A simulation of a message passing protocol for a network of transputers

Janice R. Glowacki

Florida International University

Follow this and additional works at: https://digitalcommons.fiu.edu/etd

Part of the Computer Sciences Commons

Recommended Citation

https://digitalcommons.fiu.edu/etd/3830

This work is brought to you for free and open access by the University Graduate School at FIU Digital Commons. It has been accepted for inclusion in FIU Electronic Theses and Dissertations by an authorized administrator of FIU Digital Commons. For more information, please contact dcc@fiu.edu.
ABSTRACT

A SIMULATION OF A MESSAGE PASSING PROTOCOL
FOR A NETWORK OF TRANSPUTERS

by

Janice R. Glowacki

With decreasing cost and size of processors and more sophisticated demands of computer users, it is becoming popular to execute programs in parallel on a distributed network. Processors communicate through shared memory or hard-wired links depending on the hardware and topology of the system. Simulation is an appropriate tool for the investigation of system throughput, and the projection of system behavior under various workloads.

In this paper is described the configuration and communication protocol of an INMOS Transputer network, and the construction, verification, and validation of a detailed simulation model for the network. Results obtained from the execution of the model, projecting system behavior under both heavy and moderate workloads, are presented. The most significant results obtained indicate that system throughput is severely degraded when increases are made to either message traffic distance or network buffer size. Several areas for further research are suggested, including an alternative topology for large networks.
A SIMULATION OF A MESSAGE PASSING PROTOCOL
FOR A NETWORK OF TRANSPUTERS

by

Janice R. Glowacki

A thesis submitted in partial fulfillment of the
requirements for the degree of
MASTER OF SCIENCE
in
COMPUTER SCIENCE
at
FLORIDA INTERNATIONAL UNIVERSITY

Committee in charge:
Professor John Craig Comfort           Chairperson
Professor David Barton
Professor Doron Tal

September 1988
To Professors John Comfort,  
    David Barton,  
    Doron Tal, 

This thesis, having been approved in respect to form and mechanical execution, is referred to you for judgment upon its substantial merit.

Dean James Mau  
College of Arts and Sciences

The thesis of Janice R. Glowacki is approved.

Professor David Barton

Professor Doron Tal

Major Professor John Comfort

Date of Examination: September 16, 1988
A SIMULATION OF A MESSAGE PASSING PROTOCOL
FOR A NETWORK OF TRANSPUTERS

by
Janice R. Glowacki

A Thesis submitted in Partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in

COMPUTER SCIENCE

at

FLORIDA INTERNATIONAL UNIVERSITY

1988
ACKNOWLEDGEMENTS

I wish to thank my husband, Paul, and Professor John Comfort, whose support and encouragement helped make this project a success. In addition, I give special thanks to Li Qiang and Raja Gopal for sharing their friendship and Transputer expertise.
# TABLE OF CONTENTS

LIST OF FIGURES .................................................... vi

LIST OF TABLES ..................................................... vii

1. INTRODUCTION .................................................. 1
   DISTRIBUTED NETWORKS ....................................... 1
   SIMULATION ..................................................... 2
   SUMMARY OF PREVIOUS WORK ................................. 4

2. THE REAL NETWORK ............................................. 6
   TRANSPUTER HARDWARE AND SOFTWARE ........................ 6
   THE COMMUNICATION PROTOCOL ............................... 8

   The Five Communication Processes

   Avoiding Deadlock

   Proof The Algorithm Is Deadlock-Free

   iii
3. THE SIMULATION MODEL ....................................... 16
   SIMULATION METHODOLOGY ..................................... 16
   SYSTEM REPRESENTATION ......................................... 18
   REFINEMENT OF THE SIMULATION MODEL ....................... 22
      The Original Version
      The Second Version
      The Third Version
      The Final Version

4. VERIFICATION AND VALIDATION ................................... 26
   MODEL VERIFICATION ............................................. 26
   MODEL VALIDATION ................................................. 28

5. RESULTS .................................................................. 32
   SYSTEM PERFORMANCE UNDER DIFFERENT WORKLOADS ........ 32
   EFFECT OF BUFFER SIZES .......................................... 40

6. CONCLUSIONS .......................................................... 43
APPENDICES

A. THE STATE DIAGRAMS .................................. 48
   The User Generator
   The User Receiver
   The User Front
   The Network-In (Server)
   The Network-Out (Transmitter)

B. THE NETWORK COMMUNICATION CODE ............. 54

C. THE SIMULATION CODE ............................... 70

LIST OF REFERENCES ................................. 102

VITA .................................................. 103

7. FURTHER RESEARCH ................................. 45
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Transputer network topology</td>
<td>7</td>
</tr>
<tr>
<td>2. A single node in the network</td>
<td>9</td>
</tr>
<tr>
<td>3. Pre-deadlock situation</td>
<td>14</td>
</tr>
<tr>
<td>4. Simulated network topology</td>
<td>17</td>
</tr>
<tr>
<td>5. Simulated Versus Real: Message Time in System</td>
<td>30</td>
</tr>
<tr>
<td>6. Workload Comparison</td>
<td>34</td>
</tr>
<tr>
<td>7. Average Time in System: Moderate Load #1</td>
<td>37</td>
</tr>
<tr>
<td>8. Average Time in System: Moderate Load #2</td>
<td>38</td>
</tr>
<tr>
<td>9. Average Time in System: Heavy Load #1</td>
<td>39</td>
</tr>
<tr>
<td>10. Average Time in System: Heavy Load #2</td>
<td>40</td>
</tr>
<tr>
<td>11. Alternate topology for large networks</td>
<td>45</td>
</tr>
<tr>
<td>12. Summary of State Diagram Symbols</td>
<td>48</td>
</tr>
<tr>
<td>13. The User Generator State Diagram</td>
<td>49</td>
</tr>
<tr>
<td>14. The User Receiver State Diagram</td>
<td>50</td>
</tr>
<tr>
<td>15. The User Front State Diagram</td>
<td>51</td>
</tr>
<tr>
<td>16. The Network-In (Server) State Diagram</td>
<td>52</td>
</tr>
<tr>
<td>17. The Network-Out (Transmitter) State Diagram</td>
<td>53</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table                      Page

1. Simulated Versus Real: Average Message Time in System (Seconds) .......................... 29

2. Average Time a Message Remains in a Four-Node Network With Random Message Length (Seconds) .......... 31

3. Aggregated Average Time in System: All Loads (Milliseconds) .................................. 36

4. Effect of Buffer Size for Worst Case Scenario (Milliseconds) .................................. 41

5. Effect of Buffer Size for Best Case Scenario (Milliseconds) .................................. 42
CHAPTER 1
INTRODUCTION

1.1 DISTRIBUTED NETWORKS

Large computer networks, local area networks, and multiple processor systems are considered to be distributed networks. With these systems, processes of a single program can be distributed over several processors such that each processor on the network performs a subtask of the main program. Network processors need to share mutual information and are classified as tightly or loosely coupled [7]. Because tightly coupled systems have shared memory, an algorithm must exist to insure mutually exclusive access to it. Loosely coupled systems have local memory for each processor and communicate by using a message passing scheme.

Processors (nodes) in a ring network are loosely coupled and physically connected in a circle, usually with one-way communication links. Generally, a token or store-and-forward message passing scheme is used to support communication between nodes.

In a token passing scheme, a specific message, the token, continuously circulates through the network [7]. If a node wants to send a message, it must first acquire access to the network by removing the token when it arrives. This sending node forwards a message header followed by the
message. When the message has traveled completely around
the network, the sending node removes it (guaranteed the
destination node received it) and forwards the token. Thus,
only one message may travel through the system at one time.

With a store-and-forward message passing scheme, each
node has designated storage (buffer) for incoming messages.
As messages are received, they are placed in this buffer.
When messages can be forwarded, they are removed from it.
Because the buffer is a shared resource, the communication
scheme is not trivial. The sending and receiving processes
form a producer/consumer relationship and special techniques
must be employed to prevent deadlock.

With advanced system architecture it is not uncommon
to find systems with a large number of processors. The
Ethernet\(^1\) local area network, for instance, can support up to
1024 processors [5].

1.2 SIMULATION

In order to analyze a network and evaluate system
throughput or determine the number of processors needed for
efficient communication, a simulation model can be designed.
The behavior of a simulation system, according to Banks and
Carson [1], "can be used to experiment with new designs or
policies prior to implementation". Shannon [6] explains:

---

\(^1\)Ethernet is a registered trademark of the Xerox Corporation.
Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by the criterion or set of criteria) for the operation of the system.

Simulation models are classified as continuous or discrete-event. The difference is based on the way the state of the system changes over time. Continuous simulation is used to model a system that changes continuously over time. Discrete-event simulation is used to model a system which changes state at discrete intervals of time.

Banks and Carson explain a discrete-event simulation "proceeds by producing a sequence of system snapshots (or system images) which represent the evolution of the system through time" [1]. A snapshot for time (CLOCK = t) includes:

* the system state at time t--the variables that describe the system and are needed for the study
* the Future Events Queue (FEQ)--the list containing all activities in progress and the time they will terminate
* the status of all entities--the objects of interest
* current accumulators and counters used for statistic summaries

In discrete-event simulation models, events are classified as bound or contingent. Bound events mark the ending of an activity of specified length. Contingent events are
determined by certain conditions of the system and are triggered by the occurrence of a bound event.

1.3 SUMMARY OF PREVIOUS WORK

Several distributed systems have been simulated in order to evaluate their performance. The maximum mean data rates for several local area networks are presented by Stuck [8]. He explained that transmission medium has a dual purpose: to control access to the network and to transmit the data. Traffic on the network may be of low or high delay. When the network has high delay traffic, it is a bottleneck, and more time may be spent controlling access to the network than actually transmitting data.

Stuck included an evaluation of two ring networks and two bus networks. The ring networks consisted of 100 stations using a token passing scheme. The first had a single station sending to any of the 99 other stations, while the second had all 100 stations sending messages to each other. The bus networks consisted of a token passing scheme and carrier sense multiple access with collision detection. Stuck concluded by stating "Token passing via a ring is the least sensitive to workload, offers short delay under light load, and offers controlled delay under heavy load".

Garcia and Shaw [3] studied transient behavior of a five-node network using a store-and-forward message passing scheme. Assuming message traffic would be changing in the future, they were interested in analyzing current
communication channels to determine if they were adequate for future loads. In addition they were concerned with how performance might be improved.

Both a sudden burst of messages and a sudden reduction in interarrival time for given periods were modeled. They found network performance severely degraded by these transient message loads.
CHAPTER 2
THE REAL NETWORK

The INMOS Corporation manufactures microprocessors specifically designed for parallel processing. These processors are called Transputers\(^2\) and can be put together as a distributed network connected by their fast, hard-wired communication links. Currently, the School of Computer Science at Florida International University has a four-processor distributed network of T414 Transputers.

2.1 TRANSPUTER HARDWARE AND SOFTWARE

According to the INMOS Transputer Reference Manual, these T414 Transputers context switch in a microsecond and perform approximately seven million integer/data move instructions per second [4]. The communication links between processors transmit data at a rate of 10 or 20 MHz (individually switch selectable) with effective rates of .8 and 1.6 million bytes per second, respectively.

INMOS markets several different configurations of its Transputers. The University owns several INMOS B004 and INMOS B003 boards. The B004 board is an IBM PC/XT or PC/AT

\(^2\)Transputer is a registered trademark of the INMOS Group of Companies.
add-in board containing one T414 Transputer with two megabytes of memory. In addition, it contains an IMS C002 link adaptor which connects one of the T414 communication links with the Input/Output channel of the PC/XT or PC/AT. The PC can then be used as an Input/Output device and file server for the Transputer. For this reason, the T414 Transputer on the B004 board is referred to as the "host" Transputer.

The network of four T414 Transputers, each with 256 kilobytes of memory, resides on an INMOS B003 board. Each Transputer has four bidirectional communication links which can be connected to other Transputers or local memory. Therefore, several topologies are available for a network of Transputers. The current topology of the network is shown in Figure 1.

![Diagram of Transputer network topology](image-url)

Figure 1: Transputer network topology
Occam\textsuperscript{3} is the native language of the Transputer system. The basic elements of an Occam program are processes that can run sequentially or in parallel. Occam processes communicate over user-specified logical channels. These channels can be links connecting Transputers or local soft channels connecting processes running on the same Transputer. In addition, Occam supports most of the constructs available in modern high-level languages.

One advantage of the Occam view of processes is they are assigned to processors at compile time. Thus, a program developed as a set of parallel processes on a single Transputer system may be recompiled for any valid Transputer/process mapping \cite{2}.

\subsection{THE COMMUNICATION PROTOCOL}

A store-and-forward message passing scheme for the network of four Transputers was written by Li Qiang of Florida International University \cite{9}. The system is comprised of five processes running on each node.

There exist two types of processes: network and local user. Network processes are those that have access to the physical links of the network. Local user processes do not have access to the physical network and are thereby "local" to a given node.

\footnote{Occam is a registered trademark of the INMOS Group of Companies.}
There are three local user processes. The main one, performs the application program and generates messages for the node. The second receives all messages for the node. The third acts as an intermediate process supporting communication between the network and the receiving local process.

Figure 2 displays the five processes of a single node and shows the flow of message traffic through the network.

![Diagram of the network](image)

*Figure 2: A single node in the network.*
In order to accommodate incoming messages, there exist three buffers: the user, the network, and the contingency. The user buffer contains those messages received for the local node. The network buffer holds those messages to be transmitted to the next node. The contingency buffer is a protective buffer holding a message that would otherwise overflow the network buffer. This buffer is necessary to avoid deadlock as explained by Qiang [9] and later in this chapter.

Each message contains a message header that indicates its source, destination, and length. The header itself is exactly one word regardless of the length of the message. It is important to note that messages are handled at the "word level". Each word of a message is sent individually although it is part of an entire message.

2.2.1 The Five Communication Processes

The primary responsibilities of the five processes shown in Figure 2 are explained below. To clearly identify each individual process, they have been named and underlined.

The User Generator. This process is responsible for creating messages and passing them over a soft channel to the server. The channel acts as a blocking channel. Therefore, the user generator is blocked between passing each word of a message.

The User Receiver. This process is responsible for
reading the messages sent to the current node. It sends a request over a soft channel to the **user front** to read each word. It is therefore blocked from the time it sends a request until a word is actually forwarded.

**The User Front.** This process is responsible for the user buffer. It handles the producer/consumer relationship of the **server** and **user receiver**. The **server** passes words to the user buffer via the **user front**, while the **user receiver** gets words from the user buffer via the **user front**.

Occam channels are blocking channels. That is, if process P1 sends a word to process P2, P1 cannot continue until P2 receives the word. If P2 is busy and not ready to receive, then P1 remains blocked. In order to create a non-blocking channel, an intermediate process, P3, must be created [10].

Accordingly, in order to have the **server** (P1) pass messages to the local **user receiver** (P2) without blocking, there must exist the **user front** (P3) as an intermediate process. The **user front** takes messages from the **server** and, transparent to the **server**, places them in the user buffer. Upon request, it removes them from the buffer and forwards them to the **user receiver**. Because messages are handled at the word level, a separate request must be issued for each word of the message.

