Proceedings of the 1984
Winter Simulation Conference
S. Sheppard, U. Pooch, D. Pegden (eds.)

A GPSS SIMULATION TO DETERMINE CONGESTION IN AN ETHERNET TYPE LOCAL AREA NETWORK

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ABSTRACT

A large bank has approximately 1000 terminals in a single building which perform transactions on several computer systems concentrated in a single data center. Cabling, modems and switching are required to support each terminal connection. The current methods of communication have led to congestion in the building's cabling conduit system and high per terminal costs for switching facilities, modems and relocation of terminals.

A bus type local area network is being considered as a solution to these problems, but due to the newness of this technology, experience with an installation of similar size and characteristics appears as yet unavailable. Congestion of the network due to contention for access to the bus is a major concern.

We describe a relatively simple model of the workload and communications bus operation developed to study the frequency of bus contention. A GPSS simulation program and results are presented for this model. In addition, an even more simplified analytical queueing model is used to bound the frequency of contention for the bus and the result is compared with that of the simulation.

INTRODUCTION

A bus type local area network provides a physical link and access control facilities for interconnecting a large number of heterogeneous data devices located within a limited distance. Here we consider a limited utilization of the interconnect capability with the initial objective of connecting a large number, approximately one thousand, of dumb terminals distributed throughout a large office building to several computer systems concentrated in a single data center.

The terminals operate in a full duplex mode, i.e., each character typed at a terminal does not appear on the display until it has been transmitted to a host computer system and returned to the terminal. Since the local area network imposes a large overhead in the formation of a minimum size packet to carry each character from the terminal to the host and to echo the character from the host back to the terminal, there was doubt about the ability of a single network bus to support the communications requirements without significant congestion and accompanying performance degradation.

We describe the principles of operation and relevant parameters of an Ethernet type local area network. Then a model of the terminal generated traffic is described and a simplified GPSS implementation is presented.

The GPSS model was constructed with a single server to represent the bus, a single queue to hold all delayed messages, and a feedback mechanism to represent computer generated character echoes and responses. Since it would have been much more complex to construct a model which fully tested all of the effects of contention for access to the transmission bus, it was decided instead to evaluate the frequency of collision, because it is the presence of collisions and the resolution process which can lead to significant delays on the network.

ETHERNET OPERATIONS

An overview of Ethernet and other types of local area networks is presented in [1]. A more detailed presentation of the operation of the Ethernet network is presented in [2]. In this section we present the relevant principles of operation and parameters of an Ethernet type network which enable a detail of modeling sufficient to determine whether a given traffic level will generate congestion on the network.

An Ethernet network can consist of up to 1024 nodes connected to a coaxial cable bus. The maximum internode distance is 2.8 kilometers and nodes can be:

terminals
host computers
microcomputers
file servers
print servers
concentrators
gateways to other networks

The use of concentrators can enable the connection of several terminals at a single node.

A data communication system is described in terms of a layered protocol to be followed by each of the nodes in order to control the exchange of data. Representative of the protocols used for data communication is the International Standards Organization, i.e., ISO, protocol [3]. The seven layers of the ISO protocol are:

Application
Presentation
Session
Transport
Network
Data Link
Physical

The Ethernet system provides for the two lowest layers, the Physical layer and Data Link layer. The Physical layer protocol includes specification of a 10 megabit per second transmission rate on the coaxial cable or bus, along with detailed electrical properties.

The Data Link layer specifies transmission of data in the form of packets made up of several fields, each being an integral number of bytes or 8 bit units. The fields, in order of transmission, which constitute a packet or frame are:

Field	Length (bytes)
Preamble	8
Destination Address	6
Source Address	6
Type	2
Data	46-1500
Cyclic Redundancy Check	4

In addition, each packet or frame is followed by a quiescent period, referred to as the interframe spacing, of 9.6 microseconds (equivalent to 12 bytes) duration.

Assuming the minimal data field length of 46 bytes and the 10 megabit per second signaling rate, the total service time for a packet will be taken as 67.2 microseconds.

The Ethernet system uses baseband signaling with no multiplexing. Hence to achieve communications, only one node should transmit at a time. When transmissions by two or more nodes overlap, a collision is said to occur. To control access to the bus and limit collisions, the data link protocol at each node employs a procedure known as Carrier Sense Multiple Access with Collision Detection, i.e., CSMA/CD. Each node can sense the presence of a carrier, i.e., signal, indicating that some node is transmitting. When a node has information to transmit, it defers in the presence of a carrier and does not transmit until a quiescent channel is detected, thereby avoiding interference with the transmission in progress. At the end of a packet, if two or more nodes have been waiting to transmit, they will do so simultaneously and a collision will occur.

When a collision occurs, each of the transmitting nodes involved follows a randomized backoff procedure. The node waits a random number of 'slot' times before attempting retransmission. The number of slots to backoff is drawn from a uniform distribution on the interval $[0,2^r]$ where r denotes the number of unsuccessful attempts completed. Hence after the initial collision, r=1 and the size of the interval is doubled at each retry. After 16 tries, an error condition is indicated.

