PERFORMANCE EVALUATION OF EDUCATIONAL WORKSTATION NETWORK SYSTEMS

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

KEYWORDS: LAN, Ethernet, NFS, Performance Evaluation, Educational System

1 INTRODUCTION

Large scale distributed workstation systems are widely used at computer training centers in universities in Japan. These systems have many registered users more than $10,000$ and hundreds of client workstations for students. Most of those systems maintain the users' personal data contents and public data like educational materials and large size programs using distributed file systems [1][2] like NFS [3] or AFS [4]. These data are stored in one or more file servers. When a user uses his data, his station accesses the file server through the LAN. In such educational systems, however, concentrated network access caused by many users' operations affects the performance of the LAN. Accurate estimation of access concentration to the LAN is very important to design educational systems.

For example, we consider that an instructor teaches dozens of students in a classroom. When he instructs students to operate their computers, they operate it roughly simultaneously. This teaching style is often observed in many universities in Japan. If they operate files (which might be large size movie data!) on the file server, then many messages concentrate instantly at the LAN and the file server. As a result, the LAN capacity would soon become saturated, and the students would suffer a long waiting time for the next operation. We named this situation as "Ready, Go! Situation."

To avoid the performance degradation of LAN caused by the "Ready, Go! Situation" while maintaining a low capital investment, LANs of educational systems should be designed carefully paying attention to the access concentration to the LAN and its scale. Okada[1] proposed a system that utilizes a file server workstation with plural Ethernet interfaces. Dozens of client workstations are connected to each interface. This system aims to avoid the performance degradation caused by access concentration to the LAN by reducing client workstations connected to the same Ethernet collision domain and the server's network interface. The number of the clients per one server's network interface and the selection of the proper Ethernet type are most important factors in designing cost-effective systems.

In this study we analyzed the traffic of LAN based on Okada's system in the "Ready, Go! Situation" at educational systems by detailed event-driven simulation. Although much research has been done in performance evaluation of Ethernet, most researches [5][6] neglect upper layer protocols or users' behavior. Simulation model that we developed supports not only Ethernet but also all protocol layers from the physical layer to the application layer and user behavior models based on measurements of an actual educational system.

In section 2, we introduce the method of simulation for educational workstation network systems in the "Ready, Go! Situation." In section 3, we show the results of the simulation and discuss proper cost-effective designs for educational workstation network systems.

2 MODELING APPROACH

2.1 Situation

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

- The "Ready, Go! Situation" at educational computer network systems.
- Six types of Ethernet LAN[7] consisting of one file server and $N(= 1 \sim 150)$ clients.
- Two types of file transfer application programs: FTP (File Transfer Protocol) [8] and NFS version 2[3].
- 1 MB file transferring from one server to N clients. The file size is selected to be the 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, file sizes may

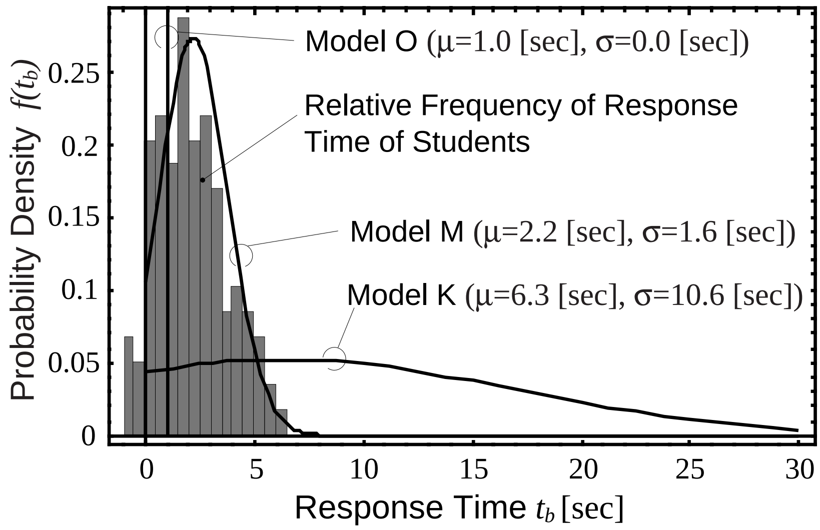

Figure 1 - User Behavior Model

be small. On the other hand, the file transmissions from a file server to clients caused by users' frequent requests occur in the classroom of educational computer systems. For example, the distribution of teaching materials, network news by NNTP, e-mail by POP and web pages.

2.2 User Behavior Models

For simulating the "Ready, Go! Situation" at educational computer systems, we measured the users' reply time of double-clicking on a mouse in an actual classroom[9]. The sample count is 127. An 80 % of the users replied within 7 [sec]. 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 these results, we developed three user behavior models, M, K and O, which correspond to mouse operation, keyboard operation (wider than model M) and completely simultaneous operation for reference. **Fig. 1** shows the result of the measurement and the user behavior models.