**The Server.** This process takes words from the incoming link and places them in the appropriate buffer. Messages for the current node are sent to the **user front** and
placed in the user buffer, while all other messages are placed in the network buffer for retransmission. It also receives messages from the user generator and places them in the network buffer for retransmission. Lastly, it answers the transmitter's requests by removing and forwarding messages from the network buffer (one word at a time).

The Transmitter. This process monitors the outgoing link. Whenever the link is available, it requests and receives a word from the server to be placed on the outgoing link.

2.2.2 Avoiding Deadlock

Deadlock can easily occur in this network if each user generator saturates the network to the point where every node is blocked from servicing incoming messages. In order to prevent this situation, there exists a protocol for filling the network buffer [9].

In short, the server receives messages from the user generator and the incoming link. Messages from the incoming link are categorized as "local" or "non-local". The server forwards local ones to the user front and fills the network buffer with non-local ones. The server places a message from the user generator into the network buffer if, and only if, the entire message can fit. Whenever the network buffer is full, however, the server blocks the user generator and processes messages from the incoming link by filling the contingency buffer. This buffer must be large
enough to hold one complete message.

This protocol enables the server to push messages through the system even when the local user process has saturated the system. In other words, if the network buffer fills, the contingency buffer is still available to buffer network traffic.

The Transputer link, like a soft channel, behaves as a blocking link. Therefore, any word sent down a link remains on it until removed by the next node. For deadlock to occur, each link must be transmitting data, and each buffer (network and contingency) must be full such that every node is blocked and will remain blocked indefinitely. To avoid this situation, it is necessary to have the priority scheme for filling the network and contingency buffers as described.

2.2.3 Proof The Algorithm Is Deadlock-Free

The store-and-forward message passing algorithm by Qiang is deadlock-free [9].

Proof by contradiction. Assume the algorithm is not deadlock-free and the network is in the state of deadlock. In other words, each network and contingency buffer is full, each link has data on it, and each user generator is blocked from submitting a message into the network. Then, there is a situation just before deadlock similar to that shown in Figure 3.
Figure 3: Pre-deadlock situation.

Suppose the last node to fill its contingency buffer was node #2. Then, when node #2 removed data from the incoming link it would enable node #1 to move data from its network buffer to its outgoing link, transfer data from its contingency buffer to its network buffer, and receive the data on its incoming link to be placed in its contingency buffer. But then the network is not in a state of deadlock.

*Contradiction of assumption.* Hence, the algorithm is deadlock free.

When the network buffer is full, the algorithm's protocol requires the data from the incoming link be received before submitting to the network messages generated by the local node. This way, it guarantees flow of traffic even when the network is saturated with messages.

When the pre-deadlock situation occurs, filling node #n's contingency buffer enables node #n-1 to unload data from its network buffer and transfer contents from its contingency buffer. Thus, node #n-1 now has an empty
contingency buffer to place data from the incoming link. This will continuously propagate such that there is never an instance where each contingency buffer is full. Thus, when traffic is intense, the network can become blocked. However, because of this protocol for filling the network and contingency buffers, the network cannot deadlock.
CHAPTER 3
THE SIMULATION MODEL

Simulating a network communication protocol requires complete understanding of both the real system and of simulation techniques. The simulation is not a duplication of the system with added statistical computations. Instead, it models the real system by recording and gathering statistical information based on the events and actions that would be occurring in the system. The computer programs for both the real and simulated systems are given in the Appendices in order to exemplify the significant difference between them.

3.1 SIMULATION METHODOLOGY

It is not uncommon for a simulation to use an enormous amount of computing time due to the number of calculations used for generating random numbers, accumulating statistics, and managing the future events queue. One attractive solution to shortening the run-time of a simulation is to incorporate a network of computing power. Comfort has investigated the idea of distributed simulation whereby related processes of the simulation can be placed on separate processors of a network [2].

Comfort has written a distributed simulation package
to run on the INMOS Transputer system [2]. The program identifies objects such as a statistics module, random number generator, and a priority queue handler. Each object is a unique process. The program can be run on a single Transputer system; however, when running the simulation on a network of Transputers, it is possible to distribute each object onto separate processors of the network and enjoy the benefit of decreased run-time.

A simulation program using this package must first instantiate specific instances of these objects. The future events queue is an instance of a priority queue. The objects are then accessed by standard calls. Statistics are updated for an entity in the simulation by sending messages to the statistics package whenever the entity changes its state.

A comprehensive simulation model, using Comfort's package, was designed to investigate system throughput of the four-node ring network on the INMOS B003 board. The topology is shown in Figure 4.

---

![Figure 4: Simulated network topology.](image-url)
Qiang's message passing protocol, as described in the previous chapter, is modeled. Also of interest were the effects of message length variation, message traffic destination (distance a message travels), and system workloads.

3.2 SYSTEM REPRESENTATION

This section explains how the processes, links, buffers, and messages were represented in the simulation model. In addition, timing of the network and parameters of the simulation are discussed.

The servers and entities. In order to simulate the real network it was necessary to determine how processes and messages should be represented. As processes service messages in the real network, servers process entities in the simulation model. Each server required a set of states and well-defined actions to be performed.

Although processes on the same processor are conceptualized as running in parallel, only one process can actually be running at a time. Thus, for every node in the model, only one server (process) could be servicing (running) at a time. Each type of server had a designated set of states and actions describing the process being modeled and could therefore be in only one state and perform only one action at a time.

Messages in the system. Messages in the real network consisted of two parts: the message header and message
body. The header contained the source, destination, and length of the message. In the simulation model, each message header was an entity.

**Simulating the buffers.** Physically, the network and contingency buffers comprise one buffer and are logically separated in software. Because the contingency part was required to accommodate the largest message size, the total buffer space needed had to be at least as large as two maximum size messages (one for each part of the buffer). Let the term network buffer now refer to the combination of the contingency and network buffer.

In order to model the user and network buffers that held messages, it was necessary to create one FIFO queue for each buffer of every node. These queues held the message header entities while local counters were updated to track the total words in a given buffer.

**Simulating the links.** A Transputer link could only hold one word at a time (message headers were single words). Because actions performed depended on the type of data sent, links were simulated using two variables. The first variable indicated the type of data on the link: a message header, a word of the message body, or indication the link was free. If a message header was on the link, then it was necessary to identify the actual entity number. This was held in the second variable.

**The Future Events Queue.** A single future events queue (FEQ) held the bound event notices for the entire
simulation. These notices included scheduling processes to time-out while waiting for a channel or because their run-time expired. Also included were notices from a node to another indicating data was sent down or removed from the link. In addition, there were batch run termination notices, as well as several others.

**System timing.** The time needed to perform each action was not easy to determine. Each Transputer cycle took about 67 nanoseconds which evaluates to 15 million cycles per second. In order to acquire accurate results, it was necessary to determine the time needed for each server to perform its various actions. The level of detail was so crucial that code for each process in the real network communication program was thoroughly evaluated to the point where instructions were literally counted [9]. In addition, the INMOS Reference manual was consulted for system timing statistics [4].

**System clock.** The simulation clock time referenced Transputer cycles rather than seconds. This was because each activity was evaluated in terms of the number of cycles necessary. If activity times were measured in nanoseconds, the clock time would become too large for some simulation runs. If activity times were measured in microseconds, then each activity would be rounded individually. Because each activity is performed a significant number of times each second, over or under estimating a time value would become significant. In order to minimize losing integrity in the
times estimated, it was decided to keep all times in reference to Transputer cycles. As a result, a single simulation clock tick evaluated to 5 Transputer cycles. Thus, to simulate one second of real time, the simulation would have to run for time = 3,000,000.

**Random number generators.** There were five random number streams used for the model. Each stream required the mean, seed, and distribution type. There were three possible distributions: constant, negative exponential, or uniform. The streams were used to generate numbers for:

* Average links a message travels (distance)
* Number of messages to send at once
* Length of the current message
* Time to run the local user application
* Operating system delay to schedule a process

**Parameters to the system.** The system required 23 parameters. They were:

* The number of nodes in the network (2 to 32)
* The speed of the links (10 or 20 MHz)
* The number of batches to run
* The length of each batch
* The maximum length of a message
* The number of messages to send at once
* The size of the network buffer
* The size of the user buffer
* The distributions, means, and seeds, for each of the five random number streams
3.3 REFINEMENT OF THE SIMULATION MODEL

To simulate a computer system it is necessary to decide the level of detail which will be modeled. Specifically, "the circuit level, gate level, register-transfer level, and system level" [3]. The initial simulation model was revised several times. Each revision increased the level of detail modeled. The state diagrams and a description of the bound event actions for the final version are given in the Appendix.

3.2.1 The Original Version

In the original model there were three servers. One for each network process and one to represent all local user processes. The model itself would deadlock even though the real network did not.

The reason the simulation would deadlock is relatively simple and can be seen in the following scenario. Suppose each link contained a word being sent to the next node, and each contingency buffer was full. Furthermore, suppose node \( n \) was the last node to fill it's contingency buffer. Then, the last bound event was for the server of node \( n \) to place a word from the incoming link into the contingency buffer. The key here is the link between node \( n-1 \) and node \( n \). Because the last bound event was for node \( n \), node \( n-1 \) was not aware of the change in status of its outgoing link. It is possible for all servers on node \( n-1 \) to be blocked. In such a case there would be no bound events for that node on the FEQ. Contingent events for node \( n \) are only checked
after a bound event has been processed for node #n. Therefore, if no bound events are scheduled for a node, then it can never reevaluate the status of its outgoing link. Hence the simulation could deadlock.

3.2.2 The Second Version

The second version eliminated the possibility of deadlock in the simulation. The "fix" was quite simple although not elegant. After a bound event was processed for node #n, the conditions for contingent events were checked for both node #n and node #n-1. Thus, the sending node would be able to update the status of the link when the receiving node made the link available. As expected, run-time of the simulation program was effected.

This model did not reflect the real network statistics as the simulated results were off by at least a factor of 5. All local user processes were handled as one server in the simulation and could not accurately reflect the real network. This was because the simulation did not account for the time needed for a context switch. In other words, the simulation modeled three separate processes running each for time t as one process running for time 3t. In reality, it requires time 3t + 2c where c is the time for a context switch to occur between running processes. Clearly, 3t + 2c is strictly greater than 3t.

3.2.3 The Third Version

In the third model, two servers were added, separating
the three local user processes and clearly defining the
duties of the user receiver, user generator, and user front.
This version attempted to adjust the timing problem in the
previous version. Although the simulation results were
significantly closer to the real network statistics, it was
clearly evident another level of detail needed to be
modeled.

3.2.4 The Final Version

Unless a priority scheme for scheduling servers was
represented, an unrealistic ordering occurred in the
simulation. Therefore, it was necessary not only to keep
track of the servers that could process an entity (message),
but also the order in which they became available to do so.

For this reason, two queues were added in the final
model: Block and Ready. The Block queue held those servers
waiting for some event or condition to occur before they
could run, while the Ready queue held those servers which
could be run. The servers in the simulation were placed on
the block queue after serving an entity (message) and moved
to the ready queue according to pre-defined conditions for
the process being modeled. Essentially, this modeled the
operating system's scheduler.

After a bound event was processed, the status of each
server on the Block queue (for that specific node) had to be
evaluated in order to determine which servers, if any,
needed to be moved to the Ready queue. Then, if no servers
were currently running, one from the Ready queue was scheduled.

Although this approach modeled the network more realistically, it did add several drawbacks. First, significantly more computations were being performed and as a result, program run-time was severely degraded. Second, as contingent events were not tested in the "traditional" scheme, the simulation would deadlock in the same manner as the original model. Therefore, it was again necessary to design a technique to avoid deadlock in the simulation.

There were two solutions investigated. The first one would require moving node #n-1's transmitter from the Block queue to the Ready queue whenever node #n removed a word from the link. However, there did not seem reasonable justification to manipulate a node's data structures while processing events of another node.

The second solution required an additional bound event notice to be scheduled. Although sending node #n could compute the time a word would arrive at node #n+1, it could not determine when the word would actually be removed. Therefore, whenever node #n+1 removed data from the link, it was required to create and schedule a bound event notice for node #n indicating the link became available.
CHAPTER 4

VERIFICATION AND VALIDATION

The simulation model must be verified and validated. Model verification deals with verifying the code performs accurately and is implemented correctly. Model validation deals with showing the code accurately models the real system. The previous chapter discussed the several versions of the simulation model. Each version was carefully evaluated in an attempt to verify and validate it. However, the earlier versions did not accurately model the real network and the revisions became evident during the evaluation process. This chapter discusses the verification and validation of the final version.

4.1 MODEL VERIFICATION

Verifying the simulation model, like verifying any computer program, can be done using very common sense techniques [1]. Banks and Carson suggest:

* make the code "self-documenting"
* make a flow diagram indicating the possibilities encountered when an action for an event occurs
* verify the input parameters are not modified
* use a program trace while testing the code
* closely examine the output for "reasonableness"
Each of these techniques were incorporated in order to verify the simulation code. An explanation of the use of each techniques as it was applied to this project is given here.

**Self-documenting code.** An Occam program is viewed as a single fold comprised of other folds. A fold is simply the concept of grouping information or code together as a separate unit. Each fold can be identified with a name (generally used to explain the fold's contents) and may contain other folds, comments, and code. In general, folds are kept small and concise. Therefore, Occam programs are "self-documenting" by nature.

The code for the simulation program is given in the Appendix. Along with explanatory fold names, documentation for all variables, states, and actions were included in the source code.

**Flow diagram.** A flow diagram is suggested in order to evaluate each possible action the system can perform after each event. The flow diagram for the simulation model consists of the state diagrams for each of the servers. These can be found in the Appendix.

**Verify input parameters.** The 23 input parameters for the system were printed after several tests to verify they were not modified during the execution of the simulation.

**Trace the execution.** The trace was used to get output while the simulation was running to determine if the code was performing accurately. The trace was very useful and
helped determine the reason the simulation would deadlock. In addition, it helped identify the unfair scheduling of processes in the earlier versions.

The trace included information about each queue (what was being added or removed from it), each random number stream (what stream was generating numbers and what the numbers were), the statistics package (what entity was entering and leaving what state), and each bound event action (what and when it was pulled from the FEQ).

Examine the output. The output for each version was evaluated. It was not until the final version that "reasonable" results were found. These results are explained and shown in the validation part of this chapter.

4.2 MODEL VALIDATION

Validation is an approach used to determine if the model accurately represents the real system. According to Banks and Carson [1]:

Validation is usually achieved through the calibration of the model, an iterative process of comparing the model to actual system behavior and using the discrepancies between the two, and the insights gained, to improve the model. This process is repeated until model accuracy is judged to be acceptable.

The rest of this chapter presents the results obtained from both the real and simulated networks. The results are compared and the simulation is "judged to be acceptable".

