Performance Evaluation of Educational Workstation LAN Systems

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ABSTRACT

Recently large scale distributed workstation LAN systems have been widely used in educational systems like educational centers in universities. In those systems, avoiding the large traffic caused by many users' continuous operations is one of the most important problems. In this paper we modeled the users' behavior in educational systems, and simulated and analyzed the traffic of the Ethernet LAN under such access concentration. Six variations of Ethernet LAN including traditional CSMA/CD Ethernet and switching Ethernet, TCP/IP and NFS are simulated. From the results of the simulation, we obtained the proper design for educational workstation LAN systems considering cost.

Keywords: LAN, Ethernet, Distributed Systems, Performance Evaluation, Educational Systems, NFS, TCP/IP.

1. INTRODUCTION

Traffic analysis of communication networks has been the subject of significant research in the last decade. Present computer network traffic consists of kinds of data from simple text to multimedia hypertext. High accurate traffic estimation and analysis of network behaviors are very important for constructing Local Area Networks (LANs) at large scale distributed computer systems. Educational LAN systems like those in educational computation centers at colleges and universities are good examples of such large systems. Most of those systems maintain personal data of all users and public data by using distributed file systems [1][2]. These data contents are stored in one or multiple file servers. When a user uses his data, his station accesses to the file server through the LAN. However, because of such style of maintenance and education, there is a network traffic problem that can not be bypassed.

For educational environments the distribution needs of educational materials are very high, for example, the instruction of the usage of network news, WWW and other applications that require large size data transmission and the distribution of custom educational materials. At the beginning of the classroom, those data would be transferred from the file server to the users' client workstations. The worst case is the situation that all the students request those data at the same time. This situation can be made on educational systems, while it is rarely made on networks for business and research. In such a situation, many network requests are generated from students' workstations and they would make the network congested instantly. Of course, if the network bandwidth were very wide, the effect of the access concentration of the network would be small. However, to offer sufficient bandwidth to the network requires large costs.

To avoid the mentioned situation and to keep the capital investment lower, LANs of educational systems should be designed carefully especially about the concentration of access to the LAN and its scale. Much research has been made on the performance evaluation of LAN systems. However, most research [3][4] neglects upper layer protocols or users' behavior.

In this study we analyzed the traffic of LAN under access concentration condition at educational system by detailed event-driven simulation. The simulation models that we made support all protocol layers from the physical layer to the application layer and users' behavior model. Proper designs of LANs for educational systems are shown.

In section 2, we discuss the general problems in designing educational computer network systems. In section 3, a modeling approach used to simulate access concentration at educational systems is described. The results of the simulations are shown in section 4 and the proper designs for educational systems are discussed.

2. EDUCATIONAL COMPUTER NETWORK SYSTEMS

2.1 Problems in Designing Educational Systems

Recently large scale distributed workstation systems (educational systems) have been used at concentrated educational computer systems like computer educational center at universities. These systems have hundreds or thousands of users and hundreds of workstations. For the purpose to offer the same operational environment for all uses at all workstations, the users' personal data or public data are often stored and managed at one or more file servers with distributed file systems (DFS) like Network File System (NFS)[5] or Andrew File System (AFS)[6]. Of course the same environment can be stored locally on the users' workstations. However it is difficult to manage local storage in hundreds of workstations and the cost of the storage would be expensive.

When users use data in a file server of DFS, request messages are sent to the file server via LAN. If many users use data in the file server at the same time, the LAN will be congested. Such a situation can often take place in educational systems. For example, when an instructor instructs dozen of students to operate their computers, the students operate them roughly simultaneously. This style of education is often observed in universities in Japan. If they operate files on the file server (it might be large size movie data!), then many messages concentrate instantly at the LAN and the file server. As a result of this, the LAN capacity would become saturated, and the students will suffer a long waiting time to their next operation. We named this situation as “Ready Go! Situation.”

2.2 Examples of Educational Workstation LAN Systems

To avoid the access concentration at the “Ready Go! Situation”, some network topologies have been proposed. The simplest way is to make users use floppy disks or other removable media for storing their own data (**Fig 1**(a)). And they cannot share public data. Workstations used by users have public data in their local storage. However, the capacity of a floppy disk is very small. Furthermore to maintain public data on each workstation is very troublesome.

Nakayama *et al*. [2] proposes a X station based network system (**Fig. 1**(b)). Users use X terminals instead of workstations. A cluster consisting of about 10 X stations are connected to a computing server which is connected to a file server workstation and other computing servers. The network in the cluster is different from the network connecting the computing workstation and the file server.

