Real Time Simulation Networking: Network Modeling and Protocol Alternatives

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ABSTRACT

In this paper, we present the findings of a comparison study using predictive detailed simulation models for three different network protocol access methods: Carrier Sense Multiple Access with Collision Detection (ANSI/IEEE 802.3 STD), Token-Passing Bus Access (ANSI/IEEE 802.4 STD) and Token-Ring Access (ANSI/IEEE 802.5 STD). Discussions of network performance, the implications of the results of the comparison study, and the insight gained from this project for improving real-time simulation networking are presented.

INTRODUCTION

A local area network (LAN) is a geographically confined communication system that uses a shared transmission medium. Various choices usually exist for the main ingredients of LAN (i.e., transmission *medium, topology, access protocols, etc.*), with each exhibiting advantages and providing benefits that depend on the objectives of the LAN. The ability to model, analyze and evaluate the impact of these choices on network performance is essential to ensuring maximum utilization of the LAN.

One of the pioneering LAN's for connecting computers was a bus-based ETHERNET *developed by Xerox Corp. in the early 1970's.* The contention access method used by each node in ETHERNET is based on a pre-emptive protocol of first listening for network activity and then broadcasting the message onto the network. If a collision with another message occurs, each sender (node) backs-off from transmitting their message for a random period of time and then attempts the transmission again. This access technique is known as Carrier Sense Multiple Access with Collision Detection (CSMA/CD) [1, 2]. Standards for CSMA/CD protocols such as ETHERNET are known as IEEE 802.3 standards approved by the American National Standards Institute (ANSI).

The networking of real-time, interactive simulation training systems departs from the traditional use of a computer network whose function is to provide sharing of computing resources among multiple users (nodes) on the network. When used to interconnect real-time training simulators, the network is used almost exclusively for communication of process state information between the simulators engaged in the training exercise.

There are many inherent limitations to using a network in this application. For example, as the number of simulators on the network and the *workload per simulator* increases, there may be a deterioration in throughput and a degradation of other network performance parameters. If throughput delays become too large, for example, the effectiveness of a real-time training simulation may be overly compromised due to the time-critical response requirements in the simulation of true-to-life, action-requiring training scenarios. *Depending upon the network communication* protocol being used, there may also be an increase in the frequency of retransmitted and lost or distorted messages.

Recently, there has been a tremendous interest in LAN's implemented using the non-contention class of network protocols known as Token-Passing protocols. Two schemes falling under this class are Token-Ring and *Virtual Token-Bus* protocols. In a Token Ring LAN, a distinctive bit sequence, called a token, is passed from one node to another in order to signify the availability of the network medium for the transmission of data for that node. Possession of the token by the node gives it,and only it, permission to transmit across the network, as opposed to having all nodes contend for this privilege. In a Virtual Token-Bus LAN, a virtual, or imaginary token, is passed from user to user thus providing access to the network. This virtual token is actually a predetermined instant in time when each user knows it is its turn to access the network. Each of these three protocols will be discussed in detail in later sections.

The primary goal of this research effort has been to develop predictive and analytical models for network performance of three LAN configurations operating under real-time, interactive simulation and training constraints. Two of these LAN's are **bus networks** which utilize baseband transmission to send messages over a coaxial cable which is common to all users. The medium-access control schemes for the first is ETHERNET which is a member of the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol family and for the second is the Generalized Broadcast Recognizing Access Method (GBRAM) [3] which is a member of the Virtual Token-Bus protocol family. The third LAN is a **ring network**, which sends its messages over either coaxial or fiber optic cable. Its medium-access control scheme is the Token-Ring [4] protocol.

NETWORK MEDIUM-ACCESS PROTOCOLS

ETHERNET

CSMA/CD protocols, including ETHERNET, are characterized by their distributed network control whereby each node on the network determines its own channel access time based only on information available from the common network channel (bus). When a node is ready to transmit a message onto the network, it first monitors the network bus to determine whether any other transmissions from other nodes are in progress. If the node senses the network channel to be busy, it simply waits for the channel to become idle before attempting to transmit its message. Once the channel is sensed to be idle, the node waits a pre-specified amount of time to assure the channel is clear and then begins transmitting its message. During its own transmission, the node also monitors the channel in order to detect whether its message is interfering (colliding) with messages from other nodes. If a collision is detected, each node involved in the collision transmits a bit sequence onto the network known as a **jam signal**, after which each node involved in the collision waits (backs-off) for a randomly generated amount of time before reattempting its transmission.

