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Performance Evaluation of Office Communications Applications over LANs Interconnected via Frame Relaying

by
Bilal Awada

A THESIS
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in partial fulfillment of the requirements
for the degree of
MASTER OF APPLIED SCIENCE
in
Electrical Engineering

Ottawa-Carleton Institute for Electrical Engineering
Department of Electrical Engineering
Faculty of Engineering
University of Ottawa
Ontario, CANADA

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Abstract

The performance evaluation of the communications networks have been the main focus in the analysis of data communications in automated office environments. This thesis is aimed at the performance evaluation of different office communications applications over LANs which are interconnected via one of the latest fast packet switching techniques called *frame relaying*. Different LAN technologies have been examined, namely Ethernet, Token ring and AppleTalk. The T1 (1.544 Mbps) link and the 56 kbps link are used as a public services for inter-site communications.

In this study, two main applications were considered: office communications which include different types of documents that pass across an office worker's desk (publications, messages, financial forms, and normal documents), and file transfer activities such as the transfer of X-RAY images or a medium size newsletter.

The transfer delay, link utilization, packet size, and the number of workstations interconnected to each LAN are the main parameters used for evaluating the system performance. Results show that the 56 kbps link is best suited for office communications under normal conditions. However as inter-site traffic increases T1 should be considered. A comparison of the performance of each LAN technology is given for both applications.

The results of this study should furnish any office organization with strategic insight for the planning of its communications services.

To my parents

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Acronyms

ALAP	Appletalk Link Access Protocol
ANSI	American National Standards Institute
ATM	Asynchronous Transfer Mode
ATP	Appletalk Transaction Protocol
BER	Bit Error Rate
BISDN	Broadband Integrated Services Digital Network
BIU	Bus Interface Unit
CCITT	Comité Consultatif International Télégraphique et Téléphonique
CPU	Control Processing Unit
CRC	Cycle Redundancy Checks
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
CTS	Clear-to-Send signal
DLCI	Data Link Control Identifier
DLL	Data Link Layer
ECMA	European Computer Manufacturers Association
FCS	Frame Check Sequence
HDLC	High Level Data Link Control
IEEE	Institute of Electrical and Electronics Engineers
ISDN	Integrated Services Digital Network
ISO	International Organisation for Standardization
I-frame	Information frame
LAN	Local Area Network
LAPD	Link Access Protocol on D-channel
LLC	Logical Link Control
MAC	Media Access Control
MAC PDU	Media Access Control Protocol Data Unit
Mb/Wd	Megabits per Working day
NIU	Network Interface Unit
OIS	Office Information Systems
OSI	Open System Interconnection
PBX	Private Branch Exchange
PDU	Protocol Data Unit
PSTN	Public Switched telephone Network

QNAP	Queue Network Analysis Package
REJ-frame	Reject supervisory frame
RR-frame	Ready to Receive supervisory frame
RTS	Request-to-Send signal
SAPI	Service Access Point Identifier
S-frame	Supervisory frame
SNA	System Network Architecture
T1	Link service for interconnecting LANs at 1.544 Mbps
TDM	Time Division Multiplexing
TEI	Terminal Endpoint Identifier
THT	Token Holding Timer
UNI	User-Network Interface
WS	Workstation

Chapter 1

Introduction

1.1 Background

The analysis of data communications in automated offices has already been undertaken by several investigators. Some case studies have been performed for assessing actual communications volumes in the office and network capacity. Schoch and Hupp have reported on the utilization of an existing Ethernet installation providing services to over 120 directly connected hosts [SCHO]. They also evaluated the capacity of the communications network by using artificial load generators. In a more recent study, Schmidt reported on the utilization of a multiple Ethernet-AppleTalk installation [SCHM]. Monitoring tools were used for visualizing the state of the internetwork system.

Some other studies have started from an analysis of the daily communications volumes per office worker [ENGEL,MCCA]. These analyses have taken into account human factors (different types of office workers) [ENGEL], the use of new technologies (multimedia systems) or new applications (computer-based conferencing systems) [MCCA]. Finally, Georganas and Naffah [GEOR87] evaluated the performance of three different LAN's technologies for supporting office activities. However, this latter study did not consider the use of intersite data communications.

1.2 Frame Relay: an Overview

Frame relaying is a fast packet-switching technique that takes advantage of the characteristics of the ISDN-environment as well as the capability of the frame structure employed by the ISDN D-channel Link Access Protocol (LAPD) to support multiplexing within the link layer [CHERU].

Many research studies that have been conducted on frame relay have suggested that frame relay implementation can potentially result in a significant improvement of a network performance. A recent study concluded that frame relay achieves approximately 10 times the packet throughput of existing X.25 packet-switching networks [BHUSH].

The birth of frame relay has been stimulated by standards taking advantage of the low error rate digital transmission medium and a network-layering concept. Under this concept, the network backbone should offer core services and the higher-level intelligence should be migrated towards the access layer of the network. These services are explained later in the following chapters.