The real four-node network was run until each node sent/received 30,000 messages of 15 words to/from the node three links away. This test was run several times with
different network buffer sizes but with the user buffer and link speed set constant at 2000 words and 10 MHz respectively. A few timers were added and the system appeared to reach stability almost immediately. The average time in the system is displayed in Table 1.

<table>
<thead>
<tr>
<th>Buffer Size</th>
<th>Real Time (Seconds)</th>
<th>Simulated Time (Seconds)</th>
<th>Difference</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>0.00767</td>
<td>0.00492</td>
<td>0.00275</td>
<td>0.3585</td>
</tr>
<tr>
<td>54</td>
<td>0.00748</td>
<td>0.00981</td>
<td>-0.00233</td>
<td>0.3115</td>
</tr>
<tr>
<td>150</td>
<td>0.03380</td>
<td>0.03900</td>
<td>-0.0052</td>
<td>-0.1538</td>
</tr>
<tr>
<td>300</td>
<td>0.08300</td>
<td>0.08300</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>500</td>
<td>0.14616</td>
<td>0.14633</td>
<td>-0.0017</td>
<td>-0.0012</td>
</tr>
<tr>
<td>2000</td>
<td>0.60320</td>
<td>0.60330</td>
<td>0.0010</td>
<td>-0.0002</td>
</tr>
</tbody>
</table>

Intuitively, we could visualize the local user generator flooding the server with messages so the network buffer would be filled to capacity. Then, the user generator would be blocked and the server would be able to handle incoming messages by placing them in the contingency buffer. At some point, the server could reach a steady state of handling both incoming and local messages.

The simulation was then tested where each of the four nodes were sending/receiving continuously to the node three links away. The user buffer size and link speed were set to constants of 2000 words and 10 MHz respectively. The test was run several times varying the network buffer size.

Each test was run for eight blocks, each representing
one second of real time. The network was presumed to have been saturated with messages and reached steady state as the results for blocks three to eight were the same (as expected for constant input parameters). A comparison of the average message time in the system for both the real and simulated networks are shown in Table 1 and Figure 5.

![Average Message Time in System](image)

**Figure 5:** Simulated Versus Real: Message Time in System.
The simulation was then run with uniformly distributed random message lengths between 1 and 31 words. Again, each node was sending messages across 3 links at 10 MHz. The user buffer was set to 2000 words. The simulation was set to run for 25 intervals each representing one-half second of real time.

The results are shown in Table 2 along with the 90% confidence interval which encapsulates the real network's average message time in the system (see Table 1). Note that network buffer sizes of 32 and 54 could not be tested because the maximum size of a message was 31 words and the network buffer was required to accommodate two maximum size messages (one for the contingency buffer, one for the network buffer).

<table>
<thead>
<tr>
<th>Network Buffer</th>
<th>Average Time in System (Seconds)</th>
<th>Standard Deviation</th>
<th>90% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>.03185</td>
<td>.00701</td>
<td>.02033 TO .04337</td>
</tr>
<tr>
<td>300</td>
<td>.09867</td>
<td>.01364</td>
<td>.07623 TO .12111</td>
</tr>
<tr>
<td>2000</td>
<td>.79333</td>
<td>.12100</td>
<td>.59426 TO .99235</td>
</tr>
</tbody>
</table>

With several test runs and the results listed here, it was decided the model was valid.
CHAPTER 5
RESULTS

In order to evaluate system performance, a well-defined, organized, and statistically sound testing method was required. Each test was run at least twice with different random number generator seeds in order to insure that no bias was added by the choice of seed. This chapter presents the major test results and findings of this research.

5.1 SYSTEM PERFORMANCE UNDER DIFFERENT WORKLOADS

When validating the model, it was noted that, message time in the system usually decreased as the buffer size decreased. However, real system performance was better at buffer size 54 than 36. This indicated that smaller buffers increased system performance, but that at some point there was a cut-off, at which time performance slightly decreased. However, as determining the cut-off point was not part of this evaluation, tests in this section incorporated the fact that smaller buffers increased system performance, but did not seek to determine an "optimal" buffer size.

Testing was extremely time consuming (12 minutes to simulate one second of real time). Therefore, not all configurations could be thoroughly studied. Although the
system had 23 parameters and could model numerous configurations, certain consistent parameters were used for all the tests described here. The network size was fixed with four processors. Because message lengths may vary, the tests used message lengths uniformly distributed between one and eleven words. The network and user buffers were kept relatively small (33 words—chosen to hold three maximum size messages). Lastly, as preliminary tests from the real and simulated networks indicated only slight improvement in system performance when the links were set at 20 MHz, it was decided to test with links set at 10 MHz.

Two workloads describing the message traffic were defined: heavy and moderate. The heavy load assumed the user application program continuously generated messages. The application program would spend only a few microseconds processing before generating its next message. The moderate workload had the application program run for a short while, thereby generating only a moderate number of messages.

There are four cases discussed in this section. Two for heavy workload and two for moderate workload. The heavy workloads used a constant of five microseconds for processing time between generating messages, while the moderate loads used a uniformly distributed processing time between zero and two milliseconds. Therefore, the heavy loads had one random number stream (message length), and the moderate loads had two (message length and processing time).
Workload Comparison
Average Message Time in System
Messages Travel 3 Links

Each load had a designated seed or seed pair used for each test. In order to compare workloads and to evaluate the effect of introducing the second random stream, the first heavy and moderate workloads used the same seed for message length. There was an additional run which used the same seed for message length but had a constant workload of one millisecond.

The simulation was run to model the network where each message destination was the previous node (message distance was three links/worst case analysis). Figure 6 displays the average message time in the system for the heavy, moderate,
and moderate constant loads with the same message length seed. The randomness introduced by the process time can be seen along with the difference between workloads.

For each test case, several preliminary tests were run in order to determine when steady state was achieved. The simulation was run such that each node sent messages to the previous node. These preliminary tests were run for approximately 25 seconds of real time in block lengths equivalent to 1/4, 1/2, and one second. The "deleted moving average" for block lengths of 1/4 and 1/2 was computed and compared to the results of the one second block length. These data were examined to determine when steady state occurred and which block size was most appropriate.

It was found, that block length of 1/2 second was less sensitive to random variation as the 1/4 second block, and captured more information than the 1 second block. Thus, it was used for the block length of the following cases.

Each test workload was run for all possible message distances, for several seconds past the time determined as "steady state". The averages for message time in the system, following the decided steady state time, were then aggregated. Table 3 displays these aggregated averages and standard deviations.
TABLE 3

Aggregate Average Time in System: All Loads
(Milliseconds)

<table>
<thead>
<tr>
<th>Message Distance</th>
<th>Heavy Load #1</th>
<th>Heavy Load #2</th>
<th>Moderate Load #1</th>
<th>Moderate Load #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Link</td>
<td>1.755</td>
<td>1.766</td>
<td>4.031</td>
<td>4.003</td>
</tr>
<tr>
<td>2 Links</td>
<td>5.145</td>
<td>5.143</td>
<td>8.949</td>
<td>9.013</td>
</tr>
<tr>
<td>3 Links</td>
<td>6.413</td>
<td>6.554</td>
<td>10.777</td>
<td>11.048</td>
</tr>
<tr>
<td>4 Links</td>
<td>15.103</td>
<td>15.263</td>
<td>19.476</td>
<td>26.586</td>
</tr>
</tbody>
</table>

Figures 7 through 10 display each 1/2 block value for the different case workloads—from start-up through a couple of seconds at steady state.
For all workloads, when message distance was one link (best case scenario), the time in the system was minimal. Clearly, no message had to compete with network messages to get into the network buffer. Each message was immediately placed in its network buffer, sent across the link, and was placed in the user buffer of the successor node, never really competing for space in any buffer.

Significant difference was found as soon as the messages had to travel more than one link. The competition for the network buffers can be seen in Figures 7 to 10.
Results of the two moderate workloads are displayed in Figures 7 and 8. Comparable results were found.

There was a dramatic degradation in system performance when messages had to travel across four links. Messages were in circulation longer, competed for even more buffers, and were affected more by the randomness of the test than any other message distance. If a network were to be increased, and message distance were significant to the size of the network, projected system performance would degrade radically.
Results of the two heavy workload systems are displayed in Figures 9 and 10. The results were consistent indicating the random seeds did not introduce a new bias. Because the application program was not really executing for any significant time, there was less time between the network processes running. As a result, message time in the system was decreased consistently across all message distances as compared with the moderate workloads. In fact, there was a minimum three millisecond increase for all message distances.
A five-node network was run with the message distance held constant at four links. The average message time in the system was found to be greater than with the four-node network with message distance of four links. Although all test cases were not run yet for the five-node network, the evidence indicated considerable degradation of system performance as the network size increased along with message distance.

5.2 EFFECT OF BUFFER SIZES

Several tests were run in order to determine the
effect of changes made to the user and network buffer sizes. The random number generator used for message lengths (uniformly distributed between one and eleven words) was run with several different test seeds. Message distance was held constant to three links. Once the system reached steady state, the averages were aggregated and some are shown in Table 4. For these tests, the link speed was set at 10 MHz and the network was run at heavy load.

**TABLE 4**

Effect of Buffer Size for Worst Case Scenario (Milliseconds)

<table>
<thead>
<tr>
<th>Test Seed #37</th>
<th>Network Buffer</th>
<th>User Buffer</th>
<th>Aggregated Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>99</td>
<td>6.322</td>
<td>0.2045</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>33</td>
<td>6.322</td>
<td>0.2045</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>33</td>
<td>33.986</td>
<td>1.2344</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Seed #83</th>
<th>Network Buffer</th>
<th>User Buffer</th>
<th>Aggregated Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>11</td>
<td>6.554</td>
<td>0.1716</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>22</td>
<td>6.554</td>
<td>0.1716</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>33</td>
<td>6.554</td>
<td>0.1716</td>
<td></td>
</tr>
<tr>
<td>333</td>
<td>33</td>
<td>131.022</td>
<td>1.5609</td>
<td></td>
</tr>
</tbody>
</table>

* Messages (Uniform) 1 to 11 Words
* Message Distance (Constant) 3 Links

These results indicated that the user buffer was not a bottleneck. Thus, for the system at heavy load, the user buffer could be small. This would be useful for
applications programs with large memory requirements. However, further research is needed in order to determine if this conclusion remains valid when the system is running at other workloads.

If the application program were required to communicate with only its successor node (best case), would it be more efficient to have larger buffers? Table 5 shows the results of the simulation program running at heavy load with message distance constant at one link. These results indicate, again, that smaller buffers improve system performance.

**TABLE 5**

<table>
<thead>
<tr>
<th>Network Buffer</th>
<th>User Buffer</th>
<th>Aggregated Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>11</td>
<td>1.766</td>
<td>0.007</td>
</tr>
<tr>
<td>33</td>
<td>33</td>
<td>1.766</td>
<td>0.007</td>
</tr>
<tr>
<td>330</td>
<td>33</td>
<td>30.928</td>
<td>2.009</td>
</tr>
<tr>
<td>330</td>
<td>330</td>
<td>30.928</td>
<td>2.009</td>
</tr>
</tbody>
</table>

* Message Distance (Constant) 1 Link
* System Running at Heavy Load #2

Consideration should be given to the type of application program being run. For instance, if a program required significant computing time, larger buffers would minimize time spent waiting to send a message. The application program could generate a message, deposit it in the buffer, and continue processing. Although the message itself would remain in the system longer, the application program would not be blocked for a significant time.
CHAPTER 6
CONCLUSIONS

Both system throughput and average message time in system were strongly influenced by the size of the network buffer. When the buffer was large, the system could accommodate more messages. However, each message would have to remain in the system longer because it had to trickle through larger buffers.

The ring network studied was quite sensitive to message distance. As message destination length increased, system performance was radically degraded. Message time in the system increased because messages, not only had to travel further, but also had to also compete for space in each network buffer with the local messages being generated. Therefore, system performance is projected to decrease as both the size of the network and the message distance increase.

Lastly, special attention should be given to the type of application program to be executed on the system. If it is more important for an application to be able to execute than to minimize message time in the system, larger buffers should be considered. The network processes would be delayed because of the longer application run time.

In order to evaluate system performance of the
Transputer network, a simulation model was designed. The model allowed investigation of workloads and conditions that would otherwise be at best difficult to monitor and analyze. With five processes running in parallel on each Transputer, the simulation attempted to model "chaos" in an organized and elegant fashion.
CHAPTER 7
FURTHER RESEARCH

When message distance is increased the network performance is severely degraded. Thus, poor performance can be projected for large ring networks demanding intensive communication between processors. Therefore, if this project were extended, it is suggested to investigate throughput of other network topologies. Specifically, topologies which reduce the number of links a message must travel. One such topology is shown in Figure 11.

Figure 11: Alternate topology for large networks.
Each "host" Transputer for a minor network would be responsible for sending its minor network messages onto the major network. Likewise, it would be responsible for receiving messages for its minor network from the major network. This particular "network of networks" could be simulated in a two-step process. First, statistics about the minor networks would be gathered. Second, the major network would be simulated by incorporating the minor network statistics.