The performance of contention protocols is directly related to how efficiently nodes avoid collisions and handle retransmissions. The problem of data collisions is directly related to the network traffic load.

Token-Ring

In Token Passing protocols [4, 5], which the Token-Ring LAN is a member, there is no contention for the network channel because only one node at a time is allowed to access the channel. In Token-Ring LAN's this is accomplished by arranging the nodes in a serial ring configuration such that the network channel actually passes through each node. The **token** is a control signal that circulates around the channel. An individual node gains the right to transmit onto the network when it first detects, and then captures a **free token** passing on the channel. Once a node captures the **free token**, it changes it to a **busy token** and begins transmitting its message onto the network. Upon completing the transmission of its message, the node generates and transmits a **free token** which begins circulating around the network channel, thus providing other nodes the opportunity to gain access to the network.

Generalized Broadcast Recognizing Access Method (GBRAM)

The GBRAM protocol is also a member of the Token Passing protocol family. It differs *significantly,however, from the* Token-Ring protocol. In the GBRAM, rather than each node having to capture the **free token** from the network to gain transmission access, an imaginary **(virtual) token** is passed from node to node achieving the same result. The **virtual token** scheme provides each node access to the network at a unique time instant which is determined by a decentralized scheduling function.

NETWORK SYSTEM CONFIGURATION MODELS

Bus Network

The bus network configuration (applicable to both ETHERNET & GBRAM) is shown in Figure 1. In this implementation, up to eight nodes can be connected through a multi-port transceiver to a single point on the coaxial cable, via a media-access unit. A single coaxial cable links all nodes together.

Ring Network

The ring network configuration (Token-Ring) is shown in Figure 2. The ring network consists of a closed sequence of individual point-to-point (node-to-node) connections.

NETWORK PROTOCOL COMPUTER SIMULATIONS

Simulation Models

The simulation models for both the bus and ring LAN topologies are written in **Concurrent C** (an extension of the **C** language with concurrent programming facilities based on the "rendezvous" concept). The powerful synchronization and concurrency aspects of **Concurrent C** [6] have provided us with a notationally

