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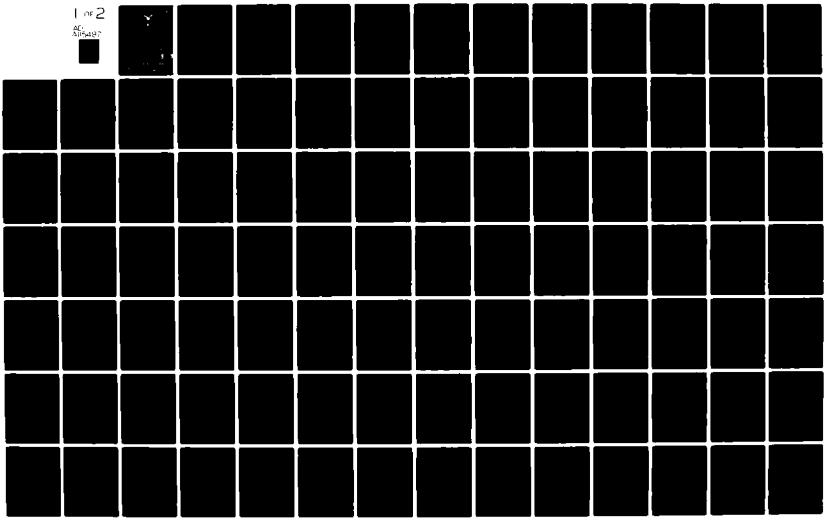

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MODELING AND ANALYSIS

OF A HYBRID

COMPUTER NETWORK

THESIS

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MODELING AND ANALYSIS OF A HYBRID COMPUTER NETWORK

BY

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THESIS

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PREFACE

The two major methods of switching in computer networks are circuit switching and packet switching. A comparison of the two methods clearly shows that neither method provides optimal results for all cases. In general, packet switching is superior for short messages and circuit switching is superior for long messages. However, a study by Kleinrock has shown other factors besides message length have a role in determining which switching method to select. These factors are the path length, the number of channels, and the traffic intensity.

This thesis effort purposes and models a hybrid switching network which dynamically changes between circuit and packet switching based on the above factors. The hybrid switching technique eliminates the need for the network designer to make assumptions about message lengths and traffic intensity since the optimal techniques is always selected.

I would like to express my thanks to MAJ Walter Seward for his interest, encouragement and friendship during this thesis effort. My loving appreciation is expressed to my wife and family whose love and understanding made this graduate program endurable.

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ABSTRACT

A hybrid computer network which dynamically changes switching techniques from packet switching to circuit switching depending upon path length, message length, traffic intensity, and number of channels is modeled and compared to the conventional switching techniques of circuit and packet switching. Initially, the circuit switching and packet switching models are constructed using Q-Gert and compared to determine which switching technique provides the smallest delays as the factors of message length, path length, traffic intensity, and number of channels are varied.

The operation of the hybrid switching network is defined and the network modeled using the results from comparing the circuit and packet switched models to determine when the hybrid network will be operating in the circuit switched or packet switched mode. The three models are compared to determine if the hybrid network as defined is feasible. The comparison clearly demonstrates the hybrid network consistently produces delays equal to the delays from circuit switching when it is the best and from packet switching when it is the best.

Chapter 1

Introduction

Background

The switching method used in a computer communication network directly effects message delay, an interval measured from the time a message enters the network until it arrives at the intended destination. The three major methods of switching are circuit switching, message switching, and packet switching.

In circuit switching, a complete path of communication must be set up between two parties before the communication begins. Path setup is established through a signaling process. Before transmission of a message, a reservation signal is sent towards the destination. While traveling node by node towards the destination node, the signal reserves channels along the path. If, at any intermediate node, it cannot find a free channel, it waits for a channel to become free while holding the channels it has reserved so far. Once a channel becomes available, the signal reserves it and goes to the next node to repeat the same process. By the time the signal reaches the destination node, a path has been reserved between the source and the destination nodes.

When the reservation signal reaches its destination, the originating node is notified through a reverse signaling process called request-for-transmission using the path which was reserved by the channel reservation signal. After receiving the request-for-transmission signal, the source node begins the transmission of the message. During the request-for-transmission signal and the message transmission, all of the channels on the path are used simultaneously. Therefore, these transmissions are equivalent to a transmission between two adjacent nodes which is called a one-hop transmission (4). After completion of the message transmission, a channel-release signal is sent from the destination along the established path. The channel-release signal frees the reserved channels which disassembles the path. The channel-release signal is also a one-hop transmission.

In message switching, messages are transmitted in a hop-by-hop fashion through the network. Each message carries its destination address in its header. At each intermediate node, the message must be completely received before it can be forwarded to the destination node. If the selected outgoing channel is busy, the message is queued while awaiting transmission.

Packet switching is almost identical to message switching except for two caveats. In packet switching, the message is divided into packets of a predetermined size with each packet carrying its destination address in its header and the packets are not required to follow identical paths between the source and destination. These differences between message switching and packet switching disappear and the two methods become identical when the message length is equivalent to one packet. For this reason, packet switching and message switching are sometimes called store-and-forward switching..

A comparison of the three switching techniques shows none of the methods provide optimal results in all cases. In general, store-and-forward switching provides smaller delays for short messages and circuit switching provides smaller delays for long messages. Two studies (4,9) have shown other factors besides message length have a role in determining which switching method to select. These factors are the number of channels between nodes, the ratio of the message arrival rate to the message service rate which is called the traffic intensity and the path length which is the number of nodes the message passes through to reach the destination.

Kleinrock's study has shown the reservation process in circuit switching causes a substantial decrease in network capacity and therefore circuit switching is not a good choice when the traffic intensity is high (4). However, the study also showed for large message lengths, large path lengths, large number of channels and moderate traffic intensity circuit switching can usually outperform store-and-forward-switching.

The proper number of channels is critical to the operation of a circuit switching network, if the line capacity between nodes is kept fixed. A small number of channels results in the network saturating quickly. However, a large number of channels results in a large transmission delay (4,9).

If the total line capacity is fixed, the number of channels also effects store-and-forward switching networks. Store-and-forward switching provides the smallest delay with only a single channel. Increasing the number of channels without increasing capacity results in longer delays because of the reduced transmission speed.

The factors of message length, path length, traffic intensity, and number of channels clearly effect the delays produced by both switching methods. Since neither circuit switching nor store-and-forward switching produce the smallest delays in all situations, interest in hybrid switching has developed. Another reason for the interest in hybrid switching is the desire to use the same network for the transmission of voice and data. In general terms, hybrid switching is a combination of two or more switching techniques in the same network. Previous studies have proposed the unified node approach (1), the pacuit approach (10) and the multiplexer approach (3) to hybrid switching.

The unified node approach to hybrid switching uses separate channels along with the required hardware to perform simultaneously circuit switching and packet switching. The aim of the unified node approach is to accomodate both voice and digital data in the same network. Since separate facilities are maintained for circuit switched voice messages and packet switched data message, the unified node approach results in some duplication with increased cost.

The pacuit approach combines circuit switching and packet switching in a different way from the unified node. The pacuit approach is designed to accomodate digital data. In the pacuit approach, messages are packet switched from subnodes to central nodes. Messages are transmitted between the central nodes by circuit switching. The pacuit approach does not result in duplicate facilities like the unified node approach. However, the pacuit approach does not provide the flexibility to accomodate both voice and digital data.

The multiplexer approach to hybrid switching again combines circuit switching and packet switching. The multiplexer approach can accomodate both voice and digital data without requiring the duplicate facilities of the unfied node approach. The nodes in the multiplexer approach are connected by a single channel. The channel is synchronously clocked and thereby partitioned into frames of fixed duration; each frame is further decomposed into time slots. Each frame may be partitioned via a boundary mechanism into two distinct regions; one dedicated to circuit-switched traffic, the other for packet-switched traffic. The boundary may be fixed so that no dynamic sharing between switching modes can take place, or moveable, whereby packets can seize currently idle circuit slots during a particular frame (but not the reverse). The multiplexer approach is the most flexible implementation of hybrid switching. The multiplexer approach can accomodate both voice and digital data by circuit switching as well as digital data by packet switching.

The three approaches to hybrid switching either are not capable of changing switching techniques or the switching method is selected by the message originator. Since the method of switching is not selected by considering the message length, path length, traffic intensity and the number of channels, the switching method used does not always result in the shortest delays. Ideally, the hybrid switching network should select the switching method to be used based upon the above factors.

Statement of the Problem

A computer network using hybrid switching which dynamically changes from circuit switching to packet switching depending on the factors of message length, path length, traffic intensity, and number of channels needs to be modeled and analyzed to determine if performance improves in comparison with circuit switching networks and store-and-forward networks. Hybrid switching, in this study, will refer to a network which dynamically changes from packet switching to circuit switching based on the above factors.

The primary question to be answered is "Does hybrid switching provide any potential for improved performance in comparison with circuit or store-and-forward switching?" The answer to this question can be determined by modeling the hybrid switching network along with a packet switching network and a circuit switching network and comparing the resulting performance of each network.

Scope

This thesis will deal only with the development of a hybrid network model which enables a comparison to be made between switching techniques. The thesis will include the rationale for the selection of the performance criteria, the specification of the hybrid network's operation, the development of simulation models for circuit switching and packet switching networks, the development of the criteria which determines if the hybrid network will be operating in the circuit switching or packet switching mode, the development of a simulation model of the hybrid switching network, and the analysis of the results.

Since the purpose of this thesis is to compare switching techniques, the following conditions are necessary to insure any changes in performance are due only to the switching technique;

(1) The routing algorithms for the hybrid, circuit, and packet switched networks are as identical as possible. The routing in all cases is assumed to be shortest path, except for a slight modification to accomodate packet switching. In order to simulate packet switching, 75 percent of the packets are assumed to take the shortest path and 25 per cent will take the shortest path plus one hop. The hybrid technique will use the same routing as the packet switched when operating in the packet switched mode. Maintaining the same routing is necessary to control path length which directly effects the time to send messages from source to destination. All other factors being equal the longer the path the greater the delay.

(2) The topology of each network is identical. This condition is again necessary to control path length. In order for the

comparison of switching techniques to be meaningful, the networks must be the same.

(3) The sum of the channel capacities between nodes is equal for all networks. This condition is necessary to ensure that any changes in delay are due to the switching techniques used. Increases in channel capacity reduce the network intensity and thus reduces the delay. This is apparent if the following formula is examined (13)

$$T = \frac{1}{UC(1-P)} \qquad (1)$$

where: P = network intensity

U = reciprocal of bits per message

C = the link capacity in bits per sec.

Approach

The performance criteria to be used in comparing the switching techniques will be determined. Next, the language to be used in developing the models will be selected. The simulation models of the circuit switched and packet switched networks will be constructed. These models will then be used to determine the switching selection criteria for the hybrid switching model. The switching selection criteria determines which switching technique will provide the best performance of the hybrid switching network based on the message length, path length, traffic intensity, and the number of channels.

The operation of the proposed hybrid network will be specified and the simulation model developed. The three simulation models will be used to analyze network performance produced by the different switching techniques as the factors of message length, path length, traffic intensity and the number of channels are varied. The results of this analysis will confirm or deny the potential usefulness of the proposed hybrid switching technique.

Sequence of Presentation

This report contains five chapters. Chapter two describes the performance criteria to be used to compare the switching technique, the selection of a simulation language, the development of the circuit switching and packet switching simulation models, and the validation and verification of the models. Chapter three describes the rationale for selecting the input parameter values, the method of inputting the parameters, and the results obtained from exercising the circuit switching and packet switching models with the specified input parameters. Chapter four describes the switching selection criteria to be used in the hybrid switching network. Additionally, the operation of the proposed hybrid switcing network is specified, the hybrid switching model is constructed and the model is validated and verified. In Chapter five, the method comparing the three switching techniques is described, the method of inputting the parameters into the hybrid switching model is described, and the results and conclusions from the comparison are presented. Additionally, recommendations for further study are made.

Chapter 2

Circuit and Packet Switching Models

Introduction

This chapter describes the design of the packet switched and circuit switched simulation models. The two models were used to determine the conditions when one switching method out performs the other. This information was required to determine the decision boundary criteria for the design of the hybrid network.

The first step in designing a simulation model is to determine the performance parameter to be measured. Performance criteria for the models is discussed in the next section. After determining the performance criteria, a language must be selected for the model. The rationale used to select the language for the models is the topic of the section following the performance criteria. The section following the language selection describes the design of the circuit switched model. The next section describes the design of the packet switched model. The final section of this chapter describes the methods used for validation and verification of the two simulation models.

Performance Criteria

Network performance is usually measured in terms of throughput, cost, and message delay. Networks are designed to maximize throughput while minimizing message delay and cost. Obtaining high throughput and small message delays are not compatible with lost cost (13). Throughput is the amount of the message transfered in a fixed amount of time. Throughput is a function of service rate, which is directly proportional to line capacity, and the amount of overhead information attached to each message. Minimal message delay is also directly proportional to line capacity. If all other factors remain constant, throughput will increase and message delay decrease as the line capacity is increased. However, cost is also directly proportional to line capacity and as throughput is increased and message delay is decreased by increasing line capacity cost is also increased. Because the design goals of low cost, high throughput, and short message delays are not compatible, compromises must be made during the design process.

Comparison Performance Criteria

The factors of cost, throughput, and message delay are all valid measures of performance for networks. However, all of the factors are not suitable for comparison of the switching techniques as performed in this investigation.

Cost was not a suitable performance measure in this comparison of network switching methods. The goal of this study was to determine if hybrid switching can provide any advantages over circuit switching or store-and-forward switching networks. The equipment and topology of the different networks must be almost identical in order to assure any changes in performance are due to the switching technique. The main differences in the implementation of the switching techniques will consist of software changes and some minor equipment changes. The cost associated with the different networks can only be estimated until the design is actually realized. Because the networks were only implemented to a degree which allowed comparisons to be made and were not completely designed and operational systems, any discussion of costs at this point is irrelevant. For these reasons, cost was not a suitable comparison factor for this study.

Throughput is defined as the amount of message information transferred from one point to another in a fixed amount of time. The two factors which effect throughput the most are service rate, which is a function of line capacity, and the amount of header information attached to each message. The line capacity for each network in this study was identical. Therefore, the differences in throughput between the networks will be due to the amount of header information. In general, the throughput for packet switching will be less than the throughput for circuit switching, if the message is large (9). For example, if a message requires the transmission of five packets, each packet will require source and destination information to be attached as a header. If we assume that the header information consists of 100 bits, then the transmission of this message will require a total overhead of 500 bits which reduces the throughput. If the same message were circuit switched and we assume the circuit establishment message, the request-to-send-message, and the circuit-release message each require 100 bits, then the total overhead for the message would be 300 bits. Again, the throughput is decreased but the decrease is much less.

The difference in throughput between packet switching and circuit switching could be reduced if the packet size was increased. If the packet size was increased to allow the message in the above example to be sent in three packets, then the throughput for circuit switching and packet switching would be the same, because the overhead for each would be 300 bits. If the packet size was increased again, then the throughput for packet switching would become greater than the throughput for circuit switching because the total overhead per message would be greater. Since the line capacity and thus the service rate for the different networks was the same and the amount of overhead information transmitted could be controlled by selecting the packet size, throughput was not a valid measure for comparing the different switching techniques in this study.

The elimination of cost and throughput as valid comparison factors left message delay as the only remaining factor to compare the various switching techniques. Message delay is an interval of time measured from the time a message enters the network until it arrives at the intended destination. This interval usually includes the time from the input device to the first node and the time from the last node to the output device. However, the input and output devices are usually switched differently than the nodes. Therefore, message delay in this investigation was measured from the time a message arrived at the first node on its path until if left the network. After determining the performance parameter which was to be used to compare the different switching techniques, a language to use in designing the switching models was selected.

Simulation Language Selection

The choice of the programming language for implementing the models is one of the basic decisions to be made when planning a simulation study. The eligible languages fall into one of the two following categories.

A. Simulation languages;

B. General languages, those which have not been purposely designed for simulation applications.

Category A includes such languages as GPSS, Simscript, Q-Gert, and Slam. Category B includes assembly languages, Fortran, Algol, and Pascal (2).

Simulation languages are intended not only to help programmers in the coding of a simulation model but also to provide them with a framework in which the model can be easily formulated. A simulation language generally contains features which facilitate: (2)

A. The static description of the system to be modeled (statements for the creation and deletion of entities and the specification of their attributes and interrelation ships);

B. The dynamic description of the system (for instance, the automatic updating of the simulated-time clock, the definition and scheduling of events);

C. The representation of stochastic phenomena (pseudo-random number generation, generation of samples from distributions given in analytic or empiric form);

D. The collection, reduction, and presentation of data (that is, all the tasks related to the instrumentation of the simulator).

Other useful features, which can be found in some languages, include mechanisms to monitor the simulation, to debug the model, and to put it into the desired initial state.

The presence in a simulation language of entities and constructs which represent the central concepts of simulation is certainly very useful, especially for the novice modeler. However, these entities and constructs may be felt as a constraint by some investigators. In certain simulation languages, for instance, it may be difficult to implement a non-distribution-drive simulator or some unusual queue management scheme. In general, it is reasonable to expect that the use of a simulation language will decrease the amount of programming time required to code and debug a simulator. Additionally, simulation languages provide a much better system-description vehicle than other languages. This makes them more effective as communication tools and the models implemented by using them easier to debut. However, these simulation models are often less efficient at run time, since object-code efficiency is usually not among the primary objectives of simulation language design. The lack of efficiency at run time increases the CPU time and the memory requirements for models implemented in a simulation language.

General languages provide better run-time efficiency than simulation languages, which is especially important when a large number of simulation runs or multiple models is required by the study being undertaken. General languages are often selected for a model due to the reluctance of certain programmers to learn a new language. The lack of availability of a simulation language at installations is another valid reason for selecting a general language for the model.

The decision was made to use a simulation language to develop the models for this study because of the guidance in model formulation, ease of implementation and debugging. These factors were considered to be of greater concern for this study than the greater run-time efficiency afforded by general languages, even considering the large number of simulations the study was expected to require. Having made the decision to use a simulation language, the next decision to be made was which simulation language to use.

The factors which should be considered in evaluating and selecting a simulation language are listed in Table 1 (12). These factors along with the knowledge that the models for packet-switched, circuit-switched, and hybrid-switched networks are process oriented models formed the decision criteria for selecting the simulation language.

Table I

Factors on Which to Evaluate

Simulation Languages

FACTORS	EVALUATION CRITERIA
Training Required	Ease of learning the language Ease of conceptualizing simulation problems
Coding Considerations	Ease of coding including random sampling and numerical integration Degree to which code is self-documenting
Portability	Language availability on other or new computers
Flexibility	Degree to which language supports different modeling concepts
Processing Considerations	Built-in statistics gather capabilities List processing capabilities Ability to allocate core Ease of producing standard reports Ease of producing user-tailored reports
Debugging and Reliability	Ease of debugging Reliability of compilers. support systems, and documentation
Run Time Consideration	Compilation speed Execution speed

Process oriented models are simulation models which include sequences that occur in defined patterns, for example, a queue where entities wait for processing by a server. Process oriented languages are GPSS, Simula, Q-Gert, and Slam. The factors in Table 1 were considered in the following priority with the most important listed first; training required, processing considerations, coding considerations, debugging and reliability, run-time considerations, flexibility and portability. Training required was given the highest priority because all of the listed process oriented languages were unfamiliar. Processing considerations, coding considerations, debugging and reliability and run-time considerations were considered to have approximately the same importance. Finally, the factors of flexibility and portability were given the lowest priority for this study and did not enter into the decision process. Flexibility was given a low priority because different modeling concepts were not required for this study. Portability was given a low priority because a requirement for the models to run on a different computer systems did not exist.

The list of process oriented languages for use in this study was reduced to Q-Gert and Slam by using the above factors. The decision to use Q-Gert instead of Slam for this study was based on training required. Slam and Q-Gert are both network oriented languages with Slam using some of the Q-Gert concepts. Both languages are available on the Cyber computer which was used for this study. However, Q-Gert was selected over Slam for the following reasons;

1. Since Slam uses Q-Gert concepts a knowledge of Q-Gert is an aid to learning Slam. However, I did not have a previous knowledge of Q-Gert.
2. Slam is a relatively new simulation language and the availability or programming assistance is presently limited. Q-Gert has been available since 1977 and the amount of programming assistance is much greater.

After completing the selection of a performance measure and of a simulation language, the actual design of the simulation models can begin.

Circuit-Switched Network Model

A circuit-switched network transmits a message from a source to destination by establishing a dedicated path between the two parties before the transmission begins. The path is established through a signaling process. Before transmission of a message, a reservation signal is sent towards the destination. While traveling node by node towards the destination node, the signal reserves channels along the path. If, at any intermediate node, the signal cannot find a free channel, it waits for a channel to become free while holding the channels it has previously reserved. The time spent waiting for a channel to become free is called queuing delay. Once a channel becomes available, the signal reserves it and goes to the next node to repeat the same process. The time spent going to the next node is called the service delay. By the time the signal reaches the destination node, a dedicated path has been reserved between the source and the destination nodes. When the signal reaches its destination, the originating node is notified through a reverse signalling process, called request-for-transmission, to start the transmission of the message. The request-for-transmission signal is transmitted along the same path established by the reservation signal. Since the path is already established, the request-for-transmission signal does not incur a queuing delay. The only delay of the request-for-transmission signal is the service delay. Service delay is the physical time required by the channel to transmit the signal.

When the request-for-transmission signal reaches the message source node, the transmission of the message begins. The message, like the request-for-transmission signal, only incurs a service delay. After completion of the message transmission, the destination node sends a channel-release signal along the established path which frees the reserved channels and has the effect of disassembling the path. Again, the channel-release message only incurs a service delay.

The hypothetical circuit switched network to be modeled and used in this investigation has the topology as shown in Figure 1. The nodes in Figure 1 represent computers and the lines connecting the nodes represent one or more data communication channels. The lines labeled λ which point to the nodes represent the total message arrival rate to the computers from sources external to the network. These sources could be teletypes, interactive devices, or other computers. The network consists of seven nodes. The nodes are connected by one or more channels, but, regardless of the number of channels, the total capacity is a constant 50,000 bits/second. External messages arrive at each node at an exponential rate of λ messages/second. The message lengths are known and therefore the service rate is fixed and not exponential. The message destinations are uniformly distributed between nodes. The channels are full-duplex. However, in order to reduce the complexity of the model, this investigation will only be concerned with traffic flowing in one direction. The circuit-reservation signal, request-for-transmission signal, and channel-release signal are each assumed to be 100 bits in length to compare the results of this model with models developed in previous studies (9). The network routing is accomplished by using the shortest path, again, to simplify the model.

Q-Gert allows models to be constructed either by modeling the flow of transactions through nodes and branches with the flow of a transactions or by halting the flow of a transaction until a specific resource type becomes available to be allocated to the transaction (11). The latter method of modeling was chosen for the circuit-switched model because of the reservation process involving the channels. The channels in this model

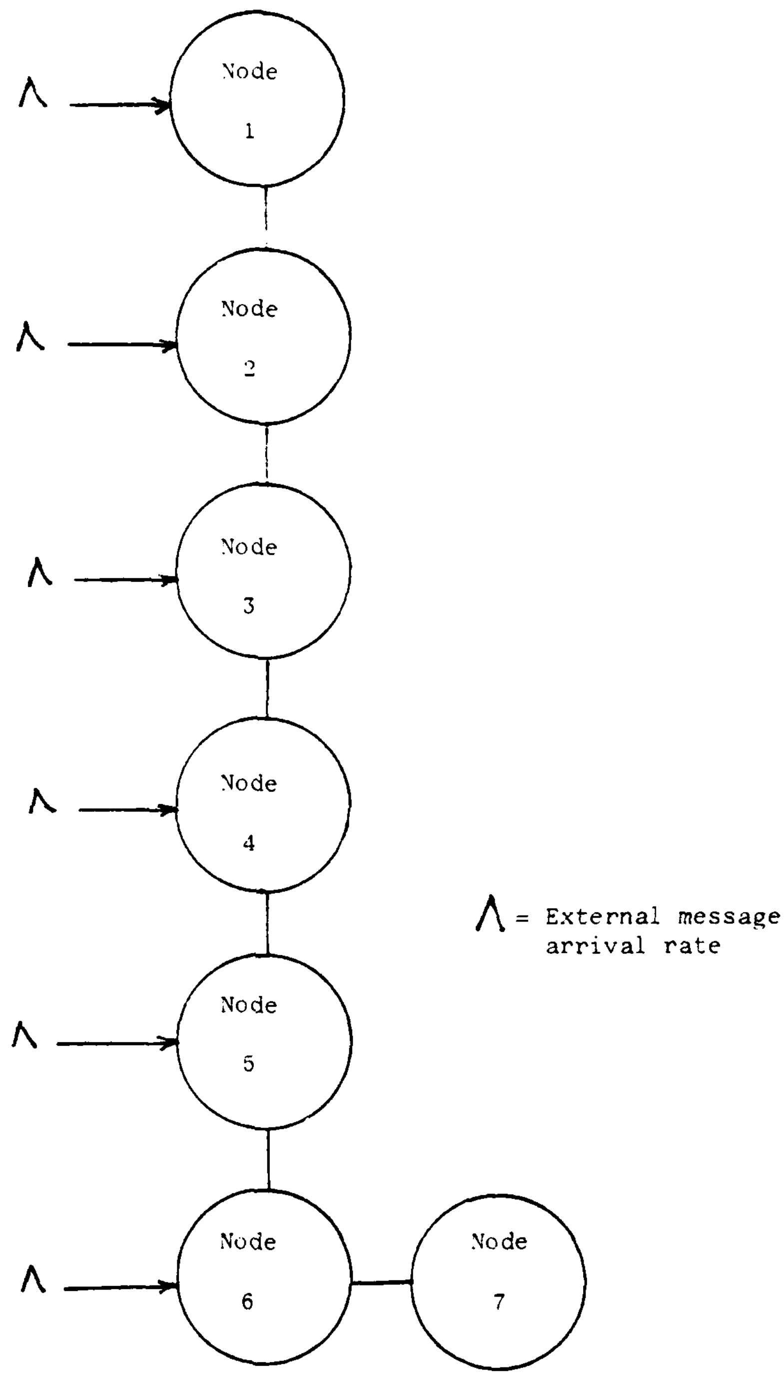


Figure 1. Circuit switched network topology

are the specific resource type. The basics of the Q-Gert model are described in the following paragraphs. A more detailed description of the model is available in the appendix from the Q-Gert design diagrams. The details of the Q-Gert language will not be discussed. This information is available in Pritsker's Book on Q-Gert (11).

External messages arrive at the nodes of the circuit-switched network at an exponential rate. The model uses the Q-Gert source node to generate the arrival of messages. The initial arrival occurs at time zero with following arrivals occuring after a delay from an exponential distribution which is generated using the Q-Gert random number generator. Q-Gert also allows attribute values to be assigned to the messages. The attributes are carried along with the message and may be accessed or changed during the messages flow through the network. The model assigns three attributes to the messages generated by the source node. The attributes are the originating node number, the destination node number, and the time required to transmit the channel reservation signal between two adjacent nodes. The origination node number is the number of the node where the message entered the network. A message is assumed to have an equal probability of having any of the nodes in the network, with the exception of the source node, as the destination. The destination attribute value is assigned from a uniform distribution using a Q-Gert standard routine. The time the messages enter the network are also assigned as an attribute value via the Q-Gert mark function at the source node. The values assigned by the mark node are special attributes used by the statistics gathering nodes.

The messages are sent to the next Q-Gert node without delay as shown in the design charts in the appendix. This node is a probabilistic branching node. The node is used to allow a mix of messages with different message lengths to be in the network at the same time. When a message arrives at this node, it is transmitted without delay to the node with the corresponding probability value. The message is then assigned an attribute value which is the total time required to transmit the message, transmit the request-for-transmission signal, and the channel release signal. The messages are then routed to a queue node which represents the first node in the network and ends the arrival process. The arrival process is duplicated at each node in the network, except the last. However, the values assigned to the source and destination attributes along with the time between arrivals is altered at each node.

The Q-Gert queue node, which is used to represent the nodes of the network, operates on the first message in is the first message out of the queue, FIFO priority scheme. The initial number of messages in the queue at the beginning of the simulation is zero. The simulation cannot start with messages in the queue because the required attribute values cannot be assigned to messages which are in the queue at the start of the simulation. The maximum number of messages allowed in a queue is assumed to be infinite. Since the performance parameter being measured is delay, messages in the queues are not limited because the delays could be reduced.

The messages wait in the queue node until a channel becomes available and is reserved. The channels are considered as resources and the channels between adjacent nodes are assigned a unique resource number. The actual assignment of a channel is accomplished in the model using the Q-Gert allocate node. After the channel assignment is made, the message is removed from the queue and placed in a regular Q-Gert node.

The message is delayed at this node for the length of time required to transmit the channel-reservation signal to the next network node.

The message is next placed in a conditional branching Q-Gert node. The message destination is compared to the next node number at this node. If the destination and the next node are not the same, the message is placed in the queue representing the node and repeats the reservation and transmission, as described above, until the destination is reached. If the destination and the next node are the same, the message is delayed for a period equal to the time required to send the request-for-transmission signal, the message and the channel-release signal.

After this delay, the message arrives at another conditional branching node which sends the message through a series of Q-Gert free nodes based upon the entry node of the message. The free node returns a resource to the allocate node for reassignment to another message. The series of free nodes simulates the actual disconnection of the message path.

If the source node of the message is the first node, the message is sent to a Q-Gert sink node. The sink node gathers the statistics on the message and computes the delay from the arrival time and the time the message enters the sink node. The network is designed to allow all the messages from the first source node to trigger the sink node or to only permit messages arriving at certain nodes to trigger the sink node. This allows the user to alter the network to study the effect of path length on message delay. The details on how to alter the network path length being measured are contained in the next chapter.

The network model above may not appear to implement the circuit switched network as described to someone unfamiliar with Q-Gert because of the order in which events occur. However, the only delays measured by the model are the time each message spends in the queue nodes and the specific delays mentioned in the description. All other events, while they do not occur without a delay in an actual computer network are assumed to require zero time by the model. This completed the design of the circuit switched model. The next activity in this study was to design the packet switched model.

Packet-Switched Network Model

A packet-switched network transmits messages in a hop-by-hop fashion through the network. First the messages are divided into packets of a predetermined size with each packet carrying its destination address in the header. The packets are transmitted to the next node individually as channels become available. Before a packet can be forwarded it must be totally received by the transmitting node. Packet-switching operates the same as message-switched networks except the messages are divided into packets and all the packets are not required to follow the same path to their destination.