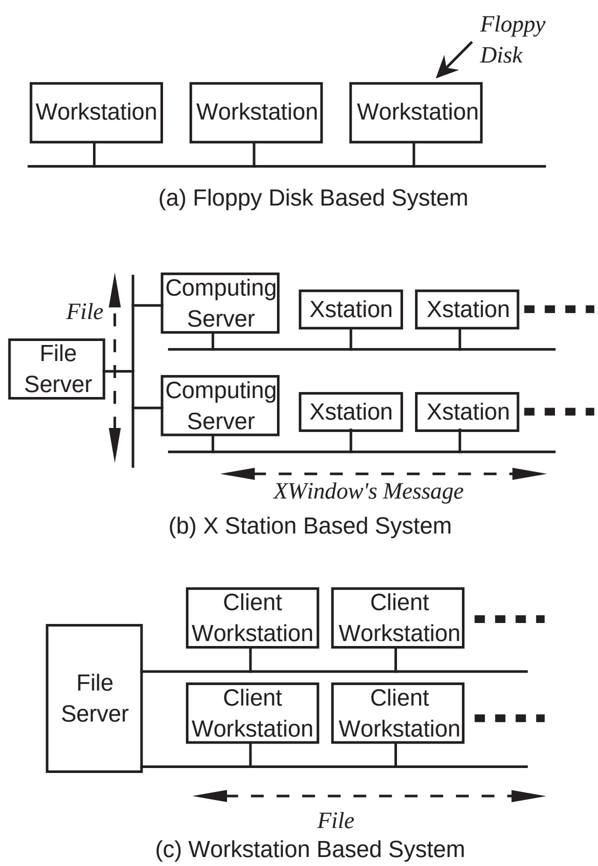

Figure 1. The Variation of Educational Workstation LAN Systems

Because the traffic of file transfer messages occurs only in the network connecting the file server and the computing server, the congestion caused by users' operations stays lower. However, the computing performance per user is restricted to small. Defining the number of X stations in a cluster requires a tradeoff of the computing performance for users and the load to the network connecting the file server and the computing servers.

Another topology is proposed by Okada *et al*. [1] (**Fig. 1**(c)). Dozens of workstations in a classroom are directly connected to a file server which has plural network interface for each classroom. The computing performance per user is higher than the former systems because only one user uses a workstation. However the messages generated from clients at the “Ready Go! Situation” makes the network very congested instantly. To offer the comfortable response time to users, it is important to define the number of clients in a network.

In this paper we handle some variations of the network topology based on the last network system.

3. MODELING APPROACH

In this section, we describe our approach to evaluate the performance of educational systems at the "Ready Go Situation." The model consists of multi-layer sub-models based on physical layer property to users' behaviors instead of only simple network protocols.

3.1 Ready Go Situation

For simulating the access concentration to a LAN, we assumed the following situations.

- The “Read Go! situation” at educational computer network systems.
- Six types of Ethernet LAN [7] consisting of one file server and N (1-150) clients. It is based on the topology presented in **Fig. 1**(c)
- 2 types of file transfer application programs from 1 one server to N clients, FTP (File Transfer Protocol) [8] and NFS.
- 1 MB file transferring. Transferred file size is selected to be same as the size of a large-size application program.

We did not simulate file transmission from clients to a file server. Of course such a situation can take place on educational systems, however, the size of the files may be small. On the other hand, the file transmissions from a file server to clients caused by users’ operation frequently occur in the classroom of educational computer systems. For example, the distribution of teaching materials, network news and WWW.

3.2 Network Simulation Model

The simulator used for this simulation is developed by the authors [9]. Details of the applications, UDP/IP and Ethernet algorithm such as message retransmission, collision detection, back off, deference mechanism, and both cable and HUB delays have been modeled by a multi layer scheme.

The simulator is an event-driven simulator. Each station in a network corresponds to a station model which consists of a users' behavior sub-model, an application sub-model and

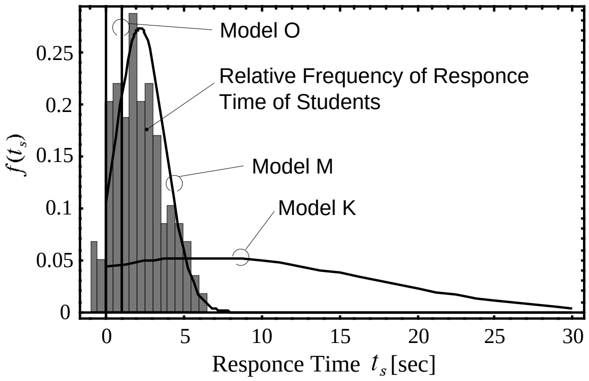

Figure 2 Users' Behavior Model

network sub-model. The network sub-model consists of sub-models corresponding to each layer network protocol. The first action in the simulation is triggered by SEND events generated by users' behavior sub-model, which generates the timings of the users' operations at the "Ready Go! Situation." When an application model on a client station model receives the SEND event, it generates a message and generates an event for the network sub-model to send the message.