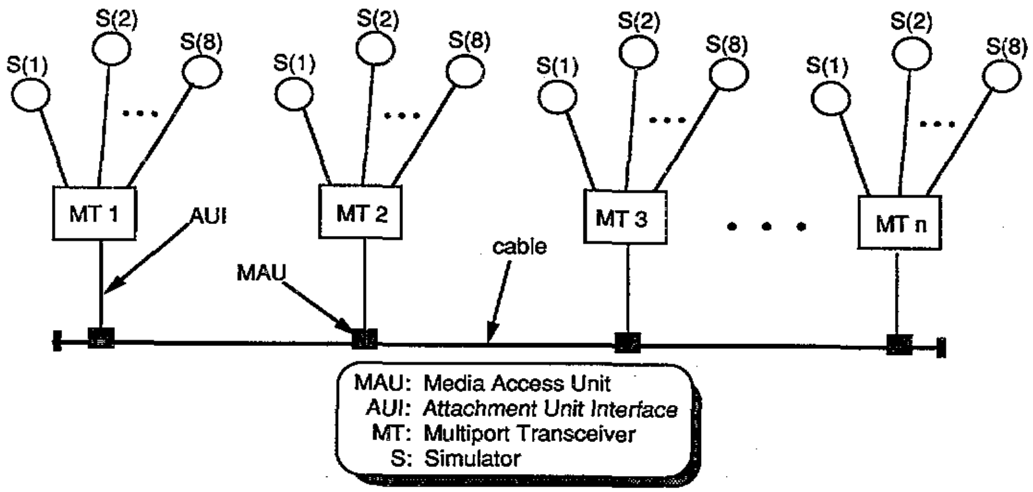


Figure 1. Bus Network Topology System Configuration

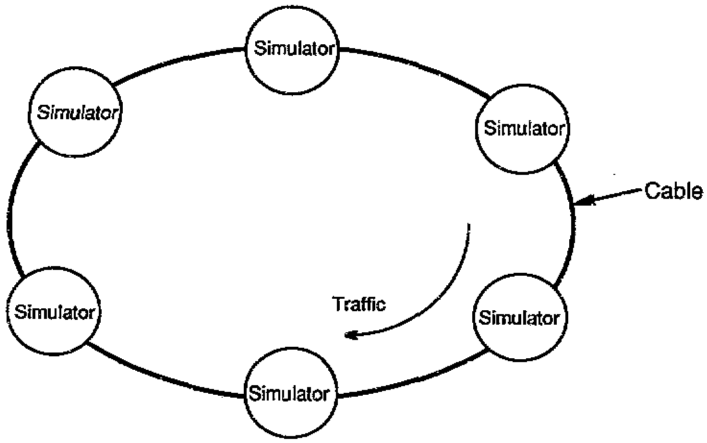


Figure 2. Ring Network Topology System Configuration

convenient and conceptually elegant tool for modeling the parallel activities of LAN nodes and the underlying networking layer.

A functional diagram of the simulation model for the bus topology is shown in Figure 3. The following process types are the major *generic entities used in our simulation for the* bus structure.

Process **Simnode** is used to represent a vehicle simulator on the network. A process of this type is created for each such simulator. This process is the source of local traffic and is capable of generating packets according to a specified input method (e.g., using traces of real data or random stochastically generated inter-arrival times such as exponential, uniform, fixed with jitters, etc.)

Process **Busnode** is used to represent the point of contact of each network node with the bus (coaxial cable). A process of type **Busnode** is created for each such point of contact on the bus. Upon receiving a transmission request from a **Simnode** process, the **Busnode** attempts to fulfill the request based on the medium access protocol of the LAN. For example, in the CSMA/CD case, the **Busnode** *process checks for a* carrier flag and will allow transmission only if the flag has been off for at least the interframe gap. If a collision is detected during transmission, the **Simnode** process sends a jam signal and increments the collision counter. This is followed by invoking a back-*off algorithm for retransmission.*

Processes **Lserver** and **Rserver** are used to simulate the propagation delay and control the flow of data packets and jam signals in the direction form right to left and from left to right, respectively, for each network node. A pair of these processes is created for each network node.

Process **Scheduler** is used to order time events and control the sequencing of activities of the entire simulation.

Figure 4 shows a block diagram showing the simulation model for the ring topology. Process **Simnode** is responsible for generating the load (data packets) on the ring. Process **Ringnode** monitors the ring traffic and implements the token-based medium access protocol. Process **Server** is used to simulate the propagational delay between *each pair of LAN nodes. As in the bus model,* the simulation of the ring structure uses a **Scheduler** process to control the sequencing of activities.

DISCUSSION

Token Ring vs Contention Access

A token passing ring is a LAN with a loop topology in which a token is passed around the network in a round-robin fashion from one node to the next. Contention for transmission is resolved by stipulating that only the node currently in possession of the token is allowed to transmit a frame or a sequence of frames onto the ring. When the transmission is finished, the token is passed to the node downstream which then gets a chance to transmit. Since there is a single token on the ring, only one node can be transmitting at a time. Other (non-transmitting) nodes, however, continuously receive the bit stream, examine it and repeat it (i.e., place it on the medium to the next station). A station repeating the bit stream may copy it into local buffers or modify some control bits as appropriate.

In general, Token-Ring LAN's are much less sensitive to increased transmission rates and smaller packet sizes compared to contention protocols (e.g., ETHERNET with CSMA/CD). Since token-rings are collision free, a maximum packet delay can be guaranteed for a given number of stations. Thus, the real-time requirements of applications having high traffic loads (e.g., networks with large number of simulation training devices) can be handled more gracefully by using a contention-free ring scheme.

Because of its point-to-point connection property, rings readily accommodate the use of optical fiber as a transmission medium. In addition to offering reduced size, weight and enhanced safety features, optical fiber also offers very high signal bandwidth. One very *promising implementation of ring networks* using optical fiber is the Fiber Distributed Data Interface (FDDI). FDDI is a 100 Mbits/sec token-ring LAN protocol that is rapidly becoming accepted as the premier high speed LAN standard [7]. With its embedded extensibility to support even higher speeds (500 to 1,000 Mbits/sec), FDDI is poised to become the dominant high-end LAN of the 1990's. The paradigm for FDDI topology is known as a "dual counter-rotating ring of trees". The physical layer topology consists of independent, full-duplex, point-to-point physical connections, while the logical layer consists of one or two rings. The FDDI Medium Access Control (MAC) protocol provides data services similar to those of the IEEE 802.5 token-rings. An extension to FDDI (known as FDDI II) is currently being investigated to add isochronous data transmission capabilities to the network, thus enabling it to handle both voice and data. FDDI technology will eventually provide the