These models are used to time the first request of NFS or FTP from each client workstation to the file server. We assumed that users' replying time distributed according to probability density functions, which are determined as a distribution so that the probability of a negative random number $t_s(i)$ is zero at the normal distribution $N[\mu, \sigma^2]$. Generated random values determine users' responses at each client workstation.

2.3 Simulation Model

The simulator used for this study is developed by the authors[9]. Details of the NFS, FTP, TCP[10], UDP/IP and Ethernet algorithm such as retransmission strategies, collision detection, back-off, deference mechanism, and both cable and hub delays have been modeled by a multi-layer scheme. The queue length of Ethernet at each host is not limited. The disk access and CPU delay on the server are neglected. The NFS model is designed to be the same implementation of Sun OS 4.1. The FTP and TCP/IP models are designed to be the same as UNIX 4.3 BSD-Tahoe[11]. Buffer sizes for FTP and TCP are shown in **Tbl. 1**

The behavior of the applications and TCP are simplified in this simulation.

NFS: Clients and the server models exchange READ request messages and reply messages including 8 KB data of the requested file per message until all clients receive the complete requested file. Other NFS messages concerning file operations are neglected.

FTP: Clients send one request message. The server sends the requested file to the clients. The messages for establishing data connections of TCP are neglected.

2.4 Network Topologies

We simulated six types of Ethernet including shared and switched Ethernet. Shared Ethernet is the traditional Ethernet, which utilizes CSMA/CD (Carrier Sense Multiple Access with Collision Detection) for access controlling[7]. Stations connecting to the network share the channel. Only one station can transmit a packet at a time. If plural stations start transmission at the same time, they can not detect the transmissions of each other because of the propagation delay between them. This event is called a collision. When the stations transmitting a packet detect collisions, they send JAM signal and back off and retry the transmission after a random-delay. The switched Ethernet is realized by connecting

Table 1 - TCP parameters

	Size [bytes]
TCP Sending Window	8192
TCP Receiving Window	8192
FTP sending buffer	32768
FTP receiving buffer	32768

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 following.

Shared-10M: One file server and N client workstations are half-duplex connected to a repeater HUB via 100m twisted-pair cables at 10 Mbps (10BASE-T).

Shared-100M: Same as Shared-10M, but the bit rate is 100 Mbps (100BASE-T)

Shared-1G: Shared Gigabit Ethernet 1000BASE-X. One file server and clients are half-duplex connected to a repeater HUB. The cable length is assumed to be same as the maximum topology for the 1000BASE-X. Two features, Frame Bursting and Carrier Extension, are added to the original Ethernet CSMA/CD algorithm to handle a slot time longer than the minimum frame length. The details of the algorithm and the performance of Gigabit Ethernet are described in [6].

Switched-10M: One file server and N client workstations are full-duplex connected to a switching HUB via 100m twisted-pair cables at 10 Mbps (10BASE-TX). The switch is assumed to be a store-and-forward type. The complete incoming packet to the HUB is stored in the HUB and forwarded to the port to the destination station. The switching time in the HUB is neglected. This is an ideal model for switching HUB.

Switched-100M: Same as Switched-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 100m twisted pair cable at 100 Mbps. N client workstations are full-duplex connected to the same HUB via 100m cables at 10 Mbps.

3 SIMULATION RESULTS

We measured the server response time T defined as the period from the moment when a client workstation sends the first request message to the server to the moment when the client receives the requested file completely. **Fig. 2** shows the mean server response time for all the client workstations.

Shared-10M, Switched-10M At model M of NFS, mean server response time T increases in proportion to the number of clients N (**Fig. 2 (a)(d)**). T increases