It is clearly evident from the results obtained that the network buffer size effects message time in the system. System performance degrades when this buffer is increased slightly. Further research may find an "optimal" message to buffer size ratio for either a given number of processors, a given workload, or both.
APPENDICES
APPENDIX A. THE STATE DIAGRAMS

A description of each state and bound event for every server in the simulation is described in this Appendix. The symbols used are described in Figure 12:

Figure 12: Summary of State Diagram Symbols.
The User Generator

The States:

0. UG.Think ---->>> running, thinking up messages
1. UG.Block ---->>> blocked waiting to send a word
2. UG.Fill.Nbuff ---->>> filling network buffer (the server process is not running)

Bound Event Actions:

2. UG. Time.Out ---->>> time out for running
3. UG. Xfer ---->>> time required to transfer a word of a message to the nbuff

Figure 13: The User Generator State Diagram.
The User Receiver

The States:

3. UR.Block.UF --------> waiting for UF to pass a word
4. UR.Block ----------> blocked waiting to read one word
5. UR.Read.Mail -------> reading one word of a message

Event Actions:

4. UR.Close.Mail -----> read one word of a message

Figure 14: The User Receiver State Diagram.
The User Front

The States:
6. UF.Block --------> blocked, waiting to run
7. UF.Fill.Ubuff ----> placing word in user buffer
8. UF.Remove.Ubuff --> removing word from user buffer

Bounding Event Actions:
5. UF. Produce ------> place word in user buffer
6. UF. Consume -------> remove word from user buffer

Figure 15: The User Front State Diagram.
The Network-In (Server)

The States:

9. NI.Sleep --------- > nothing on link to get
10. NI.Block.Nbuff ---- > waiting for room (net buffer)
11. NI.Block.Ubuff ---- > waiting for room (user buffer)
12. NI.Block.UF ------ > waiting for UF to run
13. NI.Wait.On.Link --> waiting to get word on link
14. NI.Fill.Nbuff ---- > moving word (link to net buffer)
15. NI.Fill.Ubuff ---- > put word in user buffer via UF

Bound Event Actions:

7. NI.Get.Link ------- > a word arrived on the link
8. NI.Xfer -------- > word was moved (link-buffer)

Figure 16: The Network-In (Server) State Diagram.
The Network-Out (Transmitter)

The States:

16. NO.Sleep --------> link to next node is empty
17. NO.Busy --------> link to next node is full
18. NO.Fill.Nlink ----> a word is being put on link

Bound Event Actions:

9. NO.Xfer ---------> a word arrived on link
10. NO.Received -------> the word on link was removed

Figure 17: The Network-Out (Transmitter) State Diagram.
APPENDIX B. THE NETWORK COMMUNICATION CODE

PROC net.server(CHAN from.host, to.host, from.prev.node, to.next.node)
   VAL number.of.processors IS 4:
   VAL max.msg.size IS 18:
   {{
      dcls
      {{
         channels connected to users
         CHAN OF INT user.to.front:
         CHAN OF INT user.to.server:
         CHAN OF INT front.to.user:
      }}
      }}
   }
}

PAR
   {{
      node.server processes (3 processes)
      {{
         channel dcls
         CHAN OF INT server.kill.user.front:
         CHAN OF INT server.kill.sender:
         CHAN OF INT server.to.user.front:
         CHAN OF INT msg.request:
         CHAN OF INT from.overflow:
         CHAN OF INT server.to.sender:
      }}
   }}

   {{
      network msg header opcode definition
      VAL xfer IS 0:
      VAL config IS 1:
      VAL term IS 2:
      VAL config.done IS 3:
      VAL term.done IS 4:
      VAL ring.token IS 5:
      VAL broadcast IS 6:
   }}

   {{
      misc definitions
      VAL prog.start IS "program started*n*c":
      BYTE testch:
   }}

   {{
      debug dcl
   }}

PAR
   {{
      user.front
-- process to maintain buffer

```plaintext
{ { dcl
 VAL buff.size IS 5000:
 [buff.size] INT buff:
 INT next.slot, count:
 INT next.data:
 BOOL done:
 BOOL consumer.waiting:
 INT msg:
 INT req.token:
 INT quit.token:

to.consumer IS front.to.user:
from.producer IS server.to.user.front:
consumer.request IS user.to.front:
quit IS server.kill.user.front:
BOOL msg.hanging:
}}

SEQ
 done:=FALSE
 consumer.waiting:=FALSE
 msg.hanging:=FALSE
 count:=0
 next.slot:=0

WHILE NOT done
 PRI ALT
 (NOT msg.hanging) & from.producer ? msg
  { { get a msg and pass along if consumer is waiting
  SEQ
   { { COMMENT trace Fr
   }}

  IF
   consumer.waiting
  SEQ
   to.consumer ! msg
   consumer.waiting:=FALSE
   -- done:=msg=stop.flag
  TRUE
   IF
   count < buff.size
    { { insert into buff
   SEQ
    buff[next.slot]:=msg
    next.slot:=next.slot+1
   IF
    next.slot=buff.size
    next.slot:=0
   TRUE
   SKIP
```
count:=count+1
}}

TRUE
SEQ
  msg.hanging:=TRUE
-- ENDIF
}}

consumer.request ? req.token
{{
  pass a msg to consumer if one is available
SEQ
  IF
    count=0 -- There are no msgs available
    consumer.waiting:=TRUE
    TRUE
    SEQ
      next.data:=next.slot-count
      IF
        next.data<0
          next.data:=next.data+buff.size
          TRUE
          SKIP
        -- ENDIF
        to.consumer ! buff[next.data]
        -- done:=buff[next.data]=stop.flag
        count:=count+1
      IF
        msg.hanging
        {{
          insert the hanging msg into buff
          SEQ
            buff[next.slot]:=msg
            count:=count+1
            next.slot:=next.slot+1
            IF
              next.slot=buf.size
              next.slot:=0
              TRUE
              SKIP
              msg.hanging:=FALSE
            }}
            TRUE
            SKIP
          -- ENDIF
        }}
        TRUE
        SKIP
      -- ENDIF
  }}
  quit ? quit.token
  done:=TRUE
  {{
    COMMENT trace
  }}
}}
((( server
((( dcl
to.user IS server.to.user.front:
from.user IS user.to.server:
overflow IS from.overflow:
to.sender IS server.to.sender:
kill.user.front IS server.kill.user.front:
kill.sender IS server.kill.sender:

INT my.addr:
BOOL configured:
INT opcode:
INT dest:
INT msg.header:
INT msg:
INT msg.size:
BOOL run:
BOOL out.channel.avail:
BOOL terminating:
INT kill.token:
INT req.token:

INT buff.count, next.slot, next.data:
VAL buff.size IS 2000:
VAL limit IS ((buff.size+1) - (2*max.msg.size)):

[buff.size]INT buff:
-- [1970]INT dummybuff:

PROC decode(INT msg, opcode, dest, size)
SEQ
   opcode:=(msg BITAND #F0000000) >> 28
   dest :=(msg BITAND #0FF00000) >> 20
   size :=(msg BITAND #000FFFFF)
:
PROC make.net.header(VAL INT opcode,dest,size, INT header)
   header:=( ( opcode << 28 ) BITOR ( dest << 20 ) ) BITOR size
:
PROC wait.for.out.channel()
IF
   NOT out.channel.avail
   msg.request ? req.token
   TRUE
   out.channel.avail:=FALSE
:
)))

{{ buffer routine dcls
PROC insert.buff(INT msg)
SEQ
IF
   buff.count<buff.size -- put the msg into buff
{{ put into buff
SEQ
  buff[next.slot]:=msg
  --next.slot:=((next.slot + 1) BITAND indxmask )
  next.slot:=next.slot+1
  IF
    next.slot=buf.size
    next.slot:=0
    TRUE
    SKIP
  buff.count:=buff.count+1
}}

TRUE -- buffer is full, wait for room
{{
SEQ
  IF
    NOT out.channel.avail
    msg.request ? req.token
    TRUE
    out.channel.avail:=FALSE
    next.data:=next.slot - buff.count
  IF
    next.data<0
      next.data:=next.data + buff.size
    TRUE
    SKIP
  to.sender ! buff[next.data]
  buf[next.slot]:=msg
  next.slot:=next.slot+1
  IF
    next.slot=buf.size
    next.slot:=0
    TRUE
    SKIP
    --next.slot:=((next.slot + 1) BITAND indxmask )
    -- buff.count is not changed
}}

PROC insert.a.msg(INT msg)
SEQ
  buff[next.slot]:=msg
  next.slot:=next.slot+1
  IF
    next.slot=buf.size
    next.slot:=0
    TRUE
    SKIP
    --next.slot:=((next.slot + 1) BITAND indxmask )
    -- indxmask= buf.size-1
  buff.count:=buff.count+1
PROC send.a.msg()
SEQ
  next.data:=next.slot-buff.count
IF
  next.data<0
    next.data:=next.data+buff.size
TRUE
  SKIP
  to.sender ! buff[next.data]
  buff.count:=buff.count-1
out.channel.avail:=FALSE
:
PROC try.to.send.msg()
IF
  buff.count>0
    send.a.msg()
TRUE
  out.channel.avail:=TRUE
:
}}

SEQ
{{
  ini
  configured:=FALSE
  run:=TRUE
  out.channel.avail:=FALSE
  terminating:=FALSE
  my.addr:=1

  buff.count:=0
  next.slot:=0
}}

WHILE run
ALT
  msg.request      ? req.token
    {{
      SEQ
      IF
        buff.count>0
          send.a.msg()
        TRUE
          out.channel.avail:=TRUE
      })
      -- try.to.send.msg()
from.prev.node     ? msg
    {{
      SEQ
      IF
        buff.count>0
          send.a.msg()
        TRUE
          out.channel.avail:=TRUE
      })
      -- try.to.send.msg()
}}

-- try.to.send.msg()
decode(msg, opcode, dest, msg.size)

IF
  opcode=xfer
  {{
    --INT d:
    SEQ
    -- d=dummybuff[3]
    IF
      dest=my.addr
      {{{ transfer the whole msg to local user
        SEQ
        WHILE msg.size>0
        ALT
          from.prev.node ? msg
          SEQ
          to.user ! msg
          msg.size:=msg.size-1
          msg.request ? req.token
          try.to.send.msg()
      })
  }}
  (dest<>0) OR (my.addr<>0)
  {{{ put msg into buff and
    -- try to empty the buff at same time
    SEQ
    {{{ put msg into buff
      IF
        out.channel.avail
        SEQ
        to.sender ! msg
        out.channel.avail:=FALSE
        TRUE
        insert.buff(msg)
    }}
  }}
  WHILE (msg.size>0)
  ALT
  from.prev.node ? msg
  SEQ
  {{{ put msg into buff
    IF
      out.channel.avail
      SEQ
      to.sender ! msg
      out.channel.avail:=FALSE
      TRUE
      insert.buff(msg)
  }}
  msg.size:=msg.size-1
  msg.request ? req.token
SEQ IF buff.count>0
send.a.msg()
TRUE
out.channel.avail:=TRUE
}}
-- try.to.send.msg()
}}
TRUE
{{
{ pass the whole msg to host
SEQ
to.host ! msg
WHILE msg.size>0
ALT
from.prev.node ? msg
SEQ
to.host ! msg
msg.size:=msg.size-1
msg.request ? req.token
try.to.send.msg()
}}
}}
}
}
opcode=broadcast
{{
SEQ
IF
my.addr<number.of.processors
{{
put msg into buff
IF
out.channel.avail
SEQ
to.sender ! msg
out.channel.avail:=FALSE
TRUE
insert.buf(msg)
}}
}}
TRUE
SKIP
WHILE (msg.size>0)
ALT
from.prev.node ? msg
SEQ
to.user ! msg
IF
my.addr<number.of.processors
||| put msg into buff
| IF
| out.channel.avail
| SEQ
| to.sender ! msg  
| out.channel.avail:=FALSE
| TRUE
| insert.buff(msg)
|
| TRUE
| SKIP
| msg.size:=msg.size-1

msg.request ? req.token
||| |
| SEQ
| IF
| buff.count>0
| send.a.msg()
| TRUE
| out.channel.avail:=TRUE
|
| -- try.to.send.msg()
|

opcode=config
||| |
| SEQ
| IF
| NOT configured  
| TRUE
| my.addr:=dest  
| dest:=dest+1
| make.net.header(config,dest,0,msg.header)
| wait.for.out.channel()
| to.sender ! msg.header

opcode=term
||| |
| SEQ
| IF
| NOT terminating
| TRUE
| wait.for.out.channel()
| to.sender ! msg

TRUE
SEQ
make.net.header(term.done, 0, 0, msg.header)
to.host ! msg.header
kill.user.front ! kill.token
kill.sender ! kill.token
run:=FALSE
}}

TRUE
SKIP

}})

(buff.count < limit) & from.user ? dest
{{ take the user msg into the network
SEQ
from.user ? msg.size
make.net.header(xfer, dest, msg.size, msg.header)
IF
(dest=0) AND (my.addr=1)
{{ pass the msg to host
SEQ
to.host ! msg.header
SEQ i=0 FOR msg.size
SEQ
from.user ? msg
to.host ! msg
}}
TRUE
{{ get msg into buff
SEQ
insert.a.msg(msg.header)
SEQ i=0 FOR msg.size
SEQ
from.user ? msg
insert.a.msg(msg)
IF
out.channel.avail
send.a.msg()
TRUE
SKIP
}}

)}}

(buff.count < limit) & from.host ? msg
{{ take the host msg into the network
INT temp:
SEQ
decode(msg, opcode, dest, msg.size)
IF
opcode=xfer
SEQ

{{
  IF
  dest<>my.addr -- my.addr is 1 in this case
  {{{ put the whole msg into buffer
    SEQ
      insert.a.msg(msg) -- msg header
      SEQ i=0 FOR msg.size
      SEQ
        from.host ? msg
        insert.a.msg(msg)
      IF
      out.channel.avail
        send.a.msg()
      TRUE
        SKIP
  }}}
  TRUE
  {{{ transfer the whole msg to local user
    SEQ
      SEQ i=0 FOR msg.size
      SEQ
        from.host ? msg
        to.user ! msg
  }}
}}}

opcode=broadcast

{{
  put the whole msg into buffer
  SEQ
    insert.a.msg(msg) -- msg header
    SEQ i=0 FOR msg.size
    SEQ
      from.host ? msg
      insert.a.msg(msg)
      to.user ! msg
  IF
  out.channel.avail
    send.a.msg()
  TRUE
    SKIP
}}

opcode=config

{{
  my.addr:=dest
  dest:=dest+1
  make.net.header(config,dest,0,msg.header)
  wait.for.out.channel()
  to.sender ! msg.header
}}
configured:=TRUE
}})

opcode=term
{{{
SEQ
  terminating:=TRUE
  wait.for.out.channel{}
  to.sender ! msg
}}}
TRUE
SKIP

}}}

{{{
  sender / transmitter
  {{
    from.server IS server.to.sender:
    quit IS server.kill.sender:
    BOOL run:
    INT req.token, quit.token:
    INT msg:
  }}
}}

SEQ
  run:=TRUE
  WHILE TRUE
  SEQ
    msg.request ! req.token
    from.server ? msg
    to.next.node ! msg
    {{{ COMMENT
    }}}
}}

{{{
  channel dcl for user
  get.msg IS front.to.user:
  request.msg IS user.to.front:
  send.msg IS user.to.server:
}}}

{{{
  if usernode.tsr (2 processes) * usernode.tsr
  {{
    user msg header function code definitions
    VAL data IS 0:
    VAL config IS 1:
  }}
}}
VAL config.done IS 2:
VAL term IS 3:
VAL term.done IS 4:
VAL go IS 5:
VAL test.done IS 6:
}}

{{
user msg en/decoding procedures

PROC decode(INT msg, opcode, originator, size)
  SEQ
    opcode:=(msg BITAND #F0000000) >> 28
    originator:=(msg BITAND #0FF00000) >> 20
    size :=(msg BITAND #000FFFFF)
:PROC make.msg.header(val INT opcode,originator,size, INT header)
  header:={ (opcode << 28 ) BITOR ( originator << 20 ) } BITOR size
:PROC send.msg.header(val INT opcode,dest,size,originator)
  INT header:
  SEQ
    header:={ (opcode << 28 ) BITOR ( originator << 20 ) } BITOR size
    send.msg ! dest
    send.msg ! (size+1)
    send.msg ! header
:
}}

{{
dcls
BOOL done:
INT msg, msg.header:
INT msg.size, opcode, orig:
BOOL done:
BYTE ch:
INT my.addr:
INT dest:

INT interval:
{{
PROC delay( val INT interval )
  TIMER clock:
  INT timenow:
  SEQ
    clock ? timenow
    clock ? AFTER timenow PLUS interval
:
}}

}}

{{
random number generator abbreviations
VAL unif IS 1: --uniform distribution.
VAL nexp IS 2: --negative exponential distribution.
VAL const IS 3: --constant distribution.
VAL unifb IS 4: -- uniform with bound