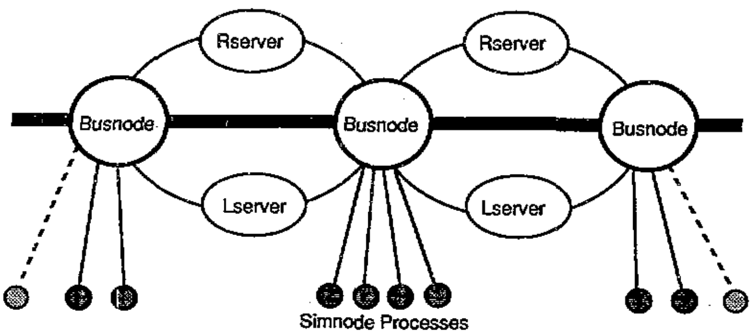


Figure 3. Simulation Model for Bus Topology Networks

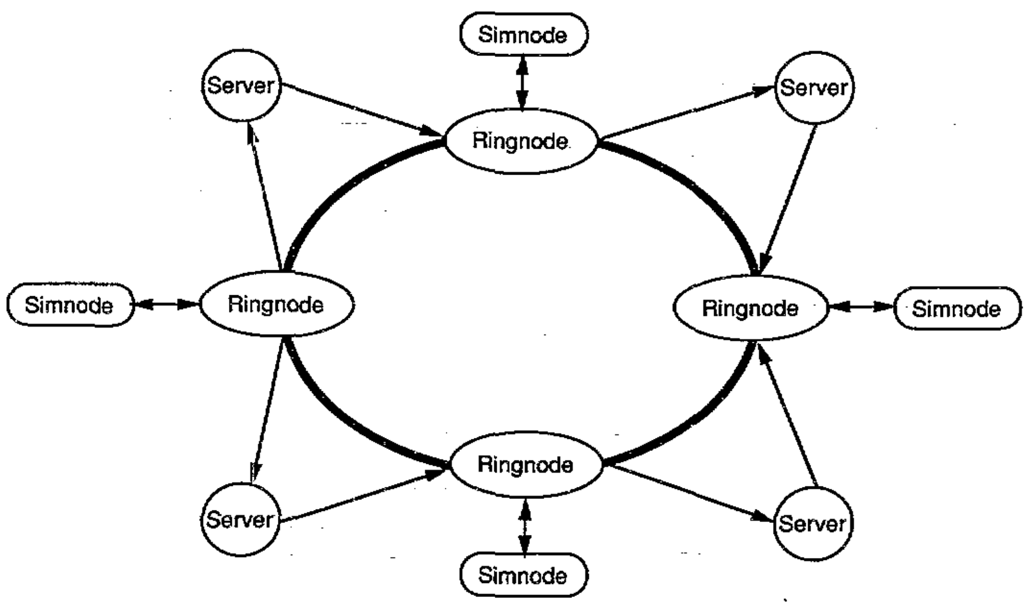


Figure 4. Simulation Model for Ring Topology Networks

simulation and training industry with powerful real-time LAN's capable of interconnecting an unprecedented number of stations.

Another promising feature of Token-Rings is that they provide a priority-based scheme for packet transmission across the network. In the ANSI/IEEE 802.5 ring implementation, the passing token has three bits indicating the current priority level of the ring (this gives a total of 8 priority levels). A station that captures the token can only transmit packets whose priority is equal to or higher than the priority of the passing token. The ANSI/IEEE 802.5 protocol also provides mechanisms that enable stations to request and change the priority of the passing token. In simulation networks, this means that it will be possible to assign levels of priority to different types of messages which may be beneficial in attempting to optimize real-time system performance, especially under peak load conditions.

On the other hand, token rings are outperformed by bus topology LAN's in certain areas. One main advantage of the bus structure over ring LAN's is the reliability of network operation following a node failure. In general, bus-based LAN's are more resistant to network crashes due to node failures since the propagation of messages on the bus does not require the participation of any given node. Failure of a station on the ring structure, however, can bring the entire LAN down. This problem has been considerably reduced by the increased reliability of today's ring chips and off-the-shelf ring attachments. Furthermore, new fiber optic ring devices use optical bypass switches in order to allow inactive (off-line) stations to pass the traveling data-carrying light waves directly from one neighboring node to the next without active power and with little or no degradation of the optical signal.

