORM.F
( 0.0, UP.DATE.PERIOD, 1 ) ) UNITS
LOOP
..
SCHEDULE A COMPUTE.CV AT 0.00
SCHEDULE A REPORT.RESULTS IN ( TIME.LIMIT / 4. ) UNITS
SCHEDULE A NEW.PACKET.MESSAGE GIVEN PACKET IN ( 2 * .1 +

```



```

EXPONENTIAL.F( MSG.GENERATION.INTERVAL, 5 ) ) UNITS
SCHEDULE A QU.SAMPLER IN ( TIME.LIMIT / 2. ) UNITS
**
START SIMULATION
**
THE NEXT GROUP OF STATEMENTS ZEROIZE ALL GLOBAL VARIABLES AND
ARRAYS IN PREPARATION FOR A RERUN OF THE SIMULATION.
**
TIME.VG.TOTAL = 0.0
LET MSG.HLT = 0
LET NET.U.LINKS = 0
LET UP.STARTS = 0
LET MAX.U.HCPS = 0
LET SMP.CNTR = 0
LET TOTAL.NUMBER.CYCLES = 0.0
LET NUMBER.CYCLES.COMPLETED = 0.0
LET TIME.FLAPSED = 0.0
LET LONGEST.PATH = 0
LET PKTS.HALF = 0
LET DEST.END = 0
LET DEST.COUNT = 0
LET TRANSIT.TIME = 0.0
LET STRANDED.WAIT = 0.0
LET T.IN.LINK = 0.0
LET Q.IN.LINK = 0.0
**
FOR A = 1 TO ( 2 * LINKS ), DO
FOR B = 1 TO ( 2 * LINKS ), DO
FOR C = 1 TO 6
DO
LET LINK.MONITOR( A, B, C ) = 0
LOOP
LCCP
LOOP
FOR A = 1 TO 2, DO
FOR B = 1 TO ( N.NODE ), DO
FOR C = 1 TO ( N.NODE ), DO
FOR D = 1 TO 4
DO
LET LINK.TIMER( A, B, C, D ) = 0.0
LOOP
LOOP
LCCP
LOOP
FOR A = 1 TO ( 10 * N.NODE ), DO
FOR B = 1 TO 2
DO
LET HCP.COUNT( A, B ) = 0

```

```

LET CLOCK.DATA( A, B ) = 0
LCCP
LOOP
FOR A = 1 TO EST.MAX.NR.MSGS, DO
FOR B = 1 TO 2, DO
LET TRACER( A, B ) = 0
LOOP
LOOP A = 1 TO 1000, DO
LET PKT.QU.DISTR(A) = 0
LET UP.QU.DISTR(A) = 0
LOOP
FOR A = 1 TO SMP.LINKS, DO
FOR B = 1 TO 2, DO
LET PKT.SMP.SET( A, B ) = 0
LET UP.SMP.SET( A, B ) = 0
LOOP
LOOP
RELEASE BEST.PATH( *, *, * )
RELEASE NEIGHBOR.LIST( *, *, * )
RELEASE HISTOGRAM( *, * )
PERFORM NEIGHBOR.INITIALIZATION
LET PKTS.PER.SEC.AVE = PKTS.PER.SEC.AVE + PKTS.PER.SEC.INC
IF PKTS.PER.SEC.AVE <= PKTS.PER.SEC.MAX
.. LET MSG.GENERATION.INTERVAL = AVE.PKTS.PER.MSG / PKTS.PER.SEC.AVE
.. IF SPECIFY.OUTPUT = 0
.. SKIP 2 OUTPUT LINES
.. PRINT 1 LINE AS FOLLGWS
##### SIMULATION KESTART #####
.. SKIP 1 OUTPUT LINE
.. PRINT 1 LINE WITH PKTS.PER.SEC.AVE AS FOLLOWS
PKTS.PER.SEC.AVE = ***.***
.. REGARDLESS
.. GO DC.IT.AGAIN
.. ELSE

```

```

** LET PKTS.PER.SEC.AVE = PKTS.PER.SEC.MIN
LET MAX.PKTS.PER.MSG = MAX.PKTS.PER.MSG + INC.PKTS.PER.MSG
IF MAX.PKTS.PER.MSG <= LIMIT.PKTS.PER.MSG
LET AVE.PKTS.PER.MSG = (MAX.PKTS.PER.MSG + 1.0) / 2
LET MSG.GENERATION.INTERVAL = AVE.PKTS.PER.MSG + 1.0
LET INC.PKTS.PER.MSG = INC.PKTS.PER.MSG + 1.0
** IF SPECIFY.OUTPUT = 0
** SKIP 2 OUTPUT LINES
** PRINT 1 LINE AS FOLLOWS
@@@@@@@@@@@@ SIMULATION RESTART @@@@@@@@@@@@@@@@@@@@@@
** SKIP 1 OUTPUT LINE
** PRINT 2 LINES WITH MAX.PKTS.PER.MSG
AND PKTS.PER.SEC.AVE AS FOLLOWS
MAX.PKTS.PER.MSG = ****.***
PKTS.PER.SEC.AVE = ****.***
** REGARDLESS
** GO DO.IT.AGAIN
ELSE
** SKIP 1 OUTPUT LINE
PRINT 1 LINE AS FOLLOWS
SIMULATION STOPS
** STCP
**
END **CF MAIN
**
** THIS ROUTINE INITIALIZES ALL THE VARIABLES IN THE SIMULATION.
BY PROPER STRUCTURING OF THIS ROUTINE AND THE "MAIN", THE
SIMULATION CAN BE MADE TO SUCCESSIVELY RERUN ITSELF USING
ANY NUMBER OF NEW INPUT PARAMETERS ON EACH RUN.
** ROUTINE FOR INITIALIZATION
**
** SPECIFY.OUTPUT IS AN INTEGER WHICH CONTROLS THE OUTPUT FORMAT.
0 => ALL INPUT DATA, THE QUARTERLY RESULTS OF THE
SIMULATION AND THE SPECIAL. OUTPUT SECTION
ARE PRINTED

```

```

.. 1 => ONLY THE INPUT DATA AND THE DATA SPECIFIED
.. BY THE PROGRAMMER IN "SPECIAL OUTPUT"
.. ARE PRINTED OUT. QUARTERLY RESULTS OF
.. THE SIMULATION ARE NOT PRINTED.
.. 2 => ONLY THE DATA SPECIFIED IN "SPECIAL OUTPUT"
.. IS PRINTED OUT.

LET SPECIFY.OUTPUT = 1
..
.. SET SOME VARIABLES
..
.. SET THE RANGE OF PACKETS PER MESSAGE ( MIN.PKTS.PER.MSG
.. AND MAX.PKTS.PER.MSG )
.. SET A LIMIT ON THE NUMBER OF MESSAGES GENERATED
.. DURING A RUN OF THE SIMULATION ( TRAF.LIMIT )
.. SET AN UPDATE MSG TO PACKET PROCESSING RATIO (U.PAC.RATIO)
.. SET AN UPDATE MSG TRANSMISSION TIME (U.XMN.TIME)

LET TRAF.LIMIT = 95000
LET U.PAC.RATIO = .1
LET U.XMN.TIME = C.002
..
.. READ AND PRINT INPUT DATA
READ N.NODE
..
IF SPECIFY.OUTPUT <= 1
PRINT 2 LINES AS FOLLOWS
NODE TRANSMIT RECEIVE GROUP FAMILY
NO. FACTOR FACTOR (PGM #) (PGM #)
REGARDLESS
..
CREATE EVERY NODE
FOR EVERY NCCE
READ TRANSMIT.PERCENT(NODE), RECEIVE.PERCENT(NODE), GROUP(NODE),
FAMILY(NCCE)
..
TRANS.PCNT AND RCV.PCNT ARE THE SUM OF TRANSMIT AND RECEIVE FACTORS.
GROUP NUMBERS ARE ADDED TO N.NODE TO GET PROGRAM GROUP NUMBERS.
FAMILY NUMBERS ARE ADDED TO N.NCCE + THE HIGHEST GROUP NUMBER.
..
WITHIN THE SIMULATION GROUPS AND FAMILIES ARE HANDLED AS IF
THEY WERE SUPER-NODES. A USEFUL ANALOGY IS TO
ENVISION MANY SUB-NODES WITHIN A GROUP OR FAMILY SUPER-
NODE ACCESS TO THE SUB-NODES IS CONTROLLED BY THE
THE SUPER-NODE'S "ADDRESS".

FOR I = 1 TO N.NODE, DC

```

```

LET TRNS.PCNT = TRNS.PCNT + TRANSMIT.PERCENT(I)
LET RCV.PCNT = RCV.PCNT + RECEIVE.PERCENT(I)
IF GRPS < GRCUP(I)
  LET GRPS = GRCUP(I)
REGARDLESS
** SET PRGCRAM GRP NUM
**
** LET GROUP(I) = GROUP(I) + N.NODE
LOOP
RESERVE FAM.CF.GRP (*) AS (GRPS + N.NODE + 25)
FOR I = 1 TO N.NODE, DO
  IF FMLS < FAMILY(I)
    LET FMLS = FAMILY(I)
  REGARDLESS
** SET PROGRAM FAM NUM
**
** LET FAMILY(I) = N.NCDE + GRPS + FAMILY(I)
** LET FAM.OF.GRP (GROUP(I)) = FAMILY(I)
LOOP
LET NGFS = N.NODE + GRPS + FMLS
LET SPECIFY.OUTPUT <= 1
FOR I = 1 TO N.NCDE, DO
  PRINT 1 LINE WITH I, TRANSMIT.PERCENT(I), RECEIVE.PERCENT(I),
  (GROUP(I) - N.NODE), GROUP(I), (FAMILY(I) - N.NODE - GRPS)
  AND FAMILY(I) AS FOLLCMS **(**) **(**)
**(**) **(**)
** LOOP
SKIP 1 OUTPUT LINE
REGARDLESS
**
** READ UP.DATE.PERIOD
** READ PROCESSING.TIME
** READ PKT.XMN.TIME
** READ TIME.LIMIT
** READ WINDOW
**
LET CYCLE.TIME = 2 * UP.DATE.PERIOD
LET TOTAL.NUMBER.CYCLES = TIME.LIMIT / CYCLE.TIME
**
** IN.GROUP MEANS THE PERCENTAGE OF GENERATED MESSAGES THAT WILL
** NOT LEAVE ITS BASIC GROUP: SIMILARLY FOR IN.FAMILY
** NOTE: IF ALL NCDES ARE SPECIFIED TO BE MEMBERS OF THE
** SAME GROUP AND FAMILY ARE THEN VALUES OF IN.GROUP AND IN.FAMILY
** ARE IGNCRD BY THE PROGRAM.
**
READ IN.GROUP, IN.FAMILY

```



```

PRINT 1 LINE WITH TRAF.LIMIT AS FOLLOWS
MAX NUMBFR CF MESSAGES GENERATED PER RUN IS *****
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH UP.DATE.PERIOD AS FOLLOWS
UPDATE PERIOD IS **.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH PROCESSING.TIME AS FOLLOWS
PACKET PROCESSING TIME IN EACH NODE IS ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH PROCESSING.TIME * UP.PAC.RATIO AS FOLLOWS
UPDATE PROCESSING TIME IN EACH NODE IS ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH PKT.XMN.TIME AS FOLLOWS
TIME REQUIRED TO TRANSMIT A PACKET IS ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH U.XMN.TIME AS FOLLOWS
TIME REQUIRED TO TRANSMIT AN UPDATE IS ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH MSG.GENERATION.INTERVAL AS FOLLOWS
MESSAGES ARE INITIATED AT AN AVERAGE INTERVAL OF ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH WINDOW AS FOLLOWS
CHANNEL VALUE CALCULATION WINDOW IS ***.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH MIN.PKTS.PER.MSG AND MAX.PKTS.PER.MSG AS FOLLOWS
EACH MESSAGE VARIES FROM **. TO **. PACKETS IN LENGTH
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH IN.GROUP AS FOLLOWS
AT LEAST **. % OF MESSAGES ARE TO NODES WITHIN A GROUP.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH IN.FAMILY AS FOLLOWS
AT LEAST **. % OF MESSAGES ARE TO NODES WITHIN A FAMILY
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH TOTAL.NUMBER.CYCLES AS FOLLOWS
TOTAL NUMBER OF UPDATE CYCLES POSSIBLE FOR THIS RUN IS *****.**
SKIP 1 OUTPUT LINE
..

```

```

PRINT 1 LINE WITH CYCLE.TIME AS FOLLOWS
CYCLE TIME IS ****.***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH NODE.FACTOR AS FOLLOWS
NODE.FACTOR = **
SKIP 1 OUTPUT LINE
..
REGARDLESS
..
..   ARRAYS ARE RESERVED AS FOLLOWS
..
RESERVE LINK.ABLE(*,*) AS LINKS BY 2
RESERVE LINK.MONITOR(*,*) AS (2*LINKS) BY (2*LINKS) BY 6
RESERVE HOP.COUNT(*,*) AS ( 10 * N.NODE ) BY 2
RESERVE CLOCK.DATA(*,*) AS ( 10 * N.NODE ) BY 2
RESERVE PKT.SMP.SET(*,*) AS SMP.LINKS BY 2
RESERVE UP.SMP.SET(*,*) AS SMP.LINKS BY 2
RESERVE UP.QU.DISTR(*,*) AS 1000
RESERVE LINK.TIMER(*,*) AS 2 BY (N.NCCE) BY (N.NODE) BY 4
..
IF SPECIFY.OUTPUT <= 1
..
PRINT 1 LINE AS FOLLOWS
LINKS
..
REGARDLESS
..
FOR I = 1 TO LINKS, DO
FOR J = 1 TO 2, READ LINK.ABLE(I,J)
..
IF SPECIFY.OUTPUT <= 1
..
PRINT 1 LINE WITH LINK.ABLE(I,1), LINK.ABLE(I,2) AS FOLLOWS
** - **
..
REGARDLESS
..
LOOP
..
PERFORM NEIGHBOR.INITIALIZATION
..
RETURN
END ** OF INITIALIZATION
..
..   THE FOLLOWING SUBROUTINE IDENTIFIES NEIGHBORS, SETS

```



```

** INITIAL CV'S, AND PRINTS THE NEIGHBOR LIST AND
** INITIAL CV'S.
**
** ROUTINE FOR NEIGHBOR_INITIALIZATION
**
RESERVE HISTOGRAM( * ) AS I0
RESERVE BEST.PATH(*,*,*) AS NGFS BY NGFS BY 4
**
FOR I = 1 TO NGFS, DO
  LET BEST.PATH(I,I,1) = I
  LET BEST.PATH(I,I,3) = I
LOOP
RESERVE NEIGHBOR_LIST(*,*,*) AS N.NODE BY MAX.LINKS.PER.NODE BY 3
FOR I = 1 TO LINKS, DO
  FOR J = 1 TO MAX.LINKS.PER.NODE, DO
    IF NEIGHBOR_LIST(LINK.ABLE(I,1),J,1) = 0
      LET NEIGHBOR_LIST(LINK.ABLE(I,1),J,1) = LINK.ABLE(I,2)
      LET NEIGHBOR_LIST(LINK.ABLE(I,1),J,3) = I
      LET M = J
      GO NEXT.STEP
    ELSE
      GO NEXT.STEP
  LOOP
ELSE
  GO NEXT.STEP
END
**
** NEXT STEP:
** FOR J = 1 TO MAX.LINKS.PER.NODE, DO
** IF NEIGHBOR_LIST(LINK.ABLE(I,2),J,1) = 0
** LET NEIGHBOR_LIST(LINK.ABLE(I,2),J,1) = LINK.ABLE(I,1)
** LET NEIGHBOR_LIST(LINK.ABLE(I,2),J,3) = I
** GO LAST.STEP
** ELSE
** GO LAST.STEP
** END
**
** LAST STEP:
** LET NEIGHBOR_LIST(LINK.ABLE(I,1),M,2) = YES
** LET NEIGHBOR_LIST(LINK.ABLE(I,2),J,2) = YES
** LOOP
**
** IF SPECIFY.OUTPUT = 0 AND RERUN = 0
**
** SKIP 3 OUTPUT LINES
** PRINT 1 LINE AS FOLLOWS
** NEIGHBORS AND CHANNEL VALUES
** FOR I = 1 TO N.NODE, DO
**   SKIP 1 OUTPUT LINE
**   PRINT 1 LINE WITH I AS FOLLOWS
**   NODE ** NEIGHBORS AND CV
**   FOR J = 1 TO MAX.LINKS.PER.NODE, DO
**     PRINT 1 LINE WITH NEIGHBOR_LIST(I,J,1) AND NEIGHBOR_LIST(I,J,3)
**     AS FOLLOWS
**   **

```

```

LOOP
LOOP
REGARDLESS
RETURN
END ** OF NEIGHBOR. INITIALIZATION
**
** THIS ROUTINE HALTS THE PROGRAM AND GIVES SEVERAL STATISTICAL
** REPORTS ON THE STATUS OF THE SIMULATION. AFTER FOUR REPORTS
** THE ROUTINE RETURNS CONTROL OF THE PROGRAM TO THE "MAIN".
**
EVENT REPORT RESULTS
DEFINE TOT.HOPS, TOT.PACKETS, TOT.HALF.PKTS, DELIVERED
AND DLVRD.AT.HALF AS VARIABLES
DEFINE AVE.TIME AND AVE.NODES.HOPPED AS REAL VARIABLES
DEFINE RATIO AND IDEAL.TIME AS REAL VARIABLES
DEFINE P.Y AND U.Y AS REAL VARIABLES
DEFINE U.SD, P.SD, U.XR, P.XR, U.Z2, P.Z2, U.Z2SUM, P.Z2SUM AS REAL VARIABLES
**
** PEEK CCUNT THE FOUR REPORTS
** TOT.PACKETS SUMS THE TOTAL PKTS GENERATED UP TO THIS POINT
** DELIVERED SUMS THE TOTAL PKTS REACHING THEIR DESTINATION
** TOT.HOPS SUMS ALL HOPS MADE BY ALL PKTS
** U.SUM AND P.SUM ARE THE SUMS OF THE SAMPLED Q SIZES
** U.X AND P.X ARE THE TOTAL NUMBER OF THE SAMPLES
** U.Z2SUM AND P.Z2SUM ARE THE SUMS OF THE SAMPLE SIZES SQUARED
LET PEEK=PEEK+1
LET TOT.PACKETS = 0
LET DELIVERED = 0
LET TOT.HOPS = 0
LET U.SUM = 0
LET P.SUM = 0
LET U.X = 0
LET P.X = 0
LET U.Z2SUM = 0.0
LET P.Z2SUM = 0.0
**
** COMPUTE THE NUMBER OF UPDATE CYCLES WHICH HAVE BEEN COMPLETED
** AT EACH REPRT INTERVAL.
**
IF PEEK = 1
LET TIME.ELAPSED = TIME.LIMIT / 4
LET NUMBER.CYCLES.COMPLETED = TIME.ELAPSED / CYCLE.TIME
REGARDLESS