}}
VAL rn.init IS 1:
VAL rn.get IS 2:
VAL rn.quit IS 3:
}}
{{ chan to rnd
CHAN to.len.rand, from.len.rand:
CHAN to.dest.rand, from.dest.rand:
}}
{{ channels between user processes
CHAN control:
}}

PAR
{{ User receiving messages
SEQ
interval:=5000
done:=FALSE
WHILE NOT done
SEQ
request.msg ! 0 -- ready to accept new msg
get.msg ? msg.header
decode(msg.header,opcode,orig,msg.size)
IF
opcode=data
{{ process data (user read/eat mail & get fat!)
SEQ
SEQ i=0 FOR msg.size
SEQ
request.msg ! 0
get.msg ? msg

{{ COMMENT
}}
}}

opcode=config
{{
SEQ
request.msg ! 0
get.msg ? my.addr
-- send.msg.header(config.done,0,0,my.addr)
control ! my.addr
}}

opcode=go
ccontrol ! 0
opcode=term
{{ terminate
SEQ
-- send.msg.header(term.done,0,0,my.addr)
done:=FALSE
ccontrol ! 0
}}
((( User sending messages
((( dcl delay
PROC delay( VAL INT interval )
    TIMER clock:
    INT timenow:
    SEQ
        clock ? timenow
        clock ? AFTER timenow PLUS interval
    ));
));

TIMER clock:
    INT start.time, finish.time:
    INT my.addr, msg:
    INT msg.size, dest:
    SEQ
        control ? my.addr
        {{{ config
            SEQ
                send.msg.header(config.done, 0, 0, my.addr)
            {{{ COMMENT
                }}}
            }}
        })
    control ? msg -- go
    SEQ i=1 FOR 30000
        {{{ place messages into the network
            SEQ
                {{{ COMMENT
                    }}
        })
    -- dest := {( ( dest-1 ) + 3 ) \ 4}+1
    -- dest := ( my.addr REM 4 ) + 1
    SEQ
        dest := my.addr
        IF
            dest>4
            dest:=dest-4
            TRUE
            SKIP
            {{{ COMMENT
                }}}
        msg.size:=14
        send.msg.header(data, dest, msg.size, my.addr)
    SEQ j=0 FOR msg.size
send.msg ! my.addr

IF
(i \ 1000)=0
SEQ
send.msg.header(data,0,1,my.addr)
send.msg ! my.addr
IF
i=20000
  clock ? start.time
i=22000
  clock ? finish.time
TRUE
  SKIP
TRUE
  SKIP
}
}
}

send.msg.header(data,0,8,my.addr)
send.msg ! my.addr
send.msg ! (finish.time-start.time)
SEQ i=1 FOR 6
  send.msg ! ( (INT '=' - (INT '0'))) 
  send.msg.header(test.done,0,0,my.addr)
  control ? msg
}
}
{ }

;
APPENDIX C. THE SIMULATION CODE

PROC xnet (CHAN keyboard, screen)

{{
  headers and declarations
  {{
    F c:\janny\tdslibjr\header09.tsr *c:\janny\tdslibjr\header09.tsr
    ATTACHED
  }}
  {{
    F c:\janny\tdslibjr\ioproc06.tsr *c:\janny\tdslibjr\ioproc06.tsr
    ATTACHED
  }}
  {{
    F c:\janny\tdslibjr\ioint004.tsr *c:\janny\tdslibjr\ioint004.tsr
    ATTACHED
  }}
  {{
    F c:\janny\tdslibjr\ioreal39.tsr *c:\janny\tdslibjr\ioreal39.tsr
    ATTACHED
  }}

  {{
    channels
    VAL max.sysqueues IS 129:   -- max # of queues needed
    VAL max.nodes IS 32:        -- max nodes in network
    VAL evs IS 0:               -- the event set queue
    [max.nodes]INT nbuff, ubuff: -- the buffer queues
    [max.nodes]INT blockq, readyq: -- the operating system queues
  }}

  [5]CHAN to.rand, from.rand:
  [max.sys.queues]CHAN to.prq, from.prq:
  CHAN to.stats, from.stats:

  {{
    random number stream names
    VAL proc.time IS 0:         -- user process time needed to do useful work
    VAL nbr.msgs IS 1:          -- number of msgs to create at once
    VAL msg.len IS 2:           -- length of a msg
    VAL os.time IS 3:           -- time for the operating system to run a proc
    VAL msg.dist IS 4:          -- the distance a msg should travel (in links)
  }}

  {{
    action codes for the simulation
  }}

  -- BOUND event actions:
  VAL s.term IS 1:             -- terminate the simulation
  VAL ug.time.out IS 2:        -- user proc times out, context switch req.
  VAL ur.close.mail IS 3:      -- user proc finishes reading a message
  VAL ug.xfer IS 4:            -- user proc moves a msg to the net buffer
  VAL uf.produce IS 5:         -- user front fills ubuff with word
  VAL uf.consume IS 6:         -- user front removes word from ubuff
  VAL ni.get.link IS 7:        -- net-in gets the msg just sent down the link
}}
VAL nl.xfer IS 8: -- net-in xferred word to the appropriate buffer
VAL no.xfer IS 9: -- net-out is putting word on the link
VAL no.word.received IS 10: -- link is now free, word was removed

-- CONTINGENT event actions:
VAL ug.do.work IS 12: -- user proc runs its application program
VAL ug.send.mail IS 13: -- user proc places message in nbuf for xmit
VAL ur.get.mail IS 14: -- user proc reads mail message
VAL uf.put.ubuff IS 15: -- user front fill ubuff
VAL uf.get.ubuff IS 16: -- user front removes word from ubuff
VAL ni.put.nbuff IS 17: -- net-in proc places the word on link in nbuf
VAL ni.put.ubuff IS 18: -- net-in proc places the word on link in ubuff
VAL no.send.ubuff IS 19: -- net-out proc places word of msg on link

{{
{{ function and distribution codes
{{ distribution codes for the RNG
VAL invalid.distr IS 0: -- invalid distribution type
VAL unif IS 1: -- uniform distribution.
VAL nexp IS 2: -- negative exponential distribution.
VAL const IS 3: -- constant distribution.
}}
{{ common function codes
VAL error IS -1:
VAL init IS 0:
VAL quit IS 1:
}}
{{ PRQ function codes
VAL sched IS 2: -- put an entity id on the queue
VAL next IS 3: -- get the next entity id from the queue
VAL dump IS 4: -- print contents of queue
VAL length IS 5: -- return length of queue
VAL view IS 6: -- return next item without removing it from queue
}}
{{ RNG function codes
VAL rn.init IS 1: -- initialize the random number generator
VAL rn.get IS 2: -- get the next random number
VAL rn.quit IS 3: -- destroy random number generator
}}
{{ entity and stat function codes
VAL get IS 2: -- get an entity id number for new entity
VAL put IS 3: -- return the entity id number for reuse later
VAL enter IS 4: -- enter a new state
VAL leave IS 5: -- leave a current state
VAL reset IS 6: -- reset the statistics
VAL cpu IS 8: -- cpu statistics
VAL dmp IS 9: -- dump statistics
}}
{{ function codes for the simulation
VAL sim.init IS 0: -- start the simulation
VAL sim.sim IS 1: -- run a block of the simulation
VAL sim.quit IS 2: -- end the simulation
}}
}}
}}
{[SC c:janny\tdslibjr\sim\random
{(F c:janny\tdslibjr\sim\random06.tsr *c:janny\tdslibjr\sim\random06.tsr
ATTACHED)
})
})
{(F c:janny\tdslibjr\sim\random07.tsr *c:janny\tdslibjr\sim\random07.tsr
ATTACHED)
})
{(SC c:janny\tdslibjr\sim\prq
{(F c:janny\tdslibjr\sim\prq00001.tsr *c:janny\tdslibjr\sim\prq00001.tsr
ATTACHED)
})
})
{(F c:janny\tdslibjr\sim\prqif002.tsr *c:janny\tdslibjr\sim\prqif002.tsr
ATTACHED)
})
{(SC c:janny\tdslibjr\sim\stats
{(F c:janny\tdslibjr\sim\stats002.tsr *c:janny\tdslibjr\sim\stats002.tsr
ATTACHED)
})
})
{(F c:janny\tdslibjr\sim\statsi03.tsr *c:janny\tdslibjr\sim\statsi03.tsr
ATTACHED)
})

[23] INT params:
{[parameter map
max.msg.len IS params[0]: -- max length of a message
max.nbuff IS params[2]: -- max number of words nbuff can hold
max.ubuff IS params[3]: -- max number of words ubuff can hold
n.blocks IS params[4]: -- number of blocks to run
block.len IS params[5]: -- length of each block
trace IS params[6]: -- values of the trace
seed.msg.dist IS params[1]: -- seed for msg dist -- # links a msg travels
seed.proc.time IS params[7]: -- seed for the process time between gen msgs
seed.genmsgs IS params[8]: -- seed for the number of msgs being created
seed.msg.len IS params[9]: -- seed for the length of msg being created
seed.ostime IS params[10]: -- seed for the ostime (op sys delay)
mean.proc.time IS params[11]: -- mean process time between generating msgs
mean.ostime IS params[12]: -- mean sleep time for the receiver
mean.genmsgs IS params[13]: -- mean number of messages created at once
mean.msg.len IS params[14]: -- mean length of a generated message
mean.msg.dist IS params[15]: -- the mean number of links a msg travels
cwmit IS params[16]: -- the speed of the link
n.nodes IS params[17]: -- the number of nodes in the system
distr.proc.time IS params[18]: -- distr type for local user process
distr.genmsgs IS params[19]: -- distr type for # msgs to generate at once
distr.msg.len IS params[20]: -- distr type for message length
distr.ostime IS params[21]: -- distr type for operating system delay
distr.msg.dist IS params[22]: -- distr type for # links a msg should travel
}}

PROC xnetsim(VAl INT opus, INT clock)
{{ run the simulation
{{ states of the system
VAL ug.think IS 0: -- user proc is thinking/processing
VAL ug.block IS 1: -- user proc blocked waiting to read/send mail
VAL ug.fill.nbuff IS 2: -- user proc is filling nbuff with a msg
VAL ur.block.uf IS 3: -- user proc is waiting for user front to run
VAL ur.block IS 4: -- user proc is blocked to read mail
VAL ur.read.mail IS 5: -- user proc is reading a mail msg
VAL uf.block IS 6: -- user front process is not doing anything
VAL uf.fill.nbuff IS 7: -- user front process filling ubuff
VAL uf.remove.nbuff IS 8: -- user front process is removing from ubuff
VAL ni.sleep IS 9: -- net-in is sleeping, nothing on link to get
VAL ni.block.nbuff IS 10: -- net-in is blocked waiting for the nbuff
VAL ni.block.uf IS 11: -- net-in is blocked waiting for the ubuff
VAL ni.block.uf IS 12: -- net-in is waiting for user front to run
VAL ni.wait.on.link IS 13: -- net-in is waiting to receive a word on link
VAL ni.fill.nbuff IS 14: -- net-in moves the msg to nbuff from the link
VAL ni.fill.uf IS 15: -- net-in moves the msg to local ubuff
VAL no.sleep IS 16: -- net-out in idle state (link is not busy)
VAL no.busy IS 17: -- net-out in xmit state (link is busy)
VAL no.fill.nlink IS 18: -- net-out is filling the link with a word
VAL msg.traffic IS 19: -- msg header is in the system
}}
{{ states of the link
VAL link.no.msg IS 0: -- link is free
VAL link.head.msg IS 1: -- link holds the header of the msg
VAL link.word.msg IS 2: -- link holds a word of the msg
}}
{{ constants for testing
VAL max.proc.time IS 3000: -- max proc time before time slice
VAL u.read.header IS 45: -- time to read header (+ 10 for clock)
VAL u.read.word IS 16: -- time to read one word of a msg
VAL u.word.gen IS 10: -- time to generate one word of msg
VAL u.header.gen IS 62: -- time to generate the header, (+10 clock)
VAL u.put.h.nbuff IS 61: -- time to put header in nbuff
VAL u.put.w.nbuff IS 19: -- time to put word in nbuff
VAL uf.get IS 40: -- time for user front to get next word
VAL uf.put IS 28: -- time for user front to put next word
VAL ni.put.h.nbuff IS 47: -- time to place header in nbuff
VAL ni.put.h.ubuff IS 42: -- time to place header in ubuff
VAL ni.insert.msg.wait IS 32: -- time to place word in nbuf if full
VAL ni.insert.msg.no.wait IS 13: -- time to place word in nbuf if not full
VAL ni.put.w.nbuff IS 21: -- time to place word in nbuf
VAL ni.put.w.ubuff IS 26: -- time to place word in ubuff
VAL no.put.word.IS 60: -- time to put word on link
}}

{{ array declarations
vars for each node
[max.nodes]INT succ, prev: -- holds successor previous node numbers
[max.nodes]INT ug,ur,uf,ni,no: -- the 5 processes for each node
[max.nodes]INT ug.state: -- holds current state for ug process
[max.nodes]INT ur.state: -- holds current state for ur process
[max.nodes]INT ni.state: -- holds current state for ni process
[max.nodes]INT no.state: -- holds current state for no process
[max.nodes]INT uf.state: -- holds current state for the user front
[max.nodes]INT ni.rest.msg: -- holds # wrds left to send/receive
[max.nodes]INT ni.block: -- holds the buffer ni is currently blocking
[max.nodes]INT ni.decode: -- holds the time to decode a msg header
[max.nodes]INT nlink: -- holds the entity on the link
[max.nodes]INT nlink.online: -- holds type of contents in nlink
[max.nodes]INT msg.header: -- holds current header of msg being read
[max.nodes]INT no.sending.words: -- holds # words no is currently sending
[max.nodes]INT u.think.time: -- holds the time for user proc to think
[max.nodes]INT u.send.nbr.msgs: -- holds # of msgs to send before thinking
[max.nodes]INT u.sending.words: -- holds the # words currently being sent
[max.nodes]INT u.reading.words: -- holds the # words currently being read
[max.nodes]INT ubuff.nwords: -- holds the nbr of words in the ubuff
[max.nodes]INT nbuf.nwords: -- holds the nbr of words in the nbuf
[max.nodes]INT ubuff.nheaders: -- holds the nbr of headers in the ubuff
[max.nodes]INT nbuf.nheaders: -- holds the nbr of headers in the nbuf
[max.nodes]BOOL proc.running: -- hold true when process is running on node
[max.nodes]BOOL u.filling: -- holds true when u is filling nbuf
[max.nodes]BOOL ni.filling: -- holds true when ni is filling nbuf
}}

INT term, sys, sid: -- index to entity objects
INT word, header: -- index to entity objects
INT dummy, prior: -- prq params prior
INT len, blockq.len: -- temp var for length of queue
INT dist, dest: -- distance and destination of a msg
INT os: -- holds random operating system time delay
INT gen.msg.can.fit: -- max length of nbuff so that g can add msg
INT send nbr.msgs: -- temp var to get random number
INT think: -- temp var & used to get random think time
INT read.time, send.time: -- time to read or send a word of a msg
INT i, j: -- loop control vars
INT act, node, nbr.words: -- holds values for an entity
INT ch:
INT stime, newtime: -- used to hold clock time
TIMER realclock: -- used for timing
INT etimer, stimer, ftime: -- more timers
REAL32 durance:
INT clock:
BOOL run: }}