Bus-based ETHERNET LAN's have enjoyed economic advantages because of their widespread use in the past two decades. These advantages, however, are about to disappear since VLSI technology, fiber optics, and other near-term advances will soon be supplying the market with ring chips and devices at the same low cost as comparable bus products. Also, hardware support for FDDI is rapidly growing and the projected increase in development and installation investments in FDDI are expected to drive down the cost of FDDI hardware considerably.

GBRAM vs Contention Access

The GBRAM LAN protocol implementation shares the same bus topology as the ETHERNET implementation (see Fig. 1). The nodes connected onto the network via the same multi-port transceiver belong to the same group and each node within the group has a unique identity. This node identity scheme plays an important part in the assignment of channel access time slots for each node. Every node on the network perceives the channel state under the GBRAM as consisting of cycles of **scheduling** and **transmission** periods. Roughly speaking, the end of a transmission period designates the beginning of a scheduling period and the end of a scheduling period signals the beginning of the next scheduling period. During a scheduling period, every node gains the right to access the network channel starting with the node whose identity sequentially follows the node which transmitted last.

GBRAM avoids collisions by scheduling different users at unique time instances. The time interval between two successive scheduling instances depends on the physical location of the users who are allowed access to the network channel at these instances. In fact, this time interval is equal to the propagation delay between the two users who are scheduled to transmit at these two unique instances. In the GBRAM, therefore, the physical location of each user on the network is extremely important in calculating the network's scheduling algorithm.

It has been observed that in large scale simulation networks not all users are active at all times. Consider, for example, a vehicle simulator which is active at the beginning of a battle, but is destroyed by enemy fire during the simulation. These inactive users must be taken out of the token passing sequence list in order to reduce the number of wasted idle slots which will be scheduled for the network. Hence, there must be a procedure to sign-off users from the network. This procedure might be implemented as follows: an active user signs off by broadcasting, at its scheduled transmission time instant, a sign-off packet which would be read by all other active users who would, in turn, update their scheduling sequence accordingly.

The successful operation of the version of the GBRAM presented in this paper depend on the fact that all the users know a common time epoch. This common time epoch corresponds to the beginning of a scheduling period. In our version of GBRAM, the beginning of a scheduling period corresponds to either the end of a transmission period (as perceived by the transmitting user) plus the propagation delay along the cable or a complete scheduling cycle after the beginning of the previous scheduling period. It is obvious that the common time epoches can be determined by any user who observes the channel state at all times and knows its propagation delay from any other user in the network. Note that contention protocols require only that users observe the state of the channel at all times. There are other versions of GBRAM [3], however, that do not require the users to have a complete knowledge of the network topology. These versions of GBRAM *will not perform as well as the GBRAM version* considered in this paper.

NETWORK SIMULATION RESULTS

ETHERNET Simulated Performance

The network protocol simulation models described earlier have been used to gather information about the performance of local area networks used for real-time training, under various conditions of node (simulator) placement on the network, traffic load levels and packet scheduling policies. One configuration considered in our analysis is unique to the application of local area networks to the interconnection of simulation and training devices. In this configuration, an optimization is made to reduce the load on the network. An explanation of this optimization for the ETHERNET case is given below.

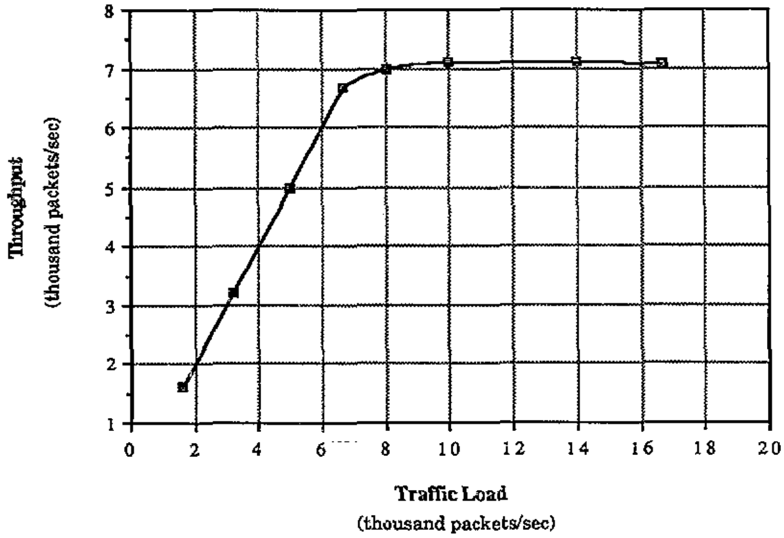
Upon a state change, a simulator (node) on the network sends the information concerning its new state to other nodes on the LAN. Each new state results in the generation of a new data packet at the **application layer** (i.e.,.at the node level). The packet is then submitted to the **data link layer** in order to start the process of its transmission. In ETHERNET, only one packet per node is delivered for transmission at a time. Other packets are normally queued up at the application level waiting for the end of the ongoing transmission attempt. In this context, the arrival of a new packet (carrying the most current state of the node) simply replaces the previous packet (stored at the application layer) which represents a now outdated state condition. The discarding of the outdated packet helps speed up the transmission of the most current state of the node. Notice that the packet already submitted to the ETHERNET data link layer is under the control of ETHERNET protocol (board) which is not accessible from the application layer and, therefore, is not affected by new packet arrivals.