The hypothetical packet-switched network to be modeled and used in this investigation has the topology as shown in Figure 2. The packet-switched network is basically the same as the circuit-switched network of Figure 1. The network consists of seven main nodes and two alternate nodes. The nodes are connected by one or more channels, but regardless of the number of channels, the total capacity of the line or lines is 50,000 bit/sec. External messages arrive at each node at an exponential rate of λ messages/sec. The message lengths are known and therefore the service rate is fixed and not exponential. The number of messages terminating at each node is uniformly distributed with the exception of alternate

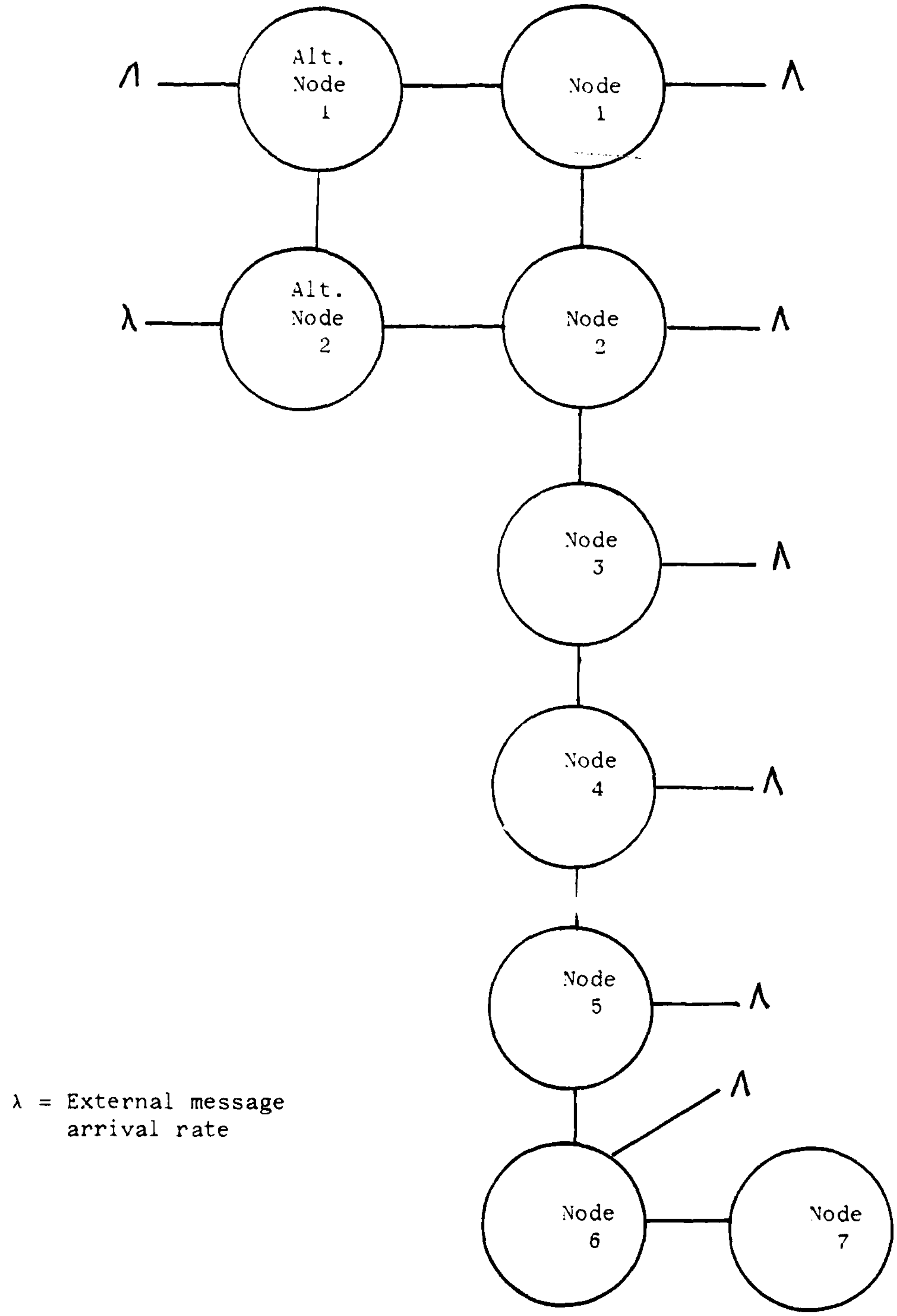


Figure 2. Packet-Switched Network Topology

node one and two. The messages entering the network at alternate nodes one and two are terminated after receiving service at the entering node. The channels are full duplex, however, the model will only be concerned with traffic flowing in one direction. The messages entering the network are packetized at the entry node. Each packet contains 1000 bits of the message and a 100 bit header. Thus the total packet is 1100 bits.

Network routing is accomplished by using the shortest path method which is used in the circuit-switched model. However in order to simulate a packet-switched network which does not force the packets to travel the same path to the destination, the network only sends seventy-five percent of the packets arriving at node 1 along the shortest path. The remaining twenty-five percent of the packets are transmitted to node 1 via alternate nodes one and two. The packets entering the network at the remaining nodes are transmitted via the shortest path. Since statistics are only calculated for messages entering node one, the lack of multiple paths for the remaining nodes will not bias the results. The percentage of packets taking the shortest path can be altered at the user's discretion by changing the probability of selecting each path from the probabilitic branching node as shown in the design chart in the appendix.

The Q-Gert model of the packet-switched network was constructed using the resource modeling technique which was used in the circuit-switched model. The resource method was chosen to minimize the differences in the two models. Packet-switching does not have a reservation process and the other modeling technique available in Q-Gert could have been applied. Employing the same technique for both models will minimize the influence of the technique on the results and help to insure any variation in the results is due to the switching technique. The following paragraphs describe the model, however, a more detailed description is available in the appendix.

Message arrivals to the nodes from outside the network are assumed to be exponential. The Q-Gert source node is used to generate the messages. The initial message arrives at time zero with following arrivals occurring after a delay period calculated from an exponential distribution. Attribute values for the source node, destination, time to transmit a packet between two adjacent nodes, and the message number are assigned at the Q-Gert source node. The values for the source node and destination are assigned identically to the circuit-switched model. The time to transmit the packet is based upon the number of channels and a packet size of 1100 bits. The message number is a unique number assigned to each message. The initial message is assigned the number 1 and the number is increment by one for every succeeding message by using the Q-Gert function, increment. The arrival time of each message is also carried along with the message by using the Q-Gert mark function. The messages are routed without delay to a probabilistic branching node. The function of this node is to allow messages of different lengths to be in the network simultaneously. The percentage of each message type and the number of different types can be altered by the user. The specific details on the altering the percentage and length of messages are in the appendix. Depending upon the branching condition, the message is routed to a node which assigns an attribute value which is equal to the number of packets the message will require. The node generates the packets required and routes each packet to a separate node which assigns a unique packet number to each packet. All the packets are identical except for the unique packet number. The packets are sent to a central node which acts as a central collection site for the packets. The arrival process is completed with this node. The arrival process for each node in the network is identical except the source node and destination node attributes change along with the exponential distribution which is used to determine the next arrival.

The packets are next placed in queue nodes which represent the network nodes. For nodes 2 thru 6 and the alternate nodes 1 and 2, the packets are immediately sent to the queue node from the central collection node. However, the packets arriving at node 1 are first sent to probabilistic branching node which routes seventy-five percent of the packets to queue node 1 and twenty-five percent of the packets to alternate node 1. Instructions for altering the above percentages at the descretion of the user are in the appendix. The method of handling packets entering node 1 simulates packets being able to take alternate paths. Multiple paths are only incorporated into node 1 because packets entering the other nodes are not measured and are used only to provide contention for resources in the network.

The queue node operates on a FIFO priority scheme. The queues are empty when the simulation begins and are assumed to have unlimited buffer capacity. The packets wait in the queue node until a channel becomes available. The Q-Gert allocate node assigns the channel to a packet. The packet is removed from the queue and placed in a regular node. The packet is delayed for a time period equal to the time required to transmit a packet between two nodes. After the delay, the packet is forwarded to a Q-Gert free node with conditional branching. The free node releases the channel assigned to the packet by the previous allocate node and returns the channel for reassignment.

The conditional branching associated with the free node routes the packet based upon the destination. If the next node is not the destination, the packet is placed in the queue for the node. If the next node is the destination, the packet is sent to another conditional branching node. If the source node of the packet is not the first node, the packet is simply removed from the network. However, if the packet's source node is the first node, the packet is routed to another conditional branching node which sorts the packets by the message size. If the entire message is contained in one packet, the packet is sent to the sink node which calculates the delay statistics. If the entire message is contained in more than one packet, the packets are sorted by the number of packets required and then placed in queues which corresponds to the individual packet number. The packets wait in these queues until all the packets of a messare received. When all the packets of a message have arrived, the message is routed to the sink node which calculates the delay. Additional details are available in the design charts in the appendix.

The process described above simulates the movement of message through the packet-switched network and is repeated at each node which has messages arriving from sources external to the network. The process is altered at alternate nodes 1 and 2. After a packet is transmitted from one of these nodes and the channel is released, the packet is only placed in the next queue if it originated at node 1. The packets which do not originate at node 1 are terminated without any statistics being calculated.

The packet-switched model can be configured by the user to gather statistics at all nodes or only at specified nodes. The instructions for reconfiguration and using the model are contained in the next chapter. Prior to using either the circuit switched model or the packet switched model, the models had to be verified and validated which was the next task in this investigation.

Validation and Verification

Prior to using any simulation model, validation and verification should be performed. Validation insures the model performs to the expectations of the modeler. Verification of the model establishes that the results produced by a model are reasonably close to the results expected from the process being modeled. Verification is necessary if the model is to be used to predict the results of a scenario for which there is no previous experience. Validation and verification can best be accomplished by exercising the model with inputs to the actual system and comparing the model results with the results produced by the actual system. This method of validation and verification could not be used because the models were of hypothetical networks.

Validation of both the circuit-switched and packet-switched models was simplified by the Q-Gert language. Along with the delay information output by Q-Gert, the language also provides the total simulation time and the total number of messages/packets passing through each node. This information was used to verify that the arrival rate generated by the model was equivalent to the arrival rate desired by the user. Additionally, the information provided on the messages/packets passing through each node was used to verify the flow through the model was as designed. The circuit-switched and packet-switched models were both validated using the described method.

Verification of the models was not as easy as validation. Since the models were not of an existing system, proving the results were within reasonable bounds of what was expected was not simple. In order to verify the two models, the packet-switched model was set-up to operate as a message-switched network. Packet-switched and message-switched networks operate identically when the packet size is equal to the message size. Therefore, the packet switched model was set up to generate messages of 1000 bits in length, the packet size, in order to force the packets/messages to follow the same path to their destination, the alternate path from node 1 to node 1 via alternate nodes 1 and 2, as shown in Figure 2, was removed. The packet-switched model was set-up to measure the delay of message which entered the network at node 1 and terminated at node 7. Three simulations of the packet-switched network in this configuration were run with the arrival rates set at 25, 50, and 75 percent of total capacity. Each simulation measured 100 messages traveling from node 1 to node 7. The results of the simulations were compared to the analytical model developed by Kermani and Kleinrock (4). The model predicts the delay in a message switched network and is as follows:

$$T = \frac{(I_M + I_h)/C}{1 - \Lambda(I_M + I_h)/C} N_H \quad (2)$$

Where T = total delay in seconds from the message arrival until it reaches its destination

Im = average message length in bits

Ih = average header length in bits

C = total line capacity between adjacent nodes in bits/sec

Λ = arrival rate of message in bits/sec

N_H = the number of intermediate nodes between the source and destination. (The packet-switched model is set up for N_H to equal 6).

The results of the comparison are in Table II. The delay as predicted by the analytical model was based on a traffic intensity of 45.9 instead of 50 and a traffic intensity of 64.3 instead of 75. The smaller traffic intensity values were used because the random method used by the Q-Gert function which generated the arrivals and the error introduced by rounding the input parameters resulted in the actual rate of arrivals being reduced to these values. Since the delays predicted by the simulation model were based on the smaller traffic intensities, the prediction of the analytical model has to be based on the same input values, if the comparison is to be valid.

Table II

Comparison of Packet-Switched model to Kleinrock's analytical model for a Message-Switched Network

Traffic Intensity	Delay from Simulation Model (std. dev.)	Delay from Analytical Model
0.25	.1393 (.0111) sec	.1821 sec
0.50 (0.459)	.1607 (.0298) sec	.2670* sec
0.75 (0.643)	.2231 (.0767) sec	.4560* sec

*Value calculated from the actual average message arrival rate, λ, to each node of 22,953.5 bits/sec and not 25,000 bits/sec.

**Value calculated from the actual average message arrival rate, λ, to each node of 32,128.8 bits/sec and not 37,500 bits/sec.

The average delay from the packet-switched model with a traffic intensity of 0.25 was 76.5 percent of the delay predicted by the analytical model. With a 0.50 traffic intensity, the average delay from the simulation model was 60.2 percent of the analytical model. The average delay from the simulation model was only 48.9 percent of the delay from the analytical model with a 0.75 traffic intensity. The correlation between the analytical and simulation models was not significant. If the results had been within 85 or more percent, the correlation would be considered significant.

The lack of correlation was attributed to the simulation queues being empty at the beginning of the simulation. The empty queues resulted in the first message generated by the model having a shorter wait in the queues which resulted in shorter delays. The decrease in the observed correlation as the traffic intensity increased was also attributed to the simulation model queues starting empty. The average queue length increases as the traffic intensity increases. The average message should have a longer wait in each queue. However, the empty queues in the simulation model resulted in the first messages being served without incurring a long wait in the queues. The differences in the delays predicted by the analytical and the simulation model were attributed to this and the packet-switched model was assumed to be verified.

Verification of the circuit-switched model was even more difficult than the packet-switched model. An analytical model for a circuit-switched system was not as readily available nor as straight-forward mathematically as the analytical model used to verify the packet-switched model. Therefore, verification of the circuit-switched model was attempted by exercising the model and comparing the results to the results of previous investigations. The model was configured to have message arriving at 50 percent of capacity (P = .50), to have one channel of 50,000 bits/sec capacity between nodes and to measure messages terminating at node 5 which originated at node 1 (i.e. path length of 4). The message lengths were fixed at 1000 bits. The average delay predicted by the model under these parameters was 4.0473 sec with a standard deviation of 2.6081 sec.

The results of the simulation was compared to the results of the study by Miyhara (9). Figure 6 of Miyahara's study graphs message length vs. delay. The delay predicted by the figure for message lengths of 1000 bits is approximately 4 seconds. The results from Miyahara's model were based on a path length of 3, a line capacity of 48000 bits/sec, and the channel-reservation, the request-for-transmission and the channel-release signal each being 50 bits in length. The simulation model had a path length of 4, a line capacity of 50,000 bits/sec and 100 bits circuit establishment signals. These differences were not significant. The difference in message transmission time because of extra 50 bits in each signal combined with the additional 2000 bits line capacity resulted in an increase in the transmission time of 0.002 seconds.

The mean delay from the simulation model was compared to the mean from Miyahara's study using the following significance test (8).

$$Z = \frac{\bar{X} - U_o}{\sigma / \sqrt{N}} \tag{3}$$

where Z = test statistic

$\bar{X}$ = mean from simulation model

U_o = mean from Miyahara's model

σ = std. dev. from simulation model

N = sample size

The test statistic calculated from the above equation was 0.1814. The test statistic for a 95 percent confidence interval to test the equality of two means is 1.96 (8). Since the calculated test statistic was smaller, the hypothesis of the means being equal was accepted and the results of the two models were considered equal. The completion of validation and verification allowed the packet-switched and circuit-switched models to be used to determine the switching selection criteria which was required to develop the hybrid switching model.

Chapter 3

Comparison of Circuit Switched and Packet Switched Models

Introduction

This chapter describes the comparison of the circuit switching and packet switching techniques. The models constructed in Chapter 2 were compared to determine which switching technique would provide the shortest delay under identical conditions. This comparison provided the selection criteria which were used in the hybrid switched model to select the method of switching for each message.

The first section describes the method of comparison, and rationale for selecting the values of the input parameters, and the rationale used in determining the number of simulations required for each model. The next section describes the rationale used to actually derive the input parameter values and the method of inputting these values into the models. The concluding section presents the results of the comparison. The values of the input parameters and the resulting delays are given in tables. Additionally, the delays are plotted against the input parameters of path length, traffic intensity and channels.

Method of Comparison

The packet-switched and circuit-switched models were constructed to measure the effects of message length, path length (hops), channels, and intensity which is defined as the ratio of the message arrival rate to the message service rate. Since these four factors all have an effect on message delay, three of the factors must be held constant as the fourth is varied in order to ensure any variation in delay is due to the varied factor. The number of simulations of each model required to investigate each factor is a multiplicant of the number of variations of each factor. If, for example, five values of each factor are being investigated the total number of simulations required for each model would be 625 (5x5x5x5) and the total number of simulations required for the models would be 1250. The models required between 30 and 60 seconds of CPU time for each simulation. The time requirements of the models and the limitations of resources necessitated limiting the number of simulations.

The values of the message length studied were 1000, 3000, and 5000 bits. The value of 1000 was chosen because the packet size was 1000 bits. The packet-switched network could then be made to operate as a message-switched network which allows for comparison of results to previous studies (4). Additionally, a 1000 bit message is considered to be small and should provide a situation which favors packet-switching over circuit-switching. The message length of 3000 bits was selected based on the studies of Kleinrock and Miyahara (4,9). In Kleinrock's comparison of circuit-switched to message-switched networks, the point at which circuit-switched networks begin to result in smaller delays than message-switched networks was 2000 bits. However, Miyahara's study, which compared circuit-switching and packet-switching found that circuit switching provided smaller delays than packet switching for messages of 5000 or more bits.

Since the 1000 bit message favored packet-switching and the 5000 bit message favored circuit-switching, the 3000 bit length was chosen to provide a point which was not biased toward either method. An attempt was made to input message lengths of 7000 bits into the models, however, the CPU time requirements increased significantly and the Q-Gert limitation which only allowed 850 active transactions in the network prevented the study of message lengths greater than 5000 bits.

The switching models were designed to have seven nodes which limits the maximum path length or hops studied to six. Again, the limitation to seven nodes was forced by time requirements and Q-Gert limitations. The path lengths selected for study were 2,4, and 6. A path length of 1 was not selected because it clearly favors packet-switching because of the extra bits which are transmitted by the reservation process in circuit-switching. The path lengths were selected to provide a short, medium and long path from the six possible paths.

The total line capacity was divided into 1, 4, and 8 channels. However, the number of channels between pairs of nodes was not varied from pair to pair. These values were chosen to compare the results with Kleinrock's study (4). A single channel between nodes favors packet switching because the transmission time is the shortest. Eight channels favor circuit-switching because of the channel reservation process. The channel reservation process established a dedicated path between the source and destination. While the path is being established, channels reserved for use in the path are unavailable to transmit messages. Therefore, multiple channels reduce the probability of a channel not being available which reduces the waiting time for a channel. Four was chosen as a value for the number of channels because it was the midpoint between the other values.

The traffic intensity of the model networks was set at 0.25, 0.50, and 0.75. An intensity of 0.25, depending on the other factors, favors circuit-switched while a value of 0.75 favors packet-switching (4). The intensity of 0.50 was selected because it is the midpoint between the other selected values. The arrival rate of messages to each node was manipulated to maintain the same intensity at each node throughout the simulation.

The selection of three values for each of the four factors of message length, path length, channels and intensity required eighty-one simulation runs for each model. With the values for path length, message length, traffic intensity and number of channels determined, the next task to input these values into the models.

Simulation Model Inputs

The models were designed to measure the effect of message length, path length, number of channels, and traffic intensity on message delay in a packet-switched or circuit-switched network. The previous section of this chapter presented the rationale used to determine the values of the four input parameters. The following paragraphs detail the method and rationale used to determine the changes necessary to input these values into the models. Each factor will be discussed independently beginning with the number of channels followed by the path length, message length, and traffic intensity.

Inputting the number of channels into the models is accomplished via the Q-Gert resource cards. The Q-Gert resource card appears as follows;

Res, 1, 1, 1 *

The Res identifies the card as a resource card. The first number is the resource number which is used to uniquely identify the resource. The second number is the number of resources/channels available. The third number represents the allocate number to which resources are reassigned after use. In order to input or change the number of channels, the second number is changed to equal the desired number of channels. When the number of channels is changed, the time to send the packet, the channel-reservation signal, and the message must also be changed. The changes in time are required because the total capacity between nodes is limited to 50,000 bits/sec. Increasing the number of channels while holding the total capacity fixed results in a reduction in the capacity of each channel. Since the capacity of each channel is reduced, the time required to transmit between nodes increases. The models assume a fixed service rate which is input as a constant attribute value. The attribute values which must be changed, when the number of channels is changed, are attribute 3, the time to transmit the channel reservation signal between two adjacent nodes, and attribute 4, the time to transmit the message, the request-for-transmission signal, and the channel-release-signal, in the circuit-switched model. For the packet-switched model attribute 3, the time to transmit a packet between adjacent nodes, must be changed. The equations for determining the values of attributes 3 and 4 for the circuit-switched model and attribute 3 for the packet-switched model are as follows; (4).

$$\text{Attribute 3 (Circuit-switched)} = \frac{H_L}{50000/\text{channels}} \tag{4}$$

$$\text{Attribute 4 (circuit-switched)} = \frac{2H_L + M_L}{50000/\text{channels}} \tag{5}$$

$$\text{Attribute 3 (Packet-switched)} = \frac{H_L + P_L}{50000/\text{channels}} \tag{6}$$

where H_L = length in bits for the channel establishment signal, request-for-transmission signal, the channel-release signal or the packet header (assumed to be 100 bits for this study).

M_L = length of message in bits

P_L = length of packet in bits (excluding header)

Channels = total number of channels between the nodes

Altering the path length is a simple operation of disconnecting the activity going to the statistics gathering node and connecting the statistics node to the desired node. The messages upon their arrival are assigned a destination from a uniform distribution. Therefore, on the average, every six arrivals to node 1 will have a different destination. The models were designed to measure the delay only on messages arriving at node 1. The external arrivals to the other nodes are only used to generate loads to compete for the channels. Therefore, the path length being measured may be altered by changing the inputs to the statistics node. Table III lists the connections to be made to measure the delay for a particular path in the circuit-switched model.

Table III

Path Length Connections for
Circuit-Switched Model

Desired Path Length	Node to be connected*	Statistics Node*
1	17	80
2	22	80
3	27	80
4	34	80
5	42	80
6	51	80

*Node numbers refer to the Q-Gert nodes in the design charts for the circuit-switched model in the appendix.

If the average delay for the entire network is desired, all the connections in the Table III are required.

The rationale for changing path lengths in the packet-switched model is identical to the circuit-switched model. Table IV lists the connections required to measure the average message delay over a specific path.

Table IV

Path Length Connections for Packet-Switched Network

Desired Path Length	Node to be connected*	Statistics Nodes*
1	38	
2	42	
3	46	58 if A1 $\neq$ 1
4	50	67 if A1 = 1
5	54	
6	57	

*Node numbers refer to packet-switched design charts in the appendix

In order to measure the average message delay for the entire network, all the connections in Table IV are required.

The inputs required to change the message length are simple for the circuit-switched model but complicated for the packet-switched model. The only change required for the circuit-switched model is the recalculation of attribute 4 using equation 5. However, changing the message length in the packet-switched network is more difficult because a change can cause the number of packets to increase or decrease. Altering the number of packets in the network requires a change in the number of nodes in the arrival process and in the statistics process. Figure 3 shows the nodes in the arrival process which must be altered. In Figure 3 the model is set-up to accomodate 5000 bit messages which require 5 packets. Nodes 22 thru 26 in Figure 3 are used to generate the packets for each arriving message. If the message lengths were changed to 3000 bits, the model would have to be modified by removing nodes 25 and 26 since the message only required three packets. Similarily, if message lengths were increased above 5000 bits, additional nodes would have to be added to generate the required number of packets.

The message reassembling process must also be changed to accomodate changes in the number of packets. Figure 4 shows the nodes in the message reassembling process which require modification. As in Figure 3, Figure 4 displays the message reassembling process designed to accomodate 5000 bit message. The message reassembling process ensures all the packets of a particular message have arrived at the intended destination before the delay is measured. When packets belonging to a 5000 bit message arrive at their destination, the packet numbers are used to route the packet to a queue for that particular packet number. When each queue has received a packet from the same message, the match node, node 11, sends a signal to the node which calculates the delay.

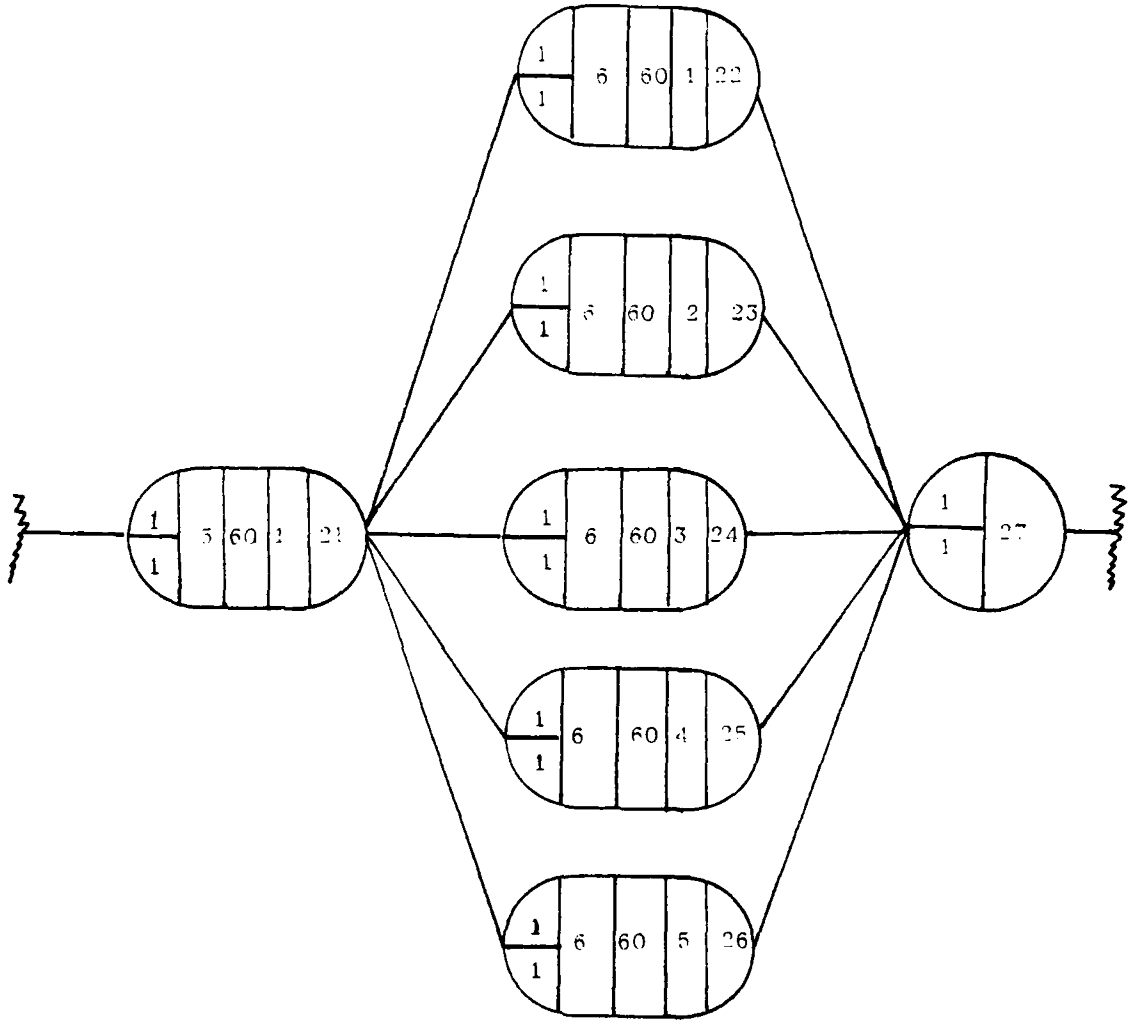


Figure 3. Packet Generation for a
5000 Bit Message

Altering the message lengths and the number of packets required to accomodate the message requires a change in queue nodes, 69, 70, 71, 13, and 14, in Figure 4. If the model was altered to study 3000 Bit messages, nodes 13 and 14 would be removed. However, no change is required to study 1000 Bit messages because they are handled in a special way which is shown in the design charts in the appendix. The study of message lengths greater than 5000 Bits cannot be accomplished by adding more queues between nodes 68 and 11. The Q-Gert language limits the number of queues attached to a match node to a maximum of five and a minimum of two. Therefore, a message length of 7000 Bits not only requires the addition of two more queues which must be connected to a different match node but also the addition of a queue after each match node followed by another match node whose output is connected to the statistics gathering nodes.

The final input into the model is the traffic intensity, P. The traffic intensity is the ratio of the message arrival rate to the message service rate which is given by the following queuing equation (13);

$$P = \frac{\Lambda}{U} \qquad (7)$$

where Λ = message arrival rate

U = message service rate

In order to determine the effects of ρ on delay, each node must have the same intensity of traffic. The requirement to maintain a constant ρ to each node in the network complicated the process of determining the actual message arrival rate required at each node. Since all possible destinations of a message are equally likely, one-sixth of the messages arriving to node one will terminate at each of the six remaining nodes. Similarily, one-fifth of the messages generated at node 2 will terminate at each of the five

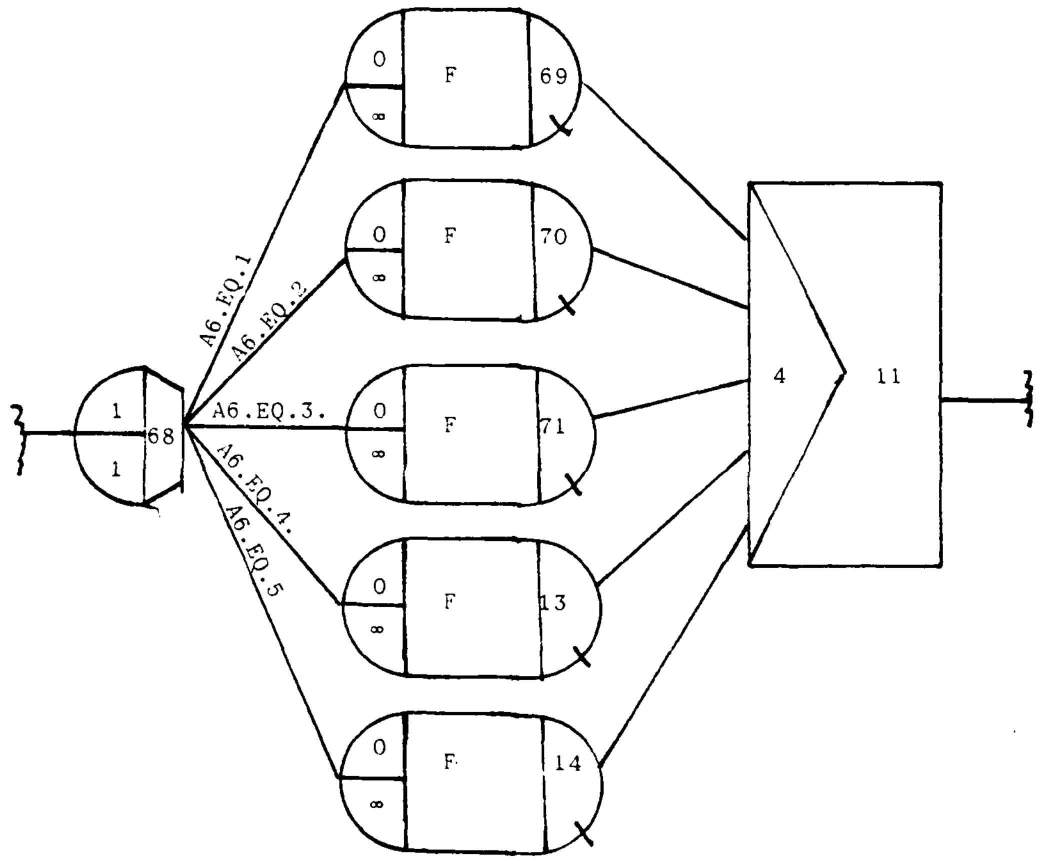


Figure 4. Packet Reassembling Process for 5000 bit messages

remaining nodes, nodes 3 thru 7. Therefore, the arrival rate of messages generated at node 2 will be one-sixth of the rate to node 1 and the arrival rate of messages generates at node 3 will be one-sixth of the rate of node 1 plus one-fifth of the rate of node 2, etc. Table V lists the external traffic intensities required at each node to maintain a constant traffic intensity throughout the network model.