{{{ entity control
{ { entity object parameters

VAL maxent IS 20000: -- the max entities in the system at once
VAL num.of.fields IS 5: -- there are five fields in an entity
VAL maxstate IS 14: -- the number of states in the system
VAL maxatr IS 4: -- attributes: node.id, n.words, fdest

-- THE FIELDS OF THE STRUCTURE ENTITY:
VAL action IS 0: -- the bound event action id
VAL link IS 1: -- used to link entities
VAL node.id IS 2: -- the node associated with the entity
VAL n.words IS 3: -- number of words in the msg / with header
VAL fdest IS 4: -- holds the node to receive the msg

-- THE STRUCTURE ENTITY:
[maxent][num.of.fields]INT entity: -- the storage for the entities

}}{{F c:\janny\tdslibjr\sim\entitys.tsrs c:\janny\tdslibjr\sim\entitys.tsrs
ATTACHED
}}}
}}}

SEQ
  IF
    opus = sim.init
    ( { { initialize the model
        SEQ
        ( { { initialize the entity object
            ent (init, sys)
        })

        ( { { determine the size of the network buffer less contingency part
            -- at least 2 maximum size msgs must be able to fit in the
            -- to insure that when a msg is placed in the network buffer
            -- there is still room for 1 max size msg.
            gen.msg.can.fit := (max.nbuff + 1) - (2 * params[0])
        })
    })
  )
}
{{ set the order of nodes in the system (successor, previous) }}

SEQ

-- compute the SUCCESSOR of every node

node := 0
succ[n.nodes - 1] := 0
WHILE node < (n.nodes - 1)
SEQ
  succ[node] := node + 1
  node := node + 1

-- compute the PREVIOUS node for every node

prev[0] := n.nodes - 1
node := 1
WHILE node < (n.nodes)
SEQ
  prev[node] := node - 1
  node := node + 1

}}

{{ create control entity term }}

SEQ

ent(get, term)
entity[term][action] := s.term -- mark the termination point

}}}

{{ schedule first user proc time out, init buffers and counters }}

SEQ

think := 0 -- think for time 0 in order to get on evs
node := 0 -- all contingent tests will fail/proc will run
WHILE (node < n.nodes) -- for all nodes
SEQ

{{ Schedule the first time out for the user procs }}

SEQ

ent(get, sys) -- get an entity id
entity[sys][node.id] := node -- set its node id
entity[sys][action] := ug.time.out -- set act to gen mail
prq(sched, evs, sys, think, (trace/\2)) -- schedule time out
proc.running[node] := TRUE -- note proc is running

}}}

{{ Initialize buffer and link counters }}

SEQ

-- initialize the buffer counters to zero
nbuff.nwords[node] := 0
ubuff.nwords[node] := 0
nbuff.nheaders[node] := 0
ubuff.nheaders[node] := 0

-- Initialize link marker to zero (nothin on link)
nlink.online[node] := link.no.msg

-- Initialize the msg counters for user processes
u.think.time[node] := 0
u.send.nbrmsgs[node] := 0
u.sending.words[node] := 0
u.reading.words[node] := 0
no.sending.words[node] := 0
ni.rest.msg[node] := 0

-- Initialize the boolean flags for user & net-in filling
-- network buffer
u.filling[node] := FALSE
ni.filling[node] := FALSE

node := node + 1  -- increment counter

{||} schedule first block end
SEQ
newtime := block.len  -- set newtime to end block
-- schedule the termination action at time newtime
prq (sched,evs,term,newtime,(trace/\1))

{||} initialize the simulation clock
clock := 0  -- set clock to time zero

{||} create the set of network processes (servers)
SEQ
node := 0
prior := 0
WHILE (node < n.nodes)
SEQ

|{| Create the user process (ug)
-- get the entity id, assign it to this process, assign
-- the node this id, let stats know start state, and
-- assign the process to the start state.
SEQ
ent(get,sys)
ug[node] := sys
entity[sys][node.id] := node
ens(get,sys,ug.think,prior,(trace/\16))

ug.state[node] := ug.think
|}|

|{| Create the user process (ur)
-- get the entity id, assign it to this process, assign
-- the node this id, let stats know start state, and
-- assign the process to the start state, and place
-- process on Block queue
SEQ
ent(get,sys)
ur[node] := sys
entity[sys][node.id] := node
ens(get,sys,ur.block.uf,prior,(trace/\16))
ur.state[node] := ur.block.uf
prq(sched,blockq[node],sys,clock,(trace/\4))
Create the user front process (uf)
-- get the entity id, assign it to this process, assign
-- the node this id, let stats know start state, and
-- assign the process to the start state, and place
-- process on Block queue

SEQ
ent(get,sys)
u[uf] := sys
entity[sys][node.id] := node
ens(get,sys,uf.block,prior,(trace/\1\6))
uf.state[node] := uf.block
prq(sched,blockq[node],sys,clock,(trace/\4))
}

Create the network receiver (ni)
-- get the entity id, assign it to this process, assign
-- the node this id, let stats know start state, and
-- assign the process to the start state, and place
-- process on Block queue

SEQ
ent(get,sys)
n[ni] := sys
entity[sys][node.id] := node
ens(get,sys,ni.sleep,prior,(trace/\1\6))
ni.state[node] := ni.sleep
prq(sched,blockq[node],sys,clock,(trace/\4))
}

Create the network transmitter (no)
-- get the entity id, assign it to this process, assign
-- the node this id, let stats know start state, and
-- assign the process to the start state, and place
-- process on Block queue

SEQ
ent(get,sys)
n[no] := sys
entity[sys][node.id] := node
ens(get,sys,no.sleep,prior,(trace/\1\6))
no.state[node] := no.sleep
prq(sched,blockq[node],sys,clock,(trace/\4))
}

node := node + 1
}
}
}
opus = sim.sim
{{ run one block
SEQ
realclock ? stimer
ens (reset,dummy,dummy,clock,(trace/\16))
run := TRUE
WHILE run
SEQ
{{ get next event, action and node
SEQ
prq(next,evs,sid,clock,(trace/\2)) -- get next event notice
act := entity[sid][action] -- get the action id
node := entity[sid][node.id] -- get node it is for
{{ if trace/\1 print action -- trace if necessary
IF
(trace \ / 1) <> 0
SEQ
IF
act = s.term
write.full.string(screen,"block end ")
act = ur.close.mail
write.full.string(screen,
" user process closes mail msg")
act = ug.time.out
write.full.string(screen,
"user process just timed-out")
act = ug.xfer
write.full.string(screen,
"user just moved msg to nbuff")
act = uf.produce
write.full.string(screen,
"user front just filled ubuff")
act = uf.consume
write.full.string(screen,
"user front just removed word from ubuff")
act = ni.get.link
write.full.string(screen,
" net process received a word on the link")
act = ni.xfer
write.full.string(screen,
" net process removed a word from the link")
act = no.xfer
write.full.string(screen,
" net process just filled link")
act = no.word.received
write.full.string(screen,
" word was removed from link")
TRUE
write.full.string(screen,"@!%@#@! @ ")
write.full.string(screen," with id ")
INTwrite(sid,4)
write.full.string(screen," at time ")
INTwrite(clock,6)
write.full.string(screen,"*c*n")
TRUE
SKIP
}}}
})

{{{
Process BOUND EVENTS
IF
act = ug.time.out
{{{
(time has expired for user process ug to run
SEQ
{{{
(Kill the control entity
ent(put,sid)
)}}

(Leave u.think state / enter u.block state
SEQ
ens(leave, ug[node], ug.think, clock, (trace/\16))
ens(enter, ug[node], ug.block, clock, (trace/\16))
ug.state[node] := ug.block
)}}

(Move user process ug from proc.running to BLOCK Queue
SEQ
prq(sched,blockq[node],ug[node],clock,(trace/\4))
proc.running[node] := FALSE
}}}
}}

act = ur.close.mail
{{{
(time has expired for user process ur to read a mail msg
SEQ
{{{
(Kill the control entity
ent(put,sid)
)}}

(Leave ur.read.mail state / enter ur.block.uf state
SEQ
ens(leave, ur[node], ur.read.mail, clock, (trace/\16))
ens(enter, ur[node], ur.block.uf, clock, (trace/\16))
ur.state[node] := ur.block.uf
)}}

(Move user process ur from proc.running to BLOCK Queue
SEQ
prq(sched,blockq[node],ur[node],clock,(trace/\4))
proc.running[node] := FALSE
}}}

(Leave msg.traffic state if last word of msg received
IF
u.reading.words[node] = 0
SEQ
ens(leave,msg.header[node],msg.traffic,
clock,(trace/\16))
ent(put,msg.header[node])
TRUE
SKIP
}}}
}}

act = ug.xfer
{{{
(time expired for user process ug to fill nbuff w/msg
}}}
}}
SEQ
{{
  Kill the control entity
  ent(put,sid)
}}

SEQ
{{
  Leave ug.fill.nbuff state / enter ug.block state
  
  ens(leave, ug[node], ug.fill.nbuff, clock, (trace/\16))
  ens(enter, ug[node], ug.block, clock, (trace/\16))
  ug.state[node] := ug.block
}}

SEQ
{{
  set u.filling false if last word of msg was xferred
}}

IF
  u.sending.words[node] = 0
  u.filling[node] := FALSE
  SKIP
}}

SEQ
{{
  Move user process ug from proc.running to BLOCK Queue
}}

SEQ
{{
  act = uf.consume
}}
ens(enter, uf[node], uf.block, clock, (trace/\16))
uf.state[node] := uf.block
}
}

{{ change ur state (move ur to block so it can read next)
SEQ
ens(leave, ur[node], ur.block.uf, clock, (trace/\16))
ens(enter, ur[node], ur.block, clock, (trace/\16))
ur.state[node] := ur.block
}}

{{ kill control entity; wait on contingent event
ent(put, sid)
}}

{{ move uf to block queue and set proc.running to false
SEQ
prq(sched, blockq[node], uf[node], clock, (trace/\4))
proc.running[node] := FALSE
}}
}
}

act = ni.get.link

{{ a word has arrived on the link
SEQ
IF
ni.state[node] = ni.sleep

{{ message header on link
SEQ
{{ get msg header & dest, set ni.rest.msg counter
SEQ
header := nlink[node]
ni.rest.msg[node] := entity[header][n.words] + 1
}}
IF
entity[header][fdest] = node

{{ message is local (let uf run first)
SEQ
ni.block[node] := ni.block.uf
ni.decode[node] := ni.put.h.ubuff
ubuff.nheaders[node] := ubuff.nheaders[node] + 1
prq(sched, ubuff[node], header,
dummy, (trace/\4))
}}
TRUE

{{ message is for another node
SEQ
ni.block[node] := ni.block.nbuff
nbuff.nheaders[node] := nbuff.nheaders[node] + 1
prq(sched, nbuff[node], header,
dummy, (trace/\4))
IF
nbuff.nwords[node] = max.nbuff
ni.decode[node] := ni.put.h.nbuff + ni.insert.msg.wait
TRUE
ni.decode[node] := ni.put.h.nbuff + ni.insert.msg.no.wait
}}
}}}}
{{( enter block state
SEQ
  ens(leave,ni[node],ni.sleep,clock,(trace/\16))
  ens(enter,ni[node],ni.block[node],
      clock,(trace/\16))
  ni.state[node] := ni.block[node]
)}}
{{( kill control entity
  ent(put,sid)
)}}
TRUE  -- ni is waiting on the link
{{( one word of the message is on link
SEQ
  {{{ enter block state
    SEQ
      ens(leave,ni[node],ni.wait.on.link,
          clock,(trace/\16))
      ens(enter,ni[node],ni.block[node],
          clock,(trace/\16))
      ni.state[node] := ni.block[node]
    }}
    {{( set time to decode word to time needed to place
        -- word in nbuff or ubuff
      IF
        ni.block[node] = ni.block.ubuff
        ni.decode[node] := ni.put.w.ubuff
        nbuff.nwords[node] = max.nbuff
        ni.decode[node] := ni.put.w.nbuff +
            ni.insert.msg.wait
      TRUE
        ni.decode[node] := ni.put.w.nbuff +
            ni.insert.msg.no.wait
    }}
      {{( kill control entity
        ent(put,sid)
    }}
{}))
}}{{
act = ni.xfer
{{( time expired to move a word from link to buffer
SEQ
  IF
    ni.rest.msg[node] > 0
      {{( message not complete, enter wait on link
        SEQ
          ens(leave,ni[node],ni.state[node],
              clock,(trace/\16))
          ens(enter,ni[node],ni.wait.on.link,
              clock,(trace/\16))
          ni.state[node] := ni.wait.on.link
        }}
    TRUE
}}
TRUE
\[
\text{act} = \text{no.xfer}
\]
\[
\text{act} = \text{no.word.received}
\]
\[
\text{act} = \text{no.}\
\]
\[
\text{act} = \text{no.}\
\]
\[
\text{act} = \text{no.}\
\]
\[
\text{act} = \text{no.}\
\]
\[
\text{act} = \text{no.}\
\]
no.state[node] := no.sleep
ent(put,sid)

act = s.term
{{ end this block
SEQ
run := FALSE
newtime := clock + block.len
ens(cpu,dummy,dummy,clock,(trace/\16))
prq (sched, evs, sid, newtime,(trace/\2))
}}
TRUE
{{ illegal control code
SEQ
write.full.string(screen,"Illegal control code\c\n")
STOP
}}{{
}}