The performance of this specific ETHERNET configuration is given in Graphs 1 & 2, and Table 1. Graph 1 gives the relationship between the throughput of the LAN and the total initial traffic load from all simulators (i.e., before any discarding at the application level). Graph 2 gives the relationship between the total initial load and the packets discarded by ETHERNET as a result of exceeding the maximum count for transmission attempts (16) due to excessive collisions. Notice that Graph 2 gives the packets discarded by the ETHERNET protocol and not the obsolete packets discarded at the application level. Statistics about the average *transmission delay and average* and maximum number of transmission attempts are given in Table 1.

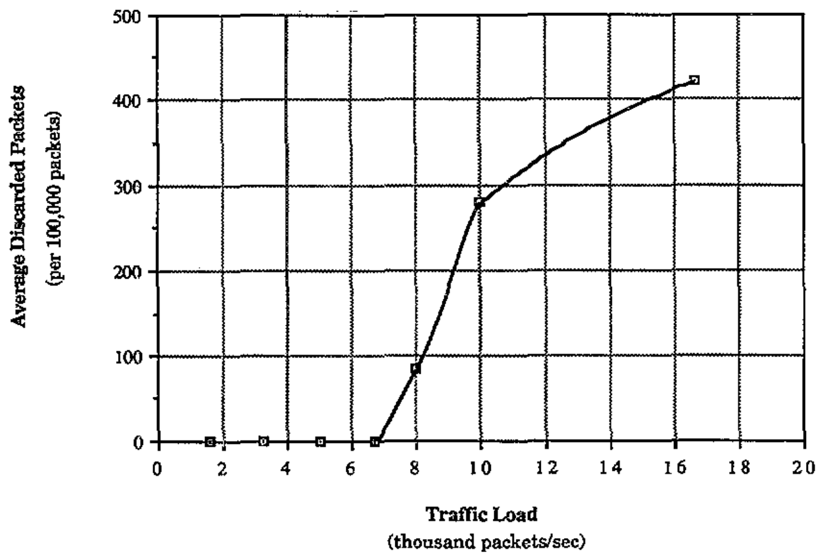
At low traffic load levels, the effect of collisions is small and no packets are discarded due to excessive collision counts. All packets submitted to the data link layer at such low loads eventually get transmitted successfully and the throughput of the network is equal to the total traffic load minus the obsolete packets discarded at the application level. As the traffic load increases, more collisions occur and the average number of transmission attempts per packet (and consequently the average packet delay) increases (see table 1). Since a packet is thrown away (by ETHERNET) if its transmission fails 16 consecutive times, the growing collision rate eventually results in the loss of some packets. At some point, the network becomes overwhelmed by the *collision overhead and less LAN bandwidth* becomes available for actual packet transmission. This is the reason that the throughput of this ETHERNET LAN starts to reach a saturation level even though the traffic load continues to increase. Since the actual throughput of this configuration is dependent on both the number of obsolete packets discarded by the application layer and the colliding packets discarded by ETHERNET boards, the performance of the network may show some slight perturbations in actual throughput; but otherwise will stay in the saturation throughput level it has attained.