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```

IF PEEK = 2
  TIME.ELAPSED = TIME.LIMIT / 2
  LET NUMBER.CYCLES.COMPLETED = TIME.ELAPSED / CYCLE.TIME
REGARDLESS
IF PEEK = 3
  TIME.ELAPSED = ( 3 * TIME.LIMIT ) / 4
  LET NUMBER.CYCLES.COMPLETED = TIME.ELAPSED / CYCLE.TIME
REGARDLESS
IF PEEK = 4
  TIME.ELAPSED = TIME.LIMIT
  LET NUMBER.CYCLES.COMPLETED = TIME.ELAPSED / CYCLE.TIME
REGARDLESS
** PRINT BP NEIGHBORS AND CV
**
** IF SPECIFY.OUTPUT = 0
**
  IF PRINT > 0
    SKIP 3 OUTPUT LINES
    FOR I = 1 TO N.NODE DC
      SKIP 1 OUTPUT LINE
      PRINT 1 LINE WITH I AS FOLLOWS
      PRINTS FROM NCDE ** TO -- DESTINATION - BP.NEIGHBOR - CV FRM BP.NODE
      FOR J = 1 TO N.NODE, CO
        IF (GROUP(I) = GROUP(J) AND I NE J)
          PRINT 1 LINE WITH J,BEST.PATH(I,J,1), BEST.PATH(I,J,2)
          AS FOLLOWS
          **
          **
          REGARDLESS
          LOOP
          FOR J = (N.NCDE+1) TO NGFS, DO
            IF (GROUP(I) NE J AND FAMILY(I) NE J AND J > N.NODE)
              IF BEST.PATH(I,J,1) NE 0
                IF (FAM.CF.GRP(I) NE FAMILY(I) AND J <= (N.NODE + GRPS))
                  GO CMT.PRINT
                ELSE
                  PRINT 1 LINE WITH J, BEST.PATH(I,J,1), BEST.PATH(I,J,2)
                  AS FOLLOWS
                  **
                  **
                  OMIT.PRINT,
                  REGARDLESS
                  REGARDLESS
                  LOOP
                  LOOP
                  REGARDLESS
                  **
                  RF REGARDLESS
                  **

```

```

.. CCUNT PKTS CREATED AND DELIVERED
..
FOR I = 1 TC NEW.MSG.TOTAL, DO
LET TOT.PACKETS = TOT.PACKETS + TRACER (I,1)
LET DELIVERED = DELIVERED + TRACER (I,2)
LOOP
..
.. COMPUTE THE AVERAGE NUMBER OF UPDATES GENERATED BY EACH NODE
.. PER UPDATE CYCLE PER DESTINATION.
..
FOR J = 1 TC N.NODE, DO
LET AVE.NUMBER.UPDATES(J) = (( U.TOTAL(J) - NUMBER.CYCLES.COMPLETED )
/ ( N.NODE - 1 )) * ( 1 / NUMBER.CYCLES.COMPLETED )
LET ALT.AVE.NUMBER.UPDATES(J) = AVE.NUMBER.UPDATES(J) *
( 1 / ( LINKS - 1 ))
LOOP
..
.. PRINT PKT STATISTICS
..
IF SPECIFY.OUTPUT = 0
BEGIN REPRCT ON A NEW PAGE
PRINT 1 LINE WITH TIME.ELAPSED AS FOLLOWS
TIME.ELAPSED IS ***** SEC.
SKIP 1 OUTPUT LINE
..
PRINT 1 LINE WITH NUMBER.CYCLES.COMPLETED AS FOLLOWS
NUMBER OF CYCLES COMPLETED IS *****
SKIP 1 OUTPUT LINE
..
PRINT 2 LINES AS FOLLOWS
MEAN TIME PER PKT HOPPED
FOR I = 1 TO ( 10 * N.NODE ), DO
IF HOP.COUNT(I,PACKET) NE 0
LET AVE.TIME = CLOCK.DATA(I,1) / REAL.F(HOP.COUNT(I,PACKET))
LET IDEAL.TIME = I*PKT.XMN.AVE.TIME + (I-1)*PROCCSSING.TIME
PRINT 1 LINE WITH I, HCP.COUNT(I,PACKET), AVE.TIME,
CLOCK.DATA(I,2) AND IDEAL.TIME AS FOLLOWS *****
** REGARDLESS
LGCP
..
.. PRINT ALERT MSG IF A PKT HOPPED MORE THAN TOTAL NUMBER OF NODES
..
.. IF MSG.HLT NE 0
.. SKIP 2 OUTPUT LINES

```

```

PRINT 1 LINE AS FCLLCWS
==== NOTE AT LEAST 1 PACKET HOPPED MORE THAN THE TOTAL NUMBER OF NODES =
SKIP 2 OUTPUT LINES
REGARDLESS
.. IF DELIVERED NE 0
LET AVE.NODES.HOPPED = REAL.F(TOT.HOPS) / REAL.F(DELIVERED)
ELSE
SKIP 1 OUTPUT LINE
PRINT 1 LINE AS FOLLOWS
.. NO PACKETS HAVE BEEN DELIVERED DURING THIS PART OF THE SIMULATION..
REGARDLESS
.. PRINT SELECTED STATISTICAL DATA
..
SKIP 3 OUTPUT LINES
PRINT 1 LINE WITH AVE.NODES.HOPPED AS FOLLOWS
MEAN NUMBER OF NODES HOPPED PER PACKET IS **.*
..
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH NEW.MSG.TOTAL AND TOT.PACKETS AS FOLLOWS
A. TOTAL OF *** NEW XMNS WERE STARTED (TCTALING ***** PACKETS ).
..
PRINT 1 LINE WITH (TOT.PACKETS - DELIVERED) AS FOLLOWS
OF THESE, *** PACKETS WERE UNDELIVERED WHEN THE TEST WAS ENDED.
..
SKIP 1 OUTPUT LINE
LET RATIO = REAL.F(NET.U.LINKS)/REAL.F(UP.STARTS)
PRINT 1 LINE WITH RATIO AS FOLLOWS
FOR EACH NEW UPDATE, AN AVERAGE OF ***.* LINKS WERE USED.
..
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH LONGEST.PATH AS FOLLOWS
LONGEST PATH TAKEN BY A PACKET WAS ***** LINKS.
..
SKIP 2 OUTPUT LINES
PRINT 4 LINES AS FOLLOWS
NODE AVE NUMBER OF UPDATES PER DESTINATION PER CYCLE
NUMBER OF UPDATES ORIGINATED OR RELAYED
NUMBER OF PACKETS RELAYED
..
SKIP 1 OUTPUT LINE
FOR J = 1 TO N.NODE, DC
PRINT 1 LINE WITH J, AVE.NUMBER.UPDATES(J), ALT.AVE.NUMBER.UPDATES(J)
,U.TOTAL(J), PKTS.RELAYED(J) AS FOLLOWS
*****.******
*****
LOC

```

```

.. REGARDLESS
..
IF PEEK = 2
  LET DLVRD.AT.HALF = DELIVERED
  LET TOT.HALF.PACKETS = TOT.PACKETS
REGARDLESS
..
IF PEEK = 4
  LET RATIO.STRANDED = REAL.F((TOT.PACKETS - TOT.HALF.PACKETS) -
    (DELIVERED - DLVRD.AT.HALF)) / REAL.F( DELIVERED
    - DLVRD.AT.HALF)
REGARDLESS
..
IF PEEK = 2 OR PEEK = 4
..
.. CALCULATE DIRECTIONAL FLOW OF PACKETS AND UPDATES IN EACH LINK.
.. P.FLOW1 IS % TIME LINK IS BUSY PASSING PACKETS IN ONE DIRECTION
.. P.FLOW2 IS % TIME LINK IS BUSY PASSING PACKETS IN OTHER DIRECTION
.. ( SIMILARLY FOR U.FLOW1 AND U.FLOW2 )
.. PERFORM FLOW.ANC.DELAY
REGARDLESS
..
END **OF BEGIN REPORT
..
IF SPECIFY.OUTPUT = 0
..
.. PRINT MAX UPDATE AND PACKET QUEUE LENGTHS
.. AT THE END OF EACH QUARTER
..
IF PRINT >= 0
  BEGIN REPORT ON A NEW PAGE
  PRINT 2 LINES AS FOLLOWS
  MAXIMUM QUEUE LENGTHS:
  FROM TO PACKET QUEUE MAX UPDATE QUEUE MAX
  FOR I = 1 TO LINKS, DO
  LET A = LINK.ABLE(I,1)
  LET B = LINK.ABLE(I,2)
  PRINT 1 LINE WITH A, B, LINK.MONITOR(A,B,3), LINK.MONITOR(A,8,5)
  AS FOLLOWS
  ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
  PRINT 1 LINE WITH B, A, LINK.MONITOR(B,A,3), LINK.MONITOR(B,A,5)
  AS FOLLOWS
  ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
  LOOP
..
END **OF BEGIN REPORT

```

```

** REGARDLESS
**
** PRINT THE QUEUE SIZES FROM 0 TO 500 AND THE NUMBER
** OF TIMES THE UPDATE OR PACKET OUTGOING QUEUES
** WERE FOUND TO BE OF THAT SIZE WHEN SAMPLED
** ( I.E. QUEUE SIZE SAMPLE DENSITY ).
**
IF SPECIFY.OUTPUT = 0
  IF PRNT >= 0
    IF PEEK >= 3
      **
      BEGIN REPRCT ON A NEW PAGE
      PRINT 3 LINES WITH SMP.LINKS AND SMP.CNTR AS FOLLOWS
      OUTGCS PKCT / UPDATE QUEUE DISTRIBUCN
      ** LINKS WERE SAMPLED WERE TAKEN
      ** SAMPLES 2 OUTPUT LINES
      SKIP 2 LINES AS FOLLOWS
      PRINT 2 LINES AS FOLLOWS
      UPDATE QUEUE
      SAMPLE DENSITY
      SIZE
      FOR I = 1 TO 1000, DO
        LET P.SUM = (I-1) * FK.T.QU.DISTR(I) + P.SUM
        LET U.SUM = (I-1) * UP.QU.DISTR(I) + U.SUM
        LET P.X = P.X + PKT.QU.DISTR(I)
        LET U.X = U.X + UP.QU.DISTR(I)
        LET P.ZZ = UP.PKT.QU.DISTR(I) * ((I-1)**2)
        LET U.ZZ = UP.PKT.QU.DISTR(I) * ((I-1)**2)
        LET P.ZZSUM = P.ZZSUM + P.ZZ
        LET U.ZZSUM = U.ZZSUM + U.ZZ
        IF P.ZZSUM = U.ZZSUM NE 0 OR UP.QU.DISTR(I) NE 0
          PKT.QU.DISTR(I) NE 0
          UP.QU.DISTR(I) NE 0
          PRINT 1 LINE WITH (I-1), PKT.QU.DISTR(I) AND
          UP.QU.DISTR(I) AS FOLLOWS
          **
          **
          REGARDLESS
          LOOP P.Y = P.SUM / P.X
          LET U.Y = U.SUM / U.X
          SKIP 1 OUTPUT LINE
          PRINT 2 LINES WITH P.Y AND U.Y AS FOLLOWS
          **
          **
          AVE UPDATE P.XR = P.ZZSUM - P.XR *(P.Y**2) / (P.XR-1.)
          AVE UPDATE U.XR = U.ZZSUM - U.XR *(U.Y**2) / (U.XR-1.)
          SKIP 1 OUTPUT LINE

```

```

PRINT 2 LINES WITH P.SD AND U.SD AS FOLLOWS
PACKET QUEUE STANDARD DEVIATION = **.****
UPDATE QUEUE STANDARD DEVIATION = **.****
..
.. CHECK ALL UNDELIVERED PKTS. REPORT ANY WITH A HOP COUNT > N.NODE
..
PRINT 1 LINE AS FOLLOWS
UNUSUAL DELAYS FOR PACKETS NOT DELIVERED DESCRIBED BELOW
FOR NC.DE = 1 TO N.NODE, DO
FOR EACH MESSAGE IN PACKET.OUT.QUEUE(NC.DE) WITH TYPE(MESSAGE)
= PACKET, DO
IF NC.DES.HOPPED(MESSAGE) >= N.NCDE
PRINT 1 LINE WITH RELEASE.TIME(MESSAGE),
PACKET RELEASED AT ***.****.****.**** MAKES ** HOPS
REGARDLESS
LOOP
..
.. END ** OF BEGIN REPORT
REGARDLESS
REGARDLESS
..
.. IF PEEK NE 4
.. SCHEDULE A REPORT.RESULTS IN ( TIME.LIMIT / 4. ) UNITS
.. ELSE
.. PERFORM SPECIAL.CUTPUT
.. PERFORM DESTRUCTION
.. REGARDLESS
RETURN
END ** OF REPCRT.RESULTS
..
.. THIS SUBROUTINE CALCULATES THE NETWORK FLOW AND
.. THE AVERAGE DELAY PER PACKET
ROUTINE FOR FLOW.AND.DELAY
..
DEFINE T.DELAY1, T.DELAY2 AND GAMMA.INVERSE AS REAL VARIABLES
DEFINE INSTANCE AND NEW.INSTANCE AS VARIABLE

```



```

IF PEEK = 4
..
.. SKIP 2 OUTPUT LINES
PRINT 3 LINES AS FOLLOWS
-- UTILIZATION FACTOR --
LINK      PACKET  UPDATE  TOTAL      PKTS IN  PKTS IN  WAIT TIME
..        ..        ..        ..        QUEUE AT  QUEUE AT  FOR PKTS
..        ..        ..        ..        END
..        ..        ..        ..        END
..
.. SKIP 1 OUTPUT LINE
..
.. FCR I = 1 TO LINKS, DO
..
..   LET A = LINK.ABLE(I,1)
..   LET B = LINK.ABLE(I,2)
..
..   LET P.FLOW1 = (LINK.TIMER(1), A, B, 3) - LINK.TIMER(1, A, B, 4))
..             / ((TIME.ELAPSED B, A, 3) - LINK.TIMER(1, B, A, 4))
..
..   LET P.FLOW2 = (LINK.TIMER(1), A, B, 3) - LINK.TIMER(1, B, A, 4))
..             / ((TIME.ELAPSED B, A, 3) - LINK.TIMER(1, B, A, 4))
..
..   LET P.FLOW.TOTAL = P.FLOW1 + P.FLOW2 + P.FLOW.TOTAL
..
..   LET U.FLOW1 = (LINK.TIMER(2), A, B, 3) - LINK.TIMER(2, A, B, 4))
..             / ((TIME.ELAPSED B, A, 3) - LINK.TIMER(2, B, A, 4))
..
..   LET U.FLOW2 = (LINK.TIMER(2), A, B, 3) - LINK.TIMER(2, B, A, 4))
..             / ((TIME.ELAPSED B, A, 3) - LINK.TIMER(2, B, A, 4))
..
..   LET U.FLOW.TOTAL = U.FLOW1 + U.FLOW2 + U.FLOW.TOTAL
..
.. DEFINE N AS A REAL VARIABLE
..
.. LET T.DELAY1 = ( ( P.FLOW1**2 / (1.0 - U.FLOW1) ) / ( 1.0 -
..   U.FLOW1 - P.FLOW1 ) ) + P.FLOW1
..
.. LET T.DELAY2 = ( ( P.FLOW2**2 / (1.0 - U.FLOW2) ) / ( 1.0 -
..   U.FLOW2 - P.FLOW2 ) ) + P.FLOW2
..
.. LET TOTAL.DELAY = TOTAL.DELAY + T.DELAY1 + T.DELAY2
..
.. LET LINK1.FLOW = P.FLOW1 + U.FLOW1
.. LET LINK2.FLOW = P.FLOW2 + U.FLOW2
..
.. LET K = 1
FOR N = 0.0 TO 1.0 BY 0.1, DO
IF LINK1.FLOW > N AND LINK1.FLOW <= ( N + 0.1 )
LET HISTOGRAM (K) = HISTOGRAM (K) + 1
REGARCLESS
IF LINK2.FLOW > N AND LINK2.FLOW <= ( N + 0.1 )
LET HISTOGRAM (K) = HISTOGRAM (K) + 1
REGARCLESS
..
..

```

AD-R126 790

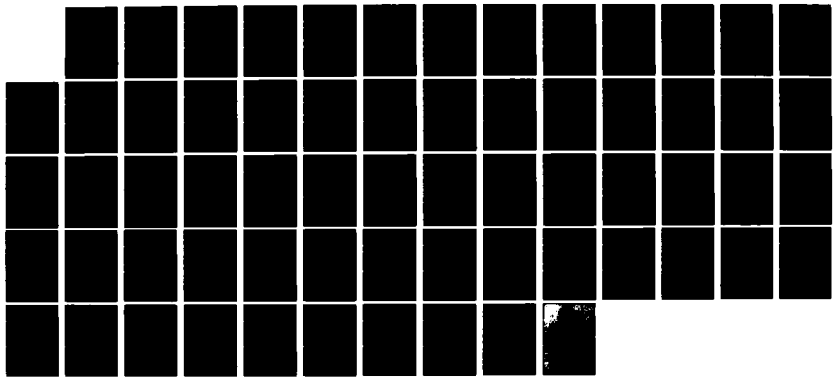
INVESTIGATIONS INTO THE PERFORMANCE OF A DISTRIBUTED
ROUTING PROTOCOL FOR PACKET SWITCHING NETWORKS(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA A W LINGERICH DEC 82

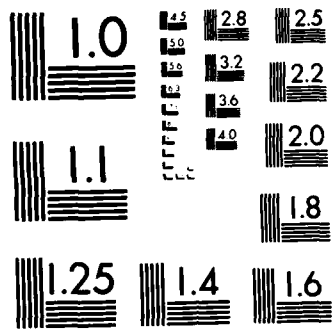
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NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