IF
act <> s.term
{{ Process CONTINGENT EVENTS
SEQ
{{ update BLOCK and READY Queues
prq(length,blockq[node],blockq.len,dummy,(trace/\4))
i := 0
WHILE i < blockq.len  -- do all items on block queue
SEQ
prq(next,blockq[node],sid,dummy,(trace/\4))
IF
sid = ug[node]
{{ update user process generator
IF
u.think.time[node] > 0
{{ run before sending mail
SEQ
dentity[sid][action] := ug.do.work
prq(sched,readyq[node],sid, clock,(trace/\4))
}}{{
}}
}}
}}{{ currently sending a message
SEQ
dentity[sid][action] := ug.send.mail
prq(sched,readyq[node],sid, clock,(trace/\4))
}}{{
}}
}}{{ send start of new mail message or block
IF
((NOT ni.filling[node]) AND
(nbuff.nwords[node] < gen.msg.can.fit))
SEQ
u.filling[node] := TRUE
entity[sid][action] := ug.send.mail
prq(sched,readyq[node],sid,
clock,(trace/\4))
TRUE.--msg can't be moved, go on BLOCK Queue
prq(sched,blockq[node],sid,
clock,(trace/\4))
}}
TRUE
{{
run the application program
SEQ
entity[sid][action] := ug.do.work
prq(sched,readyq[node],sid,
clock,(trace/\4))

rng.get(nbr.msgs, len,(trace/\32))
u.send.nbr.msgs[node] := len
rng.get(proc.time,think,(trace/\32))
uthink.time[node] := think
}}
}}
sid = ur[node]
{{
update user process receiver
SEQ
IF
ur.state[node] = ur.block
{{
move ur toREADY queue
SEQ
entity[sid][action] := ur.get.mail
prq(sched,readyq[node],sid,
clock,(trace/\4))
}}
TRUE
{{
place ur back on Block Queue
prq(sched,blockq[node],sid,
clock,(trace/\4))
}}
}}
sid = uf[node]
{{
update user front process
SEQ
IF
ni.state[node]=ni.block.uf -- ni has priority
SEQ
entity[sid][action] := uf.put.ubuff
prq(sched,readyq[node],sid,
clock,(trace/\4))
(ubuff.nwords[node] > 0)
SEQ
entity[sid][action] := uf.get.ubuff
prq(sched,readyq[node],sid,
clock,(trace/\4))
}}
TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}

sid = ni[node]
{{ update net-in process
  IF
  (ni.state[node] = ni.block.ubuff) AND
  (ubuff.nwords[node] < max.ubuff) AND
  (NOT u.filling[node]))
    SEQ
    ni.filling[node] := TRUE
    entity[sid][action] := ni.put.ubuff
    prq(sched,readyq[node], sid, clock, (trace/\4))
  }}

SEQ
  ni.filling[node] := TRUE
  entity[sid][action] := ni.put.nbuff
  prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE -- net-in can't run, go back on BLOCK Queue
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

sid = no[node]
{{ update net-out process
  IF
  (nlink.online[succ[node]] = link.no.msg) AND
  (nbuff.nwords[node] > 0))
    SEQ
    entity[sid][action] := no.send.word
    prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

TRUE
  write.full.string(screen, "Illegal control entity on BLOCK queue\n")
  i := i + 1
}}

{{ set one process running if necessary/possible
  prq(length,readyq[node],len,dummy, (trace/\4))
  IF
  (len > 0) AND (proc.running[node] = FALSE)
  SEQ
  ({{ get next action and proc, set proc.running TRUE
  SEQ
  prq(next,readyq[node],sid,len,(trace/\4))
  act := entity[sid][action]
  proc.running[node] := TRUE
}}}

TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}

sid = nodes[node]
{{ update net-in process
  IF
  (ni.state[node] = ni.block.ubuff) AND
  (ubuff.nwords[node] < max.ubuff) AND
  (NOT u.filling[node]))
    SEQ
    ni.filling[node] := TRUE
    entity[sid][action] := ni.put.ubuff
    prq(sched,readyq[node], sid, clock, (trace/\4))
  }}

SEQ
  ni.filling[node] := TRUE
  entity[sid][action] := ni.put.nbuff
  prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE -- net-in can't run, go back on BLOCK Queue
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

sid = no[node]
{{ update net-out process
  IF
  (nlink.online[succ[node]] = link.no.msg) AND
  (nbuff.nwords[node] > 0))
    SEQ
    entity[sid][action] := no.send.word
    prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

TRUE
  write.full.string(screen, "Illegal control entity on BLOCK queue\n")
  i := i + 1
}}

{{ set one process running if necessary/possible
  prq(length,readyq[node],len,dummy, (trace/\4))
  IF
  (len > 0) AND (proc.running[node] = FALSE)
  SEQ
  ({{ get next action and proc, set proc.running TRUE
  SEQ
  prq(next,readyq[node],sid,len,(trace/\4))
  act := entity[sid][action]
  proc.running[node] := TRUE
}}}

TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}

sid = nodes[node]
{{ update net-in process
  IF
  (ni.state[node] = ni.block.ubuff) AND
  (ubuff.nwords[node] < max.ubuff) AND
  (NOT u.filling[node]))
    SEQ
    ni.filling[node] := TRUE
    entity[sid][action] := ni.put.ubuff
    prq(sched,readyq[node], sid, clock, (trace/\4))
  }}

SEQ
  ni.filling[node] := TRUE
  entity[sid][action] := ni.put.nbuff
  prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE -- net-in can't run, go back on BLOCK Queue
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

sid = no[node]
{{ update net-out process
  IF
  (nlink.online[succ[node]] = link.no.msg) AND
  (nbuff.nwords[node] > 0))
    SEQ
    entity[sid][action] := no.send.word
    prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

TRUE
  write.full.string(screen, "Illegal control entity on BLOCK queue\n")
  i := i + 1
}}

{{ set one process running if necessary/possible
  prq(length,readyq[node],len,dummy, (trace/\4))
  IF
  (len > 0) AND (proc.running[node] = FALSE)
  SEQ
  ({{ get next action and proc, set proc.running TRUE
  SEQ
  prq(next,readyq[node],sid,len,(trace/\4))
  act := entity[sid][action]
  proc.running[node] := TRUE
}}}

TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}

sid = nodes[node]
{{ update net-in process
  IF
  (ni.state[node] = ni.block.ubuff) AND
  (ubuff.nwords[node] < max.ubuff) AND
  (NOT u.filling[node]))
    SEQ
    ni.filling[node] := TRUE
    entity[sid][action] := ni.put.ubuff
    prq(sched,readyq[node], sid, clock, (trace/\4))
  }}

SEQ
  ni.filling[node] := TRUE
  entity[sid][action] := ni.put.nbuff
  prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE -- net-in can't run, go back on BLOCK Queue
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

sid = no[node]
{{ update net-out process
  IF
  (nlink.online[succ[node]] = link.no.msg) AND
  (nbuff.nwords[node] > 0))
    SEQ
    entity[sid][action] := no.send.word
    prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

TRUE
  write.full.string(screen, "Illegal control entity on BLOCK queue\n")
  i := i + 1
}}

{{ set one process running if necessary/possible
  prq(length,readyq[node],len,dummy, (trace/\4))
  IF
  (len > 0) AND (proc.running[node] = FALSE)
  SEQ
  ({{ get next action and proc, set proc.running TRUE
  SEQ
  prq(next,readyq[node],sid,len,(trace/\4))
  act := entity[sid][action]
  proc.running[node] := TRUE
}}}

TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}

sid = nodes[node]
{{ update net-in process
  IF
  (ni.state[node] = ni.block.ubuff) AND
  (ubuff.nwords[node] < max.ubuff) AND
  (NOT u.filling[node]))
    SEQ
    ni.filling[node] := TRUE
    entity[sid][action] := ni.put.ubuff
    prq(sched,readyq[node], sid, clock, (trace/\4))
  }}

SEQ
  ni.filling[node] := TRUE
  entity[sid][action] := ni.put.nbuff
  prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE -- net-in can't run, go back on BLOCK Queue
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

sid = no[node]
{{ update net-out process
  IF
  (nlink.online[succ[node]] = link.no.msg) AND
  (nbuff.nwords[node] > 0))
    SEQ
    entity[sid][action] := no.send.word
    prq(sched,readyq[node], sid, clock, (trace/\4))
  TRUE
  prq(sched,blockq[node], sid,clock, (trace/\4))
}}

TRUE
  write.full.string(screen, "Illegal control entity on BLOCK queue\n")
  i := i + 1
}}

{{ set one process running if necessary/possible
  prq(length,readyq[node],len,dummy, (trace/\4))
  IF
  (len > 0) AND (proc.running[node] = FALSE)
  SEQ
  ({{ get next action and proc, set proc.running TRUE
  SEQ
  prq(next,readyq[node],sid,len,(trace/\4))
  act := entity[sid][action]
  proc.running[node] := TRUE
}}}

TRUE
  prq(sched,blockq[node], sid, clock, (trace/\4))
)}
{���� perform the contingent event
IF
act = ug.do.work
���� set user proc running its application
SEQ
���� Determine operating system delay for run
SEQ
rng.get(os.time, os, (trace/\32))
���� Determine time to run before u.time.out
SEQ
IF
u.think.time[node] > max.proc.time
SEQ
newtime := (max.proc.time + os)+clock
u.think.time[node] :=
  u.think.time[node] - max.proc.time
TRUE
SEQ
newtime := (u.think.time[node] + os)+
clock
u.think.time[node] := 0
���� Create control entity &
���� Schedule u.time.out
SEQ
ent(get, sys)
entity[sy][node.id] := node
entity[sys][action] := ug.time.out
prq{sched, evs, sys, newtime, (trace/\2)}
���� Leave ug.block / enter ug.think state
SEQ
ens{leave,ug[node],ug.block,
clock,(trace/\16)}
ens{enter,ug[node],ug.think,
clock,(trace/\16)}
ug.state[node] := ug.think
���� let user process fill nbuff with mail
SEQ
IF
u.sending.words[node] = 0
���� starting new msg
SEQ
���� Generate random length of msg
SEQ
rng.get(msg.len, len, (trace/\32))
���� Generate distance the msg should
���� travel (number of links)
SEQ
rng.get(msg.dist, dist, (trace/\32))
dest := (node + dist) REM n.nodes
}}
{{( Create MSG HEADER
SEQ
ent(get, header)
dest := (node + dist) REM n.nodes
}}
{{( Place msg in nbuff (header in -- nbuff, update buffer counters)
SEQ
prq(sched, nbuff[node], header, prior, (trace/\4))
nbuff.nheaders[node] :=
nbuff.nheaders[node]+1
nbuff.nwords[node] :=
nbuff.nwords[node]+1
}}
{{( Update counters
SEQ
u.send.nbrmsgs[node] :=
u.send.nbrmsgs[node]-1
u.sending.words[node] := len
}}
u.think.time[node] := u.header.gen
send.time := u.put.h.nbuff
}}
TRUE
{{( currently sending words of a msg
SEQ
u.think.time[node] :=
u.think.time[node]-1
u.sending.words[node] := len
send.time := u.put.w.nbuff
}}
{{( Determine time to move msg to nbuff
SEQ
rng.get(os.time, os, (trace/\32))
newtime := (send.time + os) + clock
}}
{{( Create control entity & Schedule xfer
SEQ
ent(get, sys)
dest := (node + dist) REM n.nodes
}}
}}
(( Leave ug.block / Enter ug.fill.nbuff
SEQ
ens(leave,ug[node],ug.block,
clock,(trace/\16))
ens(enter,ug[node],ug.fill.nbuff,
clock,(trace/\16))
ug.state[node] := ug.fill.nbuff
))
))

act = ur.get.mail
(( let user process read mail msg waiting
SEQ
IF
u.reading.words[node] = 0
(( get next header from ubuff, set
-- counters, set read time
SEQ
prq(next,ubuff[node],header,
dummy,(trace/\4))
u.reading.words[node]:= entity[header][n.words]
ubuff.nwords[node] :=
ubuff.nwords[node] - 1
ubuff.nheaders[node]:=
ubuff.nheaders[node] - 1
msg.header[node] := header
-- ent(put.header)
read.time := u.read.header
))
TRUE
(( update counters, set read time
SEQ
ubuff.nwords[node] :=
ubuff.nwords[node] - 1
u.reading.words[node]:= u.reading.words[node]-1
read.time := u.read.word
))
(( compute time to read the msg
SEQ
rng.get(os.time,os,(trace/\32))
newtime := (read.time + os + clock
))
(( create control entity & schedule transfer
SEQ
ent(get,sys)
entity[sys][node.id] := node
entity[sys][action] := ur.close.mail
prq(sched,sys,newtime,(trace/\2))
))
(( leave ur.block / enter ur.read.mail state
SEQ
ens(leave,ur[node],ur.block,
clock,(trace/\16))
))
\texttt{ens(enter, ur[node], ur.read.mail,}
\texttt{   clock, (trace/\16))}
\texttt{ur.state[node] := ur.read.mail}
\texttt{}})
\texttt{}}
\texttt{act = uf.get.ubuff}
\texttt{\{\{ let user front proc get next word in ubuff \}
\texttt{SEQ}
\texttt{\{\{ compute time to read the msg \}
\texttt{SEQ}
\texttt{   rng.get(os.time, os, (trace/\32))}
\texttt{   newtime := (uf.get + os) + clock}
\texttt{\}}}
\texttt{\{\{ create control entity & schedule transfer \}
\texttt{SEQ}
\texttt{   ent(get, sys)}
\texttt{   entity[sys][node.id] := node}
\texttt{   entity[sys][action] := uf.consume}
\texttt{   prq(sched, evs, sys, newtime, (trace/\2))}
\texttt{}}
\texttt{\{\{ leave uf.block / enter uf.remove.ubuff \}
\texttt{SEQ}
\texttt{   ens(leave, uf[node], uf.block,}
\texttt{      clock, (trace/\16))}
\texttt{   ens(enter, uf[node], uf.remove.ubuff,}
\texttt{      clock, (trace/\16))}
\texttt{   uf.state[node] := uf.remove.ubuff}
\texttt{}}
\texttt{}})
\texttt{act = uf.put.ubuff}
\texttt{\{\{ let user front proc put next word in ubuff \}
\texttt{SEQ}
\texttt{\{\{ Create control entity to transfer word \}
\texttt{SEQ}
\texttt{   ent(get, sys)}
\texttt{   entity[sys][node.id] := node}
\texttt{   entity[sys][action] := uf.produce}
\texttt{}}
\texttt{\{\{ Determine time needed to make transfer \}
\texttt{SEQ}
\texttt{   rng.get(os.time, os, (trace/\32))}
\texttt{   newtime := (uf.put + os) + clock}
\texttt{}}
\texttt{\{\{ Schedule the transfer \}
\texttt{   prq(sched, evs, sys, newtime, (trace/\2))}
\texttt{}}
\texttt{\{\{ leave uf.block / enter uf.fill.ubuff \}
\texttt{SEQ}
\texttt{   ens(leave, uf[node], uf.block,}
\texttt{      clock, (trace/\16))}
\texttt{   ens(enter, uf[node], uf.fill.ubuff,}
\texttt{      clock, (trace/\16))}
\texttt{   uf.state[node] := uf.fill.ubuff}
\texttt{}}\}
act = ni.put.nbuff

{{ let net-in proc fill nbuff w/ word on link
SEQ
  {{ Create control entity to transfer word
  SEQ
    ent(get,sys)
    entity[sys][node.id] := node
    entity[sys][action] := ni.xfer
  }}

  {{ Determine time needed to make transfer
  SEQ
    rng.get(os.time,os,(trace/\32))
    newtime := (ni.decode[node] + os) + clock
  }}

  {{ Schedule the transfer
  prq(sched,evs,sys,newtime,(trace/\2))
  }}

  {{ Update word counters
  SEQ
    nbuff.nwords[node] := nbuff.nwords[node]+1
    ni.rest.msg[node] := ni.rest.msg[node] - 1
  }}

  {{ leave ni.block.nbuff/ enter ni.fill.nbuff
  SEQ
    ens(leave,ni[node],ni.block.nbuff,
        clock,(trace/16))
    ens(enter,ni[node],ni.fill.nbuff,
        clock,(trace/16))
    ni.state[node] := ni.fill.nbuff
  }}