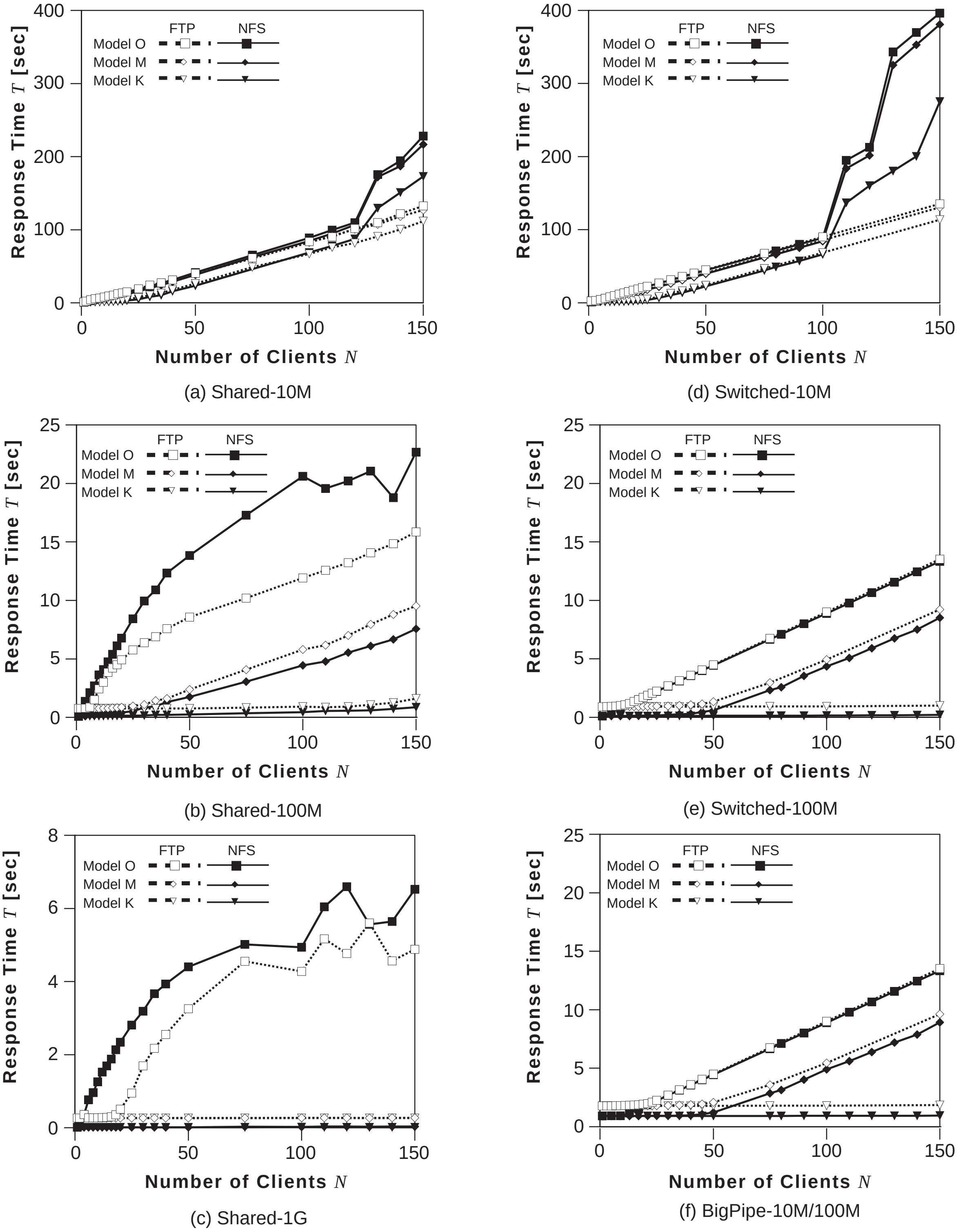

Figure 2 - Response Time to the Users' Operation

larger than 10.0 [sec] at $N > 10$. On the other hand, at model K, T maintains 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 the retransmission of NFS request often happens when $N > 100$ at client workstations. In the implementation of SunOS 4.1 NFS, the retransmission time-out of NFS request is fixed for the first retransmission of each request. The mean server response time per NFS request exceeds the time-out when $N \approx 100$. So requests are retransmitted although the previous request or the reply messages are not dropped. The retransmitted request messages and duplicate reply messages cased by retransmitted messages make the network more congested. This situation should be avoided by configuring the time-out parameter, reducing client workstations or using NFS with adaptive congestion control mechanisms. The drastic increase of FTP's T can not be seen because FTP works on TCP, which controls the retransmission time-out from the sender dynamically.

The difference in characteristics of T between Shared-10M and Switched-10M is small.

Shared-100M, Switched-100M Switched-100M (**Fig. 2 (e)**) and Shared-100M (**Fig. 2 (b)**) shows same characteristics of T. Because of the distribution of users' operations, one client workstation can finish receiving a complete requested file while other clients are not communicating with the server when N is small. We feel this condition is ideal for Ethernet LANs used in educational systems. The rapid increase of T can be seen when N is about $30 \sim 50$ When N is large plural client workstations receive files at the same time. In other words, the file server handles plural file transmissions at the same time.

Difference between Switched-100M and Shared-10M can be seen at model M with the rapid increase of T. The rapid increase of T for Shared-100M begins at smaller N than Switched-100M. Of course this is due to the difference in 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 switched Ethernet.

Another difference between them is that the disparity in the server response time between the client workstations is small at Switched-100M. The details of this have been reported by the authors in [12]. We think that this characteristic is convenient for teaching computer operations to dozens of students all together.