The queue length of Ethernet at each host is not limited in this simulator. The storage access and CPU delay on the server are neglected.

3.3 Users' Behavior Sub-Model at the "Ready Go! Situation"

For simulating the access concentration at the "Ready Go! Situation" in educational computer systems, we measured the users' reply time with a mouse double-clicking operation at an actual classroom [10]. The sample count is 147. 80 % of the users replied within 7 sec. **Figure 2** shows the results of the measurement and user behavior models. The reply time is distributed like normal distribution, and its mean and the standard deviation are μ = 2.2[sec] and σ = 1.6 [sec] respectively. From this results, we developed three users' behavior models, M, K and O, which are respectively corresponding to mouse operation, keyboard operation (wider than Model M) and completely simultaneous operation for reference.

These models are used to generate the timing when the first request is made from each user's station to the file server. We assumed that users' reply time distributed according to the probability density function Eq. (1), which is determined as a distribution such that the probability of a negative random number $t_b(i)$ is zero at the normal distribution $\left[\mu, \sigma^2\right]$.

$$f(t_s) = \begin{cases} \left[\int_0^\infty \exp\left\{-\frac{(\varepsilon-\mu)^2}{2\sigma^2}\right\} d\varepsilon\right]^{-1} \exp\left\{-\frac{(t_s-\mu)^2}{2\sigma^2}\right\} & (t_s > 0) \\ 0 & (t_s \le 0) \end{cases} \quad (1)$$

Random values generated from Eq. (1) determine the timings of users' responses of each station. Parameters of each model are defined as **Tbl. 1**.

Table. 1 Parameters of Users' Behavior Models

Model	μ [sec]	σ [sec]
M	2.2	1.6
K	6.3	10.6
O	1.0	0.0

3.4 Application Model

We selected two network applications, FTP and NFS, to evaluate client-server systems at educational computer network systems. These two applications use different schemes to achieve reliable transmission. FTP is not a distributed file system. However it also offers the functionality of file transmission like NFS. Indeed FTP is used by CAP, which offers AppleShare file services on UNIX workstations. The strategy to achieve reliable transmissions used by FTP is different from NFS. So we simulated FTP for the comparison with NFS.

FTP utilizes TCP [11] as the transport layer protocol. So, functions for reliable transmissions are processed by TCP. TCP utilizes window flow controlling and retransmission with acknowledgment to achieve reliable transmissions. On the other hand, NFS works on XDR and RPC, and utilized UDP for transport layer protocols. Because UDP does not offer reliable transmission, RPC and NFS use a simple timeout and retransmission method to achieve reliable transmissions.

FTP model: At the file transfer process of FTP, a few messages are exchanged between a server and a client before the file transfer. However, our FTP model is designed to work simply. We neglected messages required to set up a connection between the server and the client. The client model sends a request message to the server. When the file server receives the request message, it sends a replying message to the client as a stream. Other messages of the application layer are not sent from the client and the server. This is because TCP offers the reliable transmission. TCP exchanges messages between the client and the server at the transport layer.

It is well discussed that the implementation of TCP influences the performance of it in [12]. We designed our TCP model to be the same as UNIX 4.3BSD Tahoe [13] because many UNIX like OSs are based on this system. **Table 2** shows the parameters of TCP that is used in this simulation.

Table. 2 Parameters of the FTP Model

TCP Sending Window Size	8192 bytes
TCP Receiving Window Size	8192 bytes
Application Sending Buffer Size	32768 bytes
Application Receiving Buffer Size	32768 bytes

NFS model: The NFS client model has to send one or more request messages for one file transmission, while a client FTP model sends only one request. Because the maximum data size being transferred by one NFS replying message is limited to 8 Kbytes.

The operation flow of NFS model is described as follows.

1) When a users' behavior model generates a SEND event, a client NFS model sends a request message (120 byte excepting header length of UDP) to the server.
2) When the server NFS model receives a request message from a client model, it sends a replying message (less than 8268 bytes excepting header length of UDP) to the client. This message can be fragmented by IP.
3) When the client model receives a legal reply, it sends a new request message to the server model. If a client model does not receive a reply message in a specified time, it retransmits the last request message to the server NFS model with the same ID. We implemented the adaptive retransmission control to this model as same as NFS on Sun OS 4.1.