```

LET K = K + 1
LCCP
.. PRINT I LINE WITH LINK.ABLE (I,1), LINK.ABLE (I,2), P.FLOW1, U.FLOW1,
LINK1.FLOW, LINK.MCNITOR(A, B, 6), LINK.MCNITOR(A, B, 2)
ANC T.DELAY1 AS FOLLOWS
***/*** * ***/*** * ***/*** * ***/*** * ***/*** * ***/*** * ***/***
PRINT I LINE WITH LINK.ABLE (I,2), LINK.ABLE (I,1), P.FLOW2, U.FLOW2,
LINK2.FLOW, LINK.MCNITOR(B, A, 6), LINK.MCNITOR(B, A, 2)
ANC T.DELAY2 AS FOLLOWS
***/*** * ***/*** * ***/*** * ***/*** * ***/*** * ***/*** * ***/***
.. LET PKTS.END = PKTS.END + LINK.MCNITOR(A,B,2)
LCCP
.. LET GAMMA.INVERSE = 1.0 / PKTS.PER.SEC.AVE
LET AVE.DELAY.PER.PKT = GAMMA.INVERSE * TOTAL.DELAY
LET AVE.P.FLOW = P.FLOW.TOTAL / ( 2 * LINKS )
LET AVE.U.FLOW = U.FLOW.TOTAL / ( 2 * LINKS )
LET AVE.NETWORK.FLOW = AVE.P.FLOW + AVE.U.FLOW
.. FOR EACH NODE, CC
FOR EACH INSTANCE IN PACKET.OUT.QUEUE(NODE), DO
LET STRANDED.WAIT = STRANDED.WAIT + TIME.V
- QUEUE.ENTRY.TIME(INSTANCE)
LOOP
.. T.IN.LINK REPRESENTS THE TOTAL TIME ALL PACKETS WHICH ARE
NOT IN A QUEUE AND HAVE NOT BEEN DELIVERED BY THE END OF THE
HAVE BEEN IN THE CURRENT LINK
.. Q.IN.LINK REPRESENTS THE TOTAL TIME PACKETS WHICH ARE IN
QUEUE AT THE END OF THE SIMULATION HAVE BEEN IN QUEUE.
FOR EACH NEW INSTANCE IN LINK.FLAG(NODE), DO
LET T.IN.LINK = T.IN.LINK + TIME.V - LINK.ENTRY.TIME(NEW.INSTANCE)
LET Q.IN.LINK = Q.IN.LINK + TOT.QUEUE.TIME(NEW.INSTANCE)
LCCP
.. REGARDLESS
.. RETURN
END OF FLCW.AND.DELAY
..

```

```

.. THIS SUPROUTINE CCNTAINS THE SPECIAL OUTPUT FORMAT SPECIFIED
.. BY THE PROGRAMMER. THE SUBROUTINE IS ONLY EXECUTED
.. WHEN THE SIMULATION HAS COMPLETED ALL FOUR QUARTERS
.. OF ITS RUN AND SPECIFY.OUTPUT = 1.
..
.. ROUTINE FOR SPECIAL.OUTPUT
..
.. DEFINE N AND CHECK.DELAY AS A REAL VARIABLES
..
.. SKIP 1 OUTPUT LINE
.. PRINT 3 LINES WITH AVE.P.FLOW, AVE.U.FLOW AND AVE.NETWORK.FLOW
.. AS FOLLOWS
..
.. AVE.P.FLOW = **.*
.. AVE.U.FLOW = **.*
.. AVE.NETWORK.FLOW = **.*
..
.. LET CHECK.DELAY = (TRANSIT.TIME + STRANDED.WAIT + T.IN.LINK +
.. Q.IN.LINK) / REAL.F(GEN.COUNT)
..
.. PRINT 4 LINES WITH Q.IN.LINK, DEST.CCUNT, TRANSIT.TIME,
.. STRANDED.WAIT AS FOLLOWS
..
.. GEN.CCUNT = **.*
.. DEST.CCUNT = **.*
.. TRANSIT.TIME = **.*
.. STRANDED.WAIT = **.*
..
.. PRINT 3 LINES WITH T.IN.LINK AND Q.IN.LINK AND CHECK.DELAY AS FOLLOWS
..
.. T.IN.LINK = **.*
.. Q.IN.LINK = **.*
.. CHECK.DELAY = **.*
..
.. PRINT 2 LINES WITH AVE.DELAY.PER.PKT AND
.. RATIO.STRANDED AS FOLLOWS
..
.. AVE.DELAY.PER.PKT = **.*
.. RATIO.STRANDED = **.*
..
.. PRINT 2 LINES WITH PKTS.HALF AND PKTS.END
.. AS FOLLOWS
..
.. PKTS IN QUEUE AT HALF = **.*
.. PKTS IN QUEUE AT END = **.*
..
.. SKIP 1 OUTPUT LINE
.. PRINT 1 LINE AS FOLLOWS
.. INTERVAL NUMBER OF LINKS
..
.. LET N = 0.0
.. FOR I = 1 TO 10, DO
.. PRINT 1 LINE WITH N, ( N + .1 ) AND HISTOGRAM( I )
.. AS FOLLOWS
.. **.* - **.*

```

```

** LET N = N + .1
** LOOP
** THE FOLLOWING STATEMENTS CAUSE THE RESULTS OF THE
** SIMULATION TO BE WRITTEN TO THE MASS STORAGE
** SYSTEM FOR LATER RETRIEVAL BY A PLOTTING
** ROUTINE.
**
** USE UNIT 8 FOR OUTPUT
** WRITE PKTS.PER.SEC.AVE/NCDE.FACTOR, AVE.NETWORK.FLOW, CHECK.DELAY AS
** AVE.P.FLOW, AVE.U.FLOW, AVE.DELAY.PER.PKT, D(9,6),S 1, D(9,6), S 1,
** D(6,2),S 1, D(9,6),S 1, D(9,6),S 1, D(9,6),S 1,
** D(9,6)
** USE UNIT 6 FOR OUTPUT
** RETURN
** END ** OF SPECIAL.CUTPUT
**
** THE FOLLOWING SUBROUTINE CANCELS AND/OR DESTROYS ALL ENTITIES
** AND EVENTS WHICH REMAIN IN THE TIMING ROUTINE AFTER
** TIME.V = TIME.LIMIT. SINCE THIS ACTION EMPTIES THE
** TIMING ROUTINE, CONTROL OF THE PROGRAM IS RETURNED TO THE
** STATEMENT FOLLOWING *START SIMULATION* IN THE "MAIN"
** ROUTINE FOR DESTRUCTION
**
** DEFINE OCCURANCE AS VARIABLE
**
** FOR EACH QU.SAMPLER IN EV.S(I.QU.SAMPLER), DO
** CANCEL THE QU.SAMPLER
** DESTROY THE QU.SAMPLER
** LOOP
** FOR EACH SAMPLE IN EV.S(I.SAMPLE), DC
** CANCEL THE SAMPLE
** DESTROY THE SAMPLE
** LOOP
** FOR EACH COMPUTE.CV IN EV.S(I.COMPUTE.CV), DO
** CANCEL THE COMPUTE.CV
** DESTROY THE COMPUTE.CV
** LOOP
** FOR EACH ADOPT.NEW.BEST.PATH IN EV.S(I.ADOPT.NEW.BEST.PATH), DO
** CANCEL THE ADOPT.NEW.BEST.PATH
** DESTROY THE ADOPT.NEW.BEST.PATH
** LOOP
** FOR EACH NEW.UPDATE.MESSAGE IN EV.S(I.NEW.UPDATE.MESSAGE), DO
** CANCEL THE NEW.UPDATE.MESSAGE

```



```

DESTRUCT THE NEW.UPDATE.MESSAGE
LOOP EACH UPDATE.ARRIVES IN EV.S(I.UPDATE.ARRIVES), DO
  CANCEL THE UPDATE.ARRIVES
  DESTROY THE UPDATE.ARRIVES
LOOP
FOR EACH CONT.UPDATE.MESSAGE IN EV.S(I.CONT.UPDATE.MESSAGE), DO
  CANCEL THE CONT.UPDATE.MESSAGE
  DESTROY THE CONT.UPDATE.MESSAGE
LOOP
FOR EACH PACKET.ARRIVES IN EV.S(I.PACKET.ARRIVES), DO
  CANCEL THE PACKET.ARRIVES
  DESTROY THE PACKET.ARRIVES
LOOP
FOR EACH CCN.PACKET.MESSAGE IN EV.S(I.CCN.PACKET.MESSAGE), DO
  CANCEL THE CON.PACKET.MESSAGE
  DESTROY THE CCN.PACKET.MESSAGE
LOOP
FOR EACH NEW.PACKET.MESSAGE IN EV.S(I.NEW.PACKET.MESSAGE), DO
  CANCEL THE NEW.PACKET.MESSAGE
  DESTROY THE NEW.PACKET.MESSAGE
LOOP
FOR EACH COMPLETED.TRIP IN EV.S(I.COMPLETED.TRIP), DO
  CANCEL THE COMPLETED.TRIP
  DESTROY THE COMPLETED.TRIP
LOOP
FOR EACH NOICE, DO
  FOR EACH OCCURANCE CF UPDATE.OUT.QUEUE, DO
    REMOVE OCCURANCE FROM UPDATE.OUT.QUEUE
    DESTROY MESSAGE CALLED OCCURANCE
  LOOP
  FOR EACH OCCURANCE OF PACKET.OUT.QUEUE, DO
    REMOVE OCCURANCE FROM PACKET.OUT.QUEUE
    DESTROY MESSAGE CALLED OCCURANCE
  LOOP
  FOR EACH OCCURANCE OF LNK.FLAG DO
    REMOVE OCCURANCE FROM LNK.FLAG
    DESTROY MESSAGE CALLED OCCURANCE
  LOOP
FOR EACH OCCURANCE CF TIME.QUEUE, DO
  REMOVE OCCURANCE FROM TIME.QUEUE
  DESTROY PACK CALLED OCCURANCE
LOOP
..
LOOP
..

```

```

RETURN
END ** OF DESTRUCTION
**
** THIS ROUTINE IS CALLED WHEN A NCDE ORIGINATES AN UPDATE MESSAGE.
** THE INITIAL U-MSG IS SENT TO ALL OF THE INITIATING NODE'S NEIGHBORS
**
EVENT NEW.UPDATE.MESSAGE GIVEN SENDING.NCDE AND TYPE.MESSAGE
LET UP.STARTS = UP.STARTS + 1
FOR I = 1 TO LINKS, DC
** CHECK EACH LINK TO SEE IF SENDING.NCDE IS ON ONE END
** IF (LINK.ABLE(I,1) = SENDING.NODE OR LINK.ABLE (I,2) = SENDING.NODE)
CREATE A MESSAGE
LET TYPE (MESSAGE) = UPDATE
LET RELAYER (MESSAGE) = SENDING.NCDE
LET U.TOTAL (SENDING.NODE) = U.TOTAL (SENDING.NODE) + 1
IF LINK.ABLE(I,1) = SENDING.NODE
** IF OPPOSITE NCDE IS IN ANOTHER FAMILY:
IF FAMILY (LINK.ABLE(I,2)) NE FAMILY (SENDING.NODE)
LET FAMILY (MESSAGE) = FAMILY (SENDING.NODE)
LET DESTINATION (MESSAGE) = FAMILY (SENDING.NODE)
GO LIST.NEXT.STOP
ELSE
** IF OPPOSITE NCDE IS IN ANOTHER GROUP (SAME FAMILY):
IF GROUP (LINK.ABLE(I,2)) NE GROUP (SENDING.NODE)
LET GRP (MESSAGE) = GROUP (SENDING.NODE)
LET DESTINATION (MESSAGE) = GROUP (SENDING.NODE)
GO LIST.NEXT.STOP
ELSE
** IF OPPOSITE NCDE IS IN SAME BASIC GROUP
LET DESTINATION (MESSAGE) = LINK.ABLE(I,1)
LIST.NEXT.STOP:
LET NEXT.STOP (MESSAGE) = LINK.ABLE(I,2)
ELSE
IF FAMILY (LINK.ABLE(I,1)) NE FAMILY (SENDING.NODE)
LET FAMILY (MESSAGE) = FAMILY (SENDING.NODE)
LET DESTINATION (MESSAGE) = FAMILY (SENDING.NODE)
GO INCL.NEXT.STOP
ELSE
IF GROUP (LINK.ABLE(I,1)) NE GROUP (SENDING.NODE)

```

```

LET GRP (MESSAGE) = GROUP (SENDING.NODE)
LET DESTINATION (MESSAGE) = GROUP (SENDING.NODE)
GO INCL.NEXT.STOP
ELSE
LET DESTINATION(MESSAGE) = LINK.ABLE(I,2)
LET NEXT.STOP (MESSAGE) = LINK.ABLE(I,1)
REGARDLESS
IF PRNT >= 4
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH SENDING.NODE, NEXT.STOP(MESSAGE),
DESTINATION(MESSAGE) AND TIME.V AS FOLLOWS
UPDATE ORIGINATED BY *** TO *** FOR DESTINATION *** AT ****.***** SEC
REGARDLESS
**
** IF LINK TO NEIGHBCR IS IDLE, SEND OUT UPDATE
**
** IF LINK.MONITOR( RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1 ) = IDLE
**
** SCHEDULE ARRIVAL CF UPDATE AT OPPOSITE NCDE
**
** SCHEDULE AN UPDATE.ARRIVES GIVEN MESSAGE IN
U.XMN.TIME UNITS
LET LINK.TIMER( 2, RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1 )
= TIME.V
LET LINK.MONITOR( RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1 ) = BUSY
**
IF PRNT >= 4
SKIP 1 OUTPUT LINE
PRINT 2 LINES WITH SENDING.NCDE AND U.TOTAL(SENDING.NODE)
AS FOLLOWS
UPDATE DOES NOT WAIT IN QUEUE.
NODE *** HAS PASSED CR ORIGINATED ***** UPDATES
REGARDLESS
**
IF PRNT >= 5
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH RELAYER(MESSAGE), NEXT.STOP(MESSAGE) AND
TIME.V AS FOLLOWS
LINK *** / *** BUSY TRANSMITTING UPDATE AT ****.***** SEC.
REGARDLESS
**
ELSE
**
** IF THE LINK IS BUSY, STCRE UPDATE AT THE END OF THE OUTGOING
UPDATEF QUEUE FCR THAT LINK
**
** FILE MESSAGE IN UPDATE.OUT.QUEUE( RELAYER(MESSAGE) )

```



```

IF LINK.MONITOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1) = IDLE
..
..
..
SCHEDULE THE RELAYED UPDATE TO ARRIVE AT THE NEXT DESTINATION
SCHEDULE AN UPDATE ARRIVES GIVEN MESSAGE IN U.XMN.TIME UNITS
LET LINK.TIMER(2, RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1)
    = TIME.V
LET LINK.MONITOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 1)
..
..
IF PRINT >= 4
SKIP 1 OUTPUT LINE RELAYER(MESSAGE), NEXT.STOP(MESSAGE),
PRINT 3 LINES WITH DESTINATION(MESSAGE), TIME.V, LAST.NODE AND
    U.TOTAL(LAST.NODE) AS FOLLCS
UPDATE RELAYED UPDATE *** FOR DESTINATION *** AT ****.***** SEC
RELAYED UPDATE DOES NOT WAIT IN OUTGOING UPDATE QUEUE
NODE *** HAS PASSED ***** UPDATES
REGARCLESS
..
..
IF PRINT >= 5
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH RELAYER(MESSAGE), NEXT.STOP(MESSAGE) AND
LINK.MCMTOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 4) + 1
LINK.MCMTOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 4) > 1
LINK.MCMTOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 5) =
LET LINK.MONITOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 5) =
LINK.MONITOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 4)
REGARCLESS
..
..
IF PRINT >= 4
SKIP 1 OUTPUT LINE
PRINT 3 LINES WITH RELAYER(MESSAGE), NEXT.STOP(MESSAGE) AND
LINK.MONITOR(RELAYER(MESSAGE), NEXT.STOP(MESSAGE), 4)
AS FOLLCS
UPDATE FROM NODE *** TO *** WITH DESTINATION NODE *** ENTERS

```

```

OUTGGING UPDATE QUEUE AT ****.***** SEC
OUTGGING UPDATE QUEUE FROM NODE *** IS *****
REGARCLESS

..
.. REGARDLESS
..
RETURN
END **CF CONT.UPDATE.MESSAGE

..
.. THIS ROUTINE PROCESSES AN UPDATE MESSAGE AS IT ARRIVES IN A NODE,
.. RELAYING IT TO NEIGHBCRS IF APPROPRIATE
..
EVENT UPDATE.ARRIVES GIVEN ID.MESSAGE.NUMBER
..
DEFINE RELAY.NODE AND MSG.NR AS VARIABLES
..
LET MSG.NR = IC.MESSAGE.NUMBER
..
LET LINK.TIMER( 2, RELAYER(MSG.NR); NEXT.STOP(MSG.NR); 2 ) = TIME.V
LET LINK.TIMER( 2, RELAYER(MSG.NR); NEXT.STOP(MSG.NR); 3 ) = +
LET LINK.TIMER( 2, RELAYER(MSG.NR); NEXT.STOP(MSG.NR); 3 ) = -
LET LINK.TIMER( 2, RELAYER(MSG.NR); NEXT.STOP(MSG.NR); 2 ) =
LET LINK.TIMER( 2, RELAYER(MSG.NR); NEXT.STOP(MSG.NR); 1 ) =

..
.. I THIS.NOCE = NEXT.STOP(MSG.NR)
LET NET.U.LINKS = NET.U.LINKS + 1
LET NODES.HOPPED(MSG.NR) = NCDES.HOPPED(MSG.NR) + 1
..
IF PRINT >= 4 OUTPUT LINE
PRINT I LINE WITH NEXT.STOP(MSG.NR), RELAYER(MSG.NR),
DESTINATION(MSG.NR) AND TIME.V AS FOLLOWS
UPDATE ARRIVES AT *** FRCM *** FOR DESTINATION *** AT ****.***** SEC.
REGARCLESS
..
.. IC CV OF LAST RELAYING NODE
..
FOR I = 1 TC MAX.LINKS.PER.NCDE, DO
IF NEIGHBCR.LIST(THIS.NODE, I, 1) = RELAYER(MSG.NR)
LET CV.OF.LINK = NEIGHBOR.LIST(THIS.NODE, I, 3)
GO SELECT.BEST.PATH
ELSE
LOOP
SELECT.BEST.PATH
LET TOTAL.CV.OF.PATH = CV.OF.LINK + CHANNEL.VALUE(MSG.NR)
..
.. IC PREVIOUSLY SELECTED BP NEIGHBOR

```