Shared-1G The access concentration caused by users' operation does not affect the response time (**Fig. 2 (c)**). T at model M and K maintains a low value less than 0.1 [sec] until $N = 150$. Even at model O, T does not exceed 10.0 [sec]. Shared 1000BASE-X has two enhancements to CSMA/CD algorithms, Carrier Extension and Frame Bursting[6]. Carrier Extension adds extra signals to short frames of Ethernet. Because the lengths of NFS request messages are very short, Carrier Extension can not be avoided.

We examined the percentage of Carrier Extension to the transmission delay of a frame. 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.

BigPipe-10M/100M About the same performance as Switched-100M was obtained by BigPipe-10M/100M (**Fig. 2 (f)**). This means that reducing the speed between the switching-HUB and the client workstations does not affect the performance of client-server systems like educational systems. 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.

4 PROPER NETWORK DESIGNS FOR EDUCATIONAL SYSTEMS

From the results of the simulation, we obtained the proper numbers of client workstations per network interface on a file server for 6 variations of Ethernet (**Tbl. 2**). These numbers of client workstations are obtained under following assumptions. (i) The response time to a user's operation should be shorter than 10 [sec] for 1 MB file transmission. (ii) The server response time should not increase sharply with more clients.

Proposed numbers of client stations for 100 Mbps are comfortable for a classroom. The performance degradation of LAN caused by concentration of users'

Table 2 - Proper Numbers of Client Workstations for Educational Systems

Network	Mouse Operation	Keyboard Operation
Shared-10M	Less than 10	Less than 20
Shared-100M	Less than 30	Less than 150
Shared-1G	Over 150	Over 150
Switched-10M	Less than 10	Less than 20
Switched-100M	Less than 50	Over 150
BigPipe-10M/100M	Less than 50	Over 150

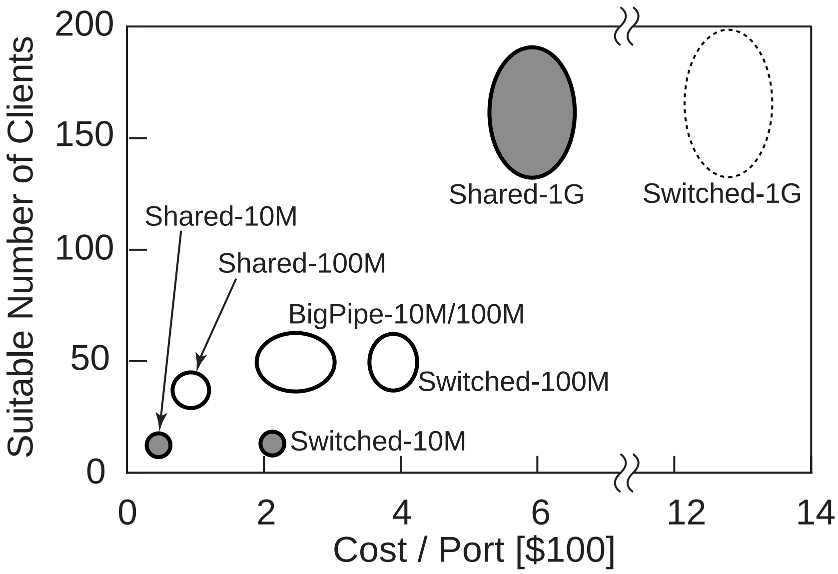

Figure 3 - Performance and Cost of Variations of Ethernet LANs for Educational Systems

operations was not observed in the simulation of Gigabit Ethernet.

Switched Ethernet including BigPipe-10M/100M can support more client workstations than shared Ethernet. They also ensure fairness of server response time between client workstations. These advantages are obtained by the avoidance of collisions. However, another advantage of switched Ethernet, which is well known, is that plural one-to-one connections can be made simultaneously. However, it is inefficient in client server systems like educational systems because most messages are exchanged between a file server and client workstations. Considering this and the high cost of switched Ethernet, we would like to say that switched Ethernet is not the best system for educational systems. **Fig. 3** shows the relation between the proper numbers of client workstations for educational systems and the estimated cost per port of HUB for variations of Ethernet in 1999[13]. One can see that Shared-100M and BigPipe-10M/100M are very cost effective. Furthermore, Shared-1G has the best cost performance.

5 SUMMARY AND CONCLUSION

We have evaluated the performance of LANs in educational distributed computer systems under user access concentration. We conclude that shared 100 Mbps Ethernet and switched 100M/10M big-pipe type topologies will be more cost-effective for educational systems in which classroom has $30 \sim 50$ client workstations. For larger systems, which have hundreds of client stations, shared Gigabit

Ethernet would be the best system. However, we neglected the server's disk access delay in the simulation, which must have affected the response time under Gigabit Ethernet. Furthermore, effects of video and other multimedia data transmission should be studied.

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