Note that the message generated in TCP and NFS are divided to fit the Ethernet frame size (64 bytes to 1518 bytes including headers).

3.5 Network Topologies

We simulated following six types of Ethernet LAN to obtain suitable designs for educational systems. They are classified in two groups, shared Ethernet and switching Ethernet.

Shared Ethernet is the traditional Ethernet, which utilizes CSMA/CD (Carrier Sense Multiple Access with Collision Detection) for access controlling [7]. The channel is shared by stations connecting to the network. Only one station can transmit a packet at a time. A station checks if other stations are transmitting packets before sending a packet. If other stations are sending packets, then it defers its transmission until the end of the transmission of other stations. However plural stations start transmission at the same time, they can not detect the transmissions each other because of the propagation delay between them. This is called as collision. If the stations transmitting a packet detect collisions, it sends JAM signal and back off and retries the transmission after random-delay.

The switching Ethernet is realized by connecting stations with a switching HUB. Plural connections can be made on the switching HUB individually without CSMA/CD.

The simulated six types of network topologies are as followings.

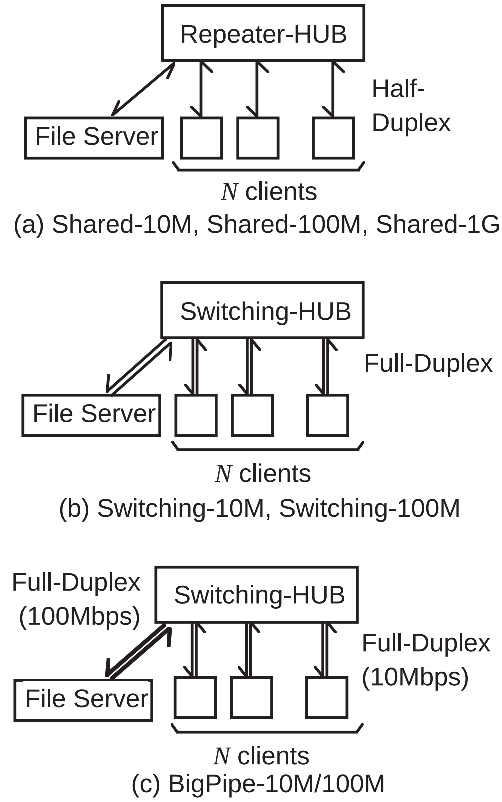

Figure 3 Network Topologies

- **Shared-10M:** 1 file server and *N* client stations are half-duplex connected to a repeater HUB via 100 m twisted-pair cables. The bit rate of Ethernet is 10 Mbps (10BASE-T). This is a sample of traditional Ethernet CSMA/CD.
- **Shared-100M:** same as the Shared-10M, but the bit rate is 100 Mbps (100BASE-TX)
- **Shared-1G:** same as the Shared-100M. But the bit rate is 1 Gbps (1000BASE-T) and two features, Frame Bursting and Carrier Extension, are added to the original Ethernet CSMA/CD algorithm. The details of the algorithm and the performance of Gigabit Ethernet are described in [4].
- **Switching-10M:** 1 file server and *N* client stations are full duplex connected to a switching HUB via 100-m twisted-pair cables. The bit rate is 10 Mbps (10BASE-T). Switching method is assumed to be store and forward. A complete incoming packet to the HUB is stored in the HUB and forward to the port to the destination station. The switching time in the HUB is neglected. This is an ideal model of switching HUB.
- **Switching-100M:** same as the Switching-10M, but the bit rate is 100 Mbps (100BASE-TX).
- **BigPipe-10M/100M:** One file server is full-duplex connected to a switching HUB via a 100 m by twisted pair cable at the bit rate of 100 Mbps. *N* client stations are full-duplex connected to the same HUB via 100 m cables at the bit rate of 10 Mbps.