Table V

External Traffic Intensity Required
to Maintain the Same Intensity at
Each Network Node

Desired ρ	External Traffic Intensity at Each Node: 1	2	3	4	5	6	For Packet-Switched Only: A-1*	A-2*
0.1	0.1	0.0167	0.02	0.025	0.0333	0.05	0.075	0.075
0.25	0.25	0.0417	0.05	0.0625	0.0833	0.125	0.1875	0.1875
0.50	0.50	0.0833	0.1	0.125	0.1667	0.25	0.375	0.375
0.75	0.75	0.125	0.150	0.1875	0.25	0.375	0.5625	0.5625

*The ρ values for the alternate nodes are 75 percent of the value for node 1 because of the probabilistic routing used to simulate the packet-switched network which sends 25 percent of the messages entering node 1 to the alternate path. The messages originating at the alternate path nodes were assumed to have a constant path length of 1. Therefore, the external intensity required at each node is the same since the only internal arrivals to the nodes are the messages originating at node 1.

The actual message arrival rate to each node can now be determined from the traffic intensities given in Table V. The following equation was used to determine the message arrival rates to each node (13).

$$\Lambda = \frac{\rho_i U}{M_L} \qquad (8)$$

where λ = average arrival rate in messages/sec.

P_i = external intensity required at the ith node from Table V.

U = message service rate (fixed at 50,000 bits/sec in this study).

M_L = message length in bits.

In order to input the message arrival rate into the model, the values calculated from equation 8 must be inverted. The Q-Gert language models the message arrival process as the time until the next arrival and not in arrivals per second, thus the value must be inverted to be used in the parameter specification. The exponential parameter specification requires three values to be specified, the average time between arrivals, the maximum time between arrivals and the minimum time between arrivals. The maximum time was set equal to the larger of 1 or twice the average rate. The minimum time was determined by assuming the capacity of the external input channel was 50,000 bit/sec and calculating the time required to input the message with the underlying assumption being only one message can be input to the node at a time.

The models were made to terminate after 100 messages had passed through the statistics gathering node. Since only messages originating at node 1 are measured and all possible destinations have an equal probability, the minimum number of messages input at node 1 will average 600. One hundred messages were used in order to allow the queues to reach equilibrium, since the queues were empty at the start of each simulation. Using 100 messages through the statistics node did minimize the effect of starting the simulation with the queues empty. This was verified by increasing the number of messages to end a simulation to 300 with all other inputs being the same.

The differences in the average delays and standard deviations between the two simulations was not significant. The next section discusses the results obtained in comparing the circuit switched and packet-switched models.

Comparison Results

The inputs and results of the 81 simulation runs of the packet-switched and circuit-switched models are listed in Tables VI thru and VIII for the circuit-switched model and in Tables IX thru XI for the packet-switched model. The results in these tables were plotted on graphs in order to provide a method of predicting performance with other input parameters.

Figures 5, 6, and 7 plot delay versus traffic intensity for message lengths of 1000, 3000, and 5000 bits. Figure 8, 9, and 10 plot delay versus number of channels for message lengths of 1000, 3000, and 5000 bits. Figures 11, 12, and 13 plot delay versus path length for the same message lengths. The following conclusions were drawn from Figures 5 thru 13 and confirm the previous work by Kleinrock and Miyahara (4);

1. The delays in a circuit-switched network increase at a greater rate with increases in traffic intensity than the packet-switched network.
2. Increases in path length have a greater impact on delays in a packet-switched network than a circuit-switched network. For large message lengths the differences in delays for different path lengths are insignificant for circuit-switching.
3. Increasing the number of channels only degrades the packet-switched network. However, improvements can be obtained by increasing channels in the circuit-switched network especially for larger traffic intensity values.

4. Increases in message length produce smaller increases in delays in the circuit-switched network than the packet-switched network.

The conclusions listed above along with Figures 5 thru 13 confirm neither the packet-switched nor the circuit-switched networks produce the minimum delays in all situations. The switching technique to be used should be selected on the factors of message length, path length, traffic intensity, and the number of channels. However, these factors are continually changing during the operation of a network. One possible solution to the problem is to design the switching-technique to change between packet-switching and circuit-switching as the factors change. The combination of the two methods is called hybrid switching. Figures 5 thru 13 can be used to determine which switching technique the hybrid-switching system should select. A hypothetical hybrid switching network can now be modeled with Figures 5 thru 13 providing the switching technique selection criteria. The next step in the study was to model this network.

Table VI
Circuit-Switched simulation
Inputs and Results

Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
1000	2	0.25	1	0.0475	0.0387
			4	0.1149	0.0108
			8	0.2246	0.0050
		0.50	1	4.6107	2.6546
			4	0.1994	0.1514
			8	0.2394	0.0325
		0.75	1	11.6701*	8.4566
			4	8.9491	5.3834
			8	4.6091	2.5074
	4	0.25	1	0.0521	0.0326
			4	0.1302	0.0088
			8	0.2562	0.0020
		0.50	1	4.0473	2.6081
			4	0.2283	0.1451
			8	0.2878	0.0553
		0.75	1	6.1294*	5.2876
			4	7.3455	4.1763
			8	3.8908	2.0168
	6	0.25	1	0.0621	0.0422
			4	0.1493	0.0153
			8	0.2886	0.0055
		0.50	1	4.1214	2.6393
			4	0.2776	0.1572
			8	0.3290	0.0564
		0.75	1	8.3626*	6.3110
			4	7.2765	4.1826
			8	4.0434	2.0144

Table VII

Circuit-Switched Simulation

Inputs and Results

Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
3000	2	0.25	1	0.0804	0.0255
			4	0.2721	0.0013
			8	0.5440	0.0000
		0.50	1	0.4309	0.4682
			4	0.2872	0.0508
			8	0.5471	0.0186
		0.75	1	35.6843	19.6655
			4	2.8835	1.1516
			8	0.8692	0.4276
	4	0.25	1	0.0905	0.0353
			4	0.2897	0.0105
			8	0.5760	0.0000
		0.50	1	0.4309	0.4503
			4	0.3257	0.0845
			8	0.5867	0.0374
		0.75	1	32.3050	17.5568
			4	2.8942	1.3018
			8	0.9460	0.4074
	6	0.25	1	0.1185	0.0678
			4	0.3091	0.0148
			8	0.6080	0.0000
		0.50	1	0.5894	0.5911
			4	0.3711	0.1033
			8	0.6277	0.0522
		0.75	1	35.2774	20.0734
			4	3.0953	1.1735
			8	1.0741	0.4823

Table VIII

Circuit-Switched Simulation
Inputs and Results

Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
5000	2	0.25	1	0.1440	0.0822
			4	0.4320	0.0000
			8	0.8640	0.0000
		0.50	1	0.4768	0.4180
			4	0.4552	0.0728
			8	0.8666	0.0135
		0.75	1	67.9457*	43.1642
			4	2.4369	1.6929
			8	0.9529	0.1802
	4	0.25	1	0.1481	0.0766
			4	0.4538	0.0252
			8	0.8971	0.0108
		0.50	1	0.6251	0.5511
			4	0.4933	0.1013
			8	0.9119	0.0531
		0.75	1	59.7457	38.6407
			4	2.5502	1.6646
			8	1.1839	0.3939
	6	0.25	1	0.1826	0.0990
			4	0.4719	0.0318
			8	0.9280	0.0000
		0.50	1	0.6085	0.5207
			4	0.5316	0.1195
			8	0.9549	0.0751
		0.75	1	70.4840*	39.8049
			4	2.9972	1.6705
			8	1.2552	0.3257

Table IX
Packet-Switched Simulation Results
Inputs and Results

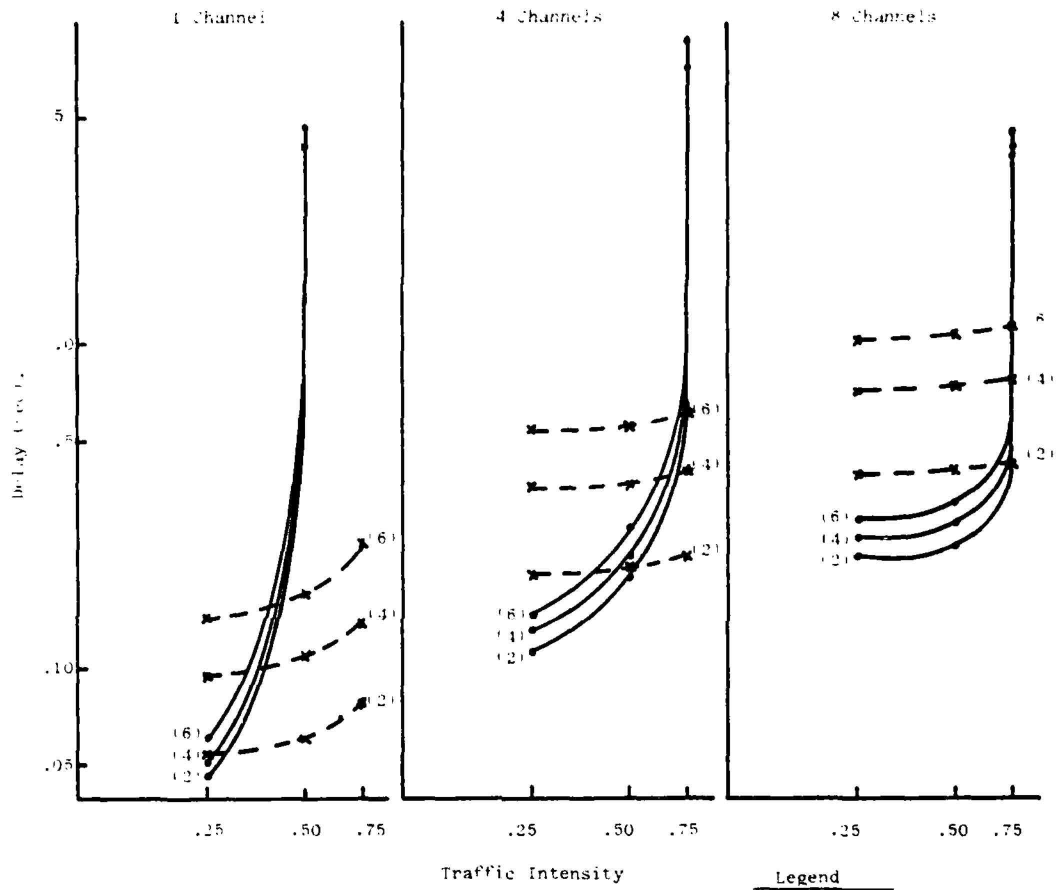
Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
1000	2	0.25	1	0.0552	0.0175
			4	0.1986	0.0397
			8	0.3960	0.0766
		0.50	1	0.0611	0.0217
			4	0.2081	0.0448
			8	0.4090	0.0824
		0.75	1	0.0795	0.0373
			4	0.2227	0.0571
			8	0.4270	0.0934
	4	0.25	1	0.0958	0.0118
			4	0.3663	0.0312
			8	0.7286	0.0614
		0.50	1	0.1107	0.0250
			4	0.3762	0.0372
			8	0.7421	0.0729
		0.75	1	0.1434	0.0496
			4	0.4038	0.0542
			8	0.7693	0.0898
	6	0.25	1	0.1423	0.0132
			4	0.5500	0.0364
			8	1.0954	0.0747
		0.50	1	0.1703	0.0335
			4	0.5653	0.0432
			8	1.0955	0.0701
		0.75	1	0.2408	0.0857
			4	0.6370	0.1039
			8	1.1602	0.1119

Table X
Packet-Switched Simulation
Inputs and Results

Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
3000	2	0.25	1	0.1016	0.0262
			4	0.2429	0.0558
			8	0.4629	0.0926
		0.50	1	0.1262	0.0401
			4	0.2532	0.0608
			8	0.4607	0.0943
		0.75	1	0.1951	0.0944
			4	0.3306	0.1034
			8	0.5444	0.1292
	4	0.25	1	0.1583	0.0348
			4	0.4236	0.0499
			8	0.8100	0.0857
		0.50	1	0.2113	0.0680
			4	0.4764	0.0744
			8	0.8482	0.0897
		0.75	1	0.3403	0.1564
			4	0.5888	0.1604
			8	0.9496	0.1667
	6	0.25	1	0.2327	0.0725
			4	0.6165	0.0709
			8	1.1577	0.0906
		0.50	1	0.3305	0.1110
			4	0.6985	0.1118
			8	1.2410	0.1220
		0.75	1	0.5400	0.2469
			4	0.9273	0.2277
			8	1.4341	0.2405

Table XI
Packet-Switched Simulation Results
Inputs and Results

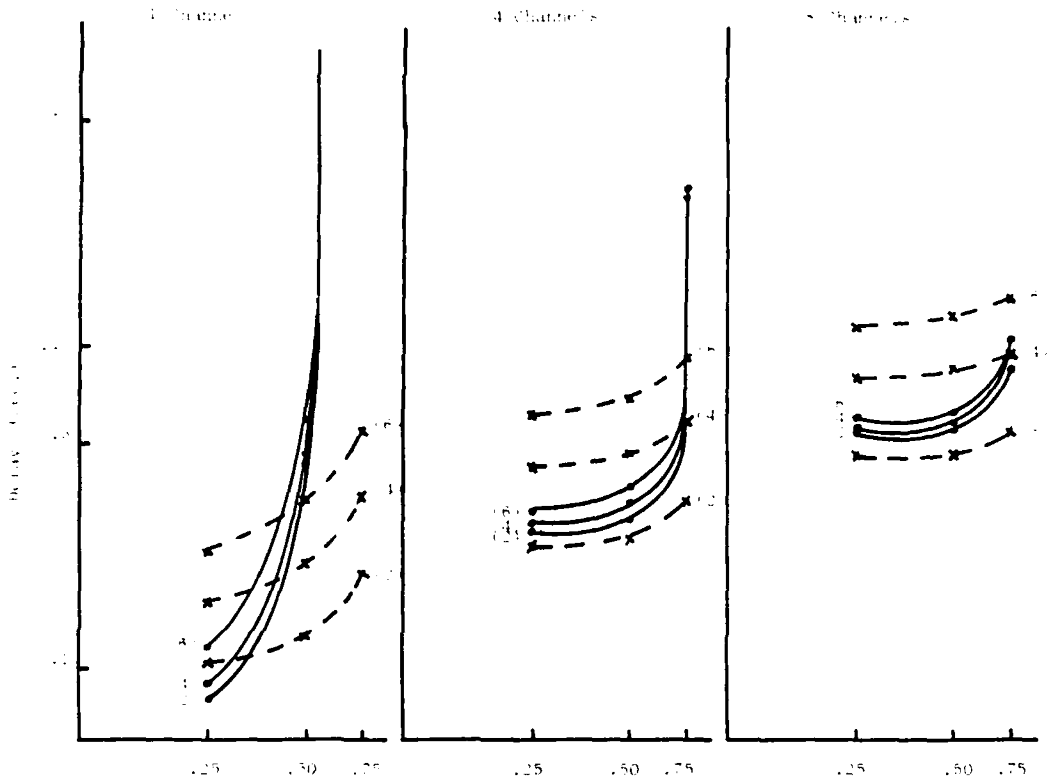
Message Length	No. of Hops	Intensity	No. of Channels	Avg Delay	Std. Dev.
5000	2	0.25	1	0.1518	0.0363
			4	0.2895	0.0420
			8	0.5087	0.0701
		0.50	1	0.1885	0.0635
			4	0.3291	0.0747
			8	0.5422	0.0989
		0.75	1	0.2825	0.1267
			4	0.4226	0.1308
			8	0.6210	0.1461
	4	0.25	1	0.2268	0.0754
			4	0.4857	0.0597
			8	0.8551	0.0876
		0.50	1	0.2982	0.1166
			4	0.5735	0.1223
			8	0.9503	0.1385
		0.75	1	0.5291	0.2318
			4	0.7912	0.2418
			8	1.1458	0.2611
	6	0.25	1	0.3184	0.0925
			4	0.7084	0.0957
			8	1.2561	0.1005
		0.50	1	0.5043	0.1836
			4	0.8420	0.1805
			9	1.3928	0.1766
		0.75	1	0.8704	0.2900
			4	1.2700	0.3126
			8	1.7585	0.3023



Legend

Packet-Switched ---
Circuit-Switched ____
Path Length (X)
Header Length = 100 Bits
Capacity = 50000 Bits/Sec

Figure 5 Delay vs Traffic Intensity for 1000 Bit message



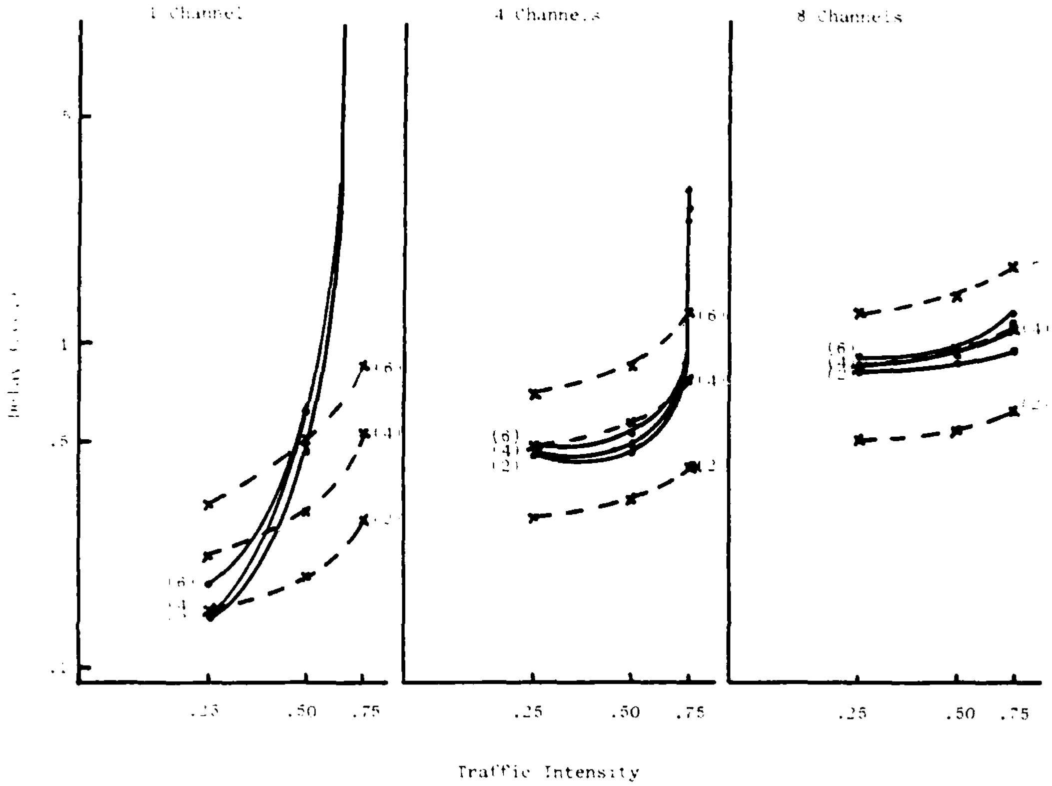
Traffic Intensity

Legend

Packet-Switched ---
Circuit-Switched ____

Path Length (X)
Header = 100 Bits
Capacity = 50000 Bit/sec

Figure 6 Delay vs. Traffic Intensity for 3000 Bit Messages

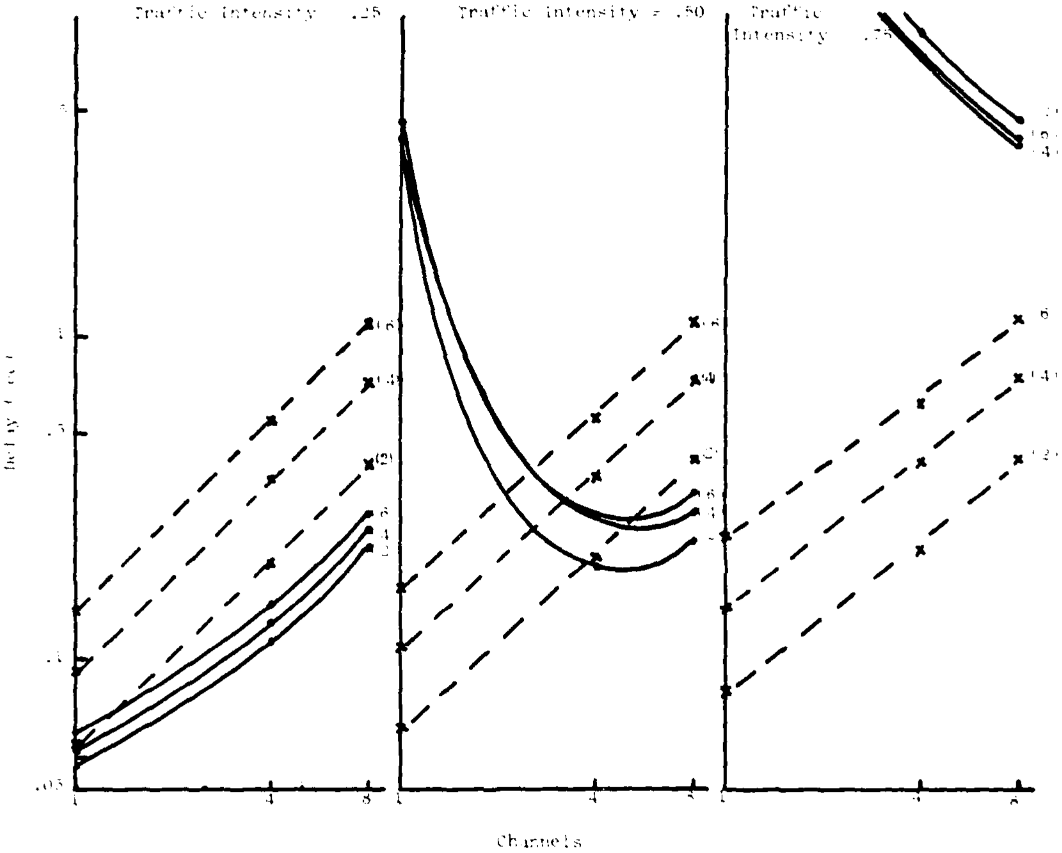


Legend

Packet-Switched ---
Circuit-Switched ________

Path Length (X)
Header = 100 Bits
Capacity = 50000 Bit sec

Figure 7 Delay vs. Traffic Intensity
for 5000 Bit Message



Legend

Packet-Switched ---
Circuit-Switched ______

Path Length (X)
Header = 100 Bits
Capacity = 50000 Bits sec

Figure 8 Delay vs. Channel
for 1000 Bit Messages

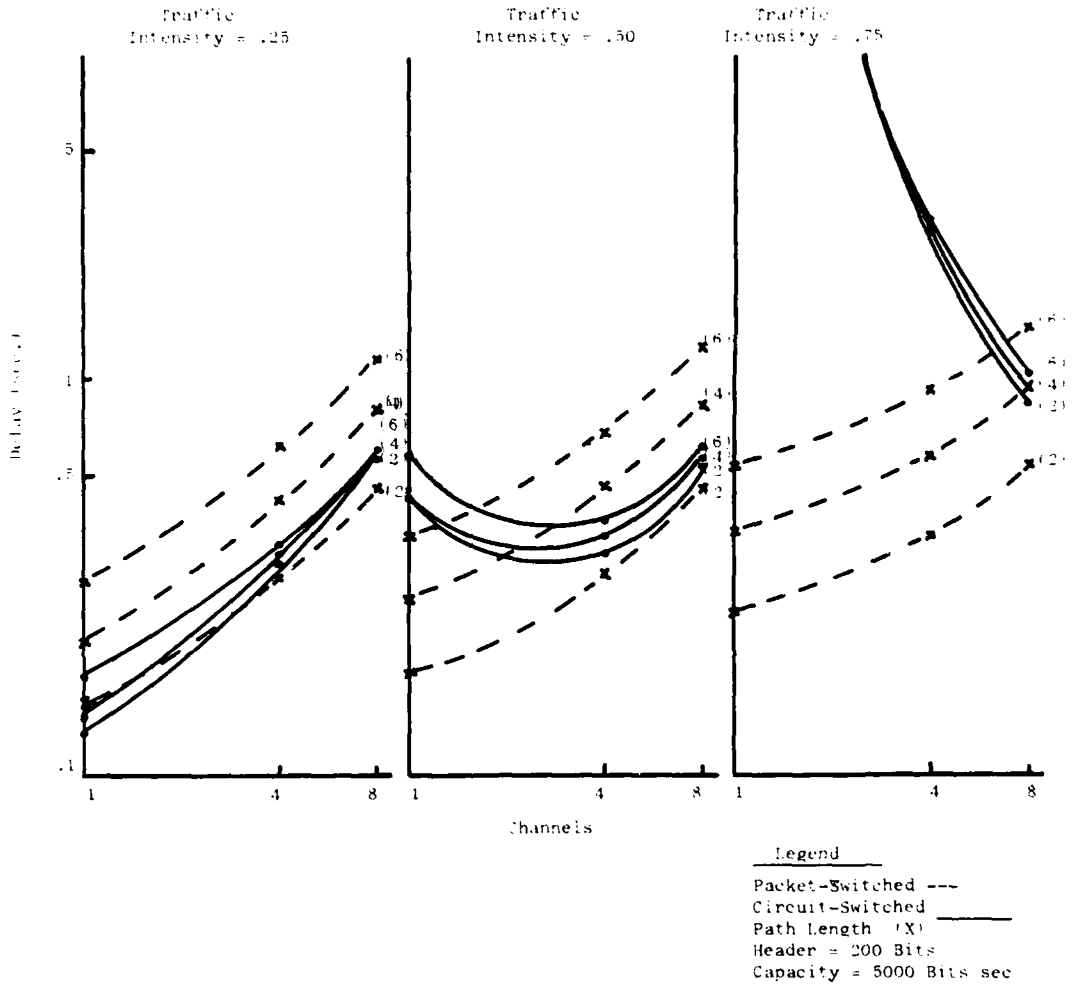


Figure 9 Delay vs. Channels
For 3000 Bit Messages

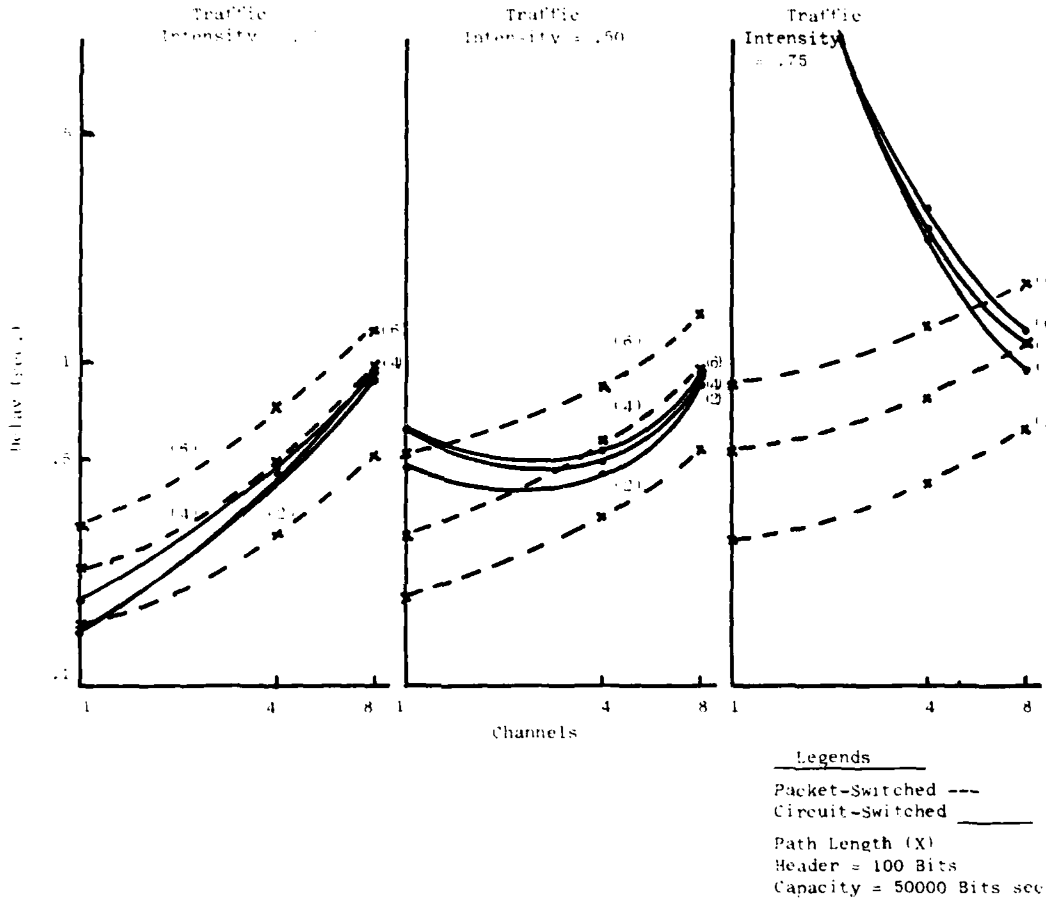
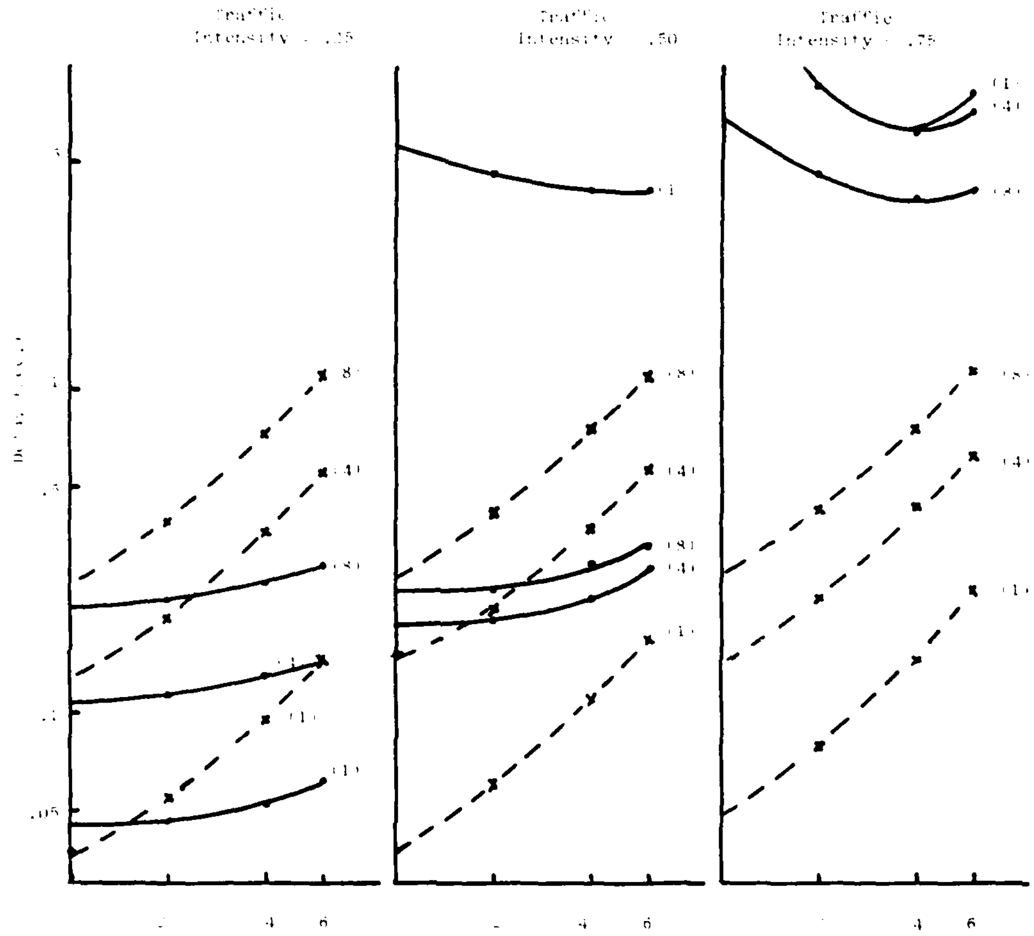