```

.. LET BP.NEIGHBOR = BEST.PATH(THIS.NODE,DESTINATION(MSG.NR),3)
..
.. IF RELAYER = CURRENT BP NEIGHBOR, UPDATE ITS CV TO THE DESTINATION
.. AND RELAY UPDATE
..
.. IF RELAYER(MSG.NR) = BP.NEIGHBOR
.. LET BEST.PATH(THIS.NODE,DESTINATION(MSG.NR),4) = CHANNEL.VALUE(MSG.NR)
..
.. IF PRINT >= 3
.. SKIP 1 OUTPUT LINE
.. PRINT 2 LINES WITH THIS.NODE, DESTINATION(MSG.NR), BP.NEIGHBOR,
.. TIME.V, CHANNEL.VALUE(MSG.NR), CV.OF.LINK AND TOTAL.CV.OF.PATH
.. AS FOLLOWS
.. NODE *** UPDATES CV THRU SAME BP TO *** (THRU ***) AT ****.***** SEC
.. CV = *** + *** = ***
.. SKIP 1 OUTPUT LINE
.. REGARDLESS
.. GO RELAY.UPDATE.TO.NEIGHBORS
ELSE
..
.. IF THERE WAS NO BP NEIGHBOR, ADAPT RELAYER AS BP NEIGHBOR AND
.. RELAY UPDATE
..
.. IF BP.NEIGHBOR = NCNE
.. LET BEST.PATH(THIS.NCDE,DESTINATION(MSG.NR),3) = RELAYER(MSG.NR)
.. LET BEST.PATH(THIS.NCDE,DESTINATION(MSG.NR),4) = CHANNEL.VALUE(MSG.NR)
.. LET BP.NEIGHBOR = RELAYER(MSG.NR)
..
.. IF PRINT >= 2
.. SKIP 1 OUTPUT LINE
.. PRINT 2 LINES WITH THIS.NCDE, DESTINATION(MSG.NR), BP.NEIGHBOR,
.. TIME.V AND TOTAL.CV.OF.PATH AS FOLLOWS
.. NEW BEST PATH FROM *** TO *** NOW THRU *** AT ****.***** SEC.
.. BEST PATH CV = ****
.. SKIP 1 OUTPUT LINE
.. REGARDLESS
.. GO RELAY.UPDATE.TO.NEIGHBORS
ELSE
..
.. IF THE RELAYER IS NOT THE BP NEIGHBOR, AND IF THE NEW PATH IS
.. SHORTER THAN THE OLD BEST PATH, MAKE RELAYER THE NEW BP NEIGHBOR
.. AND RELAY THE UPDATE
..
.. FOR I = 1 TO MAX.LINKS.PER.NCDE, DO
.. IF NEIGHBCR.LIST(THIS.NODE,I,1) = BP.NEIGHBOR

```

```

LET CV.TC.BP.NEIGHBOR = NEIGHBOR.LIST(THIS.NODE,1,3)
GO COMPARE.CVS
ELSE
LOOP
'COMPARE.CVS'
IF (BEST.PATH(THIS.NODE,DESTINATION(MSG.NR),4) + CV.TO.BP.NEIGHBOR) >
TOTAL.CV.CF.PATH NEIGHBOR
LET OLD.BP = BP
LET OLD.CV = BEST.PATH(THIS.NODE, DESTINATION(MSG.NR), 4)
LET LNK.CV = CV.TO.BP.NEIGHBOR
LET BEST.PATH(THIS.NODE, DESTINATION(MSG.NR), 3) = RELAYER(MSG.NR)
LET BEST.PATH(THIS.NODE, DESTINATION(MSG.NR), 4) = CHANNEL.VALUE
(MSG.NR)
LET BP.NEIGHBOR = RELAYER(MSG.NR)
..
IF PRNT >= 2
SKIP 1 OUTPUT LINE
PRINT 2 LINES WITH THIS.NCDE, DESTINATION(MSG.NR), BP.NEIGHBOR,
TIME.V, CHANNEL.VALUE(MSG.NR), CV.OF.LINK AND
TOTAL.CV.CF.PATH AS FCLLCWS
NEW BEST PATH FROM *** TC *** NOW THRU *** AT ****.***** SEC.
CV = *** + *** = ***
PRINT 1 LINE WITH OLD.BP, OLD.CV, LNK.CV, (OLD.CV + LNK.CV) AS FOLLOWS
OLD BP THRU *** HAD CV OF *** + *** = ***
SKIP 1 OUTPUT LINE
REGARDLESS
..
GO RELAY.UPDATE.TO.NEIGHBORS
ELSE
.. IF NEW PATH IS NOT BETTER THAN THE OLD BEST PATH, DISCONTINUE U-MSG
.. GO DISCONTINUE.ORIGINAL.MESSAGE
..
.. IF A NEW BP IS SELECTED OR AN OLD BP IS UPDATED, PREPARE INFORMATION
.. FOR THE NEXT U-MSG TO ALL NEIGHBORS
RELAY.UPDATE.TO.NEIGHBORS'
FOR I = 1 TO MAX.LINKS.PER.NCDE, DO
IF NEIGHBOR.LIST(THIS.NODE, I, 1) = BP.NEIGHBOR
LET CV.TO.BP.NEIGHBOR = NEIGHBOR.LIST(THIS.NODE, I, 3)
GO COMPUTE.NET.CV
ELSE
LOOP
'COMPUTE.NET.CV'
LET NET.CV.FROM.THIS.NCDE = BEST.PATH(THIS.NODE, DESTINATION(MSG.NR),4)
LET CV.TO.BP.NEIGHBOR
FOR I = 1 TO MAX.LINKS.PER.NCDE, DO
IF NEIGHBOR.LIST(THIS.NODE, I, 2) = YES

```



```

IF NEIGHBOR.LIST (THIS.NODE, I, 1) NE RELAYER (MSG.NR)
LET UPSTREAM.NCDE = NEIGHBOR.LIST (THIS.NODE, I, 1)
..
..
IF UPSTREAM NODE IS IN ANOTHER FAMILY AND THIS IS A INTRA-FAMILY
U-MSG, RELAY IT
..
..
IF (FAM.LY(MSG.NR) NE 0 AND FAMILY(UPSTREAM.NODE) NE FAM.LY(MSG.NR))
GO RETRANS.UPSTREAM
ELSE
..
..
IF UPSTREAM NODE IS IN ANOTHER GROUP AND THIS IS A INTRA-GROUP (SAME
FAMILY) U-MSG, RELAY IT
..
..
IF (GRP(MSG.NR) NE 0 AND GROUP(UPSTREAM.NODE) NE GRP(MSG.NR))
GO RETRANS.UPSTREAM
ELSE
..
..
IF UPSTREAM NODE IS IN THE SAME BASIC GROUP AND THIS IS A BASIC
GROUP CRIGINATED U-MSG, RELAY IT
..
..
IF (GRUP(UPSTREAM.NCDE) = GROUP(THIS.NODE)
AND FAM.LY(MSG.NR) = GRP(MSG.NR))
GO RETRANS.UPSTREAM
ELSE
..
..
IF NONE OF THE ABOVE, UPSTREAM NODE DOES NOT GET A U-MSG
GO SKIP.PRINT
GO RETRANS.UPSTREAM
LET HOPS = NODES.HCIPPED(MSG.NR)
SCHEDULE A CONT.UPDATE.MESSAGE GIVEN THIS.NODE, UPSTREAM.NODE, HOPS,
NET.CV.FROM.THIS.NODE, DESTINATION(MSG.NR), FAM.LY(MSG.NR),
AND GRP(MSG.NR) IN (PROCESSING.TIME * UP.PAC.RATIO) UNITS
*SKIP.PRINT,
REGARDLESS
LOOP
..
..
IN THE SIMULATION, ALL U-MSGS ARE DESTROYED AFTER TRAVELING ONE
LINK. HOWEVER THE UPDATE CYCLE PROCEEDS ACCORDING TO THE BASIC
CONCEPT BECAUSE THE ARRIVING U-MSG CAUSES NEW U-MSGS TO BE
INITIATED IF A NEW BP WAS SELECTED OR AN OLD BP WAS UPDATED.
IF A NODE COULD NOT USE AN INCOMING U-MSG, IT IS DESTROYED
WITHOUT GENERATING ANY NEW U-MSGS.
..
..
DISCONTINUE ORIGINAL MESSAGE
IF NODES.HOPPED(MSG.NR) > MAX.U.HOPS
LET MAX.U.HOPS = NODES.HOPPED(MSG.NR)

```

```

REGARDLESS
LET RELAY.NCCE = RELAYER(MSG.NR)
DESTROY MESSAGE CALLED MSG.NR
..
.. GO TO THE OUTGOING UPDATE QUEUE OF THE NODE WHICH RELAYED THE ABOVE
.. UPDATE, IF THE UPDATE QUEUE IS EMPTY, DEFINE THE LINK AS IDLE
.. AND CHECK THE NODE'S PACKET QUEUE FOR PACKETS TO BE RELAYED BY
.. DELIVERED TO THIS NODE. OTHERWISE, PLACE THE NEXT UPDATE ON
.. THE LINK AND ADJUST THE UPDATE QUEUE LENGTH
..
FOR EACH MESSAGE IN UPDATE.OUT.QUEUE( RELAY.NODE )
WITH NEXT STOP(MESSAGE) = THIS.NODE
FIND THE FIRST CASE
IF NONE
..
.. CHECK PACKET QUEUE AT THE NODE WHICH SENT THIS UPDATE FOR PACKETS
.. TO BE RELAYED BY OR DELIVERED TO THIS NODE. IF PACKET QUEUE IS
.. EMPTY, DEFINE THE LINK AS IDLE; OTHERWISE, PLACE THE
.. NEXT PACKET FOR THIS NODE ON THE LINK
..
FOR EACH MESSAGE IN PACKET.OUT.QUEUE( RELAY.NODE )
WITH NEXT STOP(MESSAGE) = THIS.NODE
FIND THE FIRST CASE
IF NONE
LET LINK.MCNITCR( RELAY.NODE, THIS.NODE, 1 ) = IDLE
..
IF PRNT >= 5
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH RELAY.NODE, THIS.NODE AND TIME.V AS FOLLOWS
LINK ***/ *** IDLE AT ****.***** SEC.
REGARDLESS
..
ELSE
REMOVE MESSAGE FROM PACKET.OUT.QUEUE( RELAY.NODE )
FILE MESSAGE IN LNK.FLAG(RELAY.NODE)
LET LNK.ENTRY.TIME(MESSAGE) = TIME.V
LET TOT.QUEUE.TIME(MESSAGE) = TOT.QUEUE.TIME(MESSAGE) + TIME.V
LET QUEUE.ENTRY.TIME(MESSAGE) = 0.0
..
.. SCHEDULE THE ARRIVAL OF THE PACKET JUST RELEASED FROM THE QUEUE
..
.. SCHEDULE A PACKET. ARRIVES GIVEN MESSAGE IN PKT.XMN.TIME UNITS
LET LNK.MONITCR( RELAY.NODE, THIS.NODE, 2 ) =
LINK.MCNITCR( RELAY.NODE, THIS.NODE, 1 ) + TIME.V
LET LNK.TIMER( 1, RELAY.NODE, THIS.NODE, 1 ) = TIME.V
..
IF PRNT >= 1

```

```

SKIP 1 OUTPUT LINE
PRINT 3 LINES WITH INFO1(MESSAGE), INFO2(MESSAGE), RELAY.NODE,
THIS.NODE, DESTINATION(MESSAGE), TIME.V) AS RELAY.NODE AND
LINK.MCNITCR( RELAY.NODE, 2) AS FOLLOWS ***
+***/** RELEASED FROM THE OUTGOING PACKET QUEUE OF NODE ***
WITH DESTINATION *** AT ***.***** SEC.
OUTGOING PACKET QUEUE FROM NODE *** IS *****
REGARDLESS
**
REGARDLESS
ELSE
REMOVE MESSAGE FROM UPDATE.OUT.QUEUE( RELAY.NODE )
**
SCHEDULE ARRIVAL OF UPDATE JUST RELEASED FROM QUEUE
**
SCHEDULE AN UPDATE.ARRIVES GIVEN MESSAGE IN U.XMN.TIME UNITS
LET LINK.MONITOR( RELAY.NODE, THIS.NODE, 4 ) = 1
LINK.MCNITCR( RELAY.NODE, THIS.NODE, 4 ) = 1
LET LINK.TIMER( 2, RELAY.NODE, THIS.NODE, 1 ) = TIME.V
**
IF PRNT >= 4
SKIP 1 OUTPUT LINE RELAY.NODE, THIS.NODE, TIME.V, RELAY.NODE AND
PRINT 3 LINES WITH RELAY.NODE, THIS.NODE, 4) AS FOLLOWS
LINK.MCNITCR( RELAY.NODE, THIS.NODE, 4) AS FOLLOWS
UPDATE RELEASED FROM THE OUTGOING UPDATE QUEUE OF NODE *** TO ***
AT ***** SEC.
OUTGOING UPDATE QUEUE FROM NODE *** IS *****
REGARDLESS
**
REGARDLESS
**
RETURN
END ** OF UPDATE.ARRIVES
**
**
THIS ROUTINE CALCULATES CHANNEL VALUES BASED ON A TIME-WEIGHTED
AVERAGE OF QUEUE SIZES OVER A SPECIFIED TIME CALLED THE WINDOW.
QUEUE SIZE INFORMATION OLDER THAN THE WINDOW TIME IS DISCARDED.
**
EVENT COMPUTE.CV
DEFINE EDGE, LAST, SUM, LAS.CU, SPAN, MID, AREA, WEIGHT, BLOCK
AND REMAINDER AS REAL VARIABLES
DEFINE NONE TO MEAN 0
**
IF PRNT >= 2
SKIP 1 OUTPUT LINE
PRINT 2 LINES WITH TIME.V AS FOLLOWS
UPDATE CYCLE BEGINS AT ***** SEC

```

```

NEW CHANNEL VALUES ARE BEING COMPUTED
SKIP 1 OUTPUT LINE
REGARDLESS
FOR THIS.NODE = 1 TO N.NODE, DO
  DESTROY QUEUE INFCRMATION BEYOND WINDOW SIZE. "PACK" IS A PACKAGE
  CCF INFCRMATION DESCRIBED LATER.
  FOR EACH PACK IN TIME.QUEUE (THIS.NODE) WITH ENTRY.TIME(PACK) <
    (TIME.V - WINDCW), DO
      REMOVE PACK FRM TIME.QUEUE (THIS.NODE)
      DESTROY PACK
    LCCP
  :: CALCULATE THE CV TO EACH NEIGHBOR
  FOR J = 1 TO MAX LINKS PER NODE, CC
    IF NEIGHBOR.LIST (THIS.NODE, J, 2) = YES
      LET NEIB = NEIGHBOR.LIST {THIS.NODE, J, 1}
      LET EDGE = C.O
      LET LAST = TIME.V
      LET SUM = 0.0
      LET LAS.GU = 0.0
      LET ANY.PACKS = NONE
      LET EACH.PACK IN TIME.QUEUE (THIS.NODE) WITH
        FOR PAC.NEIGHBOR (PACK) = NEIB, DO
          LET ANY.PACKS = YES
          LET SPAN = LAST - ENTRY.TIME (PACK)
          LET MID = SPAN/2 + EDGE
          LET APEA = REAL.F(NUMBER(PACK)) * SPAN
          LET BLOCK = AREA
          LET SUM = SUM + BLOCK
          LET EDGE = EDGE + SPAN
          LET TIME = ENTRY.TIME(PACK)
          LET LAS.QU = REAL.F(NUMBER(PACK))
        LOOP
      IF ANY.PACKS = NCNE
        LET LAS.QU = LINK.MCNITOR (THIS.NODE, NEIB, 2)
      REGARDLESS
      LET REMAINDER = WINDOW - EDGE
      LET MID = (REMAINDER/2) + EDGE
      LET AREA = LAS.QU * REMAINDER
      LET BLOCK = AREA
      LET SUM = SUM + BLOCK
      LET CV.OF.LINK = INT.F(SUM/WINDOW + 1.)
      LET NEIBS = NEIGHBOR.LIST (THIS.NODE, J, 3) = CV.OF.LINK
      REGARDLESS

```

```

LOOP
LOOP
SCHEDULE THE NEXT CV CALCULATION FOR ALL NEIGHBORS. IN THE
SIMULATION, THIS PROCESS IS SYNCHRONIZED FOR EVERY NODE IN
THE NETWORK.
SCHEDULE A ADOPT.NEW.BEST.PATH IN (2*UP.DATE.PERIOD) UNITS
EARLIEST.UPDATE AND LATEST.UPDATE SET THE NEXT INTERVAL DURING
WHICH ALL NODES WILL RANDOMLY INITIATE AN UPDATE MESSAGE. AFTER
THIS PERIOD THERE IS ANOTHER EQUAL LENGTH PERIOD WHICH ALLOWS ALL
UPDATE MESSAGES TO TRANSIT THE NETWORK AND REACH THEIR FINAL
"DESTINATIONS" BEFORE THE NEXT "COMPUTE.CV".
LET EARLIEST.UPDATE = TIME.V + (2* UP.DATE.PERIOD)
LET LATEST.UPDATE = TIME.V + (3* UP.DATE.PERIOD)
RETURN
END **OF CCMPUTE.CV
THIS ROUTINE ESTABLISHES THE BEST PATHS TO BE USED FOR PACKET
TRANSMISSION DURING THE NEXT UPDATE CYCLE. BEST PATHS
ARE NOT CHANGED DURING THE UPDATE CYCLE.
EVENT ADOPT.NEW.BEST.PATH
FOR I = 1 TO N.NODES, DO
FOR J = 1 TO N.GFS, DO
LET BEST.PATH ( I, J, 1 ) = BEST.PATH ( I, J, 3 )
LET BEST.PATH ( I, J, 2 ) = BEST.PATH ( I, J, 4 )
LOOP
LOOP
THE COMPUTE.CV EVENT IS NOW CALLED. THIS ENSURES THAT
THE ORDER OF ADOPTING A NEW BEST PATH AND THEN COMPUTING
THE CHANNEL VALUES FOR THE NEXT UPDATE CYCLE IS PRESERVED
DURING THE EXECUTION OF THE SIMULATION.
SCHEDULE A CCMPUTE.CV NOW
RETURN
END **OF ADOPT.NEW.BEST.PATH
THIS ROUTINE GENERATES MESSAGES MADE UP OF A RANDOM
NUMBER OF PKTS (BETWEEN PRESCRIBED LIMITS). PKTS ARE SENT OUT
CN IDLE LINKS IF AVAILABLE, OR STORED IN QUEUES IF LINKS ARE BUSY.

```

```

.. EVENT NEW PACKET MESSAGE GIVEN T.MESSAGE
DEFINE CK.XMTR, CK.RCVR, X.TCT.PERCENT AND R.TOT.PERCENT AS REAL
VARIABLES
LET X.TOT.PERCENT = 0
LET R.TOT.PERCENT = 0
LET CK.XMTR = UNIFORM.F(0.0, TRNS.PCNT, 2)
.. SELECTOR IS USED IF A PERCENTAGE OF THE MESSAGES ARE REQUIRED
.. TO BE BETWEEN NODES OF THE SAME GROUP OR FAMILY.
..
LET SELECTOR = UNIFORM.F(0.0, 100., 5)
..
.. SELECT THE TRANSMITTING NODE
FOR I = 1 TO N.NODE, DC
LET X.TOT.PERCENT = X.TOT.PERCENT + TRANSMIT.PERCENT(I)
IF CK.XMTR <= X.TOT.PERCENT
LET XMTR = I
GO FIND.RECEIVER
ELSE
LOOP
..
.. SELECT THE RECEIVER
..
.. FIND RECEIVER.
LET CK.RCVR = UNIFORM.F(0.0, RCV.PCNT, 3)
FOR J = 1 TO N.NODE, DC
LET R.TOT.PERCENT = R.TOT.PERCENT + RECEIVE.PERCENT(J)
IF CK.RCVR <= R.TOT.PERCENT
LET RCVR = J
GO CK.GROUPS.AND.FAMILIES
ELSE
LOOP
..
.. IF THE RECEIVER MUST BE WITHIN THE SAME GROUP OR FAMILY, KEEP
.. LOOKING UNTIL AN ADEQUATE RECEIVER IS FOUND.
..
.. CK.GROUPS.AND.FAMILIES'
IF SELECTOR < IN.GROUP
IF GROUP(XMTR) = GROUP(RCVR)
GO SEE.IF.XMTR.EQ.RCVR
ELSE
LET R.TCT.PERCENT = 0.0
GO FIND.RECEIVER
ELSE
IF SELECTOR < (IN.GROUP + IN.FAMILY)
IF FAMILY(XMTR) = FAMILY(RCVR)

```