Traffic Load (thousand packets/sec)	Average Transmission Delay (millisec)	Average Number of Transmission Attempts/Packet	Maximum Number of Attempts
1.60	.111	1.01	2
3.20	.152	1.16	5
5.00	.232	1.38	8
6.67	1.029	2.25	14
8.00	2.682	2.88	16
10.00	4.183	3.15	16
16.67	5.571	3.46	16

Table 1. ETHERNET Performance Statistics



Graph 1. Throughput vs Traffic Load (ETHERNET)



Graph 2. Average Discarded Packets vs Traffic Load (ETHERNET)

Token Ring Simulated Performance

Token ring LAN's exhibit quite different behavior as compared to the ETHERNET. In some versions of token ring protocols, a transmitting station recreates the free token and puts it onto the ring as soon as it finishes packet transmission. In IEEE 802.5 *rings*, however, a transmitting station checks to see if its address (affixed at the header of the transmitted packet) has returned to it (indicating a complete cycle around the ring). Only after receiving this address is the station allowed to transmit the free token onto the ring, thus giving other stations an opportunity to transmit. This latter protocol is more conservative (from a reliability point of view) but imposes extra time overhead for token management. At low network traffic loads, the IEEE 802.5 token ring protocol causes more transmission delays for packets than the CSMA/CD counterpart. Unlike collision handling, the overhead of token management is largely independent of the LAN load. Therefore, the throughput of token-ring LAN's continues to increase as the traffic load increases. No degradation in performance at high loads is exhibited by token rings in contrast to the ETHERNET LAN.

GBRAM Simulated Performance

Preliminary GBRAM simulation results indicate that GBRAM should perform well for medium to high input traffic loads, but may be inferior to contention protocols for light to medium input traffic loads. Let us try to justify *this observation based on the description of* the GBRAM protocol presented in the previous section.

Consider the case where there is only one out of a total of 100 users that generates traffic onto the network and that, for the majority of its transmissions, this *user has one packet in* its buffer every time a scheduling period of the GBRAM protocol starts. Let us assume that the propagation delay between two users in the same group is 30 bits, the propagation delay along the cable is 20 bits, and the packet length is 1000 bits. This is a case of light input traffic. It is easy to see that GBRAM induces an average and maximum packet delay of (30x100+20)/2 + 1,000 = 2,510 bits and (30x100+20) + 1,000 = 4,020 bits, respectively. Every contention protocol under the aforementioned light input traffic conditions, induces an average and a maximum packet delay of 1000 bits (the packet length).The performance difference widens as the number of the users in the network increases.

Suppose now that all 100 users in the network are active. Each one of them has exactly one packet to transmit at the beginning of a GBRAM scheduling period. This corresponds to a case of high input traffic load. Now GBRAM induces an average and a maximum packet delay of approximately (1000x100)/2 + 1000 = 51,000 bits and (1000x100) + 1000 = 101,000 bits, respectively. The length of the packet was once again taken to be equal to 1000 bits. The aforementioned input traffic load is *approximately equal to 100%* of ETHERNET capacity. Contention protocols attain a throughput smaller than 100% even under ideal conditions (i.e. small end-to-end propagation delay/packet length ratio). As a result, contention protocols are unstable (experience unbounded packet delays) for the *above high input traffic scenario.*

The above discussion, although simplified, verifies our point that there will be a region of input traffic loads (light to medium) where contention protocols outperform GBRAM and a region of input traffic loads (medium to high) *where GBRAM outperforms contention* protocols The cutoff point depends on the total number of users in the network and increases as the number of users in the network increases. The exact cutoff point will be determined by simulation.

CONCLUSIONS

In this paper we have described an ongoing effort to model and evaluate the performance of three different network protocol access methods suitable for networking of simulation training devices: a contention access method based on the CSMA/CD (ETHERNET) protocol, and two contention-free methods based on Virtual Token Bus Access such as GBRAM and Token-Ring Access protocols. The system models pertaining to the above three access methods were addressed and a high-level description of a detailed simulation software system implemented for evaluating the performance of these protocols was given.

The models developed for the three access methods will enable us to perform a comparison study and evaluate different design decisions. Some of the numerical performance measures that are being gathered by the models are:

- The impact of traffic loading on network throughput
- The utilization of the transmission medium
- The distribution of delay times of transmitted packets.

The models developed under this effort offer a very flexible tool for the evaluation and analysis of important classes of networking schemes that can be used to interconnect large numbers of real-time simulation training devices. Further research is being conducted which is focusing on implementing these two alternate protocols in a hardware and software test bed with the ultimate goal of enhancing the capability of simulation networks.

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