Figure 10 Delay vs. Channels
for 5000 Bit Messages



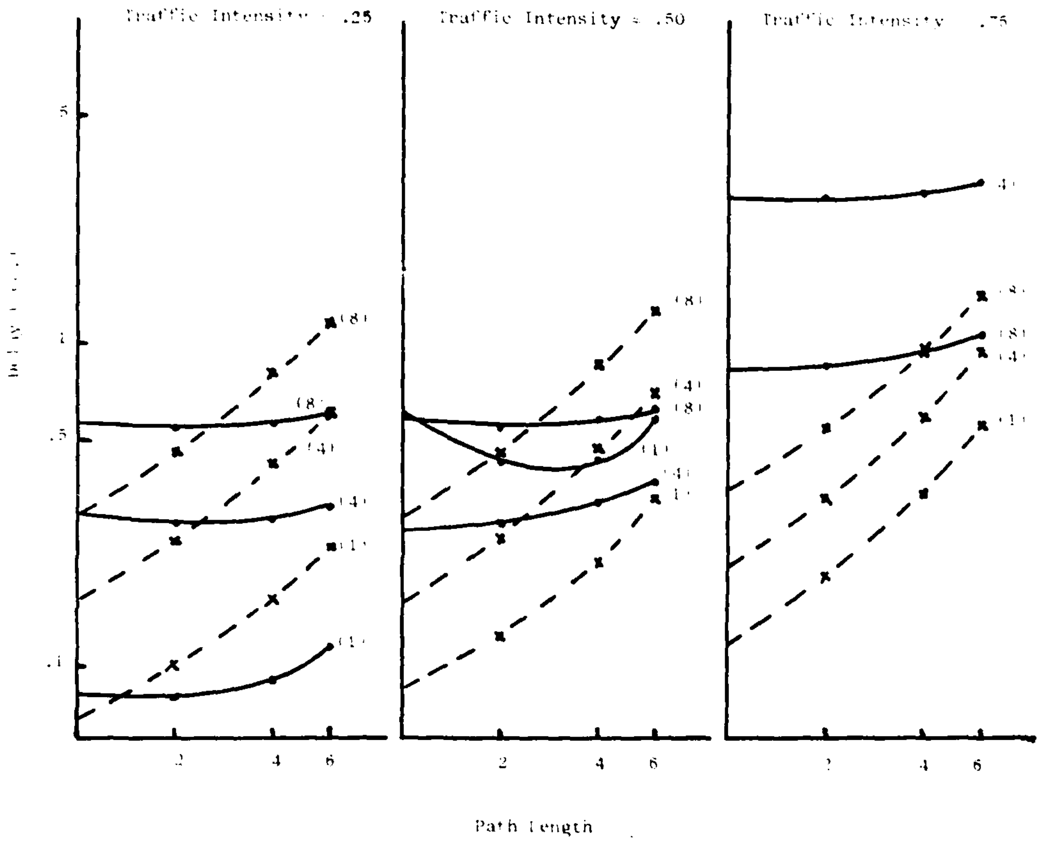
Path Length

Legends

Packet-Switched ---
Circuit-Switched ____

Channels (X)
Header = 100 Bits
Capacity = 500000 Bits sec

Figure 11 Delay vs. Path Length for 1000 Bit Messages



Legends

Packet-Switched ---
Circuit-Switched ___

Channels (X)
Header = 100 Bits
Capacity = 50000 Bits sec

Figure 12 Delay vs. Path Length for 3000 Bit Messages

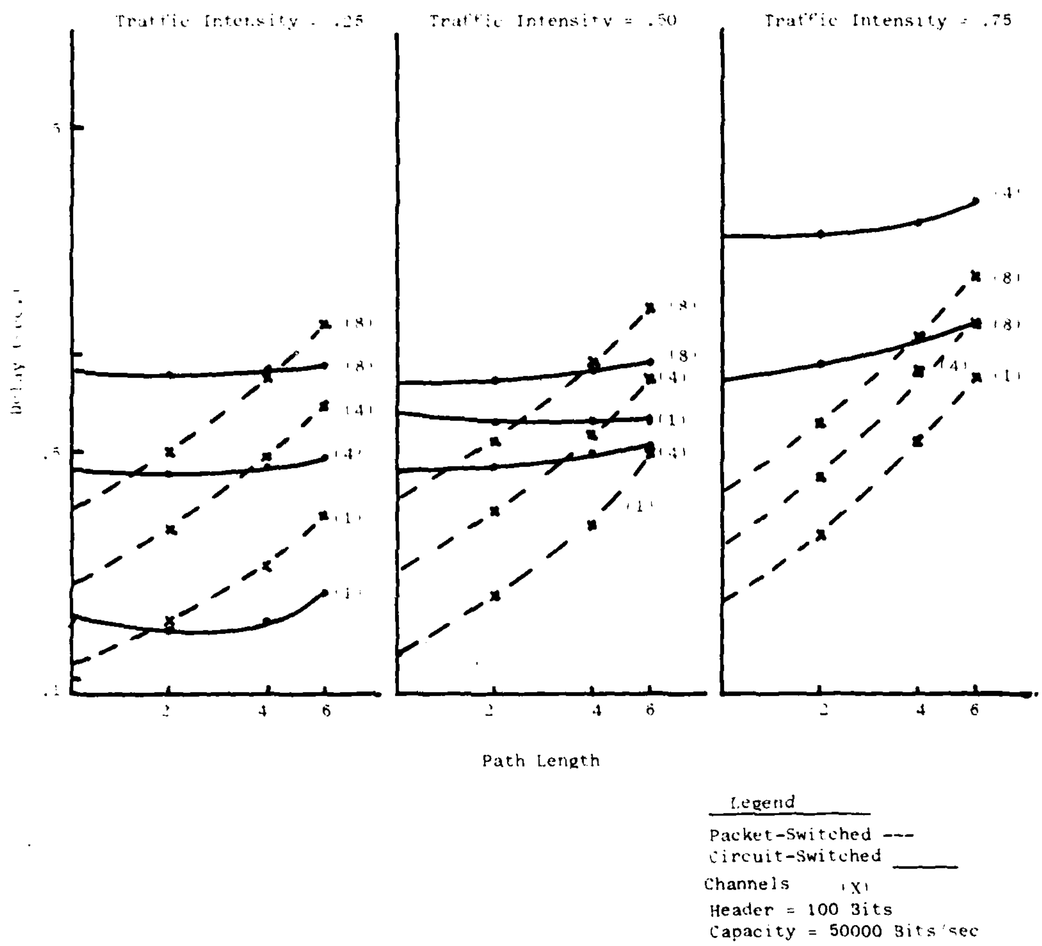


Figure 13 Delay vs. Path Length
for 5000 Bit Messages

Chapter 4

Hybrid Switching Model

Introduction

This chapter describes the development of the hybrid switching network simulation model. The development of the switching technique selection criteria in Chapter 3 was necessary prior to construction of the model. The switching technique selection criteria enables the model to determine which switching technique will provide the shortest delays for the current values of the path length, message length, traffic intensity and number of channels.

Prior to the construction of the hybrid switching simulation model the operation of the hypothetical hybrid switching network must be defined. A proposed method of operation for the hybrid switched network is the topic of the next section. The following section describes the design of the hybrid switched simulation model. The concluding section of this chapter describes the procedures used to validate and verify the hybrid switched simulation model.

Proposed Operation of a Hybrid-Switched Network

Hybrid-switching, as previously defined for this study, is a switching technique which is capable of operating as either a circuit-switching or packet-switching network. The switching technique the network uses is determined by the message length, the path length over which the message is to be transmitted, the number of channels, and the network traffic intensity, ρ . In order to develop a simulation model of any system, a clear understanding of how the system operates is necessary. However, the hybrid-switching system, as described, does not exist. The following paragraphs are devoted to describing one possible method of operation for the hybrid-switching network.

When a transmission arrives at a node in the hybrid-switched network, the node must determine the type of transmission. The arrival could be either a new message which is just entering the network, a packet forwarded from another node, or a channel-reservation signal. If the arrival is a new message, the node makes a decision on whether the message should be transmitted using a circuit-switching or packet-switching technique. However, if the arrival is either a packet or channel-reservation signal, the node simply forwards the arrival to the intended destination. The decision to packet-switch or circuit-switch only occurs at the node where the message enters the network. Once a switching technique is selected for a particular message, it is never changed.

If an arrival is a new message entering the network, the message length is known. The routing algorithm, which is a minimum path algorithm, determines the path the message will follow to its destination. Once the routing algorithm determines the path, the path length is known. The number of channels is dependent upon the network design and is a constant in the decision making process. The only remaining input needed by the decision making process is the traffic intensity.

The network traffic intensity value used in the decision making process could be either the average traffic intensity of the entire network, the traffic intensity of the node making the decision, the traffic intensity at the destination node, or the traffic intensity of a node along the intended message path. However, the network uses the largest traffic intensity value of a node along the path as the input to the decision making process. The network uses this value for the following reasons:

1. The average traffic intensity of the entire network does not always reflect the loading of the path selected for the message transmission. For instance, the average network intensity could be 0.25 but the average along the selected path could be 0.50. Clearly in this case, basing the switching decision on the average network traffic intensity would not produce optimal results.
2. The traffic intensity of the entry or destination node may not always reflect the loading of the selected path. For example, the traffic intensity of the entry or destination node might be 0.10, while the traffic intensity of a node along the path could be 0.25. If the decision on which switching method to use was based on the smaller value, the decision may not produce the smallest delays.
3. The largest traffic intensity at a node along the path will prevent selection of a switching method with an unseen bottle neck. As the message moves along the selected path, the longest delay for service will be at the node with the greatest traffic intensity because the number of messages waiting for service will be equal to or greater than the other nodes along the path. Therefore, the decision on which switching technique to use is based upon this value.

After deciding which traffic intensity value to use in the decision process, the method of providing each node with the traffic intensity of the other nodes must be determined. The hybrid network is assumed to have separate transmission lines over which the traffic intensity of each node is periodically sent to the other nodes. The separate transmission lines are not used for any purpose other than updating the traffic intensities and are not counted in the message transmission capacity. The system operates in the same manner as the ARPANET routines tables (13).

Once the values for message length, path length, traffic intensity, and number of channels are determined, the system selects the switching technique. The technique providing the shortest delay with the particular set of input values is selected. The message is then transmitted in the same manner as a packet-switched or circuit-switched message depending upon the selected method.

The design of the hybrid-switching simulation model can now begin since the operation of the proposed hybrid-switching network has been defined The design of the simulation model will be discussed in the next section.

Hybrid-Switching Model Design

The hybrid-switching model was designed by combining the circuit-switching and packet-switching models. The model was designed in this fashion to ensure the variations in message delay between models were due to the switching technique and not to differences in implementation. The Q-Gert design charts for the hybrid switching model are contained in the appendix and should be referenced in conjunction with the following paragraphs.

The topology of the hybrid-switching model is identical to the packet-switched model. In additional to the topology, the same basic assumptions made for the circuit-switched and packet-switched models were also made for the hybrid-switched model. These assumptions are as follows:

1. The nodes are connected by one or more channels but, regardless of the number of channels, the total capacity of the line or lines is 50,000 bits/second.

2. External messages arrive at each node at an exponential rate of   messages/second.
3. The message lengths are known and therefore the service rate is fixed and not exponential.
4. The message destinations are uniformly distributed between nodes, except for the alternate nodes.
5. The channels are full-duplex, however, the model will only be concerned with traffic flowing in one direction.
6. The circuit-reservation signal, request-for-transmission signal, channel-release signal and the packet header are each 100 bits in length.
7. Each packet contains 1000 bits of a message plus the packet header.
8. The messages entering the network at alternate nodes one and two are terminated at the next node.
9. The messages entering the network are packetized at the entry node.
10. The routing algorithm is the shortest path algorithm.

The Q-Gert source node was again used to generate the message arrivals as it was in the packet-switched and circuit-switched models. However, the attributes assigned to each generated message are different. The message entry node number, the destination of the message, and the message number are assigned to the message attributes as decribed earlier. In addition to these assignments, the path length was assigned to the message at the source node.

The path length was calculated by using a Q-Gert feature which allowed values to be added or subtracted from an attribute value. In order to calculate the path length, the destination was assigned to the message attribute which represented the path length. Next, the attribute value which represented the entry node of the message was subtracted from the path length attribute. The value of the path length attribute was then equal to the actual path length of the message.

The messages leaving the source node enter a probabilistic branching node which allows different message lengths to be in the network at the same time. Once the message length is determined, the model next selects the switching method to use.

The selection of the switching technique is based on the largest traffic intensity of any node along the path, the message length, the number of channels, and the path length. However, the message length, number of channels and traffic intensity, which was assumed to be the same at each node, were input by the user. The path length was determined by the model. Therefore, the selection was based upon the path length with the other factors treated as constants. The delay vs. path length graphs in Figures 11 thru 13 were used to select the switching technique.

After the message length is selected, the messages are sent to a conditional branching node. This node selects the switching method to be used for the particular message based upon the path length. If the circuit-switching method is selected, the message is sent to a node which assigns attribute values to messages. A one is assigned to an attribute to identify the switching method being used as circuit-switching. The time to send the channel reservation signal is assigned to another attribute. The time to transmit the request-for-transmission signal, the message, and the channel-release signal is the final attribute assignment made at this node. These times are determined exactly as described in the circuit-switch model design. The message is next sent to the queue node to await a channel to be assigned.

If the packet-switched method is selected, the message is also sent to a node to have attributes assigned. A two is assigned to an attribute to identify the switching method as packet-switching. The number of packets in the message is also assigned to an attribute. The final attribute assignment made at this node is the time to transmit the packet which is based on the number of channels. Duplicate messages are generated by this node, each message represents a packet, and sent to nodes which assign each packet a number. The packets are then routed to a probabilstic branching node which sends 75 percent of the packets to the queue node to await a channel to be assigned. The remaining 25 percent are sent to the alternate node to wait for a channel to be assigned. This process is used to simulate the alternate paths allowed by the packet-switching technique and is the the same method that was used in the packet-switching model. The arrival process, as described above, is repeated for the messages generated at each node.

The message or packet is removed from the queue after a channel assignment is made and sent to a conditional-branching node. If the switching method being used is circuit-switching, the message is delayed for a time period equal to the time required to transmit the channel-reservation signal between two adjacent nodes and sent to another conditional branching node. The message is checked to see if the destination is the next node in the network. If the next node is the destination, the message is delayed for a time period equal to the total time required to send the request-for-transmission signal, the message, and the channel-release signal. Next, the message entry node is determined, the message channels assigned to the message are released and statistics are gathered following the same procedure described in the circuit-switched model design. However, if the next node is not the destination, the message is placed in the queue awaiting channel assignments at the next node. The above process is then repeated until the destination is reached.

If the switching method being used is packet-switching, the packet is delayed for a time period equal to the time required to transmit a packet. After the delay, the packet is forwarded to a free node which releases the channel assigned to the packet and checks if the next node is the destination. If the next node is not the destination, the packet is placed in the queue to await channel assignment at the next node and the above process is repeated until the destination is reached. If the next node is the destination, the packet is sent to a conditional-branching node which routes the packets entering the network at node 1 to the statistics gathering routine as previously described in the packet-switching model. However, if the packet entered the network at another node, the packet is routed to a node which removes the packet from the network.

The hybrid-switching network is designed to allow statistics to be gathered on the total network or on any single or combination of path lengths. The nodes at which statistics are gathered are connected to the statistics node in the same way as the circuit-switched model for circuit-switched messages and as the packet-switched model for packet-switched messages.

The hybrid-switching network design has been briefly described in the above paragraphs. A more complete description is available in the appendix via the design charts. After completing the design, the hybrid-switching model required validation and verification prior to using the simulation results. The validation and verification of the hybrid model was the next requirement of this study.

Validation and Verification

The approach used to validate and verify the hybrid-switching mode is similar to the methods used for validation and verification of the circuit and packet switching models. In fact, the validation method is identical to the method used on the packet and circuit switching models. However, the verification was simplified because of the existence of the packet-switching and circuit-switching models.

The validation of the hybrid-switching model was accomplished by exercising the model and using the total simulation time and the total number of transactions passing through each node to verify the arrivals generated by the model were equivalent to the arrival rate desired by the user. The information provided on the transactions passing through each node was also used to verify the transactions were flowing through the model, as intended. This information demonstrated that the model was performing as expected.

The verification of the hybrid-switching model was accomplished by forcing the model to perform like a packet-switching network and comparing the results to the results produced by the packet-switched model. The hybrid-switching model was then set-up to perform like a circuit-switching network and the results compared to those produced by the circuit-switched model. The hybrid-switching model was made to perform as a circuit or packet-switching network by changing the conditional-branching nodes which are used to produce the different message lengths and by forcing the model to always select either the packet switching or circuit switching technique.

The hybrid-switching model, altered to either perform as a packet-switched or circuit-switched model, was run with a message length of 3000 Bits, traffic intensities of 0.25 and 0.50, one and four channels, and path lengths of 4 and 6. The delays calculated by the hybrid-switching model configured to operate as a circuit-switching network were equivalent to the delays calculated by the circuit-switching model. The results produced by the hybrid-switching model configured to operate as a packet-switching network were equivalent to the results produced by the packet-switching model. Based on the above results, the hybrid-switching model is considered to be verified.

The completion of the validation and verification of the hybrid-switching model allows the model to be compared with the packet-switching and circuit-switching models. The comparison will demonstrate if the hybrid-switching technique provides any improvement in delays over the circuit and packet-switching techniques. Conducting the comparison and analyzing the results were the next items accomplished in the study.

Chapter 5

Comparison of Hybrid, Packet and Circuit Switching

Introduction

This chapter describes the comparison of the three switching models. The circuit switching, packet switching, and hybrid switching models were compared to determine their performance in minimizing message delays.

The next section develops the comparison method and describes the inputs and switching selection criteria used in the hybrid model. In the following section, the results of the comparison are presented and analyzed. In the next section conclusions are made about the three switching techniques. The concluding section presents recommendations for additional study on this topic.

Comparison Methods and Inputs

The method of comparing the three switching techniques is similar to the method used to compare circuit-switching to packet switching in Chapter 3. The three simulation models were exercised under the same conditions and the resulting message delays were used to compare the effectiveness of each technique. The simulation models were operated under the following conditions;

1. Traffic intensities were 0.25, 0.50, or 0.75.
2. The number of channels was 1 or 4.
3. The path lengths were 2, 4, or 6.
4. The messages input to the models for each run were equally divided between 1000 bits and 5000 bits.

The values for the path length, traffic intensity, and channels were chosen because of their use in determining the switching selection criteria which determined the mode of switching the hybrid-switching model used. The message lengths were selected to provide short messages (1000 Bits) which favor packet-switching and long messages (5000 Bits) which favor circuit-switching. In order to determine the effect of changing the traffic intensity, path length, and channels on each model, only one factor was changed while the others remained constant in each simulation run. The number of simulations required for each model was 18. Additionally, each model was run to determine the average delay of the network for the above traffic intensities and channels which required 6 simulations. The total number of simulations required for each model was 24.

The inputs to the circuit-switched and packet-switched models are almost identical to those described in Chapter 3. However, two differences exist in the traffic intensity input and the message lengths. First, the traffic intensity was based upon message length but the message length was either 1000 or 5000 Bits for this comparison. In order to determine the traffic intensity, the average message length was calculated and this figure was used to determine the message arrival rate required to generate the desired intensity. The average message length was calculated to be 3000 Bits since 50 percent of the messages entering the network were 1000 Bits and the remaining 50 percent were 5000 Bits. Second, allowing message lengths of 1000 Bits and 5000 Bits to be of equal probability required the conditional branching node in each model to have the probability of selecting each branch set to equal to 0.5. The remaining inputs to the packet-switched and circuit-switched models were identical to those discussed in Chapter 3.

The inputs to the hybrid-switched model were identical to those described for the packet and circuit-switched model for the traffic intensity, path length, number of channels, and message lengths. However, the hybrid-switched model required the switching selection criteria to also be input. The switching selection criteria was determined from the path length vs. delay graphs developed in Chapter 3. The path length vs. delay graphs were used becuase the number of channels, message length, and traffic intensity parameters were user inputs for these models. However, the model generated the destination and therefore the path length for each message. Since the models allowed messages of 1000 and 5000 Bits the corresponding graphs for the number of channels and the traffic intensities were used to determine the switching method which the hybrid-switching model selected. The selction criteria used in the hybrid switching model was based on the path length. The path length was determined by subtracting the message entry node from the message destination which was generated from a uniform distribution with a minimum value of zero and a maximum value of seven. Therefore, a value of less than 1 corresponded to a path length of 1 and a value of less than 2 but equal to or greater than 1 corresponded to a path length of 2, etc. The path length was assigned to attribute 4 in the hybrid model. The model selected the switching method to use based on Table XII which was derived from the graphs in Chapter 3. The values for attribute 4 were used as selection conditions for the conditional branching node which routed the message to either the circuit-switching of packet-switching method.

Table XII

Switching Technique Selection
Criteria for the Hybrid Model

Message Length	No. of Channels	Traffic Intensity	Select Circuit Switching if	Select Packet Switching if
1000	1	0.25	A4 ≥ 1	A4 < 1
		0.50	A4 ≥ 7	A4 < 7
		0.75	A4 ≥ 7	A4 < 7
	4	0.25	A4 ≥ 1	A4 < 1
		0.50	A4 ≥ 1	A4 < 1
		0.75	A4 ≥ 7	A4 < 7
5000	1	0.25	A4 ≥ 1	A4 < 1
		0.50	A4 ≥ 7	A4 < 7
		0.75	A4 ≥ 7	A4 < 7
	4	0.25	A4 ≥ 3	A4 < 3
		0.50	A4 ≥ 3	A4 < 3
		0.75	A4 ≥ 7	A4 < 7

A4 = Attribute 4

The models were designed to measure the delay of only the messages which entered the network at node 1. Statistics can be obtained on any length of path by changing the inputs to the statistics node. The procedure for changing the path length for the circuit switching and packet switching models was previously described in Chapter 3. The hybrid switching model path was changed to obtain the desired path length by making the connections in Table XIII. The node numbers in Table XIII correspond to the node numbers in the design charts in the appendix. After establishing the comparison method and determining the inputs, the next task in this study was to make the simulation runs and analyze the results.

Table XIII

Path Length Connections
for the Hybrid Switched Model

Desired Path Length*	Nodes to be Connected	Statistics Nodes
1	29	95
	31	88 if A1.EQ.1
	31	38 if A1.NE.1
2	43	95
	46	88 if A1.EQ.1
	46	38 if A1.NE.1
3	51	95
	55	88 if A1.EQ.1
	55	38 if A1.NE.1
4	60	95
	65	88 if A1.EQ.1
	65	38 if A1.NE.1
5	70	95
	76	88 if A1.EQ.1
	76	38 if A1.NE.1
6	81	95
	87	88 if A1.EQ.1
	87	38 if A1.NE.1

*In order to measure the average message delay for the entire network, all the above connections are required.

Results

The input paramters and results from the simulations of the hybrid switching, the packet switching and the circuit switching models are listed in Tables XIV thru XVI. The data from these tables is presented in graphs in figures 14 thru 16.

These graphs show the hybrid switching technique closely paralleling the switching technique which produces the smallest delays. In Figure 14, for example, the hybrid switched model closely paralleled the circuit switched model when the traffic intensity was 0.25 but paralled the packet switched model when the traffic intensity was either 0.50 or 0.75. In Figure 16 the average network delay was plotted against the traffic intensity. The hybrid switching model again closely paralleled the technique which produced the smallest delay.

The delays from the hybrid switching model and the delays from the technique which produced the smallest delays were examined to determine if the differences were significant. The results were tested at the 0.05 level of significance using the hypotheses test concerning two means (8). The hypotheses test proved some of the points tested were not significant. However, for example, in Figure 14 for a traffic intensity of 0.75 the difference between the hybrid switched model and the packet switched model (technique producing the smaller delay) was significant for path lengths of 2 and 6. Since the hybrid switching model always selects the packet switching technique at this level of traffic intensity, the delays from the two models should have been equivalent.

The significant difference between the hybrid switching model and the packet switching model was attributed to the workloads not being identical. The workloads were not identical because, although each model used the same seed in the random number generator, the same random numbers were not applied to the same decision in each model. Since different numbers were used to make identical decisions in the two models, the workloads were not identical. This was confirmed by changing the seed for the random number generator which resulted not only in the significance between the delays disappearing but the delay from the hybrid switching model became less than the delay from the packet switching model.

Table XIV

Simulation Inputs and Results
For Comparing the Models with 1 Channel

Type Switching	Path Length	Traffic Intensity	Delay	Std. Dev.
Hybrid	2	0.25	0.1205	0.1067
		0.50	0.2050	0.1109
		0.75	0.4275	0.3177
	4	0.25	0.1153	0.0792
		0.50	0.3363	0.1723
		0.75	0.8179	0.5025
	6	0.25	0.1567	0.1086
		0.50	0.4790	0.2770
		0.75	1.3019	0.5656
Packet	2	0.25	0.1640	0.0565
		0.50	0.1785	0.1311
		0.75	0.3041	0.2101
	4	0.25	0.1904	0.1005
		0.50	0.3062	0.1833
		0.75	0.7420	0.5369
	6	0.25	0.2598	0.1260
		0.50	0.4360	0.2109
		0.75	1.0462	0.4915
Circuit	2	0.25	0.1499	0.1540
		0.50	9.0514	5.9402
		0.75	9.8522	9.3457
	4	0.25	0.1508	0.1333
		0.50	7.3749	4.8309
		0.75	14.6080	17.9864
	6	0.25	0.1788	0.1592
		0.50	9.7548	5.5020
		0.75	14.4395	15.4147

Table XV

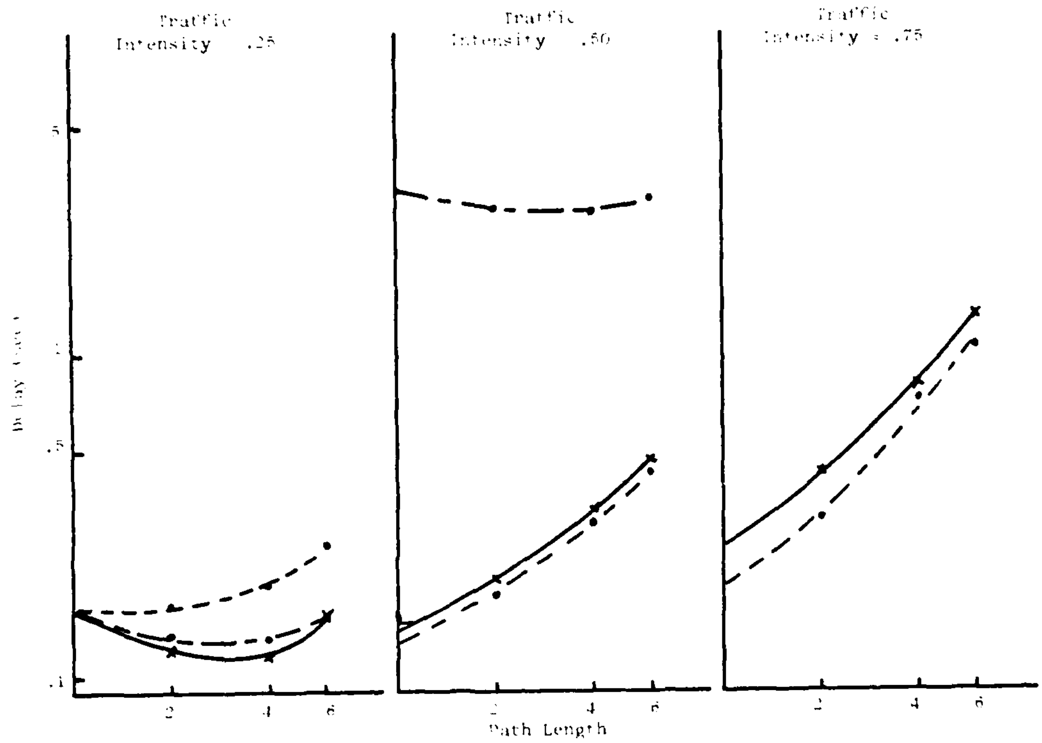
Simulation Inputs and Results
for Comparing the Models with 4 Channels

Type Switching	Path Length	Traffic Intensity	Delay	Std. Dev.
Hybrid	2	0.25	0.2382	0.1061
		0.50	0.4427	0.4276
		0.75	0.5708	0.3299
	4	0.25	0.3234	0.1723
		0.50	0.6463	0.5339
		0.75	1.0337	0.4803
	6	0.25	0.3639	0.1896
		0.50	0.6885	0.4631
		0.75	1.6601	0.5725
Packet	2	0.25	0.2415	0.0582
		0.50	0.2800	0.0957
		0.75	0.3090	0.0899
	4	0.25	0.4285	0.0604
		0.50	0.4559	0.0972
		0.75	0.5223	0.1078
	6	0.25	0.5979	0.0550
		0.50	0.6629	0.1103
		0.75	0.6881	0.1086
Circuit	2	0.25	0.3130	0.1572
		0.50	0.4072	0.2700
		0.75	13.2143	6.8644
	4	0.25	0.2974	0.1608
		0.50	0.4204	0.3051
		0.75	13.7829	8.6829
	6	0.25	0.3217	0.1668
		0.50	0.4699	0.2487
		0.75	15.1989	8.0904

Table XIV

Simulation Inputs and Results
for Comparing the Average Network Delay

Type Switching	Path Length	Traffic Intensity	Delay	Std. Dev.
Hybrid	1	0.25	0.1313	0.1169
		0.50	0.2859	0.1933
		0.75	0.6126	0.4468
Packet		0.25	0.1655	0.1038
		0.50	0.2606	0.1719
		0.75	0.5412	0.4182
Circuit		0.25	0.1260	0.1317
		0.50	1.6223	0.7962
		0.75	13.2972	9.1924
Hybrid	4	0.25	0.2744	0.1559
		0.50	0.6308	0.5757
		0.75	0.8098	0.4934
Packet		0.25	0.3779	0.1621
		0.50	0.4914	0.2438
		0.75	0.6034	0.3810
Circuit		0.25	0.2943	0.1642
		0.50	0.4046	0.2663
		0.75	7.0577	3.4339



Legend
Hybrid Switched ———
Packet Switched -----
Circuit Switched — - —
Header = 100 Bits
Capacity = 50000 Bits sec

Figure 14 Delay vs. Path Length
with 1 Channel

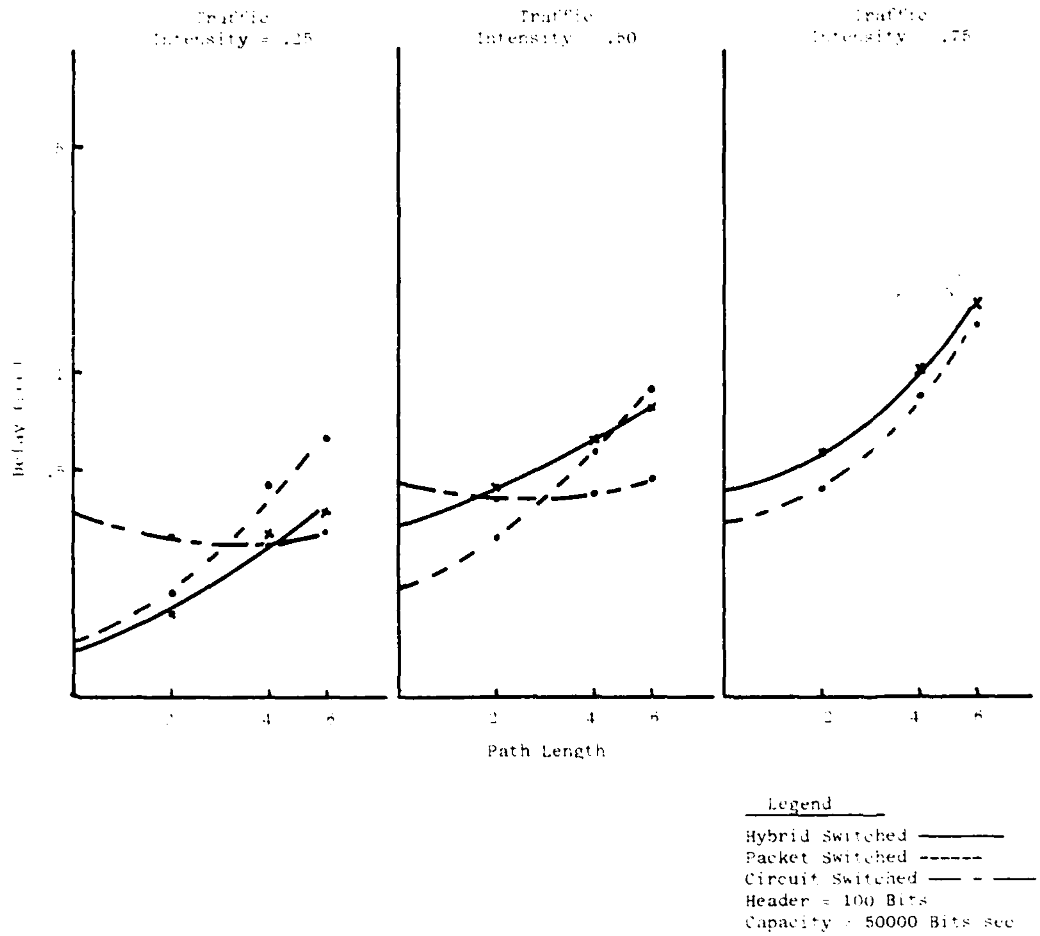


Figure 1? Delay vs. Path Length with 4 Channel

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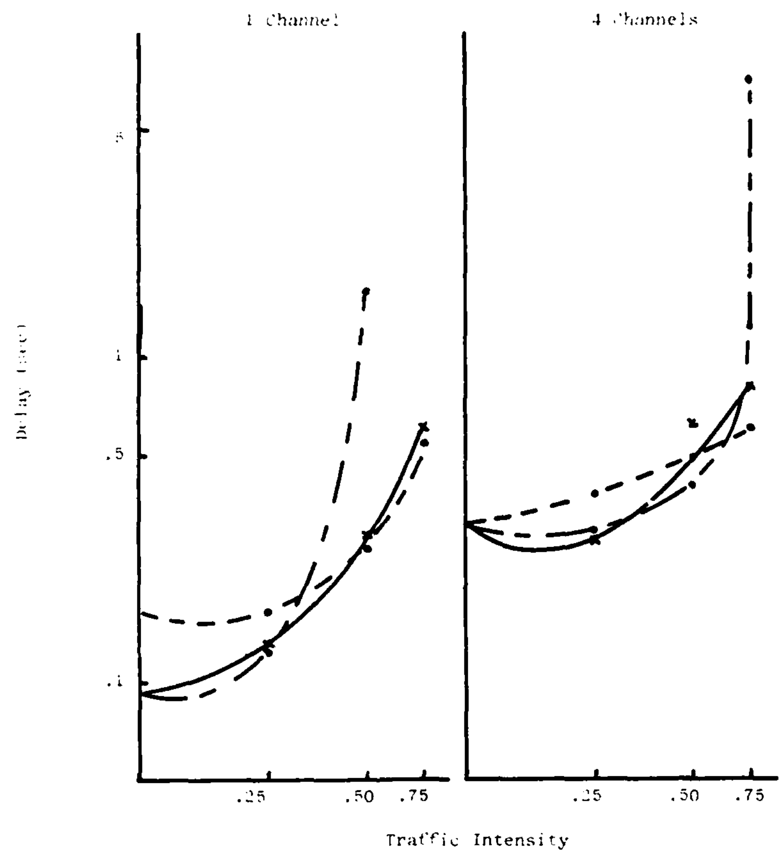


Legend

Hybrid Switched ———
Packet Switched -----
Circuit Switched— — ——

Figure 16 Average Network Delay
vs.
Traffic Intensity

Conclusions

A hybrid switching network which selects the switching method dynamically based upon message length, path length, traffic intensity and the number of channels, as defined in this study, provides the smallest delays in all situations. Packet switching provides smaller delays than circuit switching in some situations but in other situations circuit switching provides the smallest delays. However, based on the assumptions and results of this study, hybrid switching provides an excellent compromise between circuit switching and packet switching. The delays from hybrid switching closely approximates the delays from circuit switching when it is the best and packet switching when it is the best.