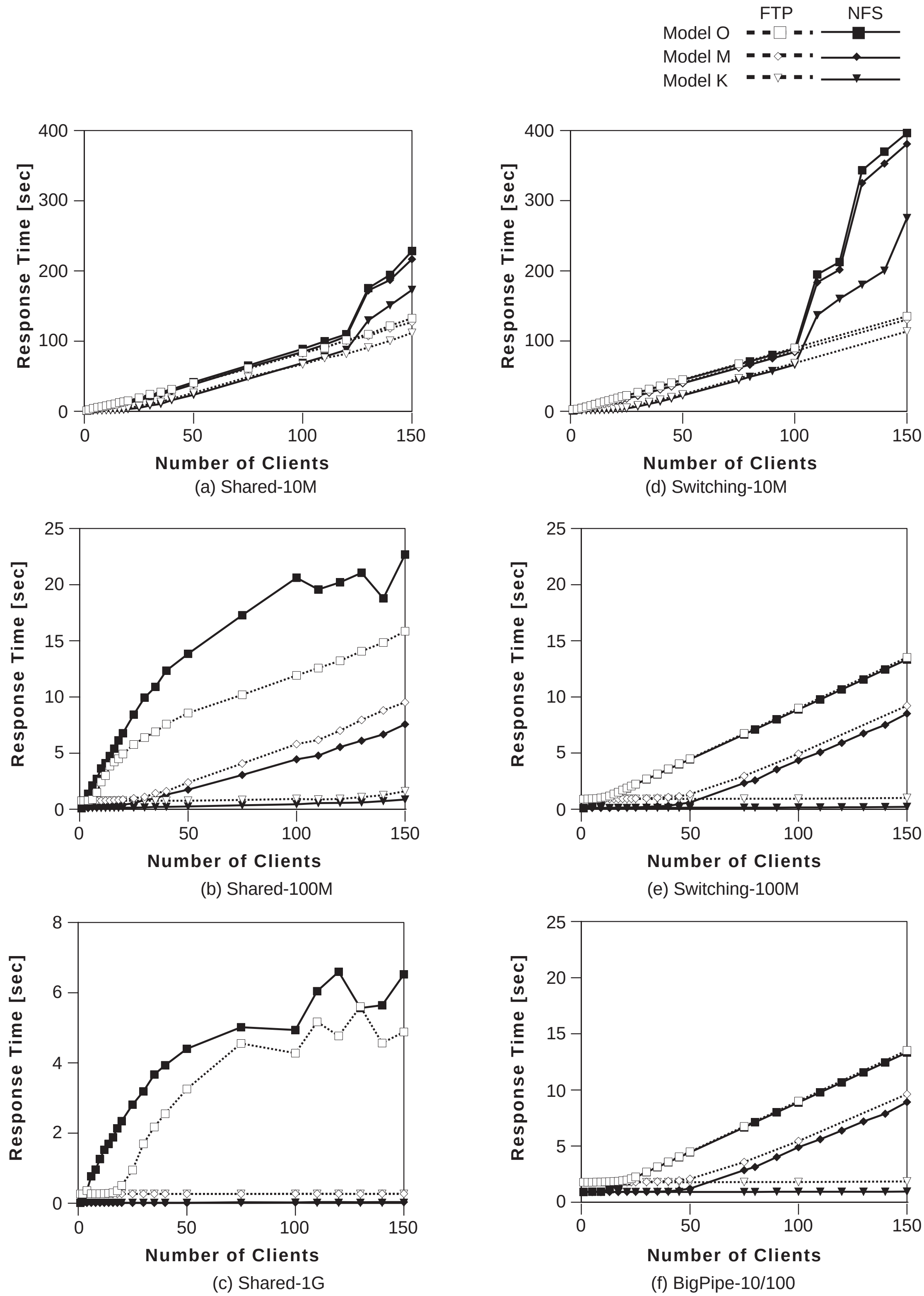

Figure 4 Response Time to the Users' Operation

4. Simulation Results

4.1 Response Time

We measured the mean response time, which is defined as the time required for a client to obtain the complete requested file to the time when the first request message is sent. **Figure 4** shows the results of the simulation. [14] Shows that the users' productivity increase drastically when the response time is less than 1 second. In this section, we define a comfortable file transfer time as 1 second.

Shared-10M: At model M, the mean response time T for NFS increases linearly with the number of clients N. T increases larger than 10.0 [sec] at $N > 10$. On the other hand, at model K, T keeps low values $T < 2.0$ [sec] until N=20, however it increases at $N > 20$. When $N > 100$, T of both two models increases drastically. This is because of NFS retransmission time-out often happens $N > 100$ (**Fig. 5**). The time-out causes the retransmissions of request messages from clients. These messages make the network more congested. In other words, a positive feedback happens there. This fact tells us that the timeout parameter is very important in designing large scale educational systems. T for FTP performs the same when $N < 120$. However the explosive increase of T is not found. We think this is because of the difference of the strategy for reliable transmission between NFS and TCP, which is utilized by FTP.