Frame relaying is a technology that is still being defined. Standards for frame relay are being developed by the CCITT (International Telegraph and Telephone Consultative Committee), ANSI (American National Standards Institute), and ECMA (European Computer Manufacturers Association). Issues that need further study at the CCITT and the ANSI level include congestion control, internetworking requirements, further refinements of the Control and User plane protocols, and quality of service parameters.

1.3 Office Automation

Office automation is the use of technology for improving the productivity and effectiveness of administrative and other related tasks in offices. In Mowshowitz's terms, "office automation is the use of information technology in an office environment to create, process, store, retrieve,

use and communicate information in the performance of managerial, professional, technical, administrative and clerical tasks" [MOWS].

Central to the efficient working of the integrated office is the workstation and broadband networking which make possible "the establishment of a reciprocal relationship among a group of people with a common interest or task that makes the smooth distribution of necessary information and thus the sharing of information" [WATA87].

Office systems are composed of many different technologies. Even though many studies have emphasized the importance of communications in linking the many components of office systems, a lot of progress has to be done towards achieving a truly integrated system.

Integration does not require that all components reside in one physical location. As stated by Lieberman et al., "this characteristic will provide an organization with the flexibility to accomplish certain office activities independent of a fixed or centralized work environment and thus to optimize the use of the demographically changing work force and lifestyles of the population" [LIEB]. Therefore, the development of integrated information systems for the office requires a clear understanding of the communications requirements of the current and emerging office applications.

1.4 Outline of the Thesis

The wide usage of Local Area Networks (LANs) in many business environment along with the growing rate of data exchange between offices has prompted the need for the interconnection of LANs either within the same corporation or between corporations. Hence the need for the performance evaluation of the overall interworking system must be considered. The main objective of this study is to evaluate the performance of LANs interconnected by public communications links and carrying various applications. To meet this objective, an office communications environment and file transfer applications have been considered. A characterization of their traffic behaviors have been made for both intra and inter-LAN communications.

In order to evaluate the performance of the systems, queueing models have been developed by using the QNAP2 (Queueing Network Analysis Package) software (see appendix A). The analysis is done by taking into account the use of current computer technologies as well as the use of advanced public communications services. The detailed level of the analysis is due, in part, to the work presented to Bell Canada under a research contract [BELL]. The performance evaluation of these communications should furnish any office organization with strategic insight for the planning of its data communications services.

This thesis is composed of six chapters and two appendices. The first chapter presents the context in which frame relay technology can be used, followed by a brief introduction to office automation. In chapter 2, an overview of communications systems and standards is presented. This overview comprises a description of current networking technologies available for the office, namely local area networks, public networks ~~and interconnection~~ devices. The description of interconnection devices covers three different types of technologies: bridges, routers and gateways.

Chapter 3 presents the system description and the different configurations that are considered for the evaluation of office communications activities under different LAN technologies. This chapter also discusses the frame relay protocol and how data transfer can be achieved in such environment. It successively presents the queueing models of the LANs, the one of the bridge interconnecting LANs and public communications link, and the one of the workstation and the database server.

In chapter 4, an analysis of the communications requirements of the automated office is presented. This analysis is done by taking into account various office applications and the communications volumes generated within a typical office environment. Then it analyzes the performance of office communications systems consisting of both local and intersite communications facilities. The page transfer delay, link utilization, and the number of workstations interconnected to each LAN are the main parameters used for evaluating the system performance.

Chapter 5 studies the performance of small and large file transfers. As in the previous chapter, it considers the use of three different LAN technologies and different scenarios. It also considers the use of T1 links for interconnecting LANs. Finally, chapter 6 presents the conclusions drawn from this thesis and suggests further work. The appendices include a description of the simulation tool and the programs used for carrying out this study.

Chapter 2

Standards and Communications Systems Review

This chapter presents a description of the communications systems and standards which are considered in the work of this thesis. First a brief review of the different LANs which are currently used for supporting office automation and file transfer applications is given. A short presentation of the various devices for interconnecting different kinds of networks follows. Then the 56 kbps and T1 services which are typical public systems used for interconnecting LANs are introduced. The fourth section presents the solutions offered by the CCITT for packet transfer services by going through the different steps from ISDN to Frame Relaying, then through ATM techniques towards achieving BISDN. The last section describes the protocols used in this thesis for performing flow control.

2.1 Local Area Networks

2.1.1 Introduction

Local Area Networks are those that involve the interconnection of terminals, computers, workstations, and other intelligent systems within a building or a number of buildings that constitute a small campus [SCHW]. A Local Area Network (LAN) is a resource-sharing data communications network which is limited in geographic scope to the range of 0.1-10 km, pro-

vides high bandwidth communication (above 1 Mbps) over inexpensive transmission media and is usually privately owned [MOUF]. The LAN is probably the best choice when a variety of devices and a mix of traffic types are involved. The LAN, alone or as part of a hybrid local network, has become a common feature of many office buildings and other installations.