The results of this study confirm the usefulness of a hybrid switching technique which selects the switching technique based upon the network parameters. If hybrid switching is used in a network, the workload estimates which are made to select a switching technique will no longer be required since hybrid switching dynamically selects the switching technique that provides the shortest delays.

Recommendations for Additional Study

The results of this study need to be confirmed under conditions which are different from those assumed in the models. For instance, the assumption that 75 percent of the message packets travel the shortest path and the remaining 25 percent travel the shortest path plus one hop, needs to be investigated to determine if the results of this study are altered where the percentages are varied. Additionally, the assumption that the arriving messages are equally divided between 1000 and 5000 bits, should be investigated to determine the effects of changing the mix on the results. Another topic for further investigation concerns the application of the study results to systems which contain a mixture of voice and digital data. These questions need to be answered to determine the possible usefulness of this hybrid switching technique.

The final recommendation is to rewrite the models using a general purpose language. Q-Gert is a Fortran based language. The array dimensions are fixed which caused problems in this study. For instance, Q-Gert only allows 850 active transactions/messages in the system which caused some of the simulation runs to terminate before intended when the traffic intensity was heavy. Another reason for changing the models to a general purpose language is memory requirements. The models require the extra large version of Q-Gert which did require 166K of memory but now requires 200K because of a change in the access procedures. The need for 200K of memory severly impacts the number of simulations. If the system is busy, jobs requiring 200K rarely run prior to 10:00 p.m. An additional reason for changing languages is the difficulty in changing the network parameters. The Q-Gert models require significant changes in the packet switching and hybrid switching models to change message lengths. The last reason for changing the language of the models is to enable the identical workloads to be input to each model. The sensitivity of the results produced by the Q-Gert models to the random number seed could be eliminated. Creating a standard workload and inputting this workload into the Q-Gert models would be very difficult. However, if the models used a general language, a standard workload could easily be created and input into each model thus providing more quantative results than achieved in this study.

Bibliography

1. Bodzioch, Kenneth J. and Bernard E. Patrusky. Evaluating the Performance of a Unified Switching Node Using a Simulated Network. Unpublished contract study for RADC Rome Air Development Center DCL.

2. Ferrari, Domenico. Computer Systems Performance Evaluation. Englewood Cliffs, N.J.: Prentice Hall Inc., 1978.

3. Gitman, Israel, etal. "Analysis and Design of Hybrid Switching Networks," IEEE Transactions on Communications Com-29: 1290-1300. (Sept 1981).

4. Kermanl, Parviz and Leonard Kleinrock. "A Tradeoff Study of Switch-Systems in Computer Communication Networks," IEEE Transactions on Computers, C-29: 1052-1059 (Dec 1980).

5. Kermanl, Parviz and Leonard Kleinrock. "Virtual Cut-Through: A New Computer Communication Switching Technique," Computer Networks, 3: 267-286 (1979).

6. Kummerle, K. and H. Rudin. "Packet and Circuit Switching: A Comparison of Cost and Performance", National Telecommunications Conference Proceedings Dallas, Texas, 3: 42-5.1 to 42-5.7 (Nov 1976).

7. Maglaris, Basil and Mischa Schwarz. "Performance Evaluation of a Variable Frame Multiplexer for Integrated Switched Networks," IEEE Transactions on Communications, Com-29: 800-807 (June 1981).

8. Miller, Irwin and John E. Freund. Probability and Statistics for Engineers (Second Edition). Englewood Cliffs, N.J.: Prentice Hall Inc., 1977.

9. Miyahara, Hideo, et al. "Delay and Throughput Evaluation of Switch-Methods in Computer Communication Networks", IEEE Transactions on Communications, Com-26: 337-343 (March 1978).

10. Port, E., et al. "A Network Architecture for the Integration of Circuit and Packet Switching," Proceedings International Conference Computer Communications: 505-514 (1976).

11. Pritsker, A. Alan B. Modeling and Analysis Using Q-Gert Networks (Second Edition). New York: Halsted Press, 1979.

12. Pritsker, A. Alan B. and Claude Dennis Pegden. Introduction to Simulation and Slam. New York: Halsted Press, 1979.

13. Schwartz, Mischa. Computer Communication Network Design and Analysis. Englewood Cliffs, N.J.: Prentice Hall Inc., 1977.

14. Sol, Inder M. and Krishan R. Aggarwal. "A Review of Computer-Communication Network Classification Schemes," IEEE Communications Magazine: 24-32 (March 1981).

Appendix: A

User Inputs to the

Simulation Models.

Introduction

The circuit switched, packet switched and hybrid switched simulation models were designed to study the effects of the number of channels, the path length, the message length and the traffic intensity on message delay. The user is required to input the values of these parameters into three models. The method of input will be described in the following paragraphs by assuming each of the models is to study a situation which has 4 channels between nodes, the path length to be studied is 6, the message lengths are equally divided between 5000 and 1000 bit messages and the traffic intensity if 0.25.

The Number of Channels

The number of channels in each model is specified by the resource card which appears as follows;

Res, 1, 1, 1*

In order to input the desired number of channels the second number in resource card must be changed to reflect the desired number. For the situation described above, all the resource cards would have the second number equal to four as follows;

Res, 1, 4, 1*

Additionally, a change in the number of channels also requires the time required to transmit a message to be altered. The time to transmit the circuit establishment signal (Attribute 3) and the time to transmit the message, request-for-transmission signal and channel release signal (Attribute 4) must be recalculated for the circuit switched model using equations 4 and 5. The time to transmit a packet (Attribute 3) in the packet switched model must be recalculated using Equation 6. The hybrid swithced model requires the transmission times for the packet, message, and circuit establishment to be recalculated. However, in the hybrid switched model attribute 6 corresponds to Attribute 3 in both the packet switched model and the circuit switched model. Therefore Equation 4 is used to determine the circuit establishment signal transmission time for the circuit-switched method and Equation 6 is used to determine the packet transmission time for the packet switched method. The message transmission time in the circuit switched model (Attribute 4) corresponds to Attribute 7 in the hybrid switched model and therefore Equation 5 is used to determine this value.

The Path Length

The path length to be studied is input into the models by connecting disconnecting nodes to the statistics gathering nodes of each model. The circuit switched model requires one connection for each path length to be studied. The packet switched requires two connections and the hybrid switched requires the connections for each path. Table XVII gives the nodes to be connected for each path in each model. The node numbers refer to the numbering used in the design charts in appendices B thru D. For a path length of six which our example requires, the circuit switched model has only node 51 connected to nodes 58 and 67 with the message preceding to the former if the source node was not node 1 ($A1 \neq 1$) and the latter if the source node was node 1 ($A1 = 1$). The hybrid switched model has node 81 connected to node 95 and node 87 connected to nodes 88 and 38 with the message selecting the path from 87 to 88 if the source node 1 ($A1 = 1$) and from 87 to 38 if the source node was not node 1 ($A1 \neq 1$).

Table XVII

Path Length Connections

Model	Desired Path Length	Connections Required
Circuit Switched	1	Node 17 to node 80
	2	Node 22 to node 80
	3	Node 27 to node 80
	4	Node 34 to node 80
	5	Node 42 to node 80
	6	Node 51 to node 80
Packet Switched	1	Node 38 to 58 if A1 ≠ 1
		Node 38 to 67 if A1 = 1
	2	Node 42 to 58 if A1 ≠ 1
		Node 42 to 67 if A1 = 1
	3	Node 46 to 58 if A1 ≠ 1
		Node 46 to 67 if A1 = 1
	4	Node 50 to 58 if A1 ≠ 1
		Node 50 to 67 if A1 = 1
	5	Node 54 to 58 if A1 ≠ 1
		Node 54 to 67 if A1 = 1
	6	Node 57 to 58 if A1 ≠ 1
		Node 57 to 67 if A1 = 1
Hybrid Switched	1	29 to 95, 31 to 88 if A1 = 1
		31 to 38 if A1 ≠ 1
	2	43 to 95, 46 to 88 if A1 = 1
		46 to 38 if A1 ≠ 1
	3	51 to 95, 55 to 88 if A1 = 1
		55 to 38 if A1 ≠ 1
	4	60 to 95, 65 to 88 if A1 = 1
		65 to 38 if A1 ≠ 1
	5	70 to 95, 76 to 88 if A1 = 1
		76 to 38 if A1 ≠ 1
	6	81 to 95, 87 to 88 if A1 = 1
		87 to 38 if A1 ≠ 1

The Message Length

A change in message length requires extensive changes to the hybrid and packet switching models. However, a change in message length is easily accomodated by the circuit switched model. Since the length of the message effects the transmission time in the circuit switched model (attribute 4), this value must be recalculated using Equation 5. The recalculation of attribute 4 is the only change required of the circuit switched model.

The message length determines the number of packets required to transmit the message. The hybrid and packet switched models must be changed to generate the required number of packets for a given message length. In design charts for the hybrid switched model in Appendix D, nodes 18 thru 22 are used to generate packets for 5000 bit messages. If the message length were increased, additional nodes would be required to generate the proper number of packets. If the message length decrease from 5000 bits, nodes would be removed starting with the largest node number until the desired number of packets is reached. Nodes 22 thru 26 in the packet switched model in Appendix C correspond to nodes 18 to 22 in the hybrid model and would be changed as described for the hybrid model.

Additionally, attribute 7 in the hybrid switched model and attribute 5 in the packet switched model are used to indicate the number of packets each message required. These attributes must be changed to reflect any increase or decrease in the number of packets a message requires.

The nodes which determine if all the packets in a message have arrived must be increased or decreased to reflect changes in message lengths. Queue nodes 90 thru 94 in the hybrid switched model and queue nodes 69, 70, 71, 13, and 14 are used in the hybrid and packet switched models for 5000 bit messages. Changes in the message length which change the number of packets generated also require a change in queue nodes which are used to reassemble the message.

Additionally, the hybrid switched model also requires the time to transmit a message (Attribute 7) when the circuit switching technique is used to be calculated using equation 5. The circuit switched, packet switched, and hybrid switched models in appendices B thru D are set-up to accomodate message lengths of 1000 and 5000 bits.

Traffic Intensity

The traffic intensity to each node is a function of the external message arrival rate and the internal message arrival rate. The messages generated in the three models have an equal probability of terminating at any of the following nodes. Therefore, in order to maintain the same traffic intensity to each node, the external traffic intensity at node must be one sixth of the external traffic intensity to node 1 and the external traffic intensity to node 3 must be one sixth of the external traffic intensity to node 1 plus one fifth of the external traffic intensity to node 2, etc. Table V gives the external traffic intensities required at each node to maintain a .25 intensity, as follows;

Node	Traffic Intensity to Maintain .25
1	0.25
2	0.0167
3	0.02
4	0.025
5	0.0333
6	0.05
A-1	0.075
A-1	0.075

The exponential parameter specifications require a mean value, a minimum value, and a maximum value. The maximum value is set to twice the mean or 1 whichever is the larger. The minimum is the time to input a message assuming the input line capacity is 50000 bits/sec.

The following parameter specifications would be used for the example problem;

Model	Node	Parameter Specification
Circuit	1	Par,2,0.24,0.06,1*
	2	Par,4,3.60,0.06,7.2*
	3	Par,6,3.00,0.06,6.0*
	4	Par,8,2.40,0.06,4.8*
	5	Par,10,1.80,0.06,3.6*
	6	Par,12,1.20,0.06,2.4*
Packet	1	Par,2,0.24,0.06,1*
	2	Par,8,3.60,0.06,7.2*
	3	Par,10,3.00,0.06,6.0*
	4	Par,12,2.40,0.06,4.8*
	5	Par,14,1.80,0.06,3.6*
	6	Par,16,1.20,0.06,2.4*
	A-1	Par,4,0.80,0.06,1.6*
	A-2	Par,6,0.80,0.06,1.6*
Hybrid	1	Par,2,0.24,0.06,1*
	2	Par,5,3.60,0.06,7.2*
	3	Par,7,3.00,0.06,6.0*
	4	Par,9,2.40,0.06,4.2*
	5	Par,11,1.80,0.06,3.6*
	6	Par,12,1.20,0.06,2.4*
	A-1	Par,3,0.80,0.06,1.6*
	A-2	Par,3,0.80,0.06,1.6*

The external traffic intensities at each node must be converted to message arrival rates using Equation 8. Since the message in our example are equally divided between 1000 and 5000 bits, the average message length is 3000 bits. The average message length is used in Equation 8 to determine the arrival rate. The message arrival rates at each node are as follows:

Node	Message Arrival Rate
1	4.1667 messages/sec
2	0.2783 messages/sec
3	0.3333 messages/sec
4	0.4167 messages/sec
5	0.5550 messages/sec
6	0.8333 messages/sec
A-1	1.2500 messages/sec
A-2	1.2500 messages/sec

However, Q-Gert requires the message arrival rate to be given as the time between arrivals which requires the above values to be inverted. The inverted values are then used as the mean values for exponential distributions in the parameter specification to generate the messages.

Switching Selection Criteria

The switching selection criteria must also be input to the hybrid switching simulation model by the user. The switching selection criteria can be determined from the graphs in Figures 11 thru 13. For the conditions specified in the example, a 1000 bit message will only be packet switched if the path length is one and a 5000 bit message will be packet switched if the path length is less than 3. The messages will be circuit switched for all other path lengths.

The switching selection criteria is input into the hybrid switching model as branching conditions as follows:

Message Length	Path From Node to Node	Condition
1000	12 to 13	A4.LT.1
	12 to 14	A4.GE.1
5000	15 to 16	A4.GE.3
	15 to 17	A4.LT.3

APPENDIX: B

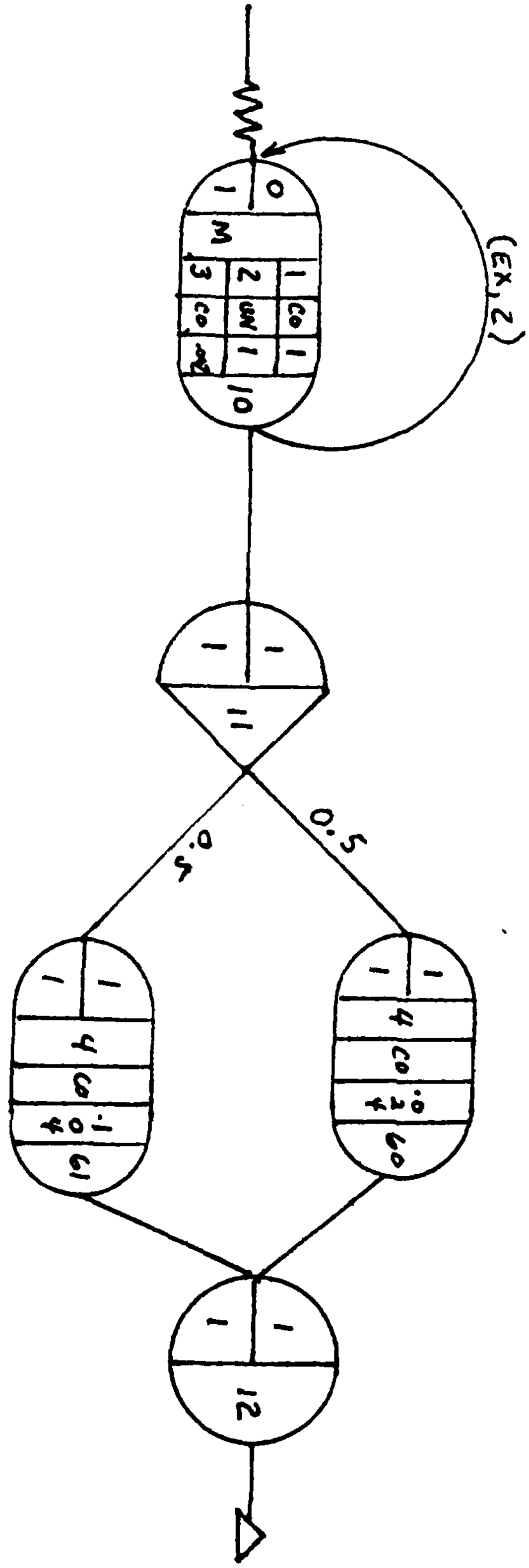
Circuit Switched

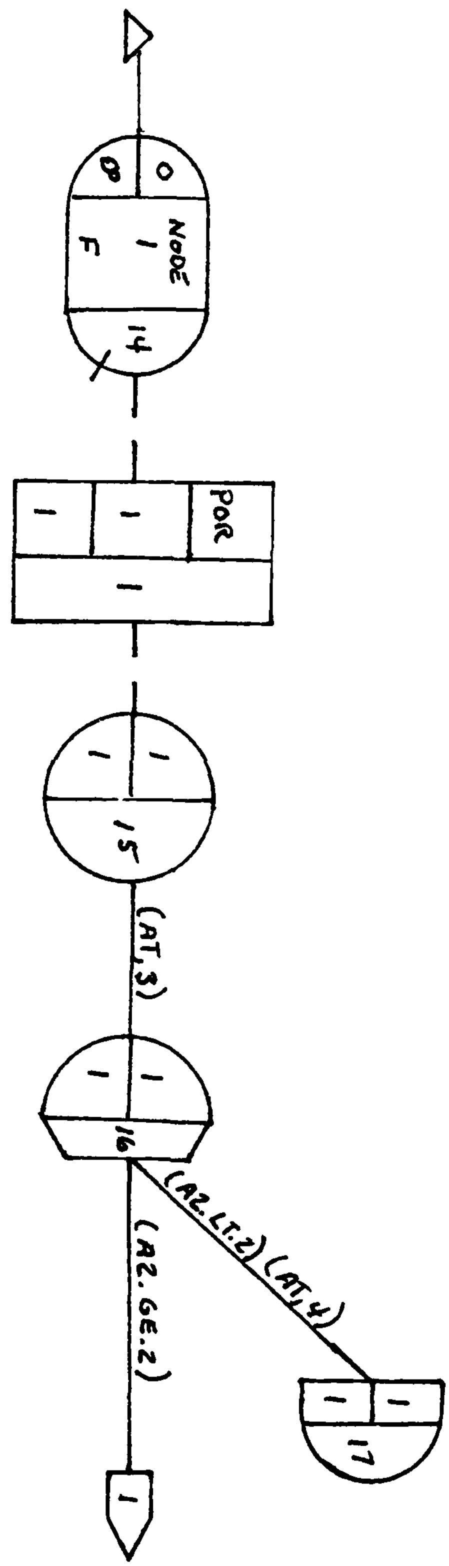
Simulation Model

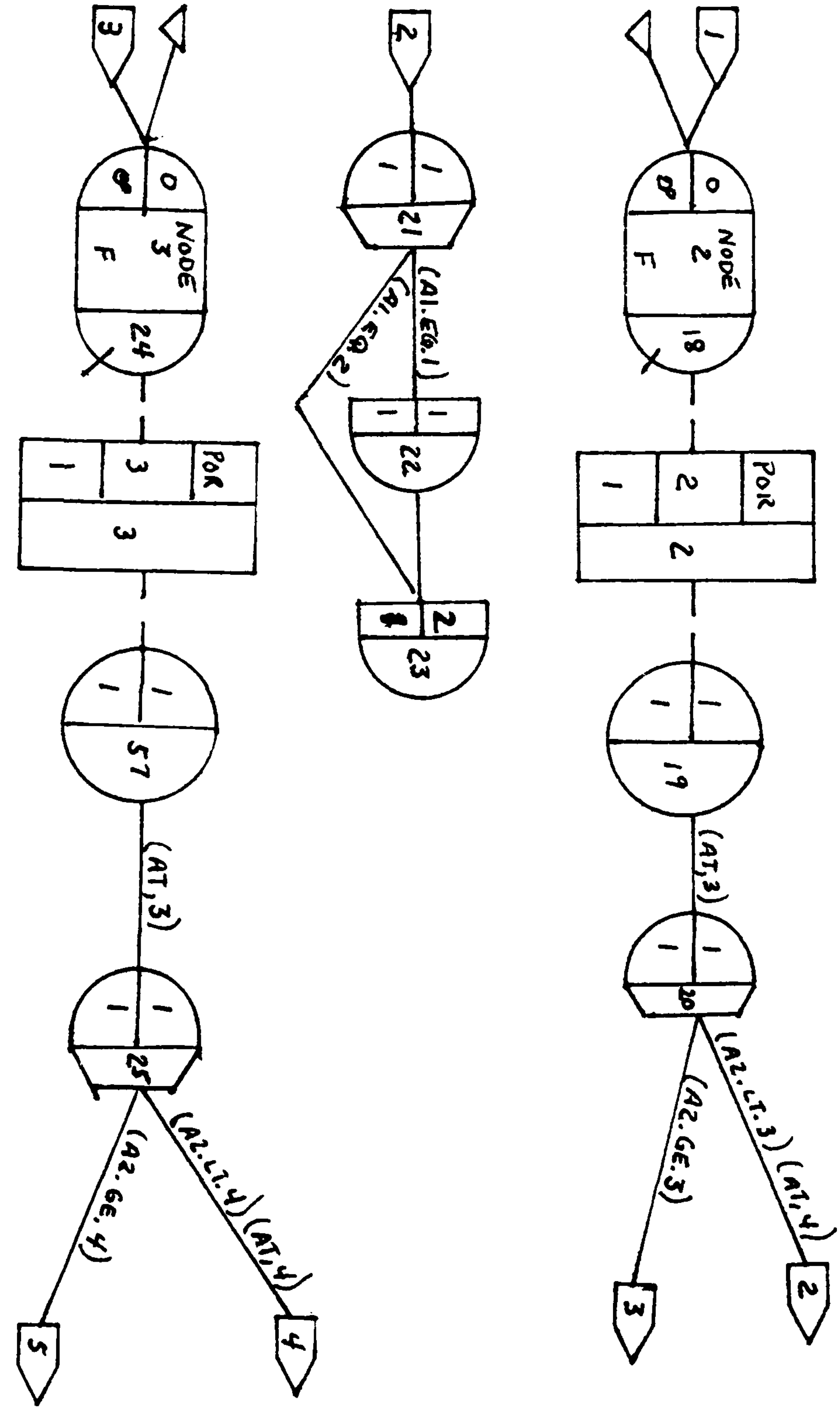
Circuit Swtiched Network

Q-Gert Design Charts

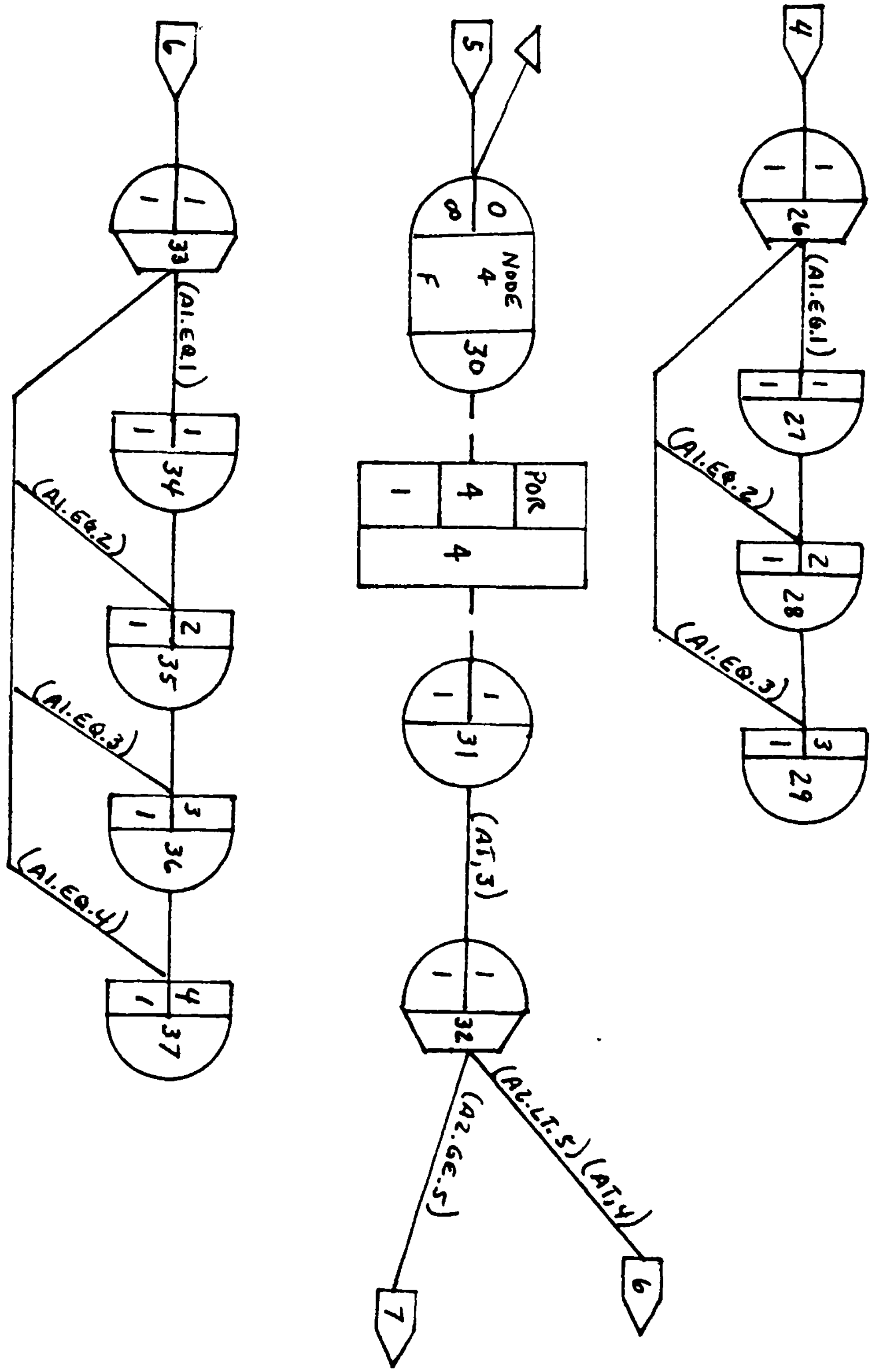
Attribute Number	Meaning of Value
1	Source node
2	Destination
3	Time to transmit circuit establishment message between two adjacent nodes
4	Time to transmit message and channel release signal