  {{ schedule control entity for previous node
  SEQ
    ent(get,sys)
    entity[sys][node.id] := prev[node]
    entity[sys][action] := no.word.received
    prq(sched,evs,sys,clock,(trace/\2))
  }}

}}

act = ni.put.ubuff

{{ let net-in proc fill ubuff w/word from link
SEQ
  {{ Determine time needed to make transfer
  SEQ
    rng.get(os.time,os,(trace/\32))
    newtime := (ni.decode[node] + (clock + (3*os))
  }}

  {{ Schedule the transfer
  SEQ
    ent(get,sys)
    entity[sys][node.id] := node
    entity[sys][action] := ni.xfer
    prq(sched,evs,sys,newtime,(trace/\2))
  }}

}}
{{{{ update word counters
SEQ
    ubuff.nwords[node] := ubuff.nwords[node] + 1
    ni.rest.msg[node] := ni.rest.msg[node] - 1
}}}
{{ leave ni.block.ubuff/ enter ni.fill.ubuff
SEQ
    ens(leave, ni[node], ni.block.ubuff,
        clock, (trace/\16))
    ens(enter, ni[node], ni.fill.ubuff,
        clock, (trace/\16))
    ni.state[node] := ni.fill.ubuff
}}}
{{ schedule control entity for previous node
SEQ
    ent(get, sys)
    entity[sys][node.id] := prev[node]
    entity[sys][action] := no.word.received
    prq(sched, evs, sys, clock, (trace/\2))
}}}
}}
act = no.send.word
{{ let net-out process place word on link
SEQ
IF
    (no.sending.words[node] > 0)
    -- still sending a msg
        {{ put word on link (decrement counters)
SEQ
            no.sending.words[node] :=
                no.sending.words[node] - 1
            nbuff.nwords[node] :=
                nbuff.nwords[node] - 1
            nlink.online[succ[node]] :=
                link.word.msg
        }}
    -- send start of msg
    {{ put header on link, decrement counters
SEQ
        {{ move the header from nbuff to
            -- nlink, update sending.words
SEQ
            prq(next, nbuff[node], header,
                prior, (trace/\4))
            no.sending.words[node] :=
                entity[header][n.words]
            nlink[succ[node]] := header
        }}
    }}
    {{ update counters controlling buffers
        -- and links
SEQ
        nbuff.nheaders[node] :=
            nbuff.nheaders[node] - 1
    }}
}}
}}
```plaintext
nbuf.nwords[node] := nbuf.nwords[node]-1
nlink.online[succ[node]] := link.head.msg

{{
  Determine time needed to do the transfer
  SEQ
  rng.get(os.time, os, (trace/\32))
  newtime := no.put.word + ((6 * os) + clock)
  }}

{{
  Create control entity & Schedule event
  SEQ
  ent(get,sys)
  entity[sys][node.id] := node
  entity[sys][action] := no.xfer
  prq(sched, evs, sys, newtime, (trace/\2))
  }}

{{
  Leave no.sleep / enter no.fill.nlink
  SEQ
  ens(leave,no[node],no.sleep,
      clock,(trace/\16))
  ens(enter, no[node], no.fill.nlink, clock,
      (trace/\16))
  no.state[node] := no.fill.nlink
  }}

TRUE
write.full.string(screen,
  "Illegal action on READY queue *c*n")

}}
TRUE
SKIP
}}
}}
TRUE
SKIP

{{
  print time elapsed
  SEQ
  realclock ? ftimer
  etimer := ftimer MINUS stimer
  durance := (REAL32 ROUND etimer)*(0.000064*(REAL32))
  write.full.string(screen,"*#07")
  write.full.string(screen,"*#07")
  write.full.string(screen,"*c*n")
  write.full.string(screen,"Elapsed time for this block is ")
  REAL32write(durance,6,2)
  write.full.string(screen," seconds*c*n")
  }}

{{
  dump the accumulated statistics
  ens {dmp,dummy,dummy,clock,(trace/\32)}
  }}

{{
  dump the priority queues
  SEQ
  }}
```
prq (dump, evs, dummy, dummy, (trace/\8))
node := 0
WHILE node < n.nodes
SEQ
  prq (dump, ubuff[node], dummy, dummy, (trace/\8))
  prq (dump, nbuf[f[node]], dummy, dummy, (trace/\8))
  prq (dump, readyq[node], dummy, dummy, (trace/\8))
  prq (dump, blockq[node], dummy, dummy, (trace/\8))
node := node + 1
}]]
opus = sim.quit
SKIP
TRUE
{}{( error
  STOP
  -- display an error from here. This path should never be taken.
}])
})
)

PROC xnetrun()
{}{ control the simulation
{}{ Get the parameters
PROC cnv.si(VAL INT len, VAL []BYTE str, INT val)
{}{ convert an integer string to the integer value
INT i, dval:
SEQ
  val := 0
  i := 0
  WHILE ((i < len) AND ((str[i] < '0') OR (str[i] > '9'))) 
    i := i + 1
  WHILE ((i < len) AND ((str[i] >= '0') AND (str[i] <= '9'))) 
    SEQ
      dval := (INT str[i]) - '0'(INT)
      val := (10*val) + (INT dval)
      i := i + 1
}])

PROC get.params(CHAN screen, keyboard, []INT P)
{}{ prompt for the parameters
INT ch:
INT i, len, val:
INT distr:
[80]BYTE str:
SEQ
{}{ print blank lines
  write.full.string(screen, **c*n*n")
}])
{}{ GET the # nodes and speed of the links (10 or 20 MHz)
{}{ # of nodes in the system
  write.full.string(screen, "Number of NODES in the system (1-32) => ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[17])
}

#include speed of the link
write.full.string(screen, "Link speed (10 or 20) --> ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[16])
IF
  P[16] = 10
  P[16] := 30
  TRUE
  P[16] := 15
ENDIF

GET the size of the buffers (nbuff, ubuff) and max words/msg
write.full.string(screen, "Max No. of words in a msg --> ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[0])
P[0] := P[0] + 1
-- account for the message header
ENDIF

network and user buffer sizes
write.full.string(screen, "Network buffer size (MAX 2000) --> ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[2])
write.full.string(screen, "User buffer size (MAX 2000) --> ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[3])
ENDIF

Explain the distribution codes
SEQ
write.full.string(screen,"*c*n"n")
write.full.string(screen,"Distribution Codes:*c*n")
write.full.string(screen,
  " Uniform Negative Exponential    Constant *c*n")
write.full.string(screen,
  "  1  2  3 *c*n")
ENDIF

GET the distribution, mean, and seed (# msgs to send at once)
GET distribution # msgs to send
write.full.string(screen,"*c*n")
write.full.string(screen,"Number of messages to send at one time *c*n")
distr := invalid.distr   -- set to an invalid distr.type
WHILE (distr <> const) AND ((distr <> nexp) AND (distr <> unif))
  SEQ
  write.full.string(screen," -- Distribution Code: ")
  read.string(keyboard,screen,len,str)
cnv.si(len,str,distr)
P[19] := distr
ENDIF

mean # msgs to send
write.full.string(screen," -- Mean: ")
read.string(keyboard,screen,len,str)
cnv.si(len, str, P[13])
IF
  P[13] > P[0]  -- if the mean is greater than the maximum
  P[13] := P[0]  -- set mean to max
  TRUE
  SKIP
)}
(() seed for # msgs to send
write.full.string(screen, " -- Seed: ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[8])
IF
  P[8] = 0
  P[8] := 37
  TRUE
  SKIP
)}
(() GET the distribution, mean, and seed (# words in a msg)
(() distribution # words in a msg
write.full.string(screen,"*c*n")
write.full.string(screen,"Number of words in a message *c*n")
distr := invalid.distr  -- set to an invalid distr.type
WHILE (distr <> const) AND ((distr <> nexp) AND (distr <> unif))
  SEQ
    write.full.string(screen," -- Distribution Code: ")
    read.string(keyboard,screen,len,str)
cnv.si(len,str,distr)
P[20] := distr
)}
(() mean # words in a msg
write.full.string(screen, " -- Mean: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,P[14])
)}
(() seed for msg length
write.full.string(screen, " -- Seed: ")
read.string(keyboard, screen, len, str)
cnv.si(len, str, P[9])
IF
  P[9] = 0
  P[9] := 61
  TRUE
  SKIP
)}
(() GET the distribution, mean, and seed (destination length)
(() distribution # links a msg should travel
write.full.string(screen,"*c*n")
write.full.string(screen,
  "Number of links a message should travel *c*n")
distr := invalid.distr  -- set to an invalid distr.type
WHILE (distr <> const) AND ((distr <> nexp) AND (distr <> unif))
  SEQ
write.full.string(screen," -- Distribution Code: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,distr)
P[22] := distr
}

{({(@ mean # links a msg should travel
write.full.string(screen, " -- Mean: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,P[15])
})

{({(@ seed for the operating system delay
write.full.string(screen," -- Seed: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,P[1])
IF
P[1] = 0
P[1] := 37
TRUE
SKIP
})
})

{({(@ GET the distribution, mean, and seed (operating system delay)
{({(@ distribution for operating system delay
write.full.string(screen,"*c*n")
write.full.string(screen,"Operating System Delay *c*n")
distr := invalid.distr -- set to an invalid distr.type
WHILE (distr <> const) AND ((distr <> nexp) AND (distr <> unif))
SEQ
write.full.string(screen," -- Distribution Code: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,distr)
P[21] := distr
})
})

{({(@ mean operating system delay
write.full.string(screen," -- Mean: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,P[12])
})

{({(@ seed for the operating system delay
write.full.string(screen," -- Seed: ")
read.string(keyboard,screen,len,str)
cnv.si(len,str,P[10])
IF
P[10] = 0
P[10] := 83
TRUE
SKIP
})
})

{({(@ GET the distribution, mean, and seed (user process run time)
{({(@ distribution for time to create a word (user process time
write.full.string(screen,"*c*n")
write.full.string(screen,"Time to process between generating msgs *c*n")
distr := invalid.distr -- set to an invalid distr.type
WHILE (distr <> const) AND ((distr <> nexp) AND (distr <> unif))
  SEQ
    write.full.string(screen, "-- Distribution Code: ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, distr)
    P[18] := distr
  }}
  {{\{ mean time to create a word
    write.full.string(screen, " -- Mean: ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, P[11])
  }}
  {{\{ seed for user process time
    write.full.string(screen, " -- Seed: ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, P[7])
  IF
    P[7] = 0
      TRUE
      SKIP
  }}
  }}
  {{\{ GET # blocks and the block length
    write.full.string(screen, "*c*n*n")
    write.full.string(screen, "Number of blocks ==> ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, P[4])
    write.full.string(screen, "Block duration ==> ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, P[5])
  }}
  {{\{ GET trace values
    write.full.string(screen, "TRACE VECTOR value ==> ")
    read.string(keyboard, screen, len, str)
    cnv.si(len, str, P[6])
  }}
  {{\{ print blank lines
    write.full.string(screen, "*c*n*n")
  }}
  }}

:}

INT i:
INT clock:
BYTE ch:
INT kint:
INT dummy:
INT len:
SEQ
  write.full.string(screen, "Simulation Of An Occam Network (1988) *c*n*n ")
  get.params(screen, keyboard, params)
{{{
 initialize the priority queue objects
 -- the priority queue objects are self initializing

INT c,c1,c2,c3,node:
SEQ
  node := 0     -- node #'s start at 0
  c := 1        -- ubuff queues #'s start at 1
  c1 := max.nodes * 1       -- nbuff queues start at max.nodes
  c2 := max.nodes * 2       -- ready queues start at 2 * max.nodes
  c3 := max.nodes * 3       -- block queues start at 3 * max.nodes

  WHILE node < max.nodes
    SEQ
      ubuff[node] := c     -- start at 1 (note: evs is queue 0)
      nbuff[node] := c + c1 -- get next queue number for this node
      readyq[node] := c + c2 -- get next queue number for this node
      blockq[node] := c + c3 -- get next queue number for this node
      node := node + 1     -- get next node number
      c := c + 1           -- increment by one
  }}}

{{{
 initialize the RNG objects

SEQ
  rng.init(nbr.msqs,distr.gen.msqs,params[13],params[8])
  rng.init(proc.time,distr.proc.time,params[11],params[7])
  rng.init(msg.len,distr.msg.len,params[14],params[9])
  rng.init(os.time,distr.ostime,params[12],params[10])
  rng.init(msg.dist,distr.msg.dist,params[15],params[1])
}}}

xnetsim(sim.init,clock)

kint := 1
WHILE (kint <= n.blocks)
  {{
    Run simulation for another block
    SEQ
      xnetsim(sim.sim,clock)
      write.full.string(screen,"*c*n")
      write.full.string(screen,"BLOCK ")
      INTwrite(kint,3)
      write.full.string(screen,"*c*n")
      kint := kint + 1
  }}

xnetsim(sim.quit,clock)

{{{
 terminate the statistics process

SEQ
  ens (quit,dummy,dummy,clock,(trace\16))
}}}

{{{
 terminate the priority queue objects

SEQ
  prq(quit, evs, dummy, dummy, (trace\2))
  i := 1
  WHILE i < max.sys.queues
}}}
SEQ
  prq(quit, i, dummy, dummy, (trace/\4))
  i := i + 1
))}
{% terminate the RNG objects
SEQ
  rng.quit(proc.time, (trace/\32))
  rng.quit(nbrmsgs, (trace/\32))
  rng.quit(msglen, (trace/\32))
  rng.quit(os.time, (trace/\32))
  rng.quit(msg.dist, (trace/\32))
)}
  write.full.string(screen,"End program execution\c\n")
  keyboard ? ch
})
}

PAR
  i = 0 FOR 5
  c.rand(to.rand[i], from.rand[i])

PAR i = 0 FOR max.sys.queues
  c.prq(to.prq[i], from.prq[i], screen)

SEQ
  c.stats(to.stats, from.stats, screen)
SEQ
  xnetrun()
LIST OF REFERENCES


8. Stuck, Bart W. "Calculating the Maximum Mean Data Rate in Local Area Networks". *Computer*, May 1983, pp. 72-76.


VITA

Master's Thesis Title:

A SIMULATION OF A MESSAGE PASSING PROTOCOL
FOR A NETWORK OF TRANSPUTERS

Janice R. Glowacki

Born in Miami, Florida, on January 11, 1963

Attended Sable Palm Elementary, John F. Kennedy Junior High,
Highland Oaks Junior High, and North Miami Beach Senior High,
all in Miami, Florida.

Attended Diablo Valley College in Pleasant Hill, California,
from September 1980 to December 1981.

Attended Florida International University in Miami, Florida,
from August 1982 to December 1986 at which time a Bachelor of
Science degree was awarded. Majored in Computer Science.

Attended Florida International University in Miami, Florida,
from January 1987 to date for graduate studies.

Member of Association of Computing Machinery.

Author of "A Simulation of a Store-and-Forward Distributed
Network of Transputers" for the Proceedings of the 1988
Winter Simulation Conference (San Diego, California).

School of Computer Science

September 16, 1988  Janice R. Glowacki