```

..      LET NEXT.STOP(MESSAGE) = BP.NODE
..
..      IF PRNT >= 1
..        SKIP 1 OUTPUT LINE
..        PRINT 1 LINE WITH NEW.MSG.TOTAL, I, XMTR, BP.NODE, FG, RCVR
..        AND TIME.V AS FOLLOWS
..      /**/ ** INITIATED FROM ** THRU ** (F/G = **) TO ** AT ****.***** SEC
..      REGARDLESS
..
..      IF LINK TO BP NEIGHBOR IS IDLE; SEND OUT PACKET
..
..      IF LINK.MCNIOR (XMTR, BP.NODE, 1) = ICLE
..        FILE.MESSAGE IN LNK.FLAG(XMTR)
..        LET LINK.ENTRY.TIME(MESSAGE) = TIME.V
..        SCHEDULE A PACKET.ARRIVES GIVEN MESSAGE IN PKT.XMN.TIME UNITS
..        LET LINK.MCNIOR(XMTR, BP.NODE, 1) = BUSY
..        LET LINK.TIMER(1, XMTR, BP.NODE, 1) = TIME.V
..        LET RELEASE.TIME(MESSAGE) = TIME.V
..
..      IF PRNT >= 1
..        SKIP 1 OUTPUT LINE LINK.MCNIOR(XMTR, BP.NODE, 2) AS FOLLOWS
..        PRINT 2 LINES WITH MESSAGE DID NOT WAIT IN OUTGOING PACKET QUEUE
..        FIRST PACKET OF OUTGOING PACKET QUEUE IS ****
..        REGARDLESS
..
..      IF PRNT >= 5
..        SKIP 1 OUTPUT LINE XMTR, BP.NODE, TRANS.NUMBER(MESSAGE),
..        PRINT 1 LINE NUMBER(MESSAGE) AND TIME.V AS FOLLOWS
..        LINK ***/ ** BUSY TRANSMITTING PACKET ***/** AT ****.***** SEC
..        REGARDLESS
..
..      ELSE
..        IF LINK IS BUSY, STCRE PKT AT END OF THE OUTGOING PACKET QUEUE
..        FOR THAT LINK
..
..      LET QUEUE.ENTRY.TIME(MESSAGE) = TIME.V
..      FILE.MESSAGE IN PACKET.OUT.QUEUE (XMTR)
..      LET LINK.MCNIOR(XMTR, BP.NODE, 2) = 1
..      LINK.MCNIOR(XMTR, BP.NODE, 2) + 1 LINK.MCNIOR(XMTR, BP.NODE, 3)
..      IF LINK.MCNIOR(XMTR, BP.NODE, 2) > LINK.MCNIOR(XMTR, BP.NODE, 3)
..        LET LINK.MCNIOR(XMTR, BP.NODE, 3) = LINK.MCNIOR(XMTR, BP.NODE, 2)
..        REGARDLESS
..
..      IF PRNT >= 1
..        SKIP 1 OUTPUT LINE

```



```

PRINT 2 LINES WITH NEW.MSG.TOTAL, 1, XMTR, TIME.V, XMTR AND
LINK.MCNITR( XMTR, BP.NCDE, 2 ) AS FOLLOWS
***/** ENTERING PACKET QUEUE AT NODE *** AT ***** SEC.
OUTGOING PACKET QUEUE AT NODE *** IS *****
REGARDLESS

** IF LINK QUEUE CHANGES, CREATE A "PACK" (A PACKAGE OF INFORMATION)
** WHICH CONTAINS THE NEW QUEUE SIZE AND THE TIME IT WAS CHANGED
** FOR THE LATER CALCULATION OF CV

CREATE A PACK
LET NUMBER(PACK) = LINK.MONITOR (XMTR,BP.NODE,2)
LET ENTRY.TIME(PACK) = TIME.V
LET PAC.NEIGHBOR(PACK) = BP.NODE
FILE PACK IN TIME.QUEUE(XMTR)
REGARDLESS

**
** LOOP
** RESCHEDULE NEXT TRAFFIC SESSION UP TO MAX SET BY TRAFFIC.LIMIT
**
IF NEW.MSG.TOTAL <= TRAF.LIMIT
SCHEDULE A NEW PACKET.MESSAGE GIVEN PACKET IN
EXPONENTIAL.F(MSG.GENERATION.INTERVAL, 1) UNITS
ELSE
SKIP 1 OUTPUT LINE
PRINT 2 LINES WITH TIME.V AS FOLLOWS
TRAFFIC GENERATION FOR THIS RUN = TRAFFIC LIMIT
SIMULATION TIME = ****.*****
REGARDLESS
RETURN
END ** CF NEW.PACKET.MESSAGE

** THIS ROUTINE PROCESSES PKTS AS THEY ARRIVE IN A NODE
**
EVENT PACKET.ARRIVES GIVEN ID.NUMBER
DEFINE MSG.NR, THIS.NCDE AND PAST.NCDE AS VARIABLES
DEFINE OCCURANCE AS VARIABLE
LET MSG.NR = ID.NUMBER
LET THIS.NODE = NEXT.STOP(MSG.NR)
LET PAST.NODE = RELAYER(MSG.NR)
**
REMOVE MSG.NR FROM LNK.FLAG(PAST.NODE)
LET LNK.ENTRY.TIME(MSG.NR) = 0.0
** CALCULATE TOTAL TIME LINK IS BUSY

```

```

.. LET LINK.TIMER( 1, PAST.NODE, THIS.NCDE, 2) = TIME.V
LET LINK.TIMER( 1, PAST.NODE, THIS.NCDE, 3) =
LINK.TIMER( 1, PAST.NODE, THIS.NCDE, 3) + -
LINK.TIMER( 1, PAST.NODE, THIS.NCDE, 2)
LINK.TIMER( 1, PAST.NODE, THIS.NCDE, 1)
.. IF PRINT >= 1
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH TRANS.NUMBER(MSG.NR), PACK.NUMBER(MSG.NR),
RELAYER(MSG.NR), NEXT.STCP(MSG.NR), TIME.V AS FOLLOWS
***/*# ARRIVES FROM ** INTC *** AT ***.*** SEC.
REGARDLESS
.. IF THE PKT HAS REACHED ITS DESTINATION, GO TO A PROCESSING ROUTINE
.. IF NEXT.STCP(MSG.NR) = DESTINATION(MSG.NR)
LET TRANSIT.TIME = TRANSIT.TIME + TIME.V - ORIG.TIME(MSG.NR)
LET DEST.COUNT = DEST.COUNT + 1
.. SCHEDULE A COMPLETED TRIP GIVEN MSG.NR NEXT
IF PRINT >= 1
PRINT 1 LINE AS FOLLOWS
AND STCPS
REGARDLESS
.. IF PKT IS TO CONTINUE, ADDRESS IT TO THE NEXT BP NEIGHBOR BASED
ON THE NODE, GROUP OR FAMILY ID OF THE DESTINATION AS APPROPRIATE.
ELSE
.. COUNT NUMBER OF PACKETS RELAYED BY THIS.NODE
LET PKTS.RELAYED(THIS.NODE) = PKTS.RELAYED(THIS.NODE) + 1
LET RELAYER(MSG.NR) = THIS.NODE
LET FM.GP(MSG.NR) = 0
LET FG = 0
IF FAMILY(THIS.NODE) NE FAMILY(DESTINATION(MSG.NR))
LET FM.CBJ = FG
LET FM.GP(MSG.NR) = FG
GO ASGN.NEXT.STOP
ELSE
IF GROUP(THIS.NCDE) NE GROUP(DESTINATION(MSG.NR))
LET FM.CBJ = GROUP(DESTINATION(MSG.NR))
LET BP.CRJ = FG

```



```

.. IF PPNT >= 5
   SKIP 1 OUTPUT LINE
   PRINT 1 LINE WITH PAST.NODE, THIS.NODE, TIME.V AS FOLLOWS
   LINK ** / *** BUSY WITH UPDATE AT ****.***** SEC.
REGARDLESS

.. GO NO.PACKET.XMT

..CHECK.PACKET.OUT.CUEUE*
..
.. GC TO THE OUTGOING PACKET QUEUE OF THE NODE WHICH RELAYED
.. THE ABOVE PACKET. IF EMPTY, DEFINE THE LINK AS IDLE; IF NOT,
.. PLACE THE NEXT PACKET ON THE LINK AND ADJUST THE QUEUE
.. INFORMATION BY CREATING A NEW "PACK"
..
FOR EACH MESSAGE IN PACKET.OUT.QUEUE(PAST.NODE)
WITH NEXT STOP(MESSAGE) = THIS.NODE
FIND THE FIRST CASE
IF NONE
  LET LINK.MONITOR( PAST.NODE, THIS.NODE, 1 ) = IDLE
..
.. IF PRINT >= 5
   SKIP 1 OUTPUT LINE
   PRINT 1 LINE WITH PAST.NODE, THIS.NODE AND TIME.V AS FOLLOWS
   LINK ** / *** IDLE AT ****.***** SEC.
REGARDLESS

..
.. ELSE
  REMOVE MESSAGE FROM PACKET.OUT.QUEUE(PAST.NODE)
  LET TOT.QUEUE.TIME(MESSAGE) = TOT.QUEUE.TIME(MESSAGE) + TIME.V
  - QUEUE.ENTRY.TIME(MESSAGE)
  LET QUEUE.ENTRY.TIME(MESSAGE) = 0.0
  FILE MESSAGE IN LNK.FLAG(RELAYER(MESSAGE))
  LET LINK.ENTRY.TIME(MESSAGE) = TIME.V
  LET LINK.MONITOR( PAST.NODE, THIS.NODE, 2 ) =
  LINK.MONITOR( PAST.NODE, THIS.NODE, 2 ) - 1
  CREATE A PACK
  LET NUMBER(PACK) = LINK.MONITOR ( PAST.NODE, THIS.NODE, 2 )
  LET ENTRY.TIME(PACK) = TIME.V
  LET PAC.WEIGHBOR(PACK) = THIS.NODE
  FILE PACK IN TIME.QUEUE(PAST.NODE)
  IF NODES.HOPPED(MESSAGE) = 0
    LET RELEASE.TIME (MESSAGE) = TIME.V
  REGARDLESS
  LET LINK.TIMER( 1, PAST.NODE, THIS.NODE, 1 ) = TIME.V
..
.. SCHEDULE THE ARRIVAL OF THE PKT JUST RELEASED FROM THE QUEUE.

```



```

.. DESTINATION.
..
EVENT COMPLETED. TRIP GIVEN MES. NUM
DEFINE DEL. TIME AS A REAL VARIABLE
LET MESSAGE = MES. NUM
LET CNTR = NODES. HOPPED(MESSAGE) + 1
..
IF LONGEST. PATH < CNTR
LET LONGEST. PATH = CNTR
REGARDLESS
..
PRINT ALERT IF NODES HOPPED >= TOTAL NODES IN NETWORK.
..
IF SPECIFY. OUTPUT = 0
..
IF (CNTR >= N. NODE AND MSG. HLT = 0)
PRINT 1 LINE AS FOLLOWS
PROBLEM -- MORE HOPS THAN NODES
LET MSG. HLT = 1
REGARDLESS
..
REGARDLESS
..
INCREMENT COUNTER FOR TOTAL NODES HOPPED FOR THIS PKT AND SUM NET
TIME FOR GIVEN NUMBER OF HOPS.
..
LET HCP. COUNT (CNTR, PACKET) = HCP. COUNT (CNTR, PACKET) + 1
LET DEL. TIME = TIME. V - RELEASE. TIME (MESSAGE)
LET CLOCK. DATA (CNTR, 1) = CLOCK. DATA (CNTR, 1) + DEL. TIME
..
NOTE IF THIS TRANSIT TIME IS A NEW MAX FOR THIS NUMBER OF HOPS.
..
IF DEL. TIME > CLOCK. DATA (CNTR, 2)
LET CLOCK. DATA (CNTR, 2) = DEL. TIME
REGARDLESS
..
INCREMENT TRACER ARRAY WHICH KEEPS THE NUMBER OF PKTS GENERATED
AND THE NUMBER REACHING THEIR DESTINATION.
..
LET TRACER (TRANS. NUMBER(MESSAGE), 2) = TRACER(TRANS. NUMBER(MESSAGE), 2) + 1
..
DESTROY MESSAGE CALLED MES. NUM
RETURN
END ** OF COMPLETED. TRIP
..
THIS ROUTINE IDENTIFIES A SET OF THE BUSIEST LINKS

```