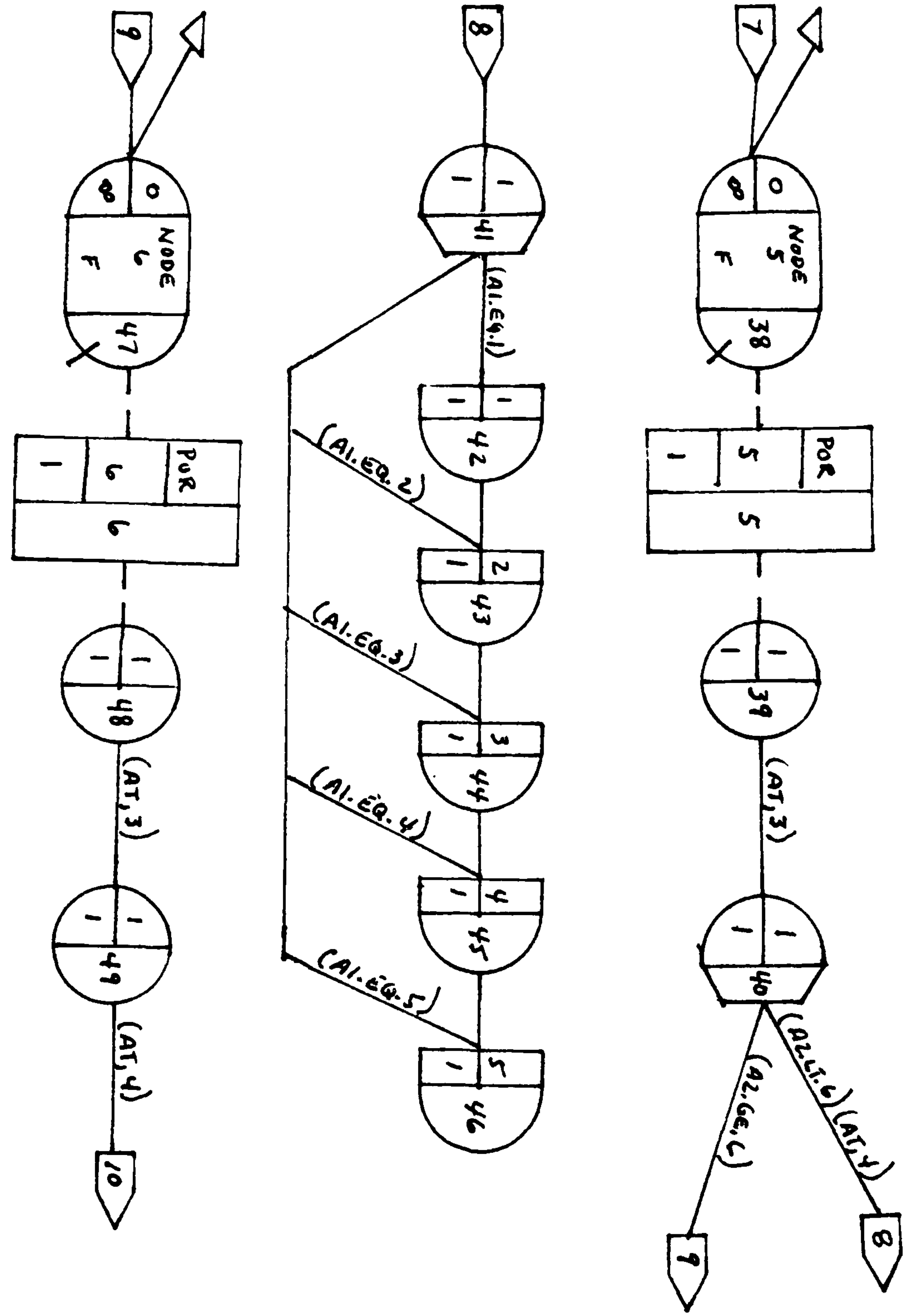

(EX, 2)
10
11
0.5
0.5
61
60
12

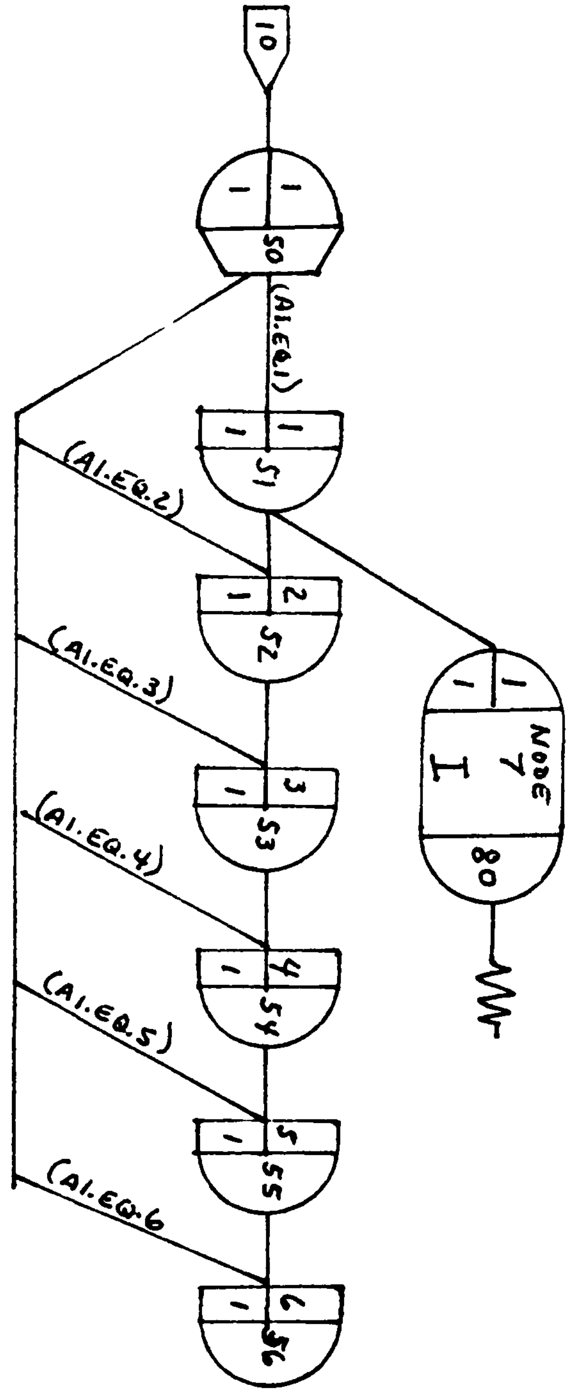

0
NODE
1
F
14
POR
15
(AT,3)
16
(AZ.LT.2)
(AT,4)
17
(AZ.GE.2)



NODE 2
F
18
POR
19
(AT,3)
20
(A2.LT.3) (AT,4)
(A2.GE.3)
21
(A1.EQ.1)
(A1.EQ.2)
22
23
NODE 3
24
57
25
(A2.LT.4) (AT,4)
(A2.GE.4)


4
5
6
7
26
27
28
29
30
31
32
33
34
35
36
37
NODE
4
F
POR
(A1.EQ.1)
(A1.EQ.2)
(A1.EQ.3)
(A1.EQ.4)
(AT,3)
(A2.LT.5)
(AT,4)
(A2.GE.5)


NODE 5
POR
(AT,3)
(A2.LT.6)
(AT,4)
(A2.GE.6)
(A1.EQ.1)
(A1.EQ.2)
(A1.EQ.3)
(A1.EQ.4)
(A1.EQ.5)
NODE 6
POR
(AT,3)
(AT,4)


10
50
(A1.EQ.1)
51
(A1.EQ.2)
52
(A1.EQ.3)
53
(A1.EQ.4)
54
(A1.EQ.5)
55
(A1.EQ.6
56
NODE
7
I
80

```
GEN,GAMBILL,CIR-SWITCHED,9,1,81,0,1,100,(14)4,(21)80*
RES,1,1,1*
RES,2,1,2*
RES,3,1,3*
RES,4,1,4*
RES,5,1,5*
RES,6,1,6*
PAR,1,0.,1.,7.,0.*
PAR,2,0.08,0.02,1.*
PAR,3,0.,2.,7.,0.*
PAR,4,0.48,0.02,1.*
PAR,5,0.,3.,7.,0.*
PAR,6,0.40,0.02,1.*
PAR,7,0.,4.,7.,0.*
PAR,8,0.32,0.02,1.*
PAR,9,0.,5.,7.,1.*
PAR,10,0.24,0.02,1.*
PAR,12,0.16,0.02,1.*
DEF,1*
SOU,10,0,1,(50)10*
VAS,10,1,CO,1.,2,UN,1,3,CO,0.002,(50)11*
ACT,10,10,EX,2,(50)12*
ACT,10,11,(50)13*
REG,11,1,1,P,(50)14*
ACT,11,60(8)0.5,(50)15*
ACT,11,61,(8)0.5,(50)15*
REG,60,1,1,(50)17*
VAS,60,4,CO,0.024,(50)18*
ACT,60,12,(50)19*
REG,61,1,1,(50)20*
VAS,61,4,CO,0.104,(50)21*
ACT,61,12,(50)22*
REG,12,1,1,(50)23*
ESN*
LIN,12/1,14*
QUE,14/NODE 1,(10)1*
ALL,1,POR,1,1,14/15*
REG,15,1,1*
ACT,15,16,AT,3*
REG,16,1,1,F*
ACT,16,17,AT,4,(8)1,A2,_T.2.*
FRE,17,D,1,1*
ACT,17,80*
ACT,16,18,(8 E,A2.GE.2.*
DUP,2,E*
REP,11,VAS,10,1,CO,2.,2,UN,3,3,CO,0.002*
REP,12,ACT,10,10,EX,4*
ESN*
LIN,12/2,18*
QUE,18/NODE 2,(10)2*
ALL,2,POR,2,1,18/19*
REG,19,1,1*
ACT,19,20,AT,3*
REG,20,1,1,F*
ACT,20,21,AT,4,(8)1,A2.LT.3.*
```

```
REG,21,1,1,F*
ACT,21,22(8)1,A1.EQ.1.*
ACT,21,23,(8)2,A1.EQ.2.*
FRE,22,D,1,1*
ACT,22,23*
ACT,22,80*
FRE,23,D,2,1*
ACT,20,24,(8)2,A2.GE.3.*
DUP,3,E*
REP,11,VAS,10,1,CO,3.,2,UN,5,3,CO,0.002*
REP,12,ACT,10,10,EX,6*
ESN*
LIN,12/3,24*
QUE,24/NODE 3,(10)3*
ALL,3,POR,3,1,24/57*
REG,57,1,1*
ACT,57,25,AT,3*
REG,25,1,1,F*
ACT,25,26,AT,4,(8)1,A2.LT.4.*
ACT,25,30,(8)2,A2.GE.4.*
REG,26,1,1,F*
ACT,26,27,(8)1,A1.EQ.1.*
ACT,26,28,(8)2,A1.EQ.2.*
ACT,26,29,(8)3,A1.EQ.3.*
FRE,27,D,1,1*
ACT,27,28*
ACT,27,80*
FRE,28,D,2,1*
ACT,28,29*
FRE,29,D,3,1*
DUP,4,E*
REP,11,VAS,10,1,CO,4.,2,UN,7,3,CO,0.002*
REP,12,ACT,10,10,EX,8*
ESN*
LIN,12/4,30*
QUE,30/NODE 4,(10)4*
ALL,4,POR,4,1,30/31*
REG,31,1,1*
ACT,31,32,AT,3*
REG,32,1,1,F*
ACT,32,33,AT,4,(8)1,A2.LT.5.*
ACT,32,38,(8)2,A2.GE.5.*
REG,33,1,1,F*
ACT,33,34,(8)1,A1.EQ.1.*
ACT,33,35,(8)2,A1.EQ.2.*
ACT,33,36,(8)3,A1.EQ.3.*
ACT,33,37,(8)4,A1.EQ.4.*
FRE,34,D,1,1,*
ACT,34,35*
ACT,34,80*
FRE,35,D,2,1*
ACT,35,36*
FRE,36,D,3,1*
ACT,36,37*
FRE,37,D,4,1*
DUP,5,E*
```

```
REP,11,VAS,10,1,CO,5.,2,UN,8,3,CO,0.002*
REP,12,ACT,10,10,EX,10*
ESN*
LIN,12/5,38*
QUE,38/NODE 5,(10)5*
ALL,5,POR,5,1,38/39*
REG,39,1,1*
ACT,39,40,AT,3*
REG,40,1,1,F*
ACT,40,41,AT,4,(8)1,A2.LT.6.*
ACT,40,47,(8)2,A2.GE.6.*
REG,41,1,1,F*
ACT,41,42,(8)1,A1.EQ.1.*
ACT,41,43,(8)2,A1.EQ.2.*
ACT,41,44,(8)3,A1.EQ.3.*
ACT,41,45,(8)4,A1.EQ.4.*
ACT,41,46,(8)5,A1.EQ.5.*
FRE,42,D,1,1,*
ACT,42,43*
ACT,42,80*
FRE,43,D,2,1*
ACT,43,44*
FRE,44,D,3,1*
ACT,44,45*
FRE,45,D,4,1*
ACT,45,46*
FRE,46,D,5,1*
DUP,6,E*
REP,11,VAS,10,1,CO,6.,2,CO,7.,3,CO,0.002*
REP,12,ACT,10,10,EX,12*
ESN*
LIN,12/6,47*
QUE,47/NODE 6,(10)6*
ALL,6,POR,6,1,47/48*
REG,48,1,1*
ACT,48,49,AT,3*
REG,49,1,1*
ACT,49,50,AT,4*
REG,50,1,1,F*
ACT,50,51,(8)1,A1.EQ.1.*
ACT,50,52,(8)2,A1.EQ.2.*
ACT,50,53,(8)3,A1.EQ.3.*
ACT,50,54,(8)4,A1.EQ.4.*
ACT,50,55,(8)5,A1.EQ.5.*
ACT,50,56,(8)6,A1.EQ.6.*
FRE,51,D,1,1*
ACT,51,52*
ACT,51,80*
FRE,52,D,2,1*
ACT,52,53*
FRE,53,D,3,1,*
ACT,53,54*
```

```
FRE,54,D,4,1*
ACT,54,55*
FRE,55,D,5,1*
ACT,55,56*
FRE,56,D,6,1*
SIN,80/NODE 7,1,1,D,I*
FIN*
```

APPENDIX: C

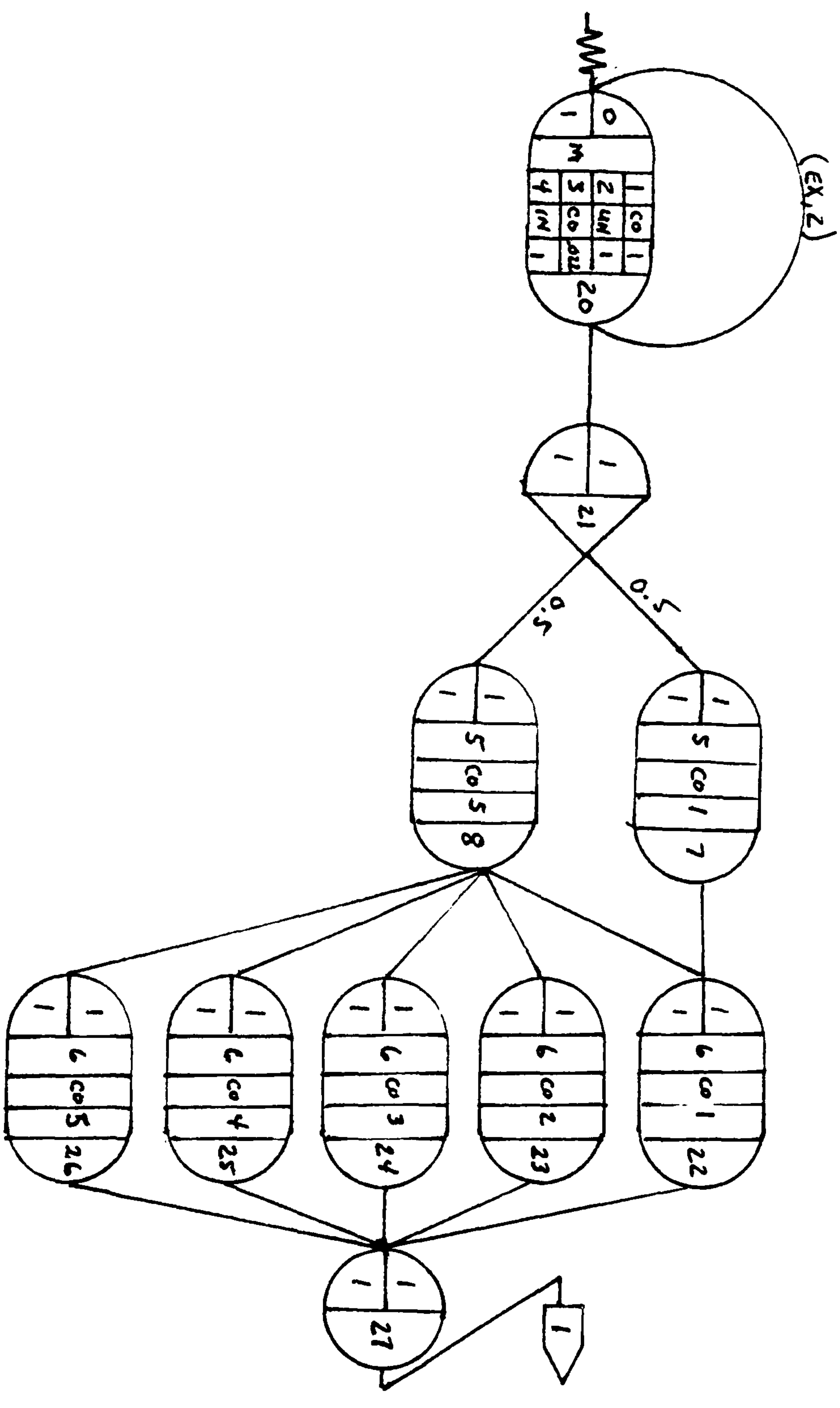
Packet Switched

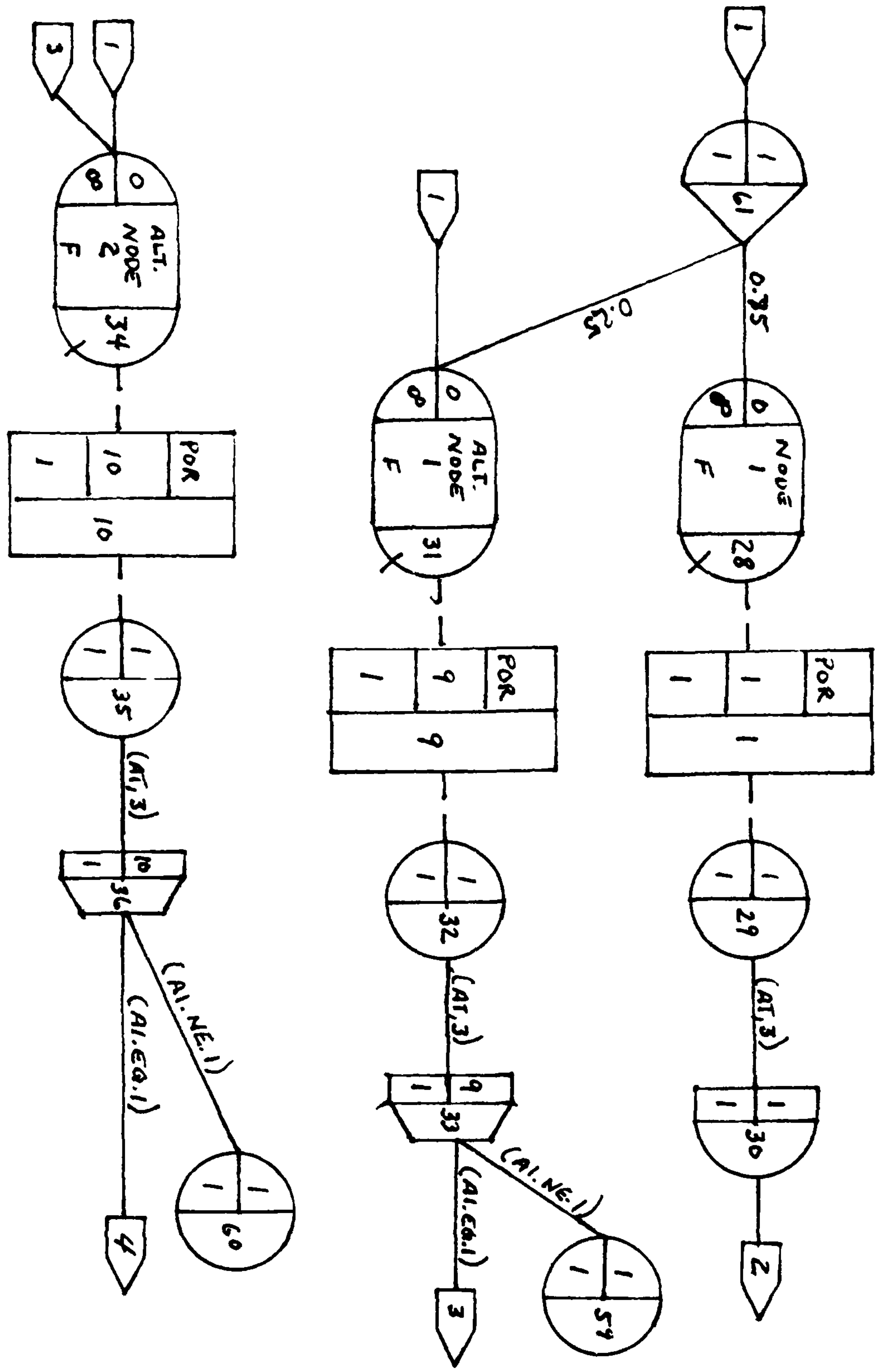
Simulation Model

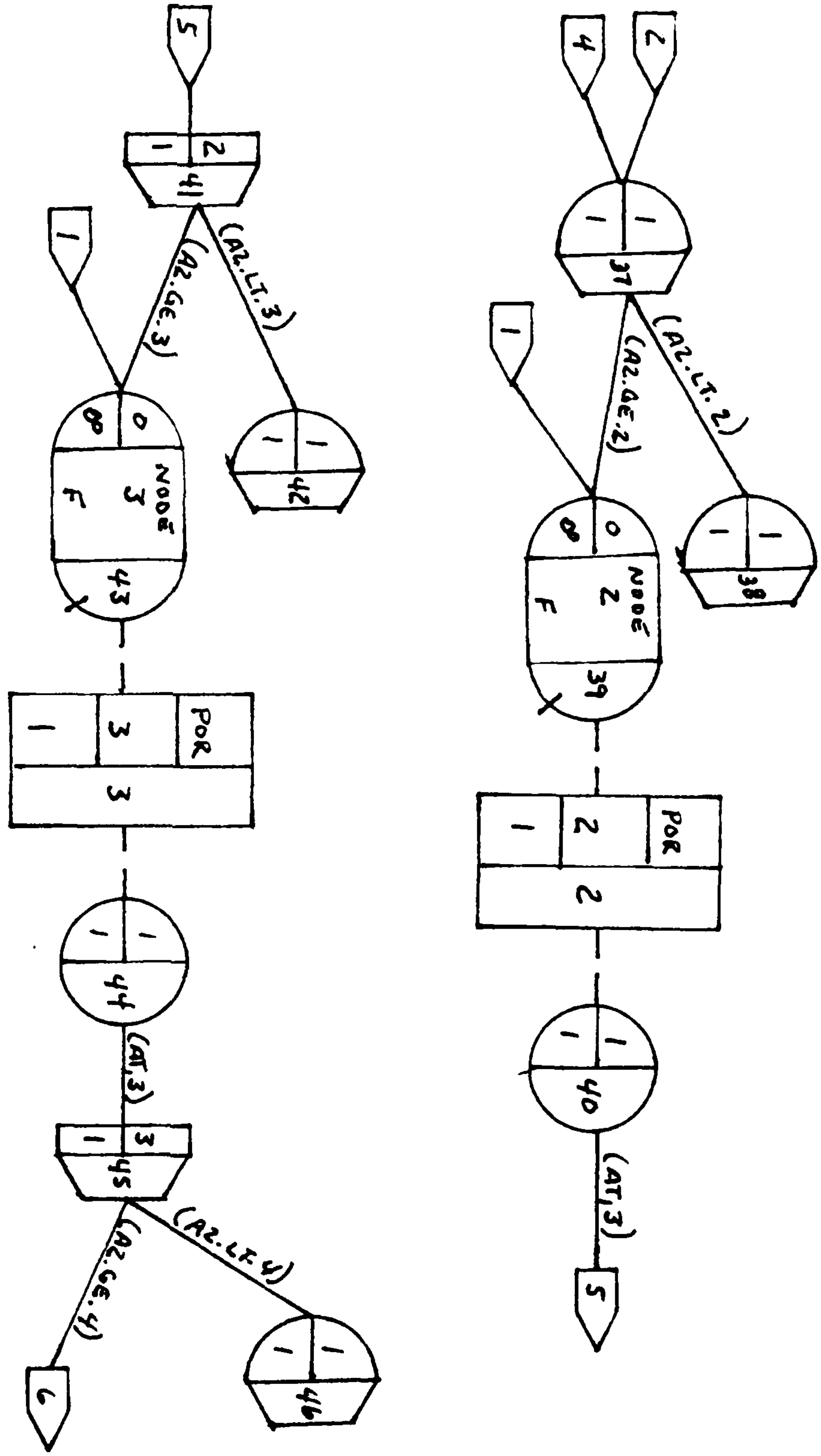
Packet Switched Network

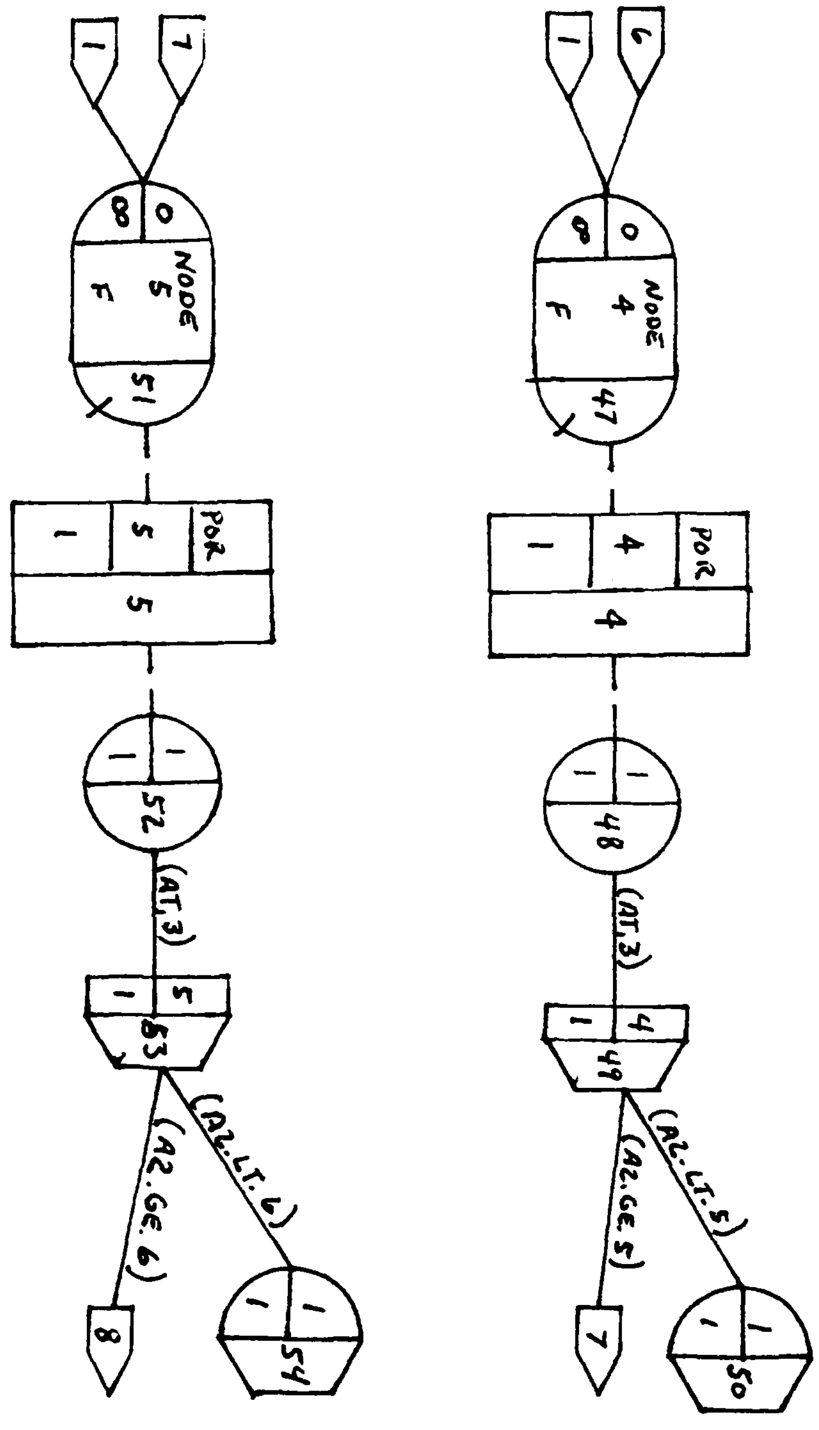
Q-Gert Design Charts

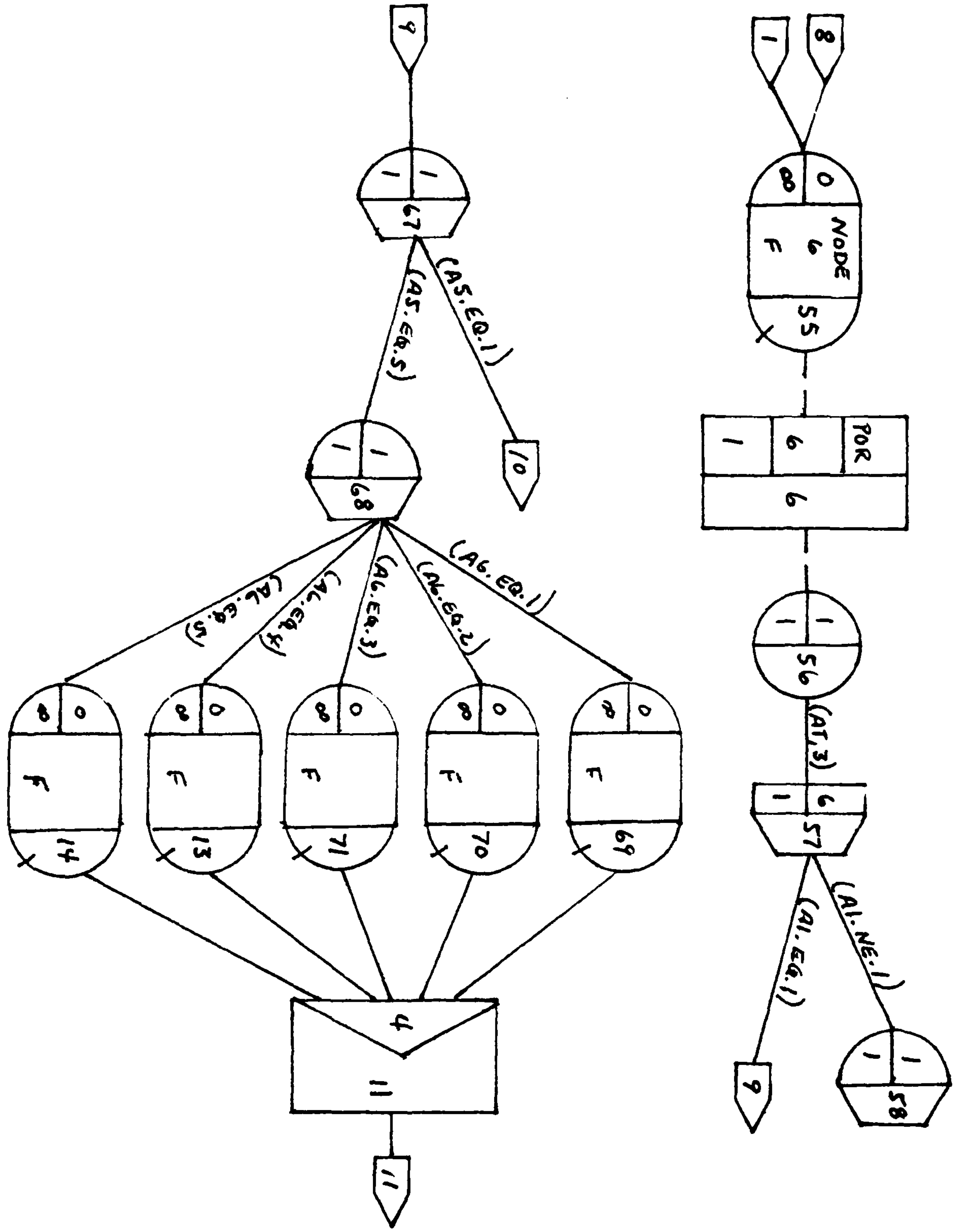
Attribute Number	Meaning of Value
1	Source Node
2	Destination
3	Time to send Packet
4	Message number
5	Number of packets in message
6	Packet number