A collision can also occur during a 'vulnerability window' following the start transmission by a node X if some other node, say Y, becomes ready to transmit before the packet from X has propagated to Y. The minimum packet length and slot time are dictated by the requirement to exceed the longest allowed round trip propagation delay between two nodes on the bus. This requirement assures that if a collision occurs, then each of the transmitting nodes will always hear the collision before completing transmission of its packet.

TRAFFIC ASSUMPTIONS

We were concerned with the ability of the Ethernet bus to support the traffic generated by the large number of terminals performing transaction processing in the full duplex mode. Since each character typed at a terminal must be transmitted to a computer and echoed back to the terminal, two packets are required to be transmitted. A character can be represented by a single byte, however the minimum packet in Ethernet was shown to occupy the bus, including the interframe spacing, for a duration equivalent to 84 bytes. Hence the transmission of single characters by a minimal Ethernet packet involves a great inefficiency!

In determining whether the character by character duplex operation of 1000 terminals could be supported without significant congestion, the traffic model considers only two types of traffic: character transmission and echoing and computer generated responses for transaction processing. Notably absent are other forms of traffic; particularly file transfer among computers and any attempt at predicting new traffic, such as electronic mail, which may be added as the enhanced communication facilities become available.

Each terminal is assumed to generate data due to filling of transactions at a rate of 20 transactions per hour with 50 characters typed per transaction. At the completion of each transaction, it is assumed that the computer sends a message to the terminal occupying 50 packets each of minimum length, i.e., 67.2 microseconds.

GPSS MODEL

The GPSS language provides convenient facilities for simulation of simple queuing models [4]. To create a GPSS model of the operation of the network, a number of simplifying assumptions were made. These assumptions are discussed here.

The network bus is represented as a single GPSS Facility. The generation of traffic in the form of typed characters is according to a Poisson process with an exponential interoccurrence time.

GPSS assumes an integer clock time. One unit of clock time was chosen as one microsecond. All packets are assumed to be of minimum length, occupying the bus for a duration of 67 microseconds.

Each packet is represented as a GPSS transaction. Transaction parameter PH1 is used to indicate the packet type: 'one' indicates a character typed at a terminal; 'two' indicates a character echoed by a computer to a terminal; and 'three' indicates a component packet of a computer generated message being sent to a terminal.

Whenever a character or echo packet is ready, it is inserted in a single queue called WAITQ. This aggregates the real world situation where waiting packets are distributed among the individual nodes. When a character packet completes utilization of the bus, its PH1 is changed to 'two' and it is fed back to the WAITQ to represent the echo.

When an echo character completes transmission, Savevalue parameter XH1 is incremented by one to maintain a count of the aggregate number of characters received by a computer since the last message. Recall that the traffic model assumes a computer generated message of fifty packets upon receipt of a completed transaction of fifty characters from any given terminal. Here again we aggregate, sending a computer message whenever a total of fifty characters have been transmitted. This creates the appropriate average frequency of one computer generated message for each of fifty characters typed at a terminal.

The fifty message packets are fed to the WAITQ one at a time, each completed message or type 3 transaction decrementing Savevalue XH2, the number of message packets remaining to be sent. In effect, all but one member of the queue of message packets waiting to be sent by the computers are maintained by the value of XH2 and are outside of WAITQ. We are treating the multiple host computers as a single aggregate computer by this artifice.

Our model does not include the effects of collision resolution. Instead we measure the frequency of collision, assuming a priori that only a small percentage of packets experience collision. The validity of this assumption can then be verified or disputed by the frequency of collision observed in the simulation.

Recall that a collision can occur in two ways: if at the end of a transmission two or more nodes are waiting to transmit, or if a second node becomes ready and begins transmission during the vulnerability window of a first node that has begun transmission. The duration of the vulnerability window depends upon the distance between the first and second node. We have not included a level of detail sufficient to account for this second type of collision.

Our measure of collision frequency is based on tabulating the number of transactions in WAITQ at the instant when the bus becomes available following a transmission, denoted by the quantity QLNG. We assume that QLNG estimates the number of nodes ready to transmit. In our model, QLNG is the number of packets ready to transmit, where we impose the condition that the aggregate computer node can contribute at most one message unit to QLNG and assume that there is negligible likelihood that a single terminal will have two or more packets waiting to send.

The detailed GPSS program is included in Appendix A.

SIMULATION RESULTS

Six runs of the simulation model were performed, two each with Start values of 10,000; 20,000 and 40,000 respectively. Note that the Start value in our model reflects the total number of characters typed at the terminals. For each character typed, one character packet and one echo packet are transmitted. In addition, after 50 character and echo pairs, a computer message of 50 packets is transmitted. Hence, the total packets transmitted in a run is triple the Start value.