Consider a message is dropped between the server and a client. If the packet is transferred by TCP, the sender-station detects the drop of the packet by the time-out of receiving the acknowledgment packet to the message. The sender retransmits the same message to the receiver. In the situation we simulated, the file server station is only one sender, and all the client stations are receivers. Therefore the dropped messages are retransmitted only from the file server. The retransmissions are controlled by only one station. On the other hand, if the packet is transferred by NFS, the server does not detect the drop. The client detects the drop by a time-out of a reply from the server to a request message. The client sends the same request message to the server again. If many clients are connected to a server and they detect drops of messages, many duplicated messages are sent from the clients. They make the network more congested. In other words, a positive feedback happens there.

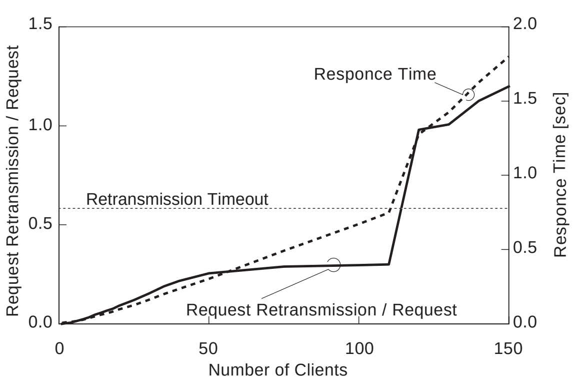

Figure. 5 Mean request time to a NFS request message and time-out of retransmission of NFS request. (Shared-10M Model M)

Shared-100M: T of model M keeps a low value when $N < 30$. When $N > 30$, T increases in proportion to linearly with number of clients N. T of model K does not exceed 1.0 [sec] even at $N = 150$. T of model M exceeds 1.0 [sec] at $N > 40$.

Shared-1G: The access concentration caused by users' operation does not affect the response time. T of model M and K keeps a low value less than 0.1 [sec] until $N = 150$. Even Model O, T does not exceed 10.0 [sec].

Shared 1000BASE-X applies two enhancements to CSMA/CD algorithms, Carrier Extension and Frame Bursting [4]. Carrier Extension adds an extra signal to short frames of Ethernet. Because the lengths of NFS request messages are very short, the effect of Carrier Extension can not be bypassed.

We examined the percentage of Carrier Extension to the transmission delay of a frame. However, when $N > 50$ for model M, the cost of the Carrier Extension is less than 30%, most of the delay is occupied by the back-off delay caused by collisions. We could not find any bad effect of Carrier Extension to NFS file transmission except for the case of small N.

Switching-100M: Switching-100M shows about the same performance of Shared-100M. The rapid increase of T can be seen when N is about 50. Because of the distribution of users' operations, one client station can finish receiving a complete requested file while other stations do not communicating with the server. When N is large (in this case it is 50) plural client stations receive files at the same time. In other words, the file server handles plural file transmissions at the same time.

Difference between Switching-100M and Shared-10M can be seen at model M with the rapid increases of T. The rapid increase of T for Shared-10M begins at small N than Switching-100M. Of course this is because at the difference of the access controlling mechanism between them. In shared Ethernet, collisions occur when plural stations start transmissions at the same time, while collisions do not occur in switching Ethernet.

Figure 6 shows the percentage of back-off delay and other causes of Ethernet packet transmission delay to the total transmission delay of client stations for Shared-100M (Model M). The total transmission delay is now defined as the period from the time when a packet is queued in the Ethernet controller to the time when the complete packet is sent to the network successfully. The large percentage of back-off delay means that the packets from client stations frequently collide with each other. **Figure 6** shows that collisions frequently occur when $N > 30$.