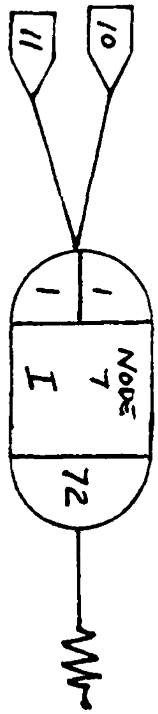

(EX,2)
20
21
0.5
0.5
7
8
22
23
24
25
26
27


0.75
0.25
NODE 1 F
ALT. NODE 1 F
ALT. NODE 2 F
POR
(AT,3)
(AI.NE.1)
(AI.EQ.1)


5
1
2
41
(AZ.LT.3)
(AZ.GE.3)
1
42
NODE 3
F
43
POR
3
44
(AT,3)
45
(AZ.LT.4)
(AZ.GE.4)
46
6
4
2
37
(AZ.LT.2)
(AZ.GE.2)
38
NODE 2
39
POR
2
40
(AT,3)
5


NODE
4
F
0
8
47
POR
4
1
4
48
(AT,3)
4
1
49
(AZ.LT.5)
(AZ.GE.5)
7
50
6
1
NODE
5
F
0
8
51
POR
5
1
5
52
(AT,3)
5
1
53
(AZ.LT.6)
(AZ.GE.6)
8
54
7
1


NODE
POR
(AS.EQ.1)
(AS.EQ.5)
(A6.EQ.1)
(A6.EQ.2)
(A6.EQ.3)
(A6.EQ.4)
(A6.EQ.5)
(AT,3)
(A1.NE.1)
(A1.EQ.1)


NODE 7
I
72
1
1
10
11

```
GEN,GAMBILL,PAC-SWITCHED,9,1,81,0,1,100,(14)6,(21)72*
RES,1,4,1*
RES,2,4,2*
RES,3,4,3*
RES,4,4,4*
RES,5,4,5*
RES,6,4,6*
RES,9,4,9*
RES,10,4,10*
PAR,1,0.,1.,7.,0.*
PAR2,0.24,0.02,1.*
PAR3,0.,1.,7.,0.*
PAR,4,0.32,0.02,1.*
PAR,5,0.,1.,7.,0.*
PAR,6,0.32,0.02,1.*
PAR,7,0.,2.,7.,0.*
PAR,8,1.437,0.02,3.*
PAR,9,0.,3.,7.,0.*
PAR,10,1.20,0.02,2.4*
PAR,11,0.,4.,7.,0.*
PAR,12,0.96,0.02,2.*
PAR,13,0.,5.,7.,0.*
PAR,14,0.72,0.02,1.5*
PAR,15,0.48,0.02,1.*
DEF,1*
SOU,20,0,1,D,M,L,(50)10*
VAS,20,1,CO,1,2,UN,1,3,CO,0.088,4,IN,1,(50)11*
ACT,20,20,EX,2,(50)12*
ACT,20,21,(50)13*
REG,21,1,1,P,(50)14*
ACT,21,7,(8)0.5,(50)15*
ACT,21,8,(8)0.5,(50)16*
REG,7,1,1,(50)17*
VAS,7,5,CO,1,(50)18*
ACT,7,22,(50)19*
REG,8,1,1,(50)20*
VAS,8,5,CO,5,(50)21*
ACT,8,22,(50)22*
ACT,8,23,(50)23*
ACT,8,24,(50)24*
ACT,8,25(50)25*
ACT,8,26,(50)26*
REG,22,1,1,(50)27*
VAS,22,6,CO,1,(50)28*
ACT,22,27,(50)29*
REG,23,1,1,(50)30*
VAS,23,6,CO,2,(50)31*
ACT,23,27,(50)32*
REG,24,1,1,(50)33*
VAS,24,6,CO,3,(50)34*
ACT,24,27,(50)35*
REG,25,1,1,(50)36*
VAS,25,6,CO,4,(50)37*
ACT,25,27,(50)38*
REG,26,1,1,(50)39*
VAS,26,6,CO,5,(50)40*
ACT,26,27,(50)41*
```

```
REG,27,1,1,(50)42*
ESN*
LIN,27/1,61*
REG,61,1,1,P*
ACT,61,28,(8)0.75*
ACT,61,31,(8)0.25*
QUE,28/NODE-1,0, ,D,F,(10)1*
ALL,1,POR,1,1,28/29*
REG,29,1,1*
ACT,29,30,AT,3*
FRE,30,D,1,1*
ACT,30,37*
DUP,9,E*
REP,11,VAS,20,1,CO,10,2,UN,3,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,4*
ESN*
LIN,27/9,31*
QUE,31/ALT-1,0, ,D,F,(10)9*
ALL,9,POR,9,1,31/32*
REG,32,1,1*
ACT,32,33,AT,3*
FRE,33,F,9,1*
ACT,33,59,(8)1,A1.NE.1.
ACT,33,34,(8)2,A1.EQ.1.*
REG,59,1,1*
DUP,10,E*
REP,11,VAS,20,1,CO,11,2,UN,5,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,6*
ESN*
LIN,27/10,34*
QUE,34/ALT-2,0, ,D,F,(10)10*
ALL,10,POR,10,1,34/35*
REG,35,1,1*
ACT,35,36,AT,3*
FRE,36,F,10,1*
ACT,36,37,(8),A1.EQ.1.*
ACT,36,60,(8)2,A1.NE.1.*
REG,60,1,1*
REG,37,1,1,F*
ACT,37,38,(8)1,A2.LT.2.*
REG,38,1,1,F*
ACT,38,58,(8)1,A1.NE.1.*
ACT,38,67,(8)2,A1.EQ.1.*
ACT,37,39(8)2,A2.GE.2.*
DUP,2,E*
REP,11,VAS,20,1,CO,2.,2,UN,7,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,8*
ESN*
LIN,27/2,39*
QUE,39/NODE-2,0, ,D,F,(10)2*
ALL,2,POR,2,1,39/40*
REG,40,1,1*
ACT,40,41,AT,3*
FRE,41,F,2,1*
ACT,41,42,(8)1,A2.LT.3.*
REG,42,1,1,F*
ACT,42,58,(8)1,A1.NE.1.*
```

```
ACT,42,67,(8)2,A1.EQ.1.*
ACT,41,43,(8)2,A2.GE.3.*
DUP,3,E*
REP,11,VAS,20,1,CO,3,2,UN,9,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,10*
ESN*
LIN,27/3,43*
QUE,43/NODE-3,0, ,D,F,(10)3*
ALL,3,POR,3,1,43/44*
REG,44,1,1*
ACT,44,45,AT,3*
FRE,45,F,3,1*
ACT,45,46,(8)1,A2.LT.4.*
REG,46,1,1,F*
ACT,46,58,(8)1,A1.NE.1.*
ACT,46,67(8)2,A1.EQ.1.*
ACT,45,47,(8)2,A2.GE.4.*
DUP,4,E*
REP,11,VAS,20,1,CO,4,2,UN,11,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,12*
ESN*
LIN,27/4,47*
QUE,47/NODE-4,0, ,D,F,(10)4*
ALL,4,POR,4,1,47/48*
REG,48,1,1*
ACT,48,49,AT,3*
FRE,49,F,4,1*
ACT,49,50,(8)1,A2.LT.5.*
REG,50,1,1,F*
ACT,50,58,(8)1,A1.NE.1.*
ACT,50,67,(8)2,A1.EQ.1.*
ACT,49,51,(8)2,A2.GE.5.*
DUP,5,E*
REP,11,VAS,20,1,CO,5,2,UN,13,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,14*
ESN*
LIN,27/5,51*
QUE,51/NODE-5,0, ,D,F,(10)5*
ALL,5,POR,5,1,51/52*
REG,51,1,1*
ACT,52,53,AT,3*
FRE,53,F,5,1*
ACT,53,54,(8)1,A2.LT.6.*
REG,54,1,1F*
ACT,54,58,(8)1,A1.NE.1.*
ACT,54,67(8)2,A2.EQ.1.*
ACT,53,55,(8)2,A2.GE.6.*
DUP,6,E*
REP,11,VAS,20,1,CO,6.,2,CO,7.,3,CO,0.088,4,IN,1*
REP,12,ACT,20,20,EX,16*
ESN*
LIN,27/6,55*
QUE,55/NODE-6,0, ,D,F,(10)6*
ALL,6,POR,6,1,55/56*
REG,56,1,1*
```

```
ACT,56,57,AT,3*
FRE,57,F,6,1*
ACT,57,58(8)1,A1.NE.1.*
ACT,57,67,(8)2,A1.EQ.1.*
REG,58,1,1,F*
REG,67,1,1,F*
ACT,67,72,(8)1,A5,EQ.1.*
ACT,67,68,(8)2,A5.EQ.5.*
REG,68,1,1,F*
ACT,68,69,(8)1,A6.EQ.1.*
QUE,69,0, ,D,F,(10)11*
ACT,68,70,(8)2,A6.EQ.2.*
QUE,70,0, ,D,F,(10)11*
ACT,68,71,(8)3,A6.EQ.3.*
QUE,71,0, ,D,F,(10)11*
ACT,68,13,(8)4,A6.EQ.4.*
QUE,13,0, ,D,F,(10)11*
ACT,68,14,(8)5,A6.EQ.5.*
QUE,14,0, ,D,F,(10)11*
MAT,11,4,69,70,71,13,14/72*
SIN,72/NODE-7,1,1,D,I*
FIN*
```

APPENDIX: D

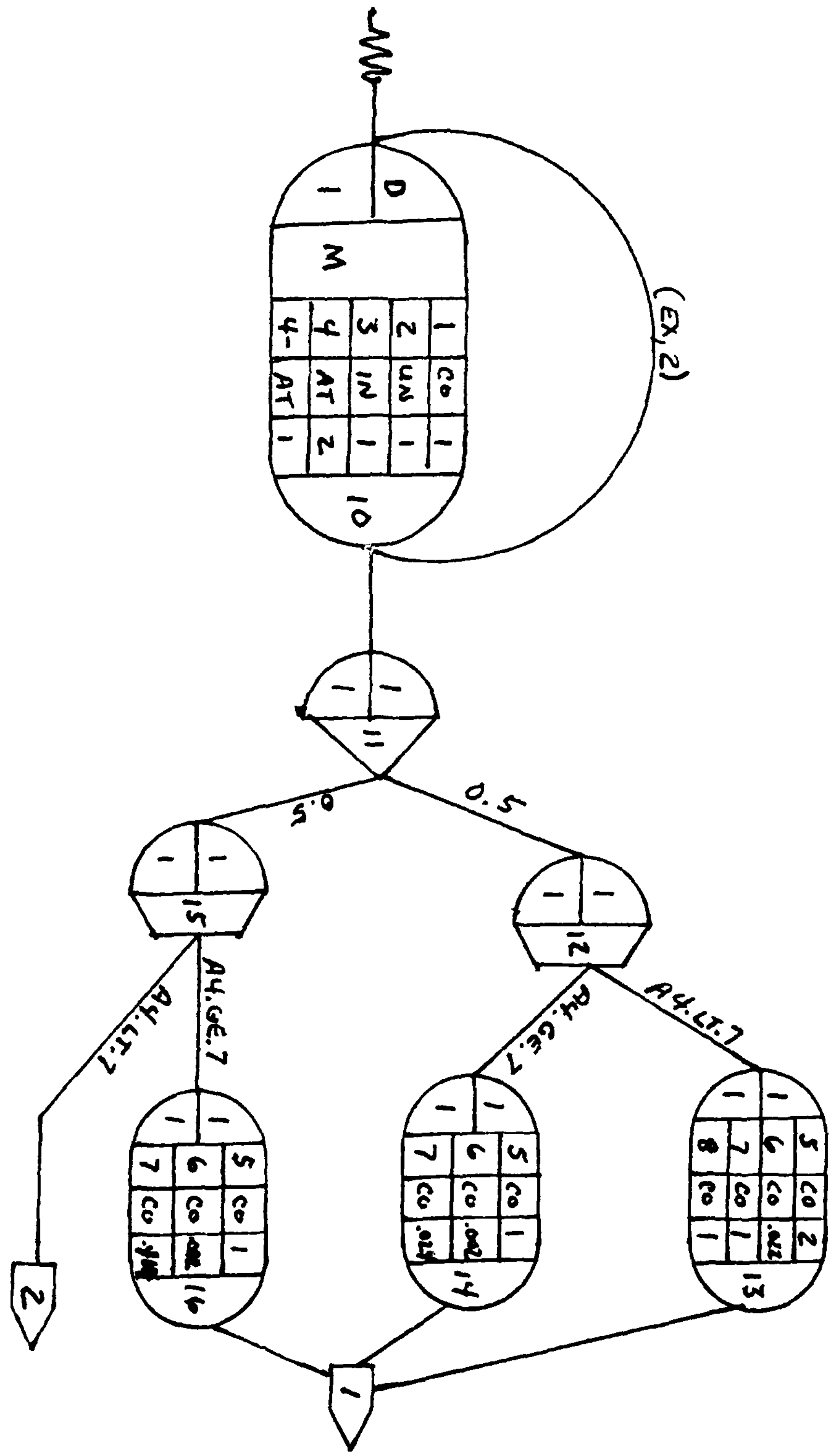
Hybrid Switched

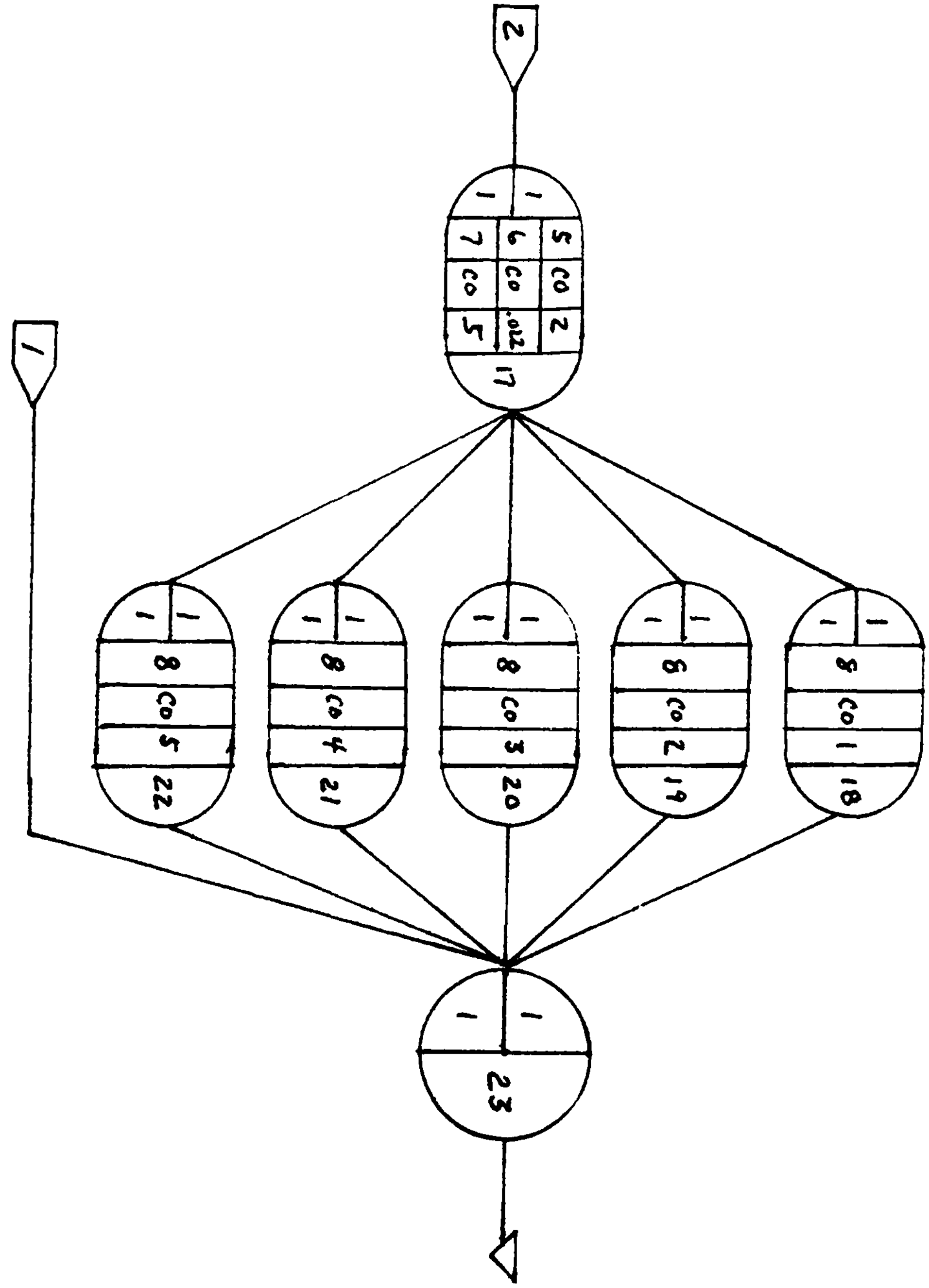
Simulation Model

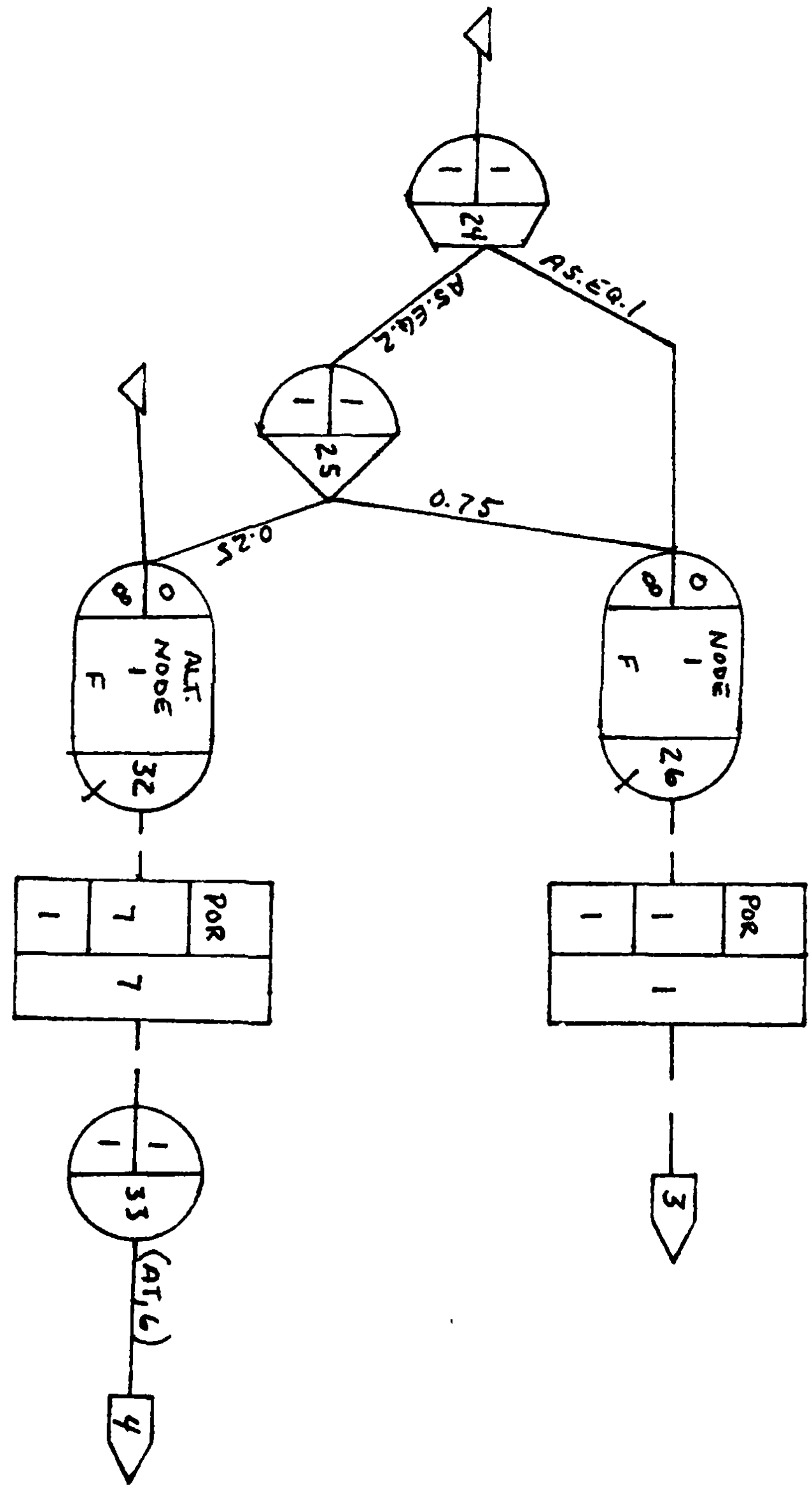
Hybrid Switched Network

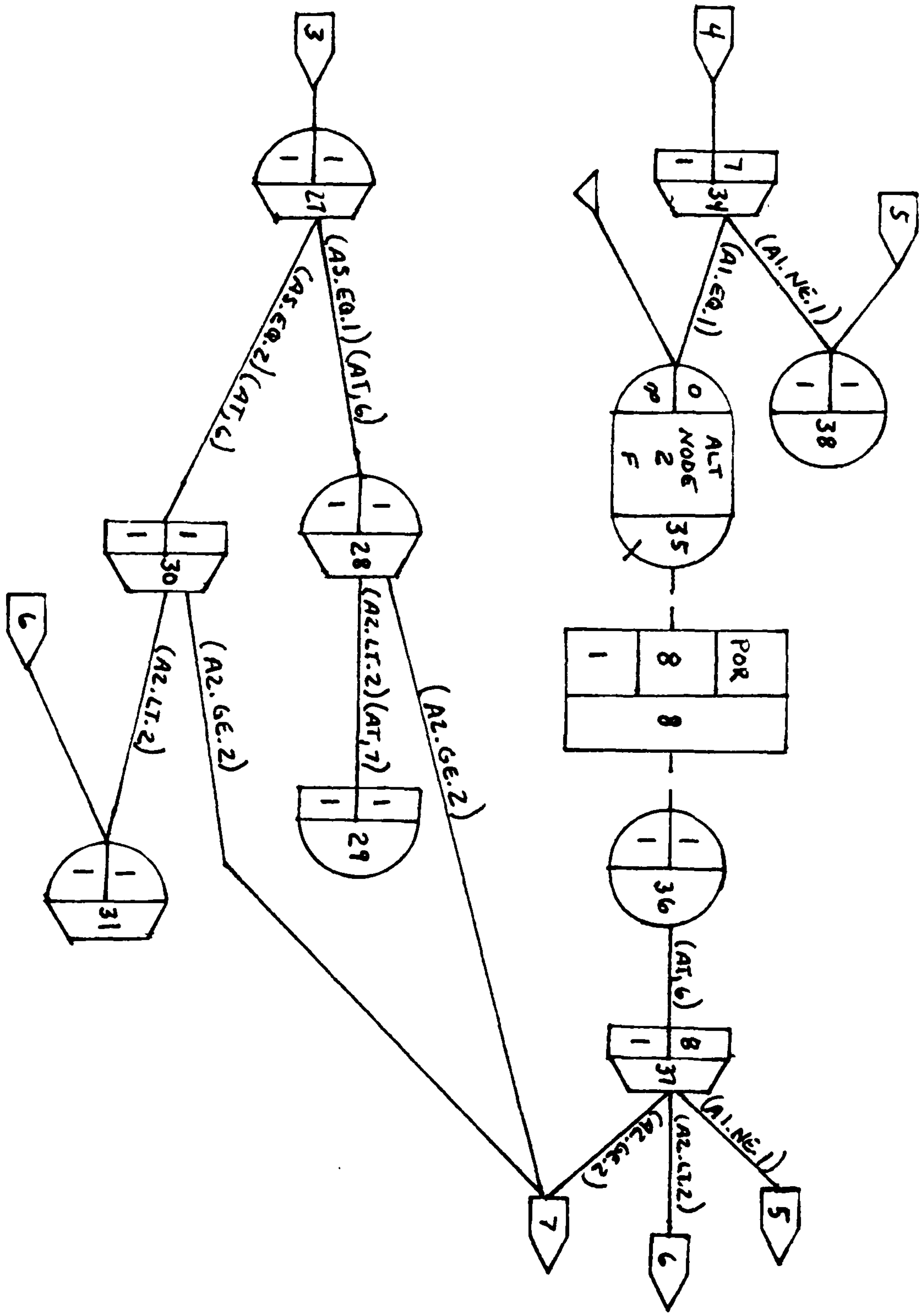
Q-Gert Design Charts

Attribute Number	Meaning Value
1	Source Node
2	Destination
3	Message Number
4	Path Length
5	Type of Switching being used 1 = Circuit Switching 2 = Packet Switching
6	Time to send circuit establishment message if circuit switching or time to send packet if packet switching
7	Time to send message and channel release signal if circuit switching or number of packets in a message if packet switching
8	Packet Number