As each packet clears the bus, the value of QLNG is tabulated and the distribution is expressed as percentage relative frequencies in Appendix B.

Those cases where a completed packet leaves behind value of QLNG of 2 or more correspond to occurrence of a collision due to two or more nodes beginning transmission simultaneously. In addition, some small fraction of the cases where QLNG equals one represent packets that would have caused collision by having arrived during the 'vulnerability window' of the just completed packet.

Taking the frequency of QLNG $\geq$ 2 as the estimate of the percentage of packets that experience collision, the average frequency of collision observed was 3.54 percent of packets.

M/D/1 APPROXIMATION

Because of the low utilization, a simple analytical approximation to the frequency of collision is investigated. Observe that

packet rate = 1/1200 per microsecond
service time = 67 microseconds

Hence

utilization = 5.58 percent

Since the packet service times are constant, we consider an M/D/1 queuing model as an approximation to our simulated Ethernet system. In the M/D/1 model, the number of transactions left behind by a departing transaction, QLNG in our system, is an embedded markov chain with known steady state distribution [5]. Using the steady state formulas for the M/D/1 queuing model in Table 15, Appendix C of [5], we obtain the estimates:

QLNG	Probability (%)
0	94.42
1	5.43
$\geq$2	.15

Note that the observed distribution of QLNG in Appendix B differs significantly from that computed above using the M/D/1 model. All or part of this difference may be explained by the departure of the simulated system from the assumptions of the M/D/1 model in the timing dependence of the arrivals of the echo and message packets which constitute two thirds of the traffic.

REFERENCES

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4. Gordon, G. The Application of GPSS V to Discrete System Simulation, Prentice-Hall, Englewood Cliffs, 1975.

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APPENDIX A: GPSS V PROGRAM

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BLOCK
NUMBER  *LOC    OPERATION  A,B,C,D,E,F,G,H,I         COMMENTS
         SIMULATE
        ************************************************************
        *     SIMULATION OF ETHERNET SERVING 1000 TERMINALS        *
        *            CLOCK UNIT IS ONE MICROSECOND                 *
        ************************************************************
        *
         EXP    FUNCTION   RN1,C24     EXPONENTIAL DISTRIBUTION
        0.0,0.0/0.1,0.104/0.2,0.222/0.3,0.355/0.4,0.509/0.5,0.69
        0.6,0.915/0.7,1.2/0.75,1.38/0.8,1.6/0.84,1.83/0.88,2.12
        0.9,2.3/0.92,2.52/0.94,2.81/0.95,2.99/0.96,3.2/0.97,3.5
        0.98,3.9/0.99,4.6/0.995,5.3/0.998,6.2/0.999,7/0.9997,8
        *
1               GENERATE   3600,FN$EXP     TYPE A CHARACTER
2               ASSIGN     1,1,PH          PACKET IS A CHARACTER
3        WAIT   QUEUE      WAITQ           WAIT TO TRANSMIT
4               SEIZE      BUS
5               DEPART     WAITQ
6               ADVANCE    67              TRANSMITTING
7               TABULATE   QLNG
8               RELEASE    BUS
9               TRANSFER   FN,1            TEST PACKET TYPE
         1      FUNCTION   PH1,L3
        1,CHAR/2,ECHO/3,MSG
        *
10       CHAR   ASSIGN     1,2,PH          CREATE ECHO PACKET
11              TRANSFER   ,WAIT
        *
12       ECHO   SAVEVALUE  1+,1,XH         INCREMENT CHARACTERS SINCE LAST MSG
13              TEST GE    XH1,50,TERM     TEST IF COMPUTER GENERATES MSG
14              ASSIGN     1,3,PH          CREATE MESSAGE PACKET
15              SAVEVALUE  1-,50,XH        DECREMENT CHARACTERS COUNTER
16              SAVEVALUE  2+,50,XH        INCREMENT MSG PACKETS TO SEND
17              TRANSFER   ,WAIT
        *
18       MSG    SAVEVALUE  2-,1,XH         DECREMENT MSG PACKETS TO SEND
19              TEST LE    XH2,0,WAIT      TEST FOR NO MORE MSG PACKETS
20       TERM   TERMINATE  1
        *
         QLNG   TABLE      Q1,0,1,10
                INITIAL    XH1,0
                INITIAL    XH2,0
                START      10000
                END
```

APPENDIX B: DISTRIBUTION OF QLNG

Start Value	% Distribution of QLNG							
	0	1	2	3	4	5	6*	≥2
10,000	85.87	10.29	2.89	.70	.14	.06	.03	3.82
10,000	87.11	9.14	2.87	.82	.03	–	–	3.72
20,000	84.16	12.95	2.37	.41	.04	.03	.01	2.86
20,000	85.72	11.13	2.47	.50	.16	–	–	3.03
40,000	85.36	10.84	2.89	.73	.11	.04	.01	3.78
40,000	84.76	11.42	2.99	.64	.14	.02	–	3.79

* 6 was the maximum observed value of QLNG