```

GC HCP.NEW.P.Q.MAX
ELSE
IF NEW.P.Q.MAX < LINK.MCNITOR(F,T,3) AND LINK.MONITOR(F,T,3)
< P.Q.MAX
LET NEW.P.Q.MAX = LINK.MONITOR(F,T,3)
REGARDLESS
'HOP.NEW.P.Q.MAX'
LCCP
LOOP
LET P.Q.MAX = NEW.P.Q.MAX
GO FILL.PKT.SMP.SET
!!
'NOW.FILL.UP.SMP.SET'
LET I = 1
!!
'FILL.UP.SMP.SET'
FOR F = 1 TO N.NODE, DC
FOR T = 1 TO N.NODE, DC
IF LINK.MCNITCR(F,T,5) = U.Q.MAX
LET UP.SMP.SET(I,1) = F
LET UP.SMP.SET(I,2) = T
IF I = SMP.LINKS
GO BEGIN.SAMPLING
ELSE
LET I = I + 1
GO HCP.NEW.U.Q.MAX
ELSE
IF NEW.U.Q.MAX < LINK.MONITOR(F,T,5) AND LINK.MONITOR(F,T,5)
< U.Q.MAX
LET NEW.U.Q.MAX = LINK.MONITOR(F,T,5)
REGARDLESS
'HOP.NEW.U.Q.MAX'
LCCP
LOOP
LET U.Q.MAX = NEW.U.C.MAX
GO FILL.UP.SMP.SET
!!
!! SCHEDULE FIRST SAMPLE OF ALL LINKS IN SMP.SET
!!
'BEGIN.SAMPLING'
LET TT.MER = TIME.LIMIT/(2.*REAL.F(ND.OF.SAMPLES))
SCHEDULE A SAMPLE IN (EXPONENTIAL.F(TI.MER, 8)) UNITS
RETURN
END !! OF QU.SAMPLER
!!
!! THIS ROUTINE SAMPLES THE LINKS IDENTIFIED IN QU.SAMPLER WITH AN
EXPONENTIAL SAMPLING RATE.

```


APPENDIX D

LISTING OF ARRAYS USED IN THE SIMULATION PROGRAMS

Arrays common to all programs:

1 - dimensional arrays

FAM.OP.GRP (no. of nodes + groups + 25)
1st -- program ID of the i-th group

HISTOGRAM (10)
1st -- no. of links with utilization
factor = $i/10$

PKT.QU.DISTR (1000)
1st -- number of times packet queue size = i

UP.QU.DISTR (1000)
1st -- number of times update queue size = i

2 - dimensional arrays

CLOCK.DATA (10 * no. of nodes, 2)
1st -- number of hops = N
2nd -- 1 = net time for all packets hopping
N nodes
2 = highest individual trip time for
a N hop packet

HOP.COUNT (1) * no.of nodes, 2)
1st -- number of hops = N
2nd -- 1 = 1st used
2 = no.of packets hopping N nodes

LINK.ABLE (no. of links, 2)
1st -- link number
2nd -- 1 = first end node
2 = second end node

PKT.SMP.SET (selected links to be sampled, 2)
1st -- sample link ID number
2nd -- 1 = 'from' node ID
2 = 'to' node ID

TRACER (estimate of the maximum number of
messages, 2)
1st -- message number
2nd -- 1 = number of packets in the message
2 = number of packets of the message
which reach their destination

UP.SMP.SET (selected links to be sampled, 2)
1st -- sample link ID number
2nd -- 1 = 'from' node ID
2 = 'to' node ID

3 - dimensional arrays

BEST.PATH (no. of nodes + groups, no. of nodes
+ groups, 4)
1st -- 'from' node, group or family ID
2nd -- 'to' node, group or family ID
3rd -- 1 = current best path neighbor
2 = channel value through the current
best path neighbor
3 = best path neighbor to be adopted
during next update cycle
4 = channel value to best path
neighbor which will be adopted
during next update cycle

LINK.MONITOR (2 * no. of links, 2 * no. of links, 6)
1st -- 'from' node ID
2nd -- 'to' node ID
3rd -- 1 = link status (idle/busy)
2 = current packet queue of link
3 = max packet queue thus far
4 = current update queue of link
5 = max update queue thus far
6 = no. of packets in queue at the
simulation half

NEIGHBOR.LIST (no. of nodes, max links per node, 3)
1st -- i-th node ID
2nd -- ID number of link
3rd -- 1 = neighbor node ID
2 = link status (idle/busy)
3 = channel value from node to neighbor

4 - dimensional array

LINK.TIMER (2, 2 * no. of links, 2 * no. of links,
3)
1st -- 1 = packet
 2 = update
2nd -- sending node ID
3rd -- receiving node ID
4th -- 1 = start time for busy link
 2 = stop time for busy link
 3 = cumulative time link is busy
 4 = cumulative time link busy up to
 simulation half

Additional arrays for Dijkstra algorithm:

2 - dimensional arrays