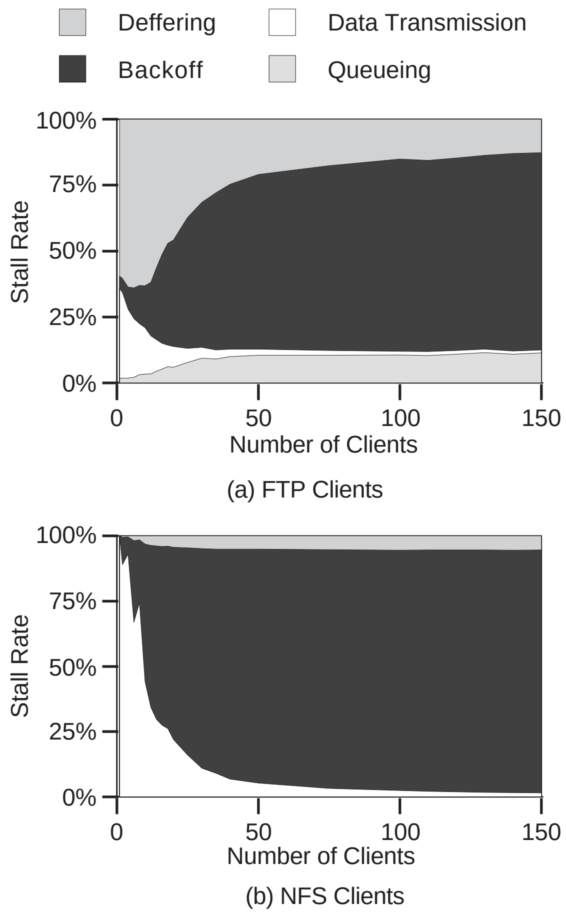

Figure 6 Percentage of causes of Ethernet Packet Transmission Delay (Shared-10M, Model M)

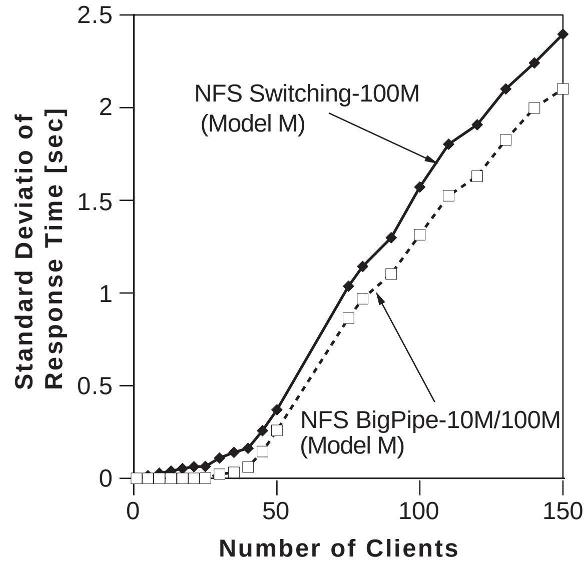

Figure 7 Standard Deviation of Response Time (NFS Model M)

BigPipe-10/100: About the same performance as Switcing-100M was obtained by BigPipe-10M/100M. This means that reducing the speed between the switching-HUB and client stations does not affect the performance of client-server systems like educational system. At the assumed situation, the file is transferred from the file server to clients. The link between the HUB and the file server is most frequently used.

The difference between BigPipe-10M/100M can be seen at the standard distribution of the response time between the clients (**Fig 7**). This means the fairness of file transmission to the clients. The standard deviation of the response time of BigPipe-10M/100M is slightly smaller than Switching-100M.

4.2 Proper Design of Educational LAN Systems

From the results of 4.1, we can conclude that the proper number of client stations in one Ethernet collision domain should be as **Tbl. 3**.

Table 3 Proper Number of Client Stations for Educational Systems

	Mouse Operation	**Keyboard Operation**
Shared-10M	Less than 10	Less than 20
Shared-100M	Less than 30	Less than150
Shared-1G	Over 150	Over 150
Switching-10M	Less than 10	Less than 20
Switching-100M	Less than 50	Over 150
BigPipe-10M/100M	Less than 50	Over 150

These number of client stations are obtained under the assumption that the response time to the users' operation should be shorter than 1 sec for 1 MB file transmission and the rapid increasing of response time to the number of stations should not occur.

10Mbps Ethernet should not to be used for the LAN at educational systems where large size files are transmitted at "Ready Go! Situation." Proposed numbers of client stations for 100Mbps are comfortable for a classroom. Effect of access concentration caused by users' operations was not observed in the simulation of Gigabit Ethernet.

Cost is one of most important factors in designing networks. **Figure 8** shows the cost and speed of simulated Ethernet variations. Generally the cost of switching network is higher than shared network. Recently switching Ethernet has been widely used. Plural one-to-one connections can be made on a switching HUB. However, on client server systems like educational systems, most connections are made between the server and clients. The advantage of switching networks is senseless in such environment. **Figure 4**(b) and **Figure 4**(c) show it clearly.

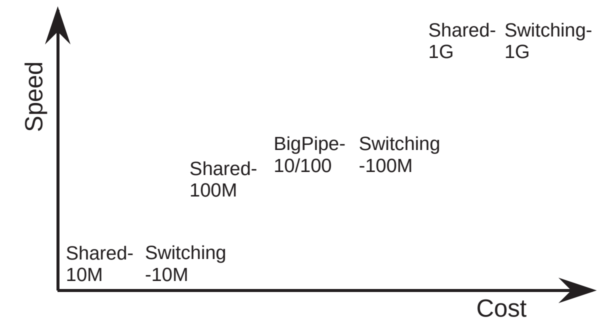

Figure 8 Speed and Cost of Variations of Ethernet LANs for Educational Systems

Difference between shared Ethernet and switching Ethernet is small.