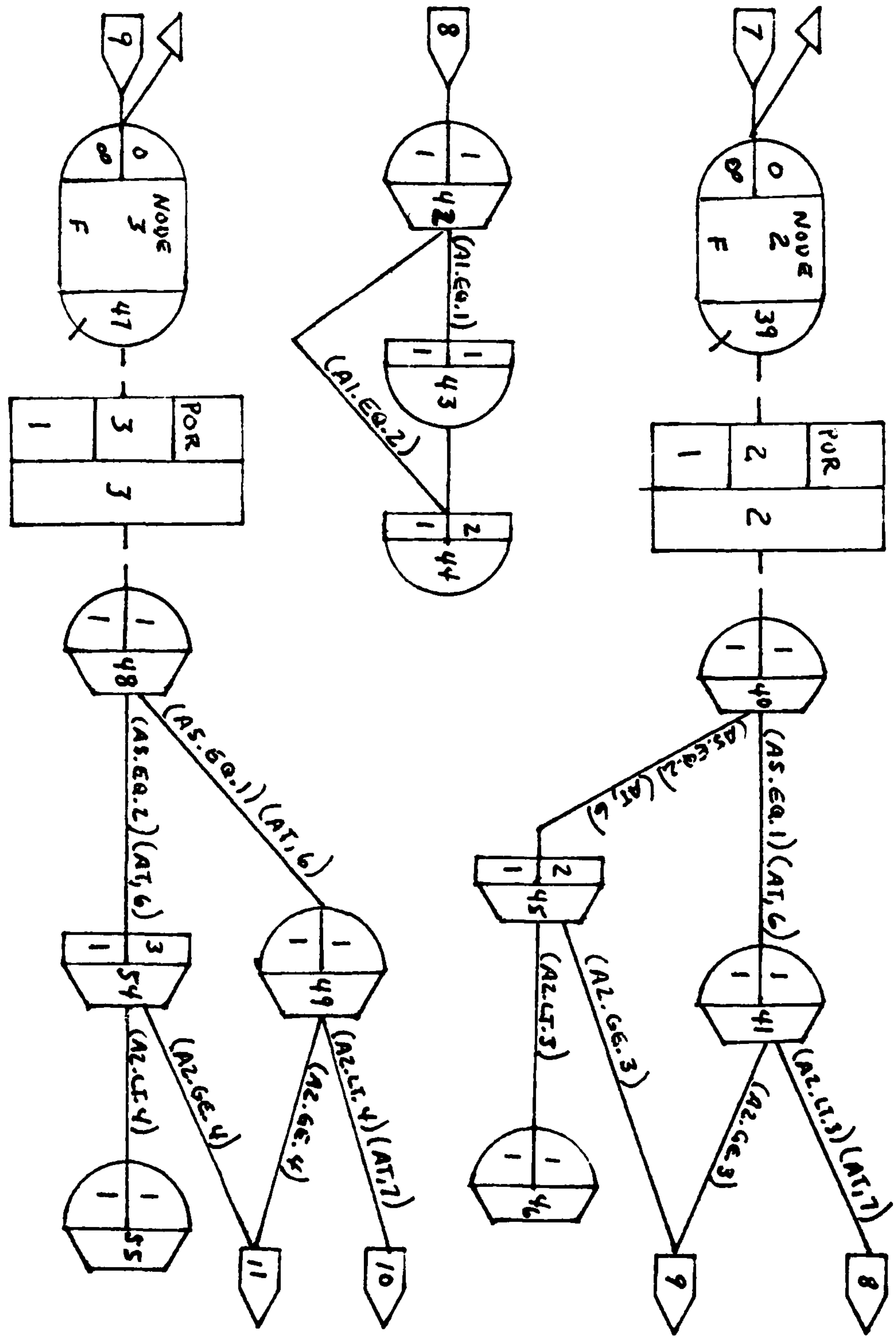

(EX,2)
0.5
0.5
A4.GE.7
A4.LT.7
A4.GE.7
A4.LT.7

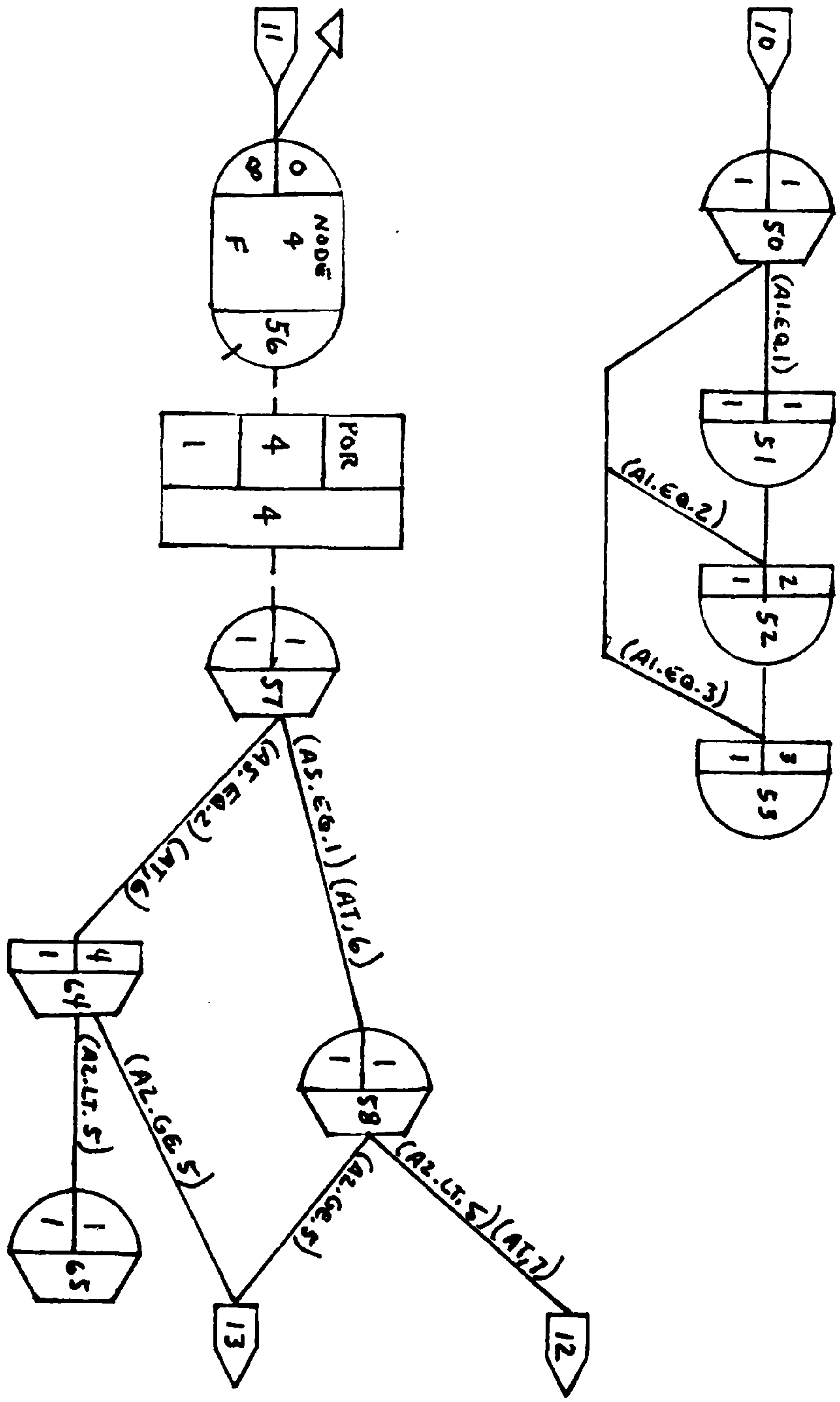

1
2
17
18
19
20
21
22
23
CO 1
CO 2
CO 3
CO 4
CO 5
.022

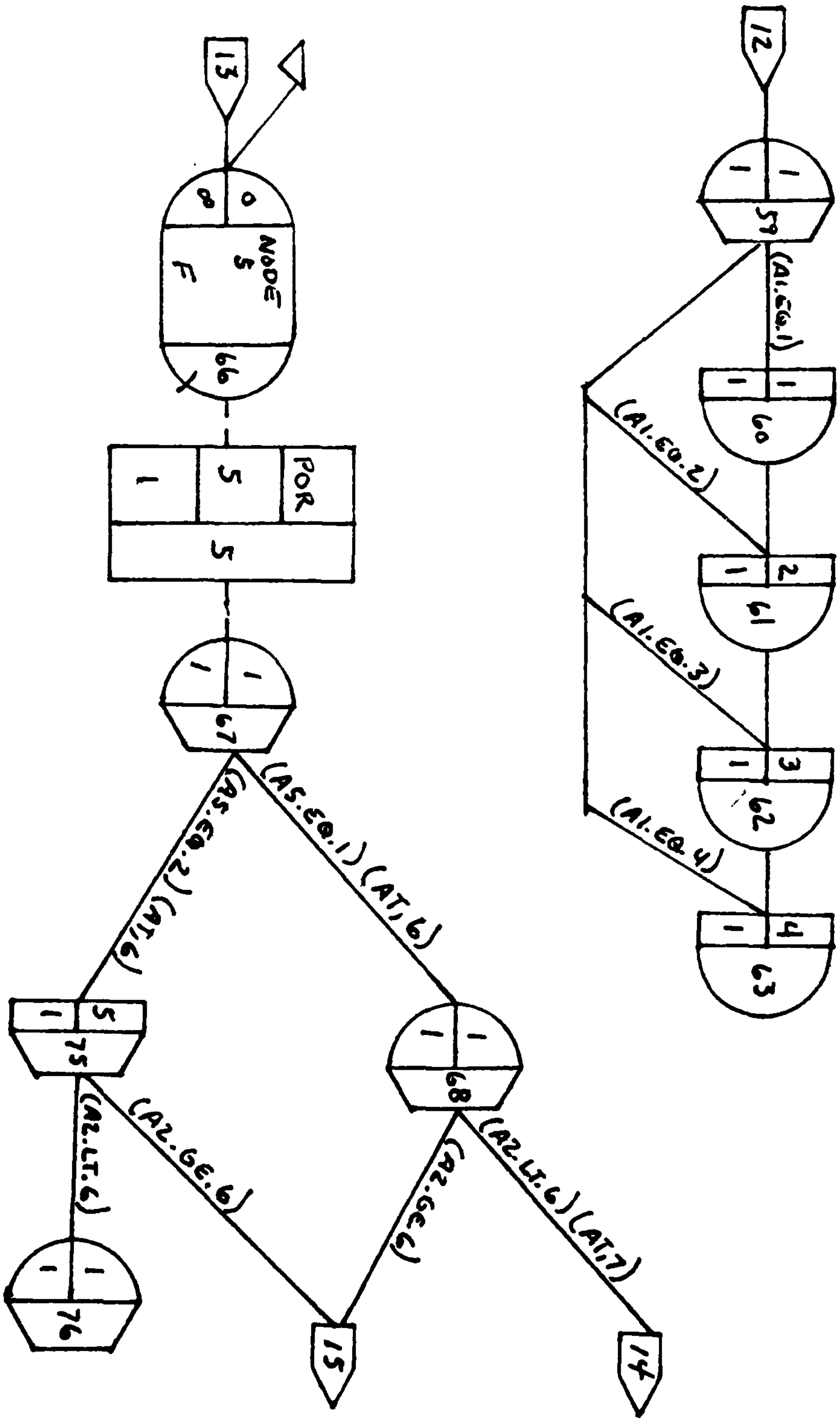

24
AS.EQ.2
AS.EQ.1
25
0.25
0.75
ALT. NODE 1
F
32
NODE 1
F
26
POR
7
POR
33
(AT,6)
3
4



ALT NODE 2 F
POR
(A1.EQ.1)
(A1.NE.1)
(A5.EQ.1)(AT,6)
(A5.EQ.2)(AT,6)
(A2.LT.2)(AT,7)
(A2.GE.2)
(A2.LT.2)
(AT,6)


NODE 2
F
POR
NODE 3
F
POR
(A1.EQ.1)
(A1.EQ.2)
(A5.EQ.1)(AT,6)
(A5.EQ.2)(AT,6)
(A2.LT.3)(AT,7)
(A2.GE.3)
(A2.LT.3)
(A2.GE.3)
(A5.EQ.1)(AT,6)
(A5.EQ.2)(AT,6)
(A2.LT.4)(AT,7)
(A2.GE.4)
(A2.GE.4)
(A2.LT.4)


10
50
(A1.EQ.1)
51
(A1.EQ.2)
52
(A1.EQ.3)
53
11
NODE
4
F
56
POR
57
(A5.EQ.1)(AT,6)
(A5.EQ.2)(AT,6)
58
64
(A2.LT.5)
(A2.GE.5)
(A2.LT.5)(AT,7)
(A2.GE.5)
65
13
12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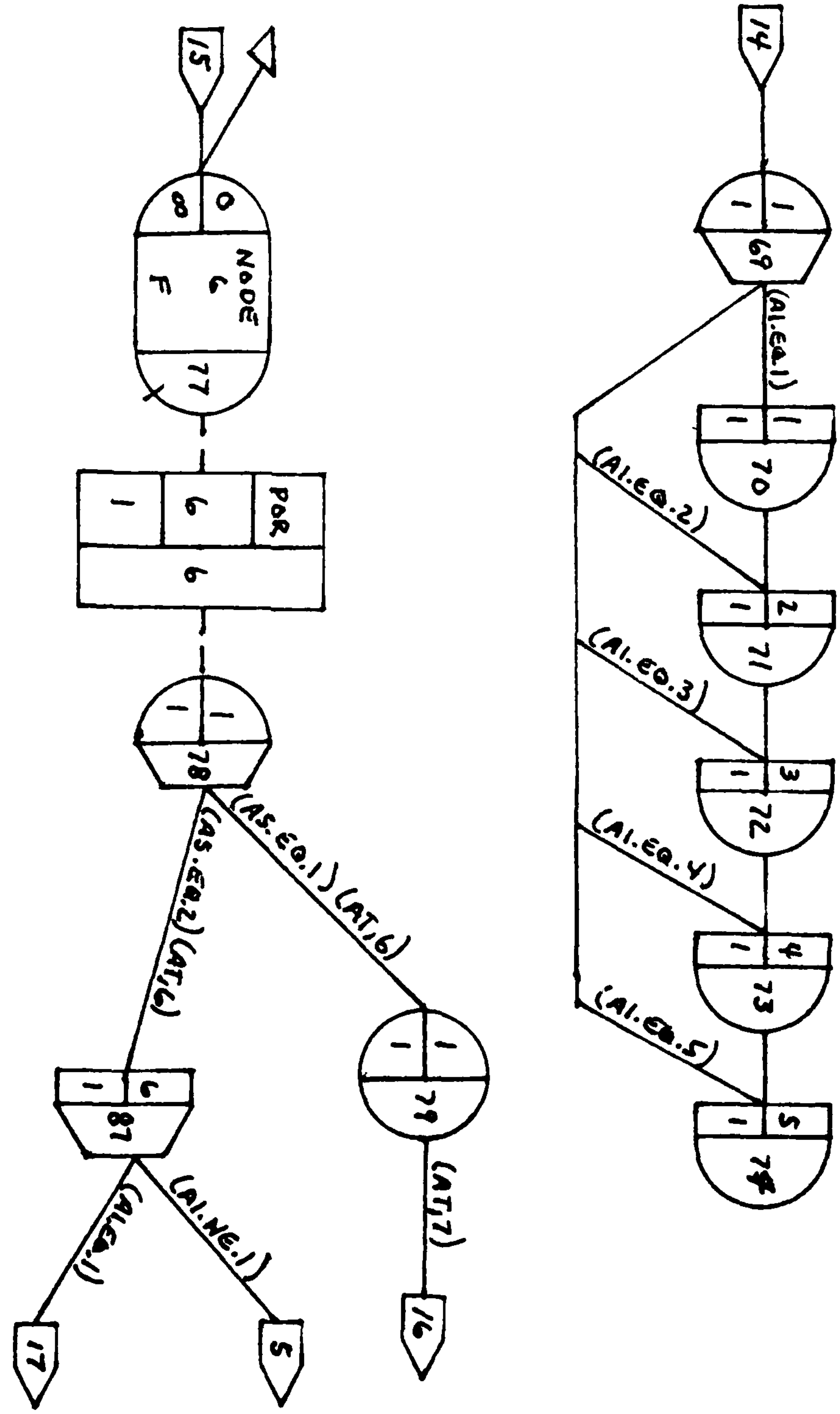
(A1.EQ.2)
2
61
(A1.EQ.3)
3
62
(A1.EQ.4)
4
63
13
NODE 5
F
66
POR
5
67
(A5.EQ.1) (AT,6)
(A5.EQ.2) (AT,6)
68
75
(A2.LT.6) (AT,7)
(A2.GE.6)
(A2.LT.6)
(A2.GE.6)
76
15
14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NODE 6
F
POR
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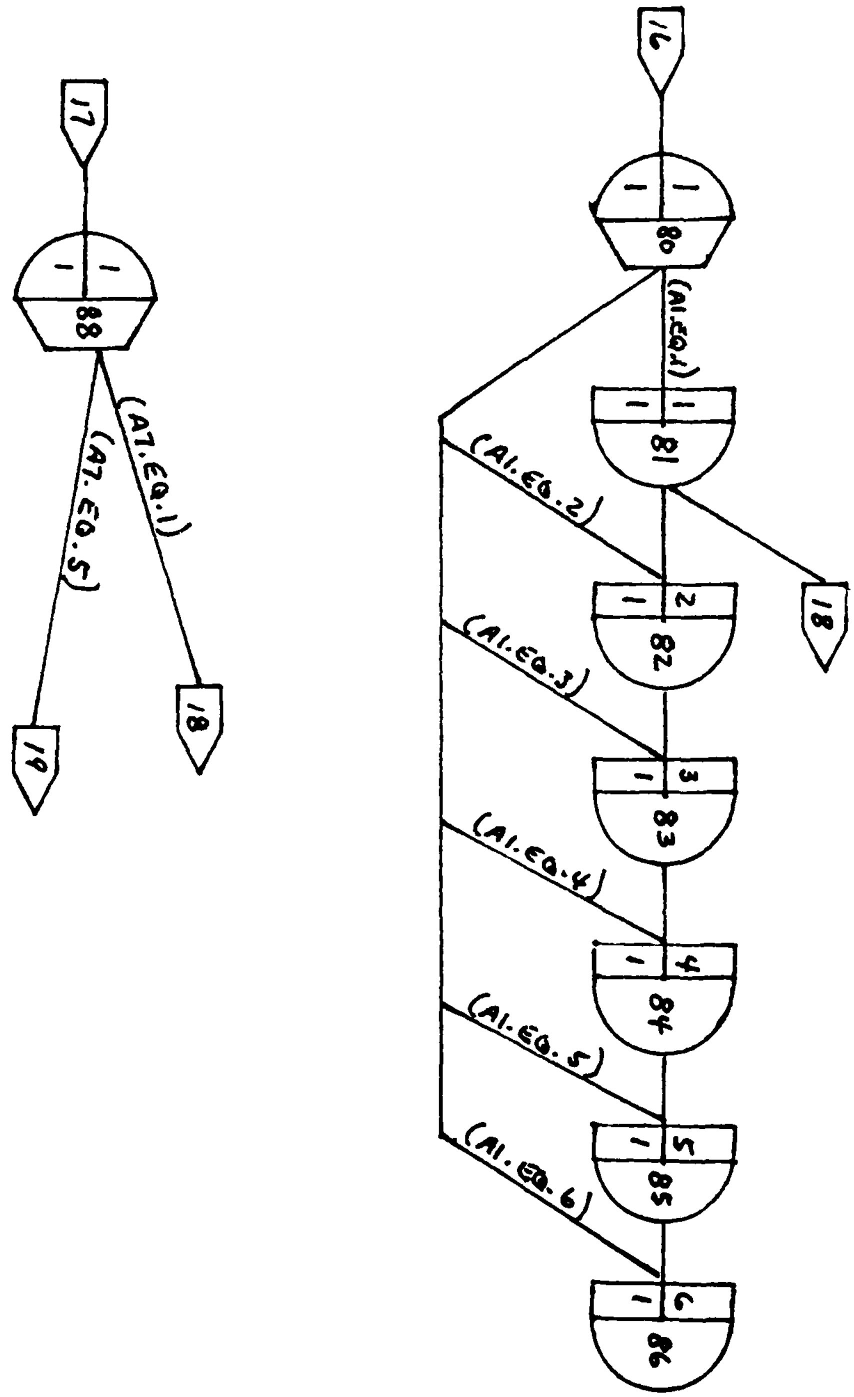
(AI.EQ.3)
(AI.EQ.4)
(AI.EQ.5)
(AS.EQ.1) (AT,6)
(AS.EQ.2) (AT,6)
(AT,7)
(AI.NE.1)
(AI.EQ.1)
17
5
16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(A7.EQ.1)
(A7.EQ.5)
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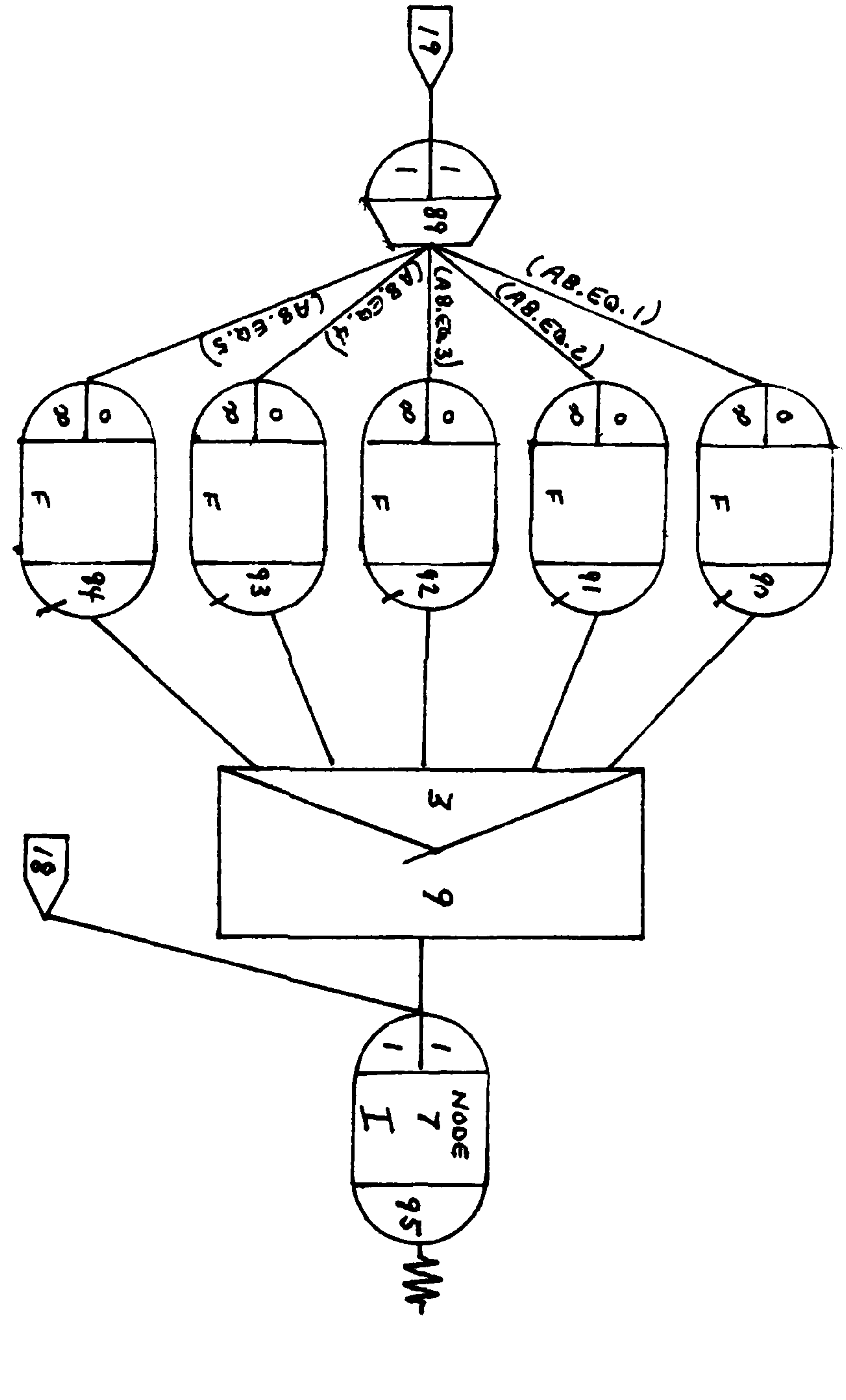
19
16
80
(A1.EQ.1)
81
18
(A1.EQ.2)
82
(A1.EQ.3)
83
(A1.EQ.4)
84
(A1.EQ.5)
85
(A1.EQ.6)
86


19
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(AB.EQ.2)
(AB.EQ.3)
(AB.EQ.4)
(AB.EQ.5)
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91
92
93
94
18
NODE 7
95

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GEN,GAMBILL, HY-SWITCHED,9,1,81,0,1,300,(14)8,(21)95*
RES,1,1,1*
RES,2,1,2*
RES,3,1,3*
RES,4,1,4*
RES,5,1,5*
RES,6,1,6*
RES,7,1,7*
RES,8,1,8*
PAR,1,0.,1.,7.,0.*
PAR,2,0.08,0.02,1.*
PAR,3,0.107,0.02,1.*
PAR,4,0.,2.,7.,0.*
PAR,5,0.48,0.02,1.*
PAR,6,0.,3.,7.,0.*
PAR,7,0.40,0.02,1.*
PAR,8,0.,4.,7.,0.*
PAR,9,0.32,0.02,1.*
PAR,10,0.,5.,7.,0.*
PAR,11,0.24,0.02,1.*
PAR,12,0.16,0.02,1.*
DEF,1*
SOU,10,0,1,D,M,L,(50)10*
VAS,10,1,CO,1,2,UN,1,3,IN,1,4,AT,2,(50)11*
ACT,10,10,EX,2,(50)12*
ACT,10,11,(50)13*
REG,11,1,1,P,(50)14*
VAS,11,4-,AT,1,(50)15*
ACT,11,12,(8)0.5,(50)15*
REG,12,1,1,F,(50)17*
ACT,12,13,(8)1,A4,LT.7.,(50)18*
REG,13,1,1,(50)19*
VAS,13,5,CO,2,6,CO,0.022,7,CO,1,8,CO,1,(50)20*
ACT,13,23,(50)21*
ACT,12,14,(8)2,A4,GE,7.,(50)22*
REG,14,1,1,(50)23*
VAS,14,5,CO,1,6,CO,0.002,7,CO,0.024,(50)24*
ACT,14,23.(50)25*
ACT,11,15,(8)0.5,(50)25*
REG,15,1,1,F,(50)27*
ACT,15,16,(8)1,A4.GE.7.,(50)28*
REG,16,1,1,(50)29*
VAS,16,5,CO,1,6,CO,0.002,7,CO,0.104,(50)30*
ACT,16,23,(50)31*
ACT,15,17,(8)2,A4.LT.7.,(50)32*
REG,17,1,1,(50)33*
VAS,17,5,CO,2,6,CO,0.022,7,CO,5,(50)34*
ACT,17,18,(50)35*
REG,18,1,1(50)36*
VAS,18,8,CO,1,(50)37*
ACT,18,23,(50)38*
ACT,17,19,(50)39*
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REG,19,1,1,(50)40*
VAS,19,8,CO,2,(50)41*
ACT,19,23,(50)42*
ACT,17,20,(50)43*
REG,20,1,1,(50)44*
VAS,20,8,CO,3,(50)45*
ACT,20,23,(50)46*
ACT,17,21,(50)47*
REG,21,1,1,(50)48*
VAS,21,8,CO,4,(50)49*
ACT,21,23,(50)50*
ACT,17,22,(50)51*
REG,22,1,1,(50)52*
VAS,22,8,CO,5,(50)53*
ACT,22,23,(50)54*
REG,23,1,1,(50)55*
ESN*
LIN,23/1,24*
REG.24,1,1,F*
ACT,24,25,(8)1,A5.EQ.2*
REG,25,1,1,P*
ACT,25,26,(8)0.75*
ACT,24,26,(8)2,A5.EQ.1.*
ACT,25,32,(8)0.25*
QUE,26/NODE 1,0, ,D,F,(10)1*
ALL.1,POR,1,1,26/27*
REG,27,1,1,F*
ACT,27,28,AT,6,(8)1,A5.EQ.1.*
REG,28,1,1,F*
ACT,28,29,AT,7,(8)1,A2._T.2.*
FRE,29,D,1,1*
ACT,29,95*
ACT,28,39,(8)2,A2.GE.2.*
ACT,27,30,AT,6,(8)2,A5.EQ.2.*
FRE,30,F,1,1*
ACT,30,31,(8)1,A2.LT.2.*
REG,31,1,1,F*
ACT,31,38,(8)1,A1.NE.1.*
ACT,31,88,(8)2,A1.EQ.1.*
ACT,30,39,(8)2,A2.GE.2.*
DUP,8,E*
REP,11,VAS,10,1,CO,8,2,CO,8.5,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,3*
ESN*
LIN,23/8,32*
QUE,32/ALT 1,0, ,D,F,(10)7*
ALL,7,POR,7,1,32/33*
REG,33,1,1*
ACT,33,34,AT,6*
FRE,34,F,7,1*
ACT,34,38,(8)1,A1.NE.1.*
REG,38,1,1*
ACT,34,35,(8)2,A1.EQ.1.*
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DUP,9,E*
REP,11,VAS,10,1,CO,9,2,CO,9.5,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,3*
ESN*
LIN,23/9,35*
QUE,35/ALT 2,0, ,D,F,(10)8*
ALL,8,POR,8,1,35/36*
REG,36,1,1,*
ACT,36,37,AT,6*
FRE,37,F,8,1*
ACT,37,38,(8)1,A1.NE.1.*
ACT,37,31,(8)2,A2.LT.2*
ACT,37,39,(8)3,A2.GE.2*
DUP,2,E*
REP,11,VAS,10,1,CO,2,2,UN,4,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,5*
ESN*
LIN,23/2,39*
QUE,39/NODE 2,0, , D,F,(10)2*
ALL,2,POR,2,1,39/40*
REG,40,1,1,F*
ACT,40,41,AT,6,(8)1,A5.EQ.1.*
REG,41,1,1,F*
ACT,41,42,AT,7,(8)1.A2,LT.3.*
REG,42,1,1,F*
ACT,42,43,(8)1,A1.EQ.1.*
FRE,43,D,1,1*
ACT,43,44*
ACT,43,95*
ACT,42,44,(8)2,A1.EQ.2.*
FRE,44,D,2,1*
ACT,41,47,(8)2,A2.GE.3.*
ACT,40,45,AT,6,(8)2,A5.EQ.2.*
FRE,45,F,2,1*
ACT,45,46,(8)1,A2.LT.3.*
REG,46,1,1,F*
ACT,46,38,(8)1,A1.NE.1.*
ACT,46,88,(8)2,A1.EQ.1.*
ACT,45,47,(8)2,A2.GE.3.*
DUP,3,E*
REP,11,VAS,10,1,CO,3,2,UN,6,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,7*
ESN*
LIN,23/3,47*
QUE,47/NODE 3,0, ,D,F,(10)3*
ALL,3,POR,3,1,47/48*
REG,48,1,1,F*
ACT,47,49,AT,6,(8)1,A5.EQ.1.*
REG,49,1,1,F*
ACT,49,50,AT,7,(8)1,A2.LT.4.*
REG,50,1,1,F*
ACT,50,51,(8)1.A1.EQ.1.*
ACT,50,52,(8)2,A1.EQ.2.*
ACT,50,53,(8)3,A1.EQ.3.*
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FRE,51,D,1,1*
ACT,51,52*
ACT,51,95*
FRE,52,D,2,1*
ACT,52,53*
FRE,53,D,3,1*
ACT,49,56,(8)2,A2.GE.4.*
ACT,48,54,AT,6,(8)2,A5.EQ.2.*
FRE,54,F,3,1*
ACT,54,56,(8)1,A2.GE.4.*
ACT,54,55,(8)2,A2.LT.4.*
REG,55,1,1,F*
ACT,55,38,(8)1,A1.NE.1.*
ACT,55,88,(8)2,A1.EQ.1.*
DUP,4,E*
REP,11,VAS,10,1,CO,4,2,UN,8,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,9*
ESN*
LIN,23/4,56*
QUE,56/NODE 4,0, ,D,F,(10)4*
ALL,4,POR,4,1,56/57*
REG,57,1,1,F*
ACT,57,58,AT,6,(8)1,A5.EQ.1.*
ACT,57,64,AT,6,(8)2,A5.EQ.2.*
REG,58,1,1,F*
ACT,58,59,AT,7,(8)1,A2.LT.5.*
ACT,58,66,(8)2,A2.GE.5.*
REG,59,1,1,F*
ACT,59,60,(8)1,A1.EQ.1.*
ACT,59,61,(8)2,A1.EQ.2.*
ACT,59,62,(8)3,A1.EQ.3.*
ACT,59,63,(8)4,A1.EQ.4.*
FRE,70,D,1,1,*
ACT,60,61*
ACT,60,95*
FRE,61,D,2,1*
ACT,61,62*
FRE,62,D,3,1*
ACT,62,63*
FRE,63,D,4,1*
FRE,64,F,4,1*
ACT,64,66,(8)1,A2.GE.5.*
ACT,64,65,(8)2,A2.LT.5.*
REG,65,1,1,F*
ACT,65,38,(8)1,A2.NE.1.*
ACT,65,88,(8)2,A1.EQ.1.*
DUP,5,E*
REP,11,VAS,10,1,CO,5,2,UN,10,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,11*
ESN*
LIN,23/5,66*
QUE,66/NODE 5,0, ,D,F,(10)5*
ALL,5,POR,5,1,66/67*
REG,67,1,1,F*
ACT,67,68,AT,6,(8)1,A5.EQ.1.*
ACT,67,75,AT,6,(8)2,A5.EQ.2.*
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REG,68,1,1,F*
ACT,68,69,AT,7,(8),1,A2.LT.6.*
ACT,68,77,(8),2,A2.GE.6.*
REG,69,1,1,F*
ACT,69,70,(8)1,A1.EQ.1.*
ACT,69,71,(8)2,A1.EQ.2.*
ACT,69,72,(8)3,A1.EQ.3.*
ACT,69,73,(8)4,A1.EQ.4.*
ACT,69,74,(8)5,A1.EQ.5.*
FRE,70,D1,1*
ACT,70,71*
ACT,70,95*
FRE,71,D,2,1*
ACT,71,72*
FRE,72,D,3,1*
ACT,72,73*
FRE,73,D,4,1*
ACT,73,74*
FRE,74,D,5,1*
FRE,75,F,5,1*
ACT,75,77,(8)1,A2.GE.6.*
ACT,75,76,(8)2,A2.LT.6.*
REG,76,1,1,F*
ACT,76,38,(8)1,A1.NE.1.*
ACT,76,88,(8)2,A1.EQ.1.*
DUP,6,E*
REP,11,VAS,10,1,CO,6,2,CO,7,3,IN,1,4,AT,2*
REP,12,ACT,10,10,EX,12*
ESN*
LIN,23/6/77*
QUE,77/NODE 6,0, , D,F,(10)6*
ALL,6,POR,6,1,77/78*
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ACT,78,87,AT,6,(8)2,A5.EQ.2.*
REG,79,1,1*
ACT,79,80,AT,7*
REG,80,1,1,F*
ACT,80,81,(8)1,A1.EQ.1.*
ACT,80,82,(8)2,A1.EQ.2.*
ACT,80,83,(8)3,A1.EQ.3.*
ACT,80,84,(8)4,A1.EQ.4.*
ACT,80,85,(8)5,A1.EQ.5.*
ACT,80,86,(8)6,A1.EQ.6.*
FRE,81,D,1,1*
ACT,81,82*
ACT,81,95*
FRE,82,D,2,1*
ACT,82,83*
FRE,83,D,3,1*
ACT,83,84*
FRE,84,D,4,1*
ACT,84,85*
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ACT,85,86*
FRE,86,D,6,1*
FRE,87,F,6,1*
ACT,87,38,(8)1,A1.NE.1.*
ACT,87,88,(8)2,A1.EQ.1.*
REG,88,1,1,F*
ACT,88,95,(8)1,A7.EQ.1.*
ACT,88,89,(8)2,A7.EQ.5.*
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ACT,89,90,(8)1,A8.EQ.1.*
ACT,89,91,(8)2,A8.EQ.2.*
ACT,89,92,(8)3,A8.EQ.3.*
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QUE,91,0, ,D,F,(10)9*
QUE,92,0, ,D,F,(10)9*
QUE,93,0, ,D,F,(10)*
QUE,94,0, ,D,F,(10)*
MAT,9,3,90,91,92,93,94/95*
SIN,95/NODE 7,1,1,D,I*
FIN*
```

VITA

Jack C. Gambill was born on 17 January 1948 in Athens, Tennessee. He received a Bachelor of Science degree co-operative plan in Industrial Engineering from the Georgia Institute of Technology in December 1971. Mr. Gambill was employed by Texas Instruments prior to beginning his civil service career at Warner Robins Air Logistics Center in December 1972. He has held positions as a maintenance engineer and staff engineer prior to begining assigned to the Electronic Warfare Division in May 1980. He was selected to attend The School of Engineering, Air Force Institute of Technology in June 1980. Mr. Gambill is a member of Tau Beta Pi.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hybrid Switching, Circuit Switching, Packet Switching, Simulation, and Modeling.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A hybrid computer network which dynamically changes switching techniques from packet switching to circuit switching depending upon path length, message length, traffic intensity, and number of channels is modeled and compared to the conventional switching techniques of circuit and packet switching. Initially, the circuit switching and packet switching are construed using Q-Gert and compared to determine which switching technique provides the smallest delays as the factors of message length, path length,

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traffic intensity, and number of channels are varied.

The operation of the hybrid switching network is defined and the network modeled using the results from comparing the circuit and packet switched models to determine when the hybrid network will be operating in the circuit switched or packet switched mode. The three models are compared to determine if the hybrid network as defined is feasible. The comparison clearly demonstrates the hybrid network consistently produces delays equal to the delays from circuit switching when it is the best and from packet switching when it is the best.

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