ADDRESS.LIST (no. of nodes, no. of nodes)
1st -- sending node ID
2nd -- destination node ID

ADD.RESS.LIST (no. of nodes, no. of nodes)
1st -- sending node ID
2nd -- destination node ID

DJIKSTRA.MATRIX (no. of nodes, no. of nodes)
1st -- sending node ID
2nd -- destination node ID

PATH.AVAIL (no. of nodes, no. of nodes)
1st -- sending node ID
2nd -- destination node ID

Output data set:

#####

NEW SIMULATION

#####

MAX.FKTS.PER.MSG = 10.00
PKTS.PER.SEC.AVE = 150.00

LINK		-- UTILIZATION FACTOR --			PKTS IN QUEUE AT HALF	PKTS IN QUEUE AT END	WAIT TIME FOR PKTS
	PACKET	UPDATE	TOTAL				
1	1/ 2	.61665E	.C44519	.661177	0	2	1.791269
	2/ 1	.56665E	.046663	.613318	10	20	1.437093
	1/ 3	.60665E	.C47601	.654255	6	13	1.724311
	3/ 1	.543331	.C45593	.588924	1	14	1.295772
	1/ 4	.609999	.045454	.655453	4	14	1.741389
	4/ 1	.569994	.C45723	.615717	0	0	1.455954
	1/ 5	.549987	.C45596	.595583	0	0	1.333076
	5/ 1	.649981	.046126	.696107	0	0	2.107410
	1/ 3	.606654	.C45332	.651986	1	0	1.714302
	3/ 2	.623334	.C47988	.671322	0	0	1.865066
	2/ 4	.656654	.C45329	.701983	1	3	2.172239
	4/ 2	.579990	.C47192	.627182	4	10	1.722339
	2/ 5	.543325	.C46062	.589987	1	2	1.526905
	5/ 2	.593328	.C47728	.641056	0	0	1.298540
	2/ 4	.579990	.C47586	.627585	0	0	1.623242
	4/ 3	.639987	.C49457	.689444	0	16	1.528421
	3/ 5	.546652	.C47190	.593843	0	7	2.027481
	5/ 3	.666648	.C50806	.717454	14	5	1.518638
	4/ 5	.579988	.C47987	.627975	6	9	2.323752
	5/ 4	.639984	.C47727	.687710	12	4	1.529767

AVE.P.FLOW = .598490
AVE.U.FLOW = .046913
AVE.NETWORK.FLOW = .645403
GEN.COUNT = 4421
DEST.COUNT = 4314
TRANSIT.TIME = 3051.942139
STRANDED.WAIT = 49.100677
T.IN.LINK = .401688
Q.IN.LINK = 10.718658
CHECK.DELAY = .703950
AVE.DELAY.PER.PKT = .225555
RATIO.STRANDED = .024803
PKTS IN QUEUE AT HALF = 98
PKTS IN QUEUE AT ENC = 93

INTERVAL	NUMBER	OF LINKS
0. - .10	0	0
.10 - .20	0	0
.20 - .30	0	0
.30 - .40	0	0
.40 - .50	0	0
.50 - .60	4	4
.60 - .70	14	14
.70 - .80	2	2
.80 - .90	0	0
.90 - 1.00	0	0

SIMULATION STEPS

APPENDIX F
GRAPHICAL RESULTS

DELAY : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 5, LINKS - 10

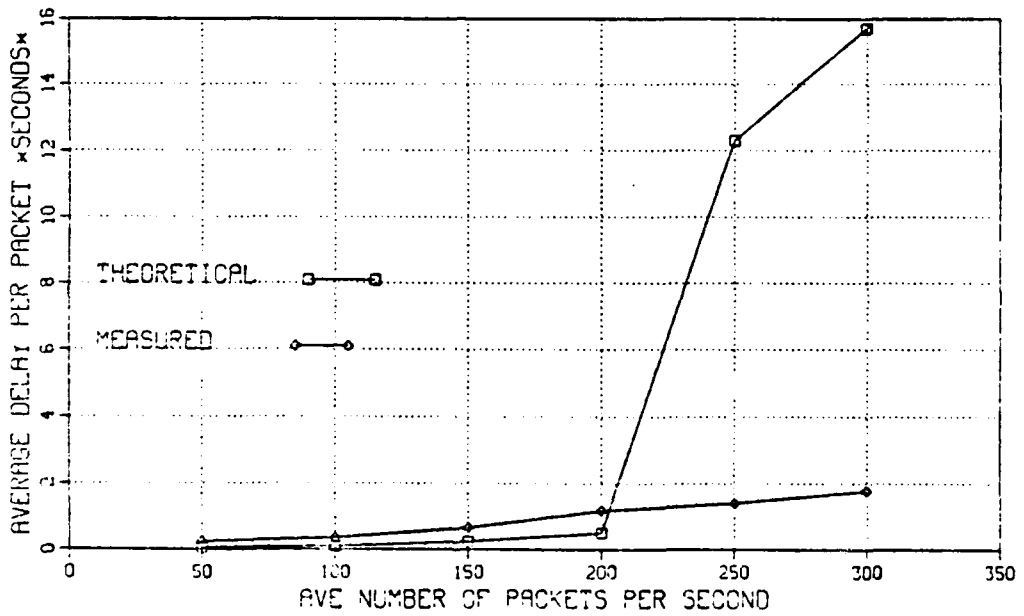


Fig. F.1. Delay: Heritsch (synch), Network 5/10

DELAY : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 10, LINKS - 20

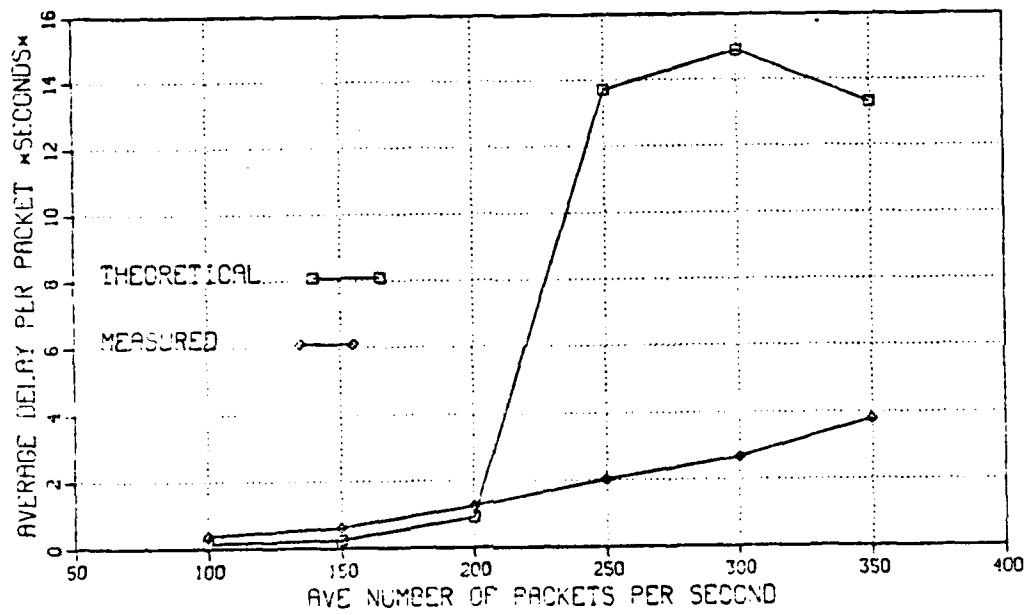


Fig. P.2. Delay: Heritsch (synch), Network 10/20

DELAY : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 15, LINKS - 30

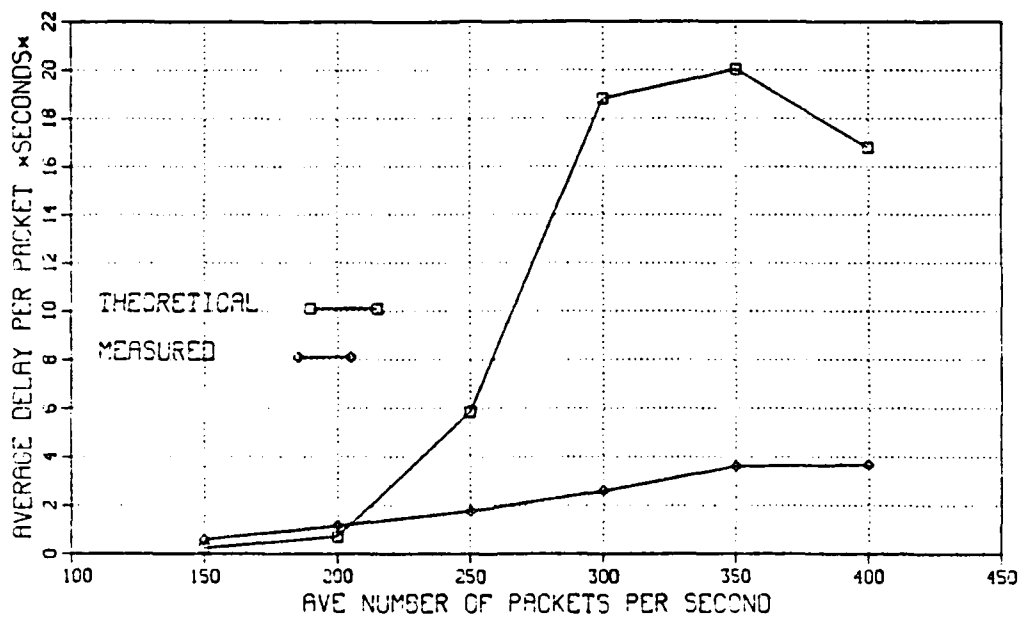


Fig. F.3. Delay: Heritsch (synch), Network 15/30

DELAY : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 20, LINKS - 40

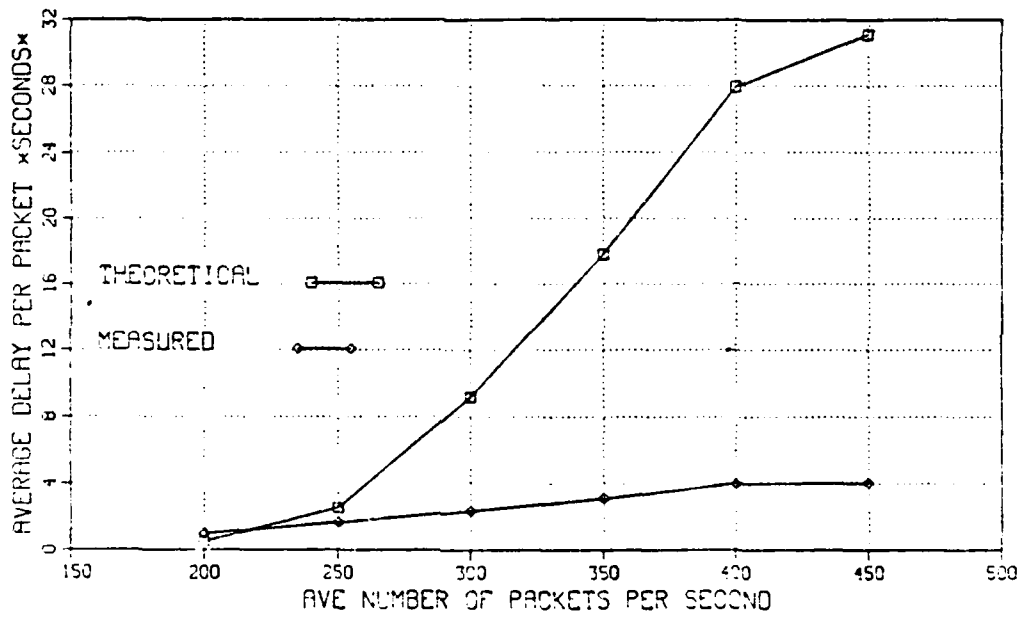


Fig. F.4. Delay: Heritsch (synch), Network 20/40

DELAY : HERITSCHE ALGORITHM ; ASYNCHRONOUS
NODES - 10, LINKS - 20

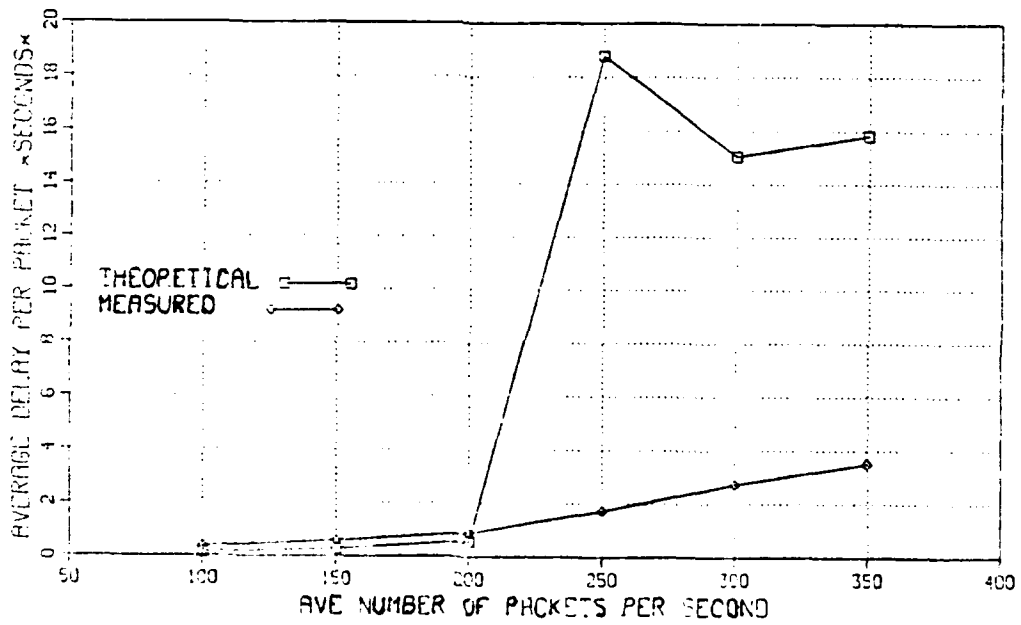


Fig. P.5. Delay: Heritsch (synch), Network 10/20 (2 groups)

DELAY : HERITSCH ALGORITHM ; PSYNCHRONOUS
NODES - 15, LINKS - 30

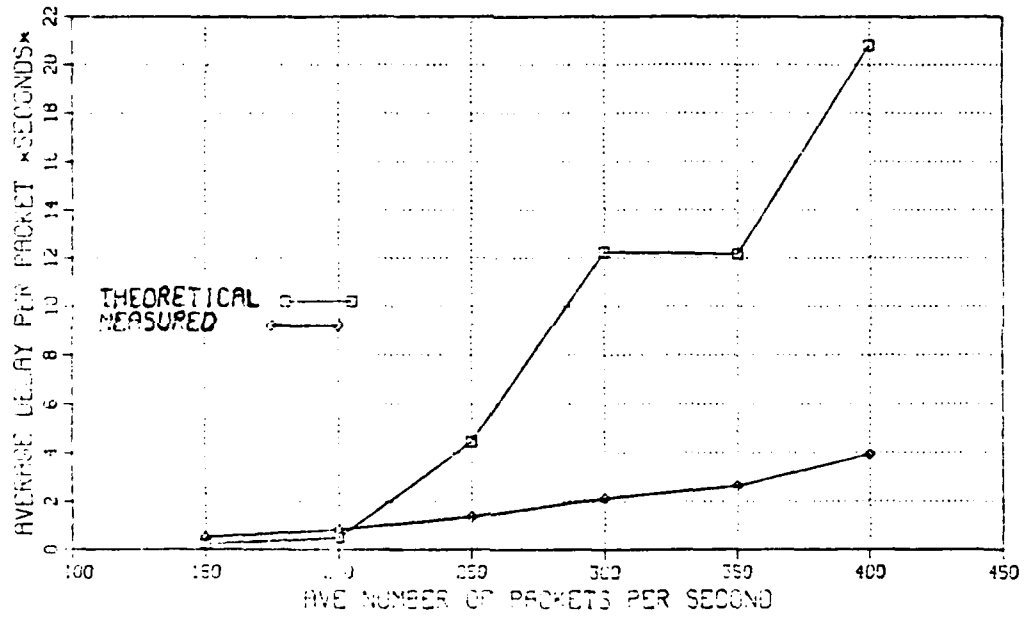


Fig. F.6. Delay: Heritsch (synch), Network 15/30 (3 groups)

DELAY : HERITSCH ALGORITHM ; SYNCH : GROUP
 NODES - 10, LINKS - 20

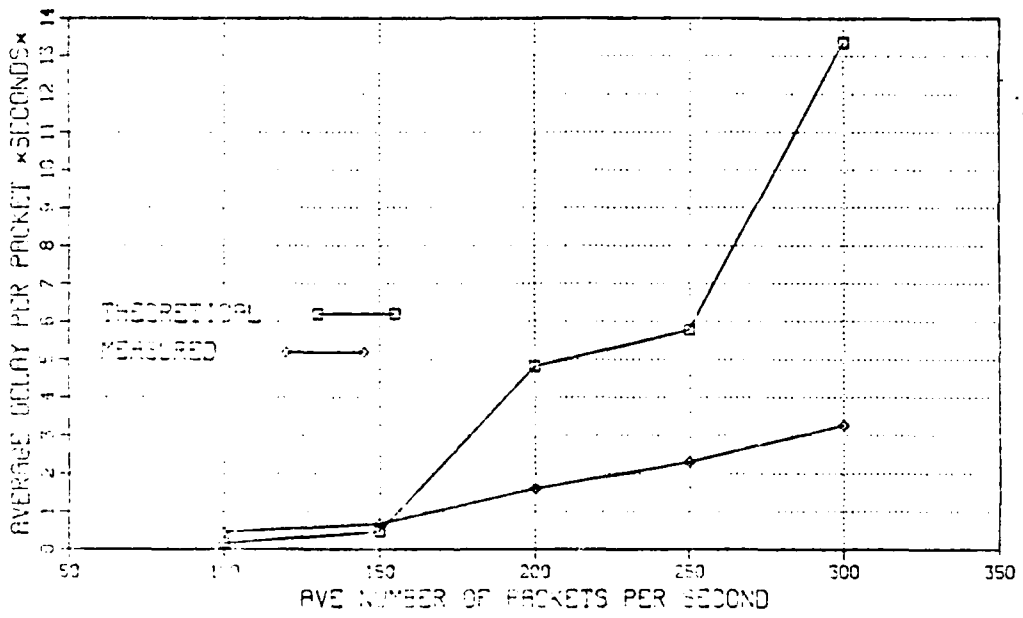


Fig. P.7. Delay: Heritsch (asynch), Network 10/20

DELAY : HERITSCH ALGORITHM ; SYNCH : GROUP
 NODES - 15, LINKS - 30

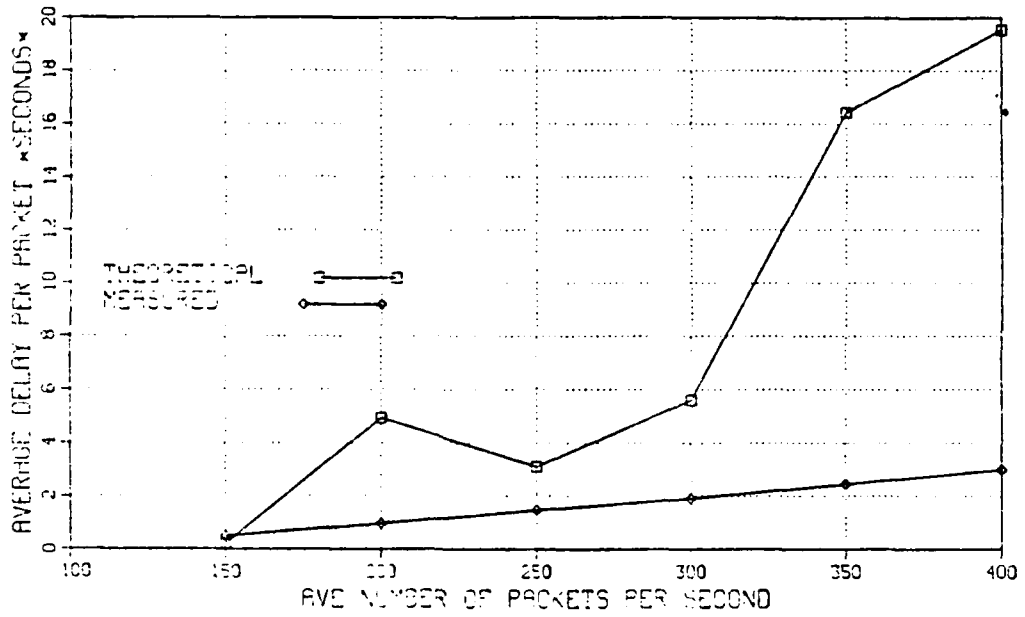


Fig. F.8. Delay: Heritsch (asynch), Network 15/30

DELAY : DJIKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 5, LINKS - 10

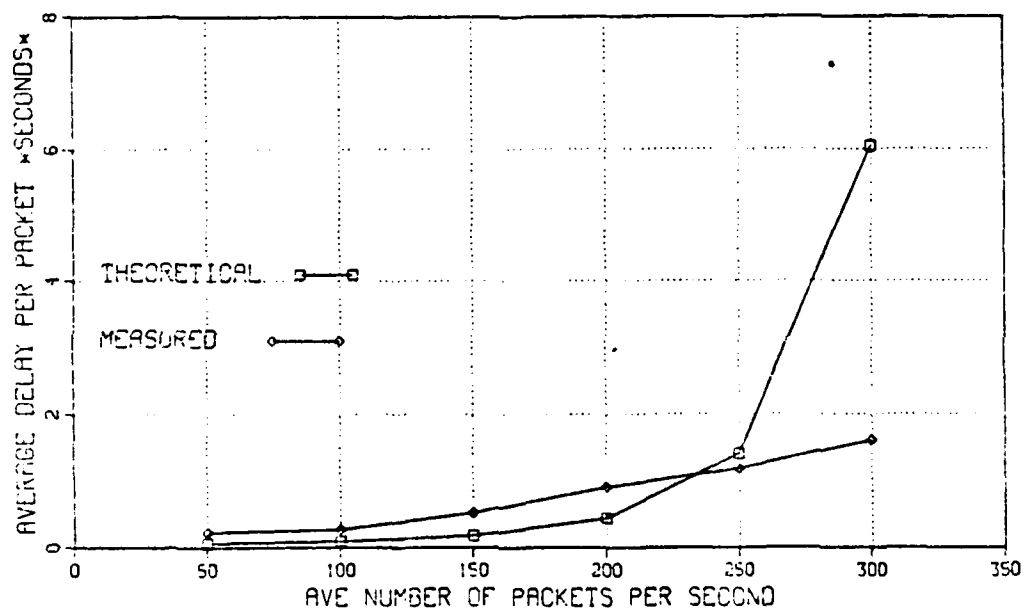