We obtained the same performance from the simulation of Switching-100M and BigPipe-10M/100M. This high performance of bagpipe depends on the direction of file transmission from the server to the clients. If large files are transferred from the clients to the server, the performance will be worse because of the narrow bandwidth between the HUB and the clients. However such a case in educational systems would be rare. For keeping the cost lower the bagpipe type topologies would be effective for educational systems.

5. SUMMARY AND CONCLUSIONS

In this paper we showed the problems in designing the educational workstation LAN systems. We evaluated the performance of Ethernet variations for educational distributed computer systems under the users' access concentration to the LAN named “Ready Go! Situation.” The suitable numbers of client workstations for a file server are obtained for six types of LANs including traditional CSMA/CD Ethernet and switching Ethernet environments. In this paper we simulated only workstation based systems, which all workstations used by users in a classroom are connected to one fileserver, however, this result can be also applied to X station based systems.

To offer comfortable response time to the users’ operation, the number of client workstations connected to the LAN should be restricted. 100Mbps Ethernet offers sufficient performance for about 30-50 client stations. This number would be comfortable number for a classroom. The difference of performance at “Ready Go! Situation” between shared Ethernet and switching Ethernet is small. 100Mbps or higher bit rate shared Ethernet have high cost performance for educational systems. Especially shared Gigabit Ethernet is not affected by the access concentration at “Ready Go! Situation.”

In the future, the needs of distributing large size multimedia teaching material will arise at educational systems. Effects of video and other multimedia data transmission should be studied. We neglected the server's storage access delay and CPU processing delay in the simulation. This must affect the response time under Gigabit Ethernet environments. The consideration of the delay of them remains for future study. Furthermore, the performance of other network topologies should be studied. For example, networks including routers and more than one HUB.

6. REFERENCES

[1] Okada, M., Sakurai, K. and Iwata, A., “An implementation of large scale workstation system for computer science education”, Trans. IPS Japan, Vol. 37, No. 12, pp.2447-2456, 1996 (in Japanese)

[2] Nakayama, H., Ohnishi, Y., Suenaga, T. and Arita, I., “A design and construction of educational computer environment for engineering students,” Trans. IPS Japan, Vol. 35, No. 11, pp. 2225-2238, 1994 (in Japanese)

[3] Ibe, O.C., Choi, H. and Trivedi, K.S., “Performance evaluation of client-server systems,” IEEE Trans. Parallel and Distributed Systems, Vol. 4, No. 11, pp.1217-1229, 1993.

[4] Molle, M., “Frame bursting: a technique for scaling CSMA/CD to gigabit speeds,” IEEE Network Mag., pp. 6-15, Jul/Aug 1997

[5] Sun Microsystems, Inc, “NFS: network file system protocol specification,” RFC 1094, 1989

[6] Howard, J.H., Kazar, M.L., Menees, S.G., Nichols, D.A. Satyanarayanan, M., and Sidebothan, R.N., “Scale and performance in a distributed file system,” ACM Trans. Comput. Syst. Vol. 6, No. 1 pp. 55-81, 1988

[7] ANSI/IEEE Standard 802.3, “Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications,” IEEE Press, 1993.

[8] Postel, J. and Reyolds, J., “File Transfer Protocol,” RFC 1094, 1989

[9] Ishihara, S. and Okada, M., “A modeling and simulation method for transient traffic LAN,” IEICE Trans. Comm., Vol. E-80-B, No.8, pp.1239-1247, 1997

[10] Ishihara, S. Okada, M., Iwata, A. and Sakurai, K., “Traffic analysis on the LAN for education,” Proc. of Symposium on Informatics 1996, pp. 17-23, 1996 (in Japanese).

[11] Postel, J., “Transmission control protocol,” RFC 793, Information Science Institute / University of Southern California, 1981

[12] Bolot, J.C., Shankar, A.U. and Plateaau, B.D., “Performance analysis of transport protocols over congestive channels,” Performance Evaluation, vol. 11, pp. 45-66, 1990

[13] Leffler, S. J., McKusick, M. K., Karels, M. J. and Quarterman, J. S., “The design and implementation of the 4.3 BSD UNIX operating system,” Addison-Wesley Pub., 1989

[14] Hennessy, H. L. and Patterson, D. A., “Computer Architecture: A quantitative Approach,” Morgan Kaufmann Publishers, Inc., 1990