Fig. F.9. Delay: Dijkstra, Network 5/10

DELAY : DIJKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 10, LINKS - 20

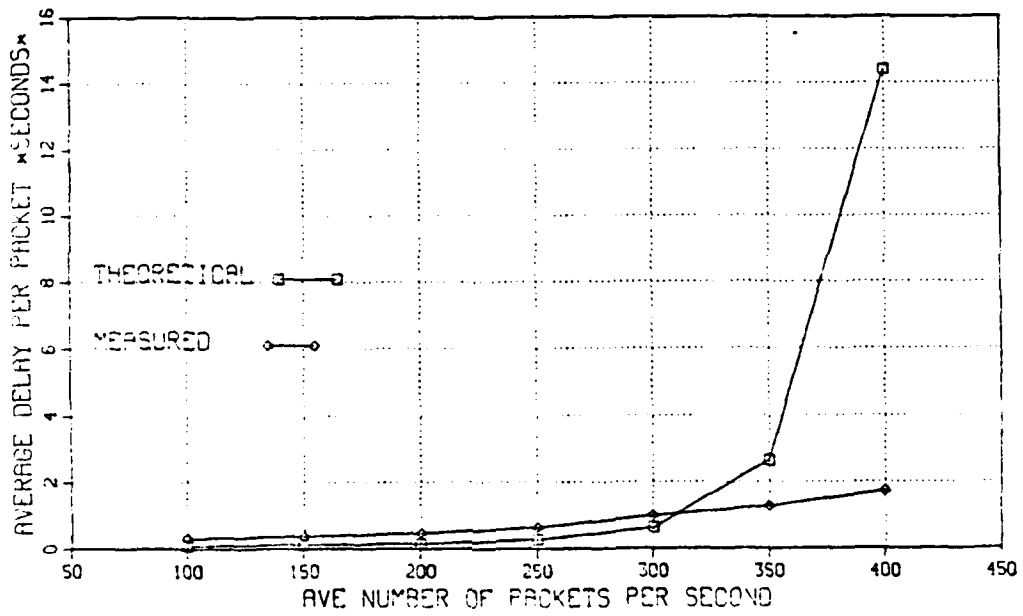


Fig. F.10. Delay: Dijkstra, Network 10/20

DELAY : DIJKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 15, LINKS - 30

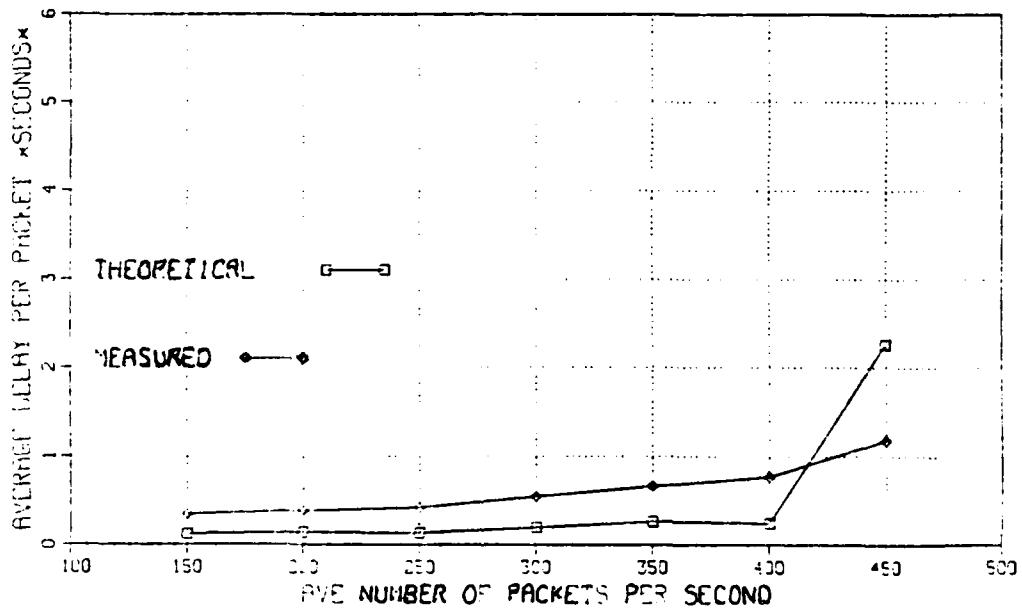


Fig. F.11. Delay: Dijkstra, Network 15/30

DELAY : DIJKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 20, LINKS - 40

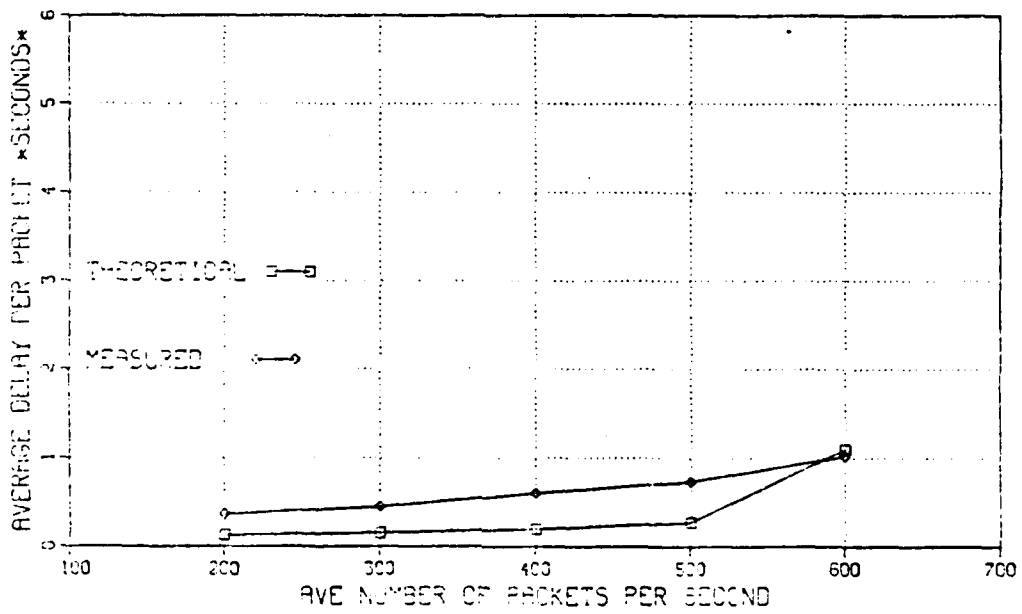


Fig. P.12. Delay: Dijkstra, Network 20/40

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 5, LINKS - 10

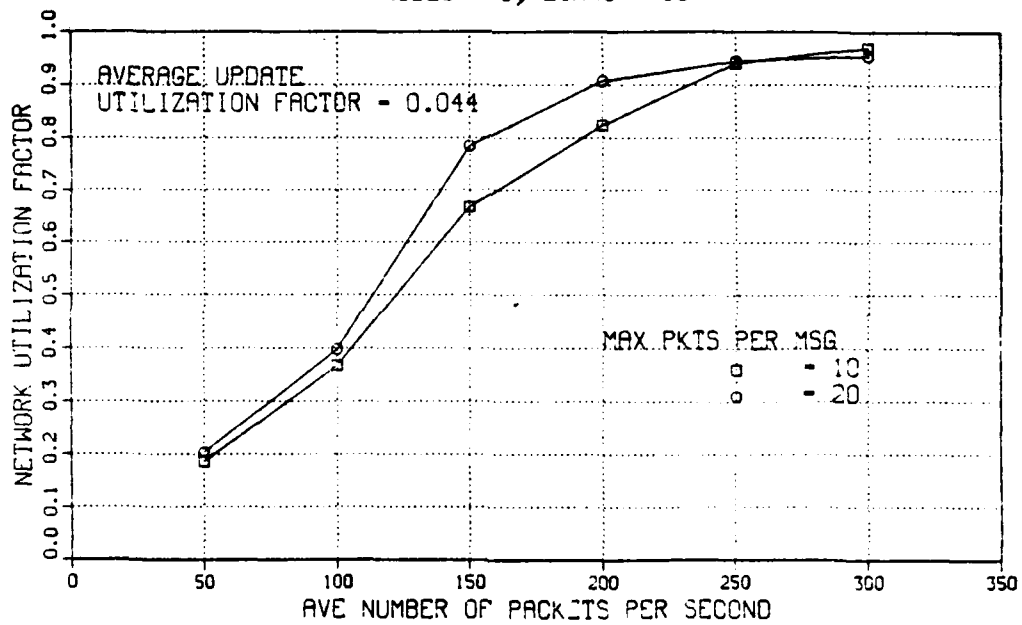


Figure F.13. Utilization Factor: Heritsch (synch), Network 5/10

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 10, LINKS - 20

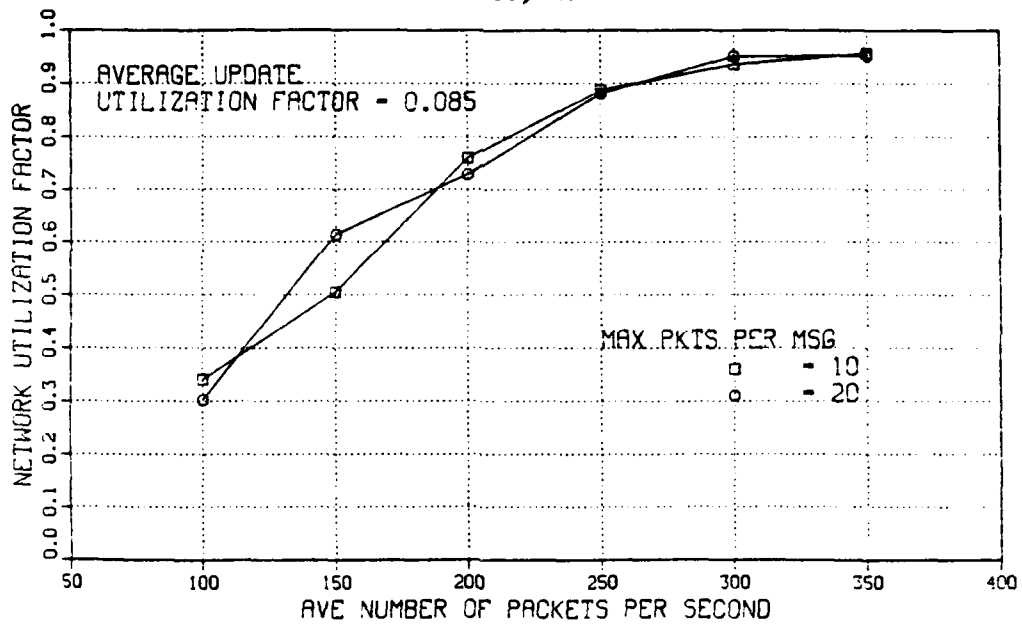


Figure F.14. Utilization Factor: Heritsch (synch), Network 10/20

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 15, LINKS - 30

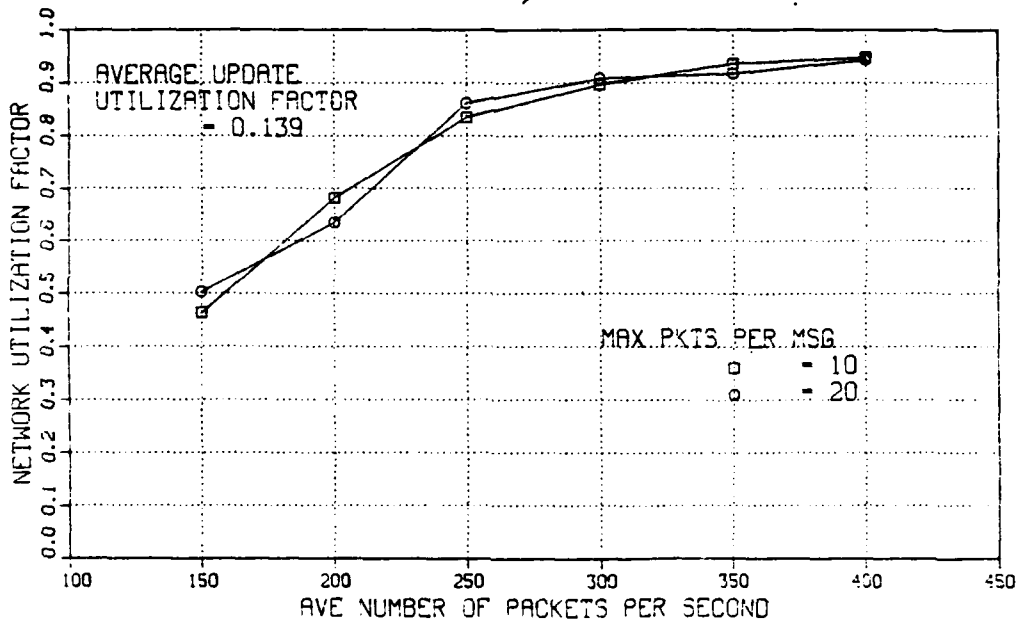


Figure F.15. Utilization Factor: Heritsch (synch), Network 15/30

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCHRONOUS
NODES - 20, LINKS - 40

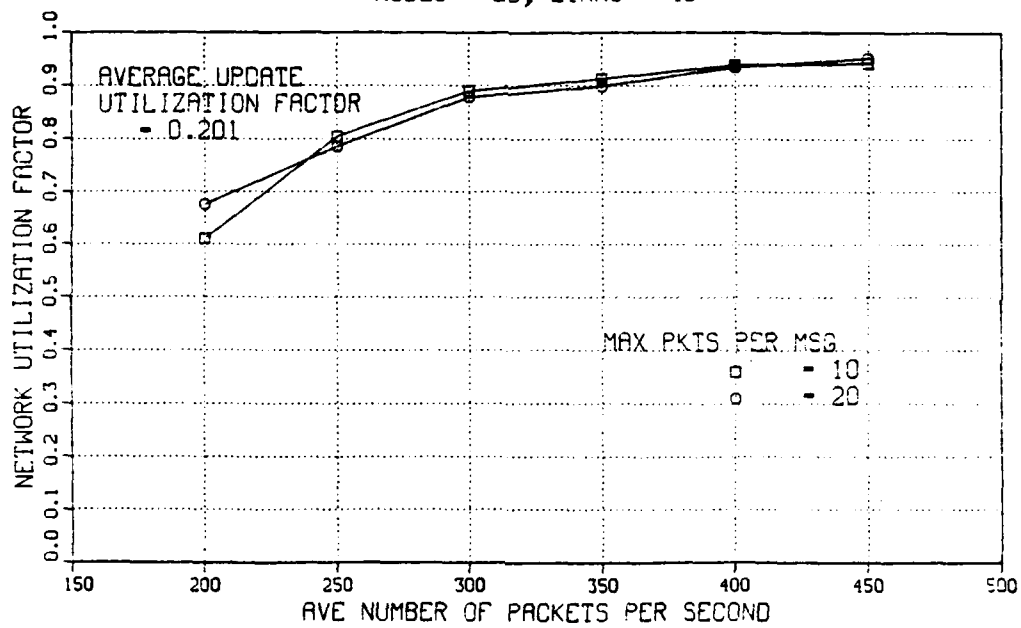


Figure F.16. Utilization Factor: Heritsch (synch), Network 20/40

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCH : GROUPS
NODES - 10, LINKS - 20

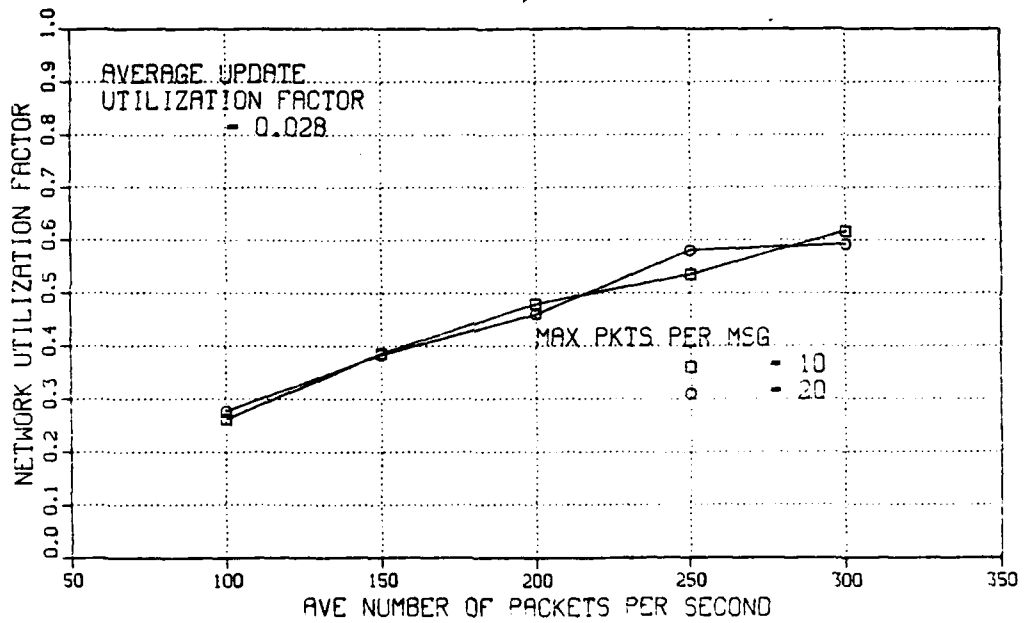


Figure F.17. Utilization Factor: Heritsch (synch), Network 10/20 (2 groups)

UTILIZATION FACTOR : HERITSCH ALGORITHM ; SYNCH : GROUPS
NODES - 15, LINKS - 30

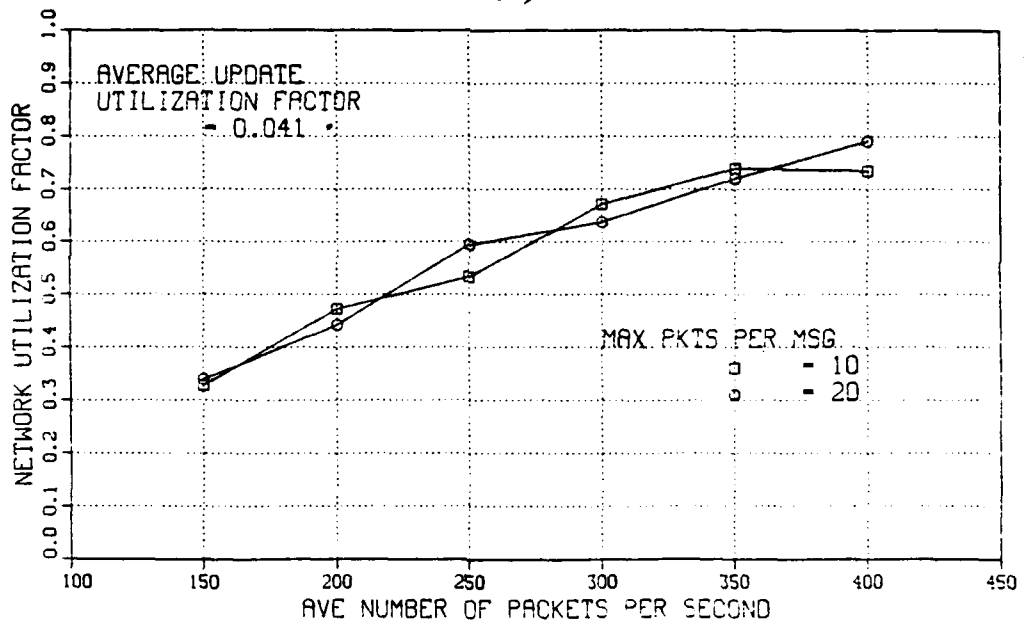


Figure F.f8. Utilization Factor: Heritsch (synch), Network 15/30 (3 groups)

UTILIZATION FACTOR : HERITSCH ALGORITHM ; ASYNCHRONOUS
NODES - 15, LINKS - 30

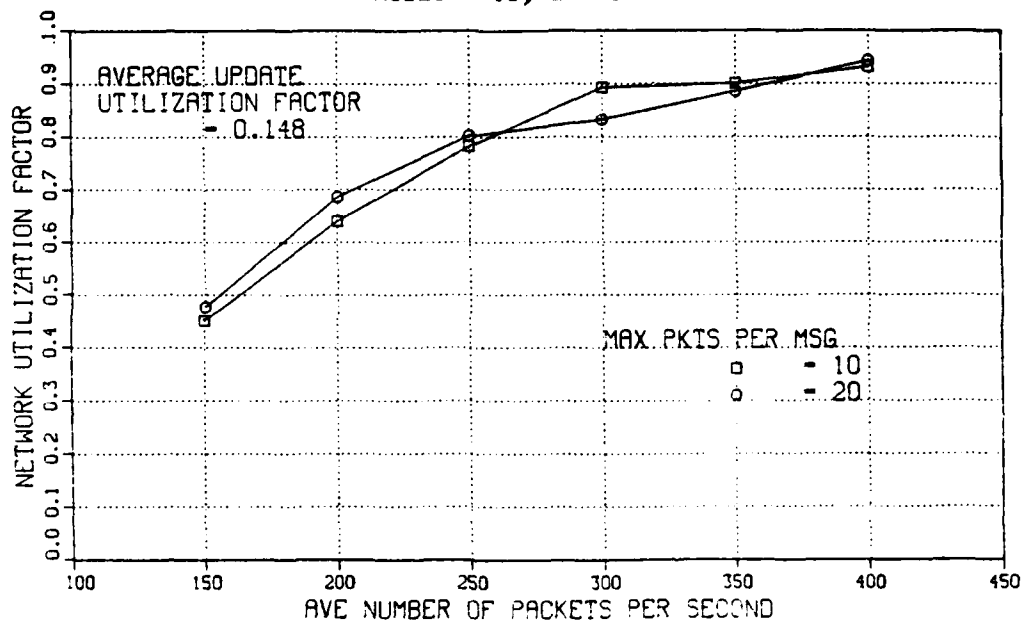


Figure P.19. Utilization Factor: Heritsch (asynch), Network 10/20

UTILIZATION FACTOR : HERITSCH ALGORITHM ; ASYNCHRONOUS
NODES - 10, LINKS - 20

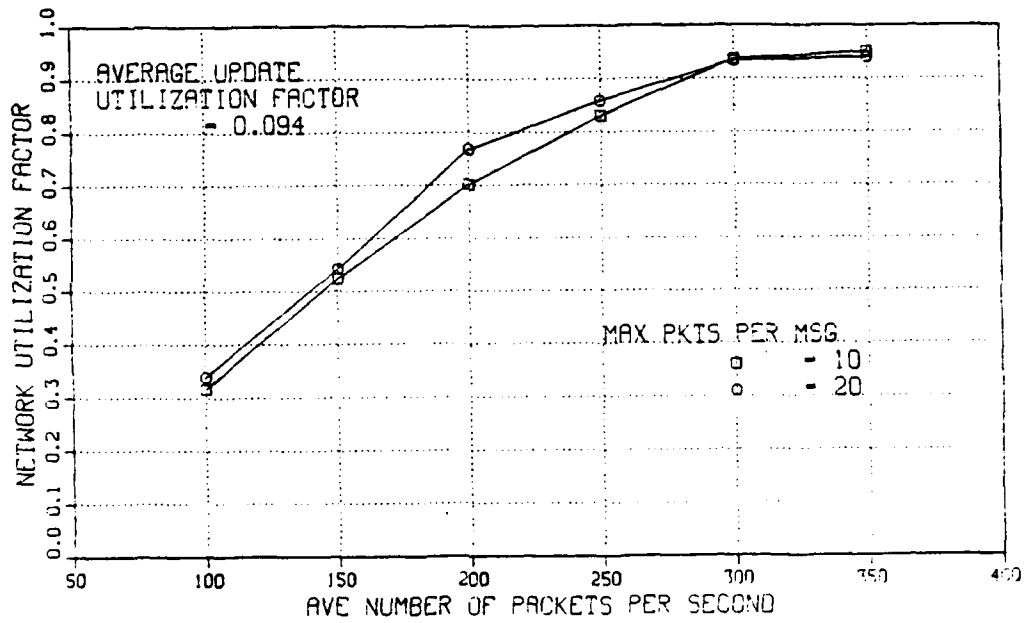


Figure P.20. Utilization Factor: Heritsch (asynch), Network
15/30

UTILIZATION FACTOR : DJIKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 5, LINKS - 10

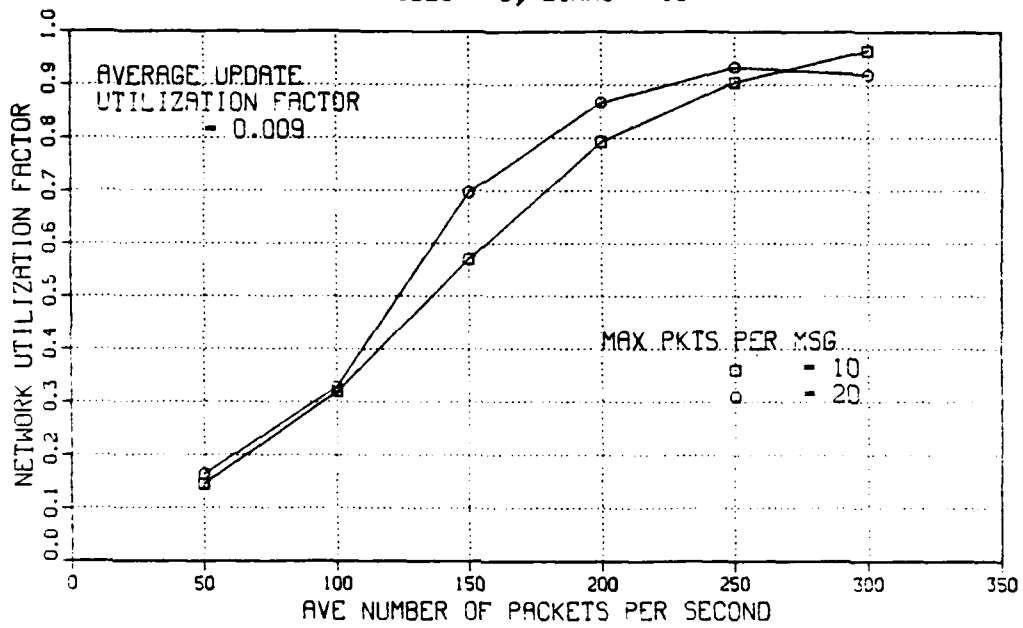


Fig. F.21. Utilization Factor: Dijkstra, Network 5/10

UTILIZATION FACTOR : DJIKSTRA ALGORITHM ; SYNCHRONOUS
• NODES - 10, LINKS - 20

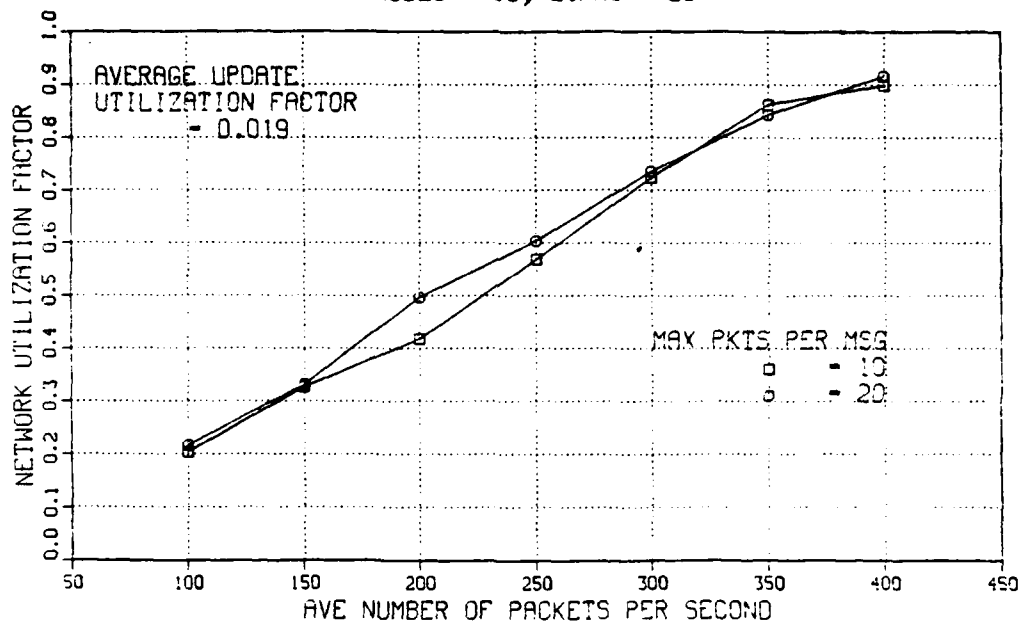


Fig. F.22. Utilization Factor: Dijkstra, Network 10/20

UTILIZATION FACTOR : DJIKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 15, LINKS - 30

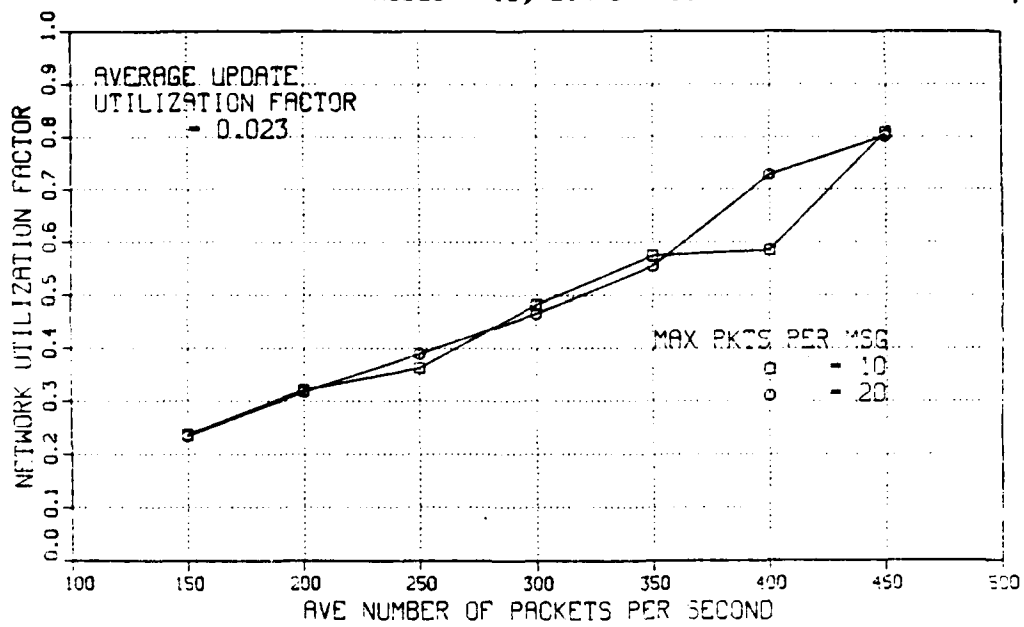


Fig. F.23. Utilization Factor: Dijkstra, Network 15/30

UTILIZATION FACTOR : DJIKSTRA ALGORITHM ; SYNCHRONOUS
NODES - 20, LINKS - 40

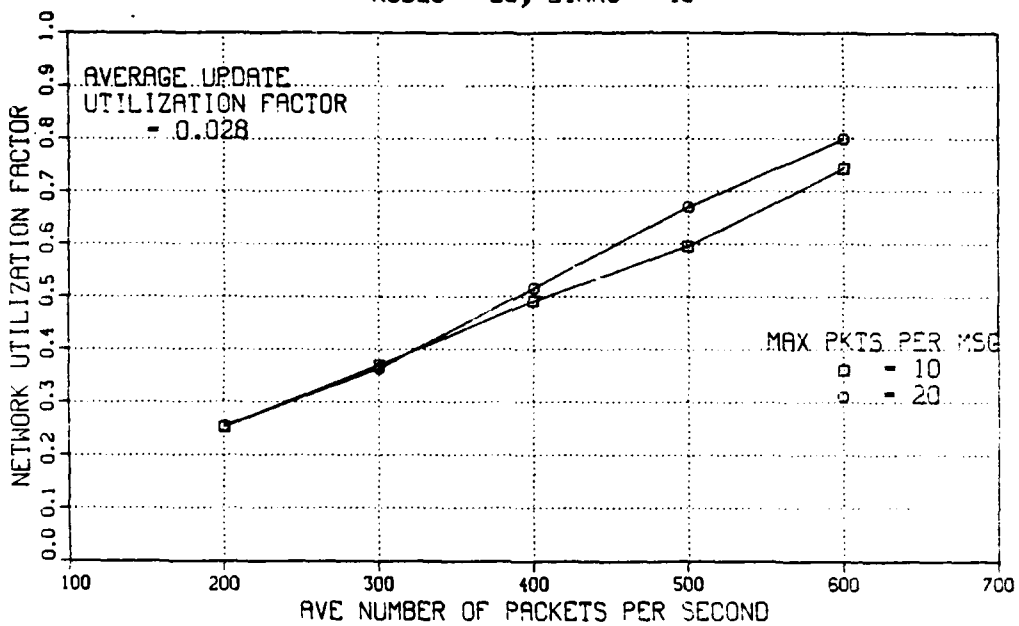


Fig. P.24. Utilization Factor: Dijkstra, Network 20/40

LIST OF REFERENCES

1. Tanenbaum, Andrew, S., Computer Networks, p.16-21, Prentice Hall Inc., 1981.
2. Heritsch, Robert, A Distributed Routing Protocol for a Packet Radio Network, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1982.
3. Dijkstra, E.W., "A Note on Two Problems in Connexion with Graphs" Numerische Mathematik 1, p. 269-271, 1959
4. Kiviat, P.J., Villanueva, R., and Markowitz, H.M., SIMSCRIPT II.5 Programming Language, CACI Inc., 1975.
5. Gross, Donald, and Harris, Carl, M., Fundamentals of Queueing Theory, p. 52-59, Wiley, 1974.
6. Kleinrock, Leonard, Queueing Systems Volume 2: Computer Applications, p. 320-322, Wiley, 1976.

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