LANs are frequently characterized in terms of their topologies. Four topologies are common: star, tree, ring and bus.

The distinctive feature of a star is the existence of a central switching point, known as a hub, which is shared among all the stations. Stations are connected to the hub by means of point-to-point transmission links. The central element uses circuit switching to establish a dedicated path between two stations wishing to communicate [STAL]. The major drawback of this set-up is the existence of a common central point susceptible to failures.

A tree consists of several links which direct the transmissions from every station towards a common end point being the root of the tree, called the headend. Then data is broadcasted from the headend back through the same tree towards the interconnecting devices.

A ring is composed of several unidirectional point-to-point links connected together by active repeaters in a closed loop. Each station communicates with the ring through one of the repeaters with a short line. A station wishing to transmit waits for its next turn and then sends data out onto the ring in the form of a packet. A distributed control protocol is used to determine the sequence in which nodes transmit.

A bus is a long broadcast medium. Stations are attached to the medium through taps better known as Bus Interface Units (BIUs). Since all the devices share a common communication medium, only one pair of devices on a bus can communicate at a time.

Logically however, there are only two network topologies: the broadcast bus and the ring with active repeaters. The significant difference between them is that, in the first configuration, what is being transmitted by one station on the bus can be heard by all the other stations, while on the ring, transmissions have to be relayed by the repeaters one by one in

order to propagate around the ring. This difference has an influence on the choice of the media access protocols that can be applied to each configuration. Moreover, looking the configurations from the reliability point of view, the ring topology is much more vulnerable to failures and provision has to be taken to address this weakness.

The most used transmission media in Local Area Networks' implementations are the wire (twisted pair), the coaxial cable (baseband and broadband) and recently the optical fiber. Coaxial cable is very common in broadcast bus configurations because of its quite good bandwidth-distance characteristics and the tapping easiness. Optical fibers on the other hand can increase our ability to transmit at higher data rates for longer distances without using any repeaters, but they are very difficult to tap. Therefore their usage is limited mostly to rings and more generally to point-to-point connections. Finally twisted pair is mostly used in ring applications, where repeaters are needed in short distances to recover the conveying signal. because of the very poor bandwidth-distance characteristics of the wire. However, there are cases where bus configurations are implemented in twisted pair (twisted pair ETHERNET, twisted pair STARLAN, etc). Star configurations have been given less attention than the ring and bus architectures, at least in the recent literature and standards, although there exist several commercial applications of networks with star configuration.

Many access mechanisms have been proposed or implemented for local area networks. In this thesis, focus is made on three mechanisms that have been designated as standards: the CSMA/CD (Ethernet), the CSMA/CA (Appletalk) and the token-passing ring. Other types of access methods have been proposed or implemented for special-purpose use and are described in the literature but are of no interest for this study.

The LAN standards have been developed by the IEEE (The Institute of Electrical and Electronics Engineers) through a special committee called the IEEE 802 committee. These standards cover the physical layer and a portion of the data link layer and they conform to the OSI Reference Model. The standards defining the three type of media access technologies are:

1. IEEE Std 802.3, a bus utilizing CSMA/CD as the access method.
2. IEEE Std 802.4, a bus utilizing token passing as the access method.
3. IEEE Std 802.5, a ring utilizing token passing as the access method.

The IEEE std 802.2, which is the Logical Link Control (LLC) standard, is used in conjunction with the medium access standards.

2.1.2 IEEE 802.3 CSMA/CD

General Description

The CSMA/CD (Carrier Sense Multiple Access with Collision Detection) standard [ANSI85B], often juxtaposed with the Ethernet protocol, is based on the use of a common bus shared by a number of stations (see Fig. 2.1). While the Ethernet specification just calls for a coaxial cable physical channel driven at 10 Mbps, the IEEE 802.3 standard is intended to encompass several media types and techniques for signal rates from 1 Mbps up to 20 Mbps. In the CSMA/CD protocol, each station, before transmitting, must listen to the bus. If there is no energy detected on the medium during an idle time (slot time), the station can transmit the queued packet. If, after initiating a transmission, the message collides with that of another station, then each transmitting station intentionally sends a few additional bytes (jam signal) to guarantee that all transmitting stations on the network detect the collision. The station remains silent for a random amount of time (backoff) before attempting to transmit again. To perform retransmission of frames, the CSMA/CD protocol uses a truncated binary-backoff algorithm: the delay before retransmitting is assumed to be a random integer number r which is multiple of slot times (defined in the next paragraph) and it is distributed uniformly over the range 0 to 2^n , with n denoting the n^{th} retransmission attempt, until n reaches 10. The retrial interval then remains at 0 to 2^{10} until n reaches 15. At this point the collision event is reported as an error to the higher layers. This doubling of the interval is referred to as binary backoff

procedure and is found to improve system performance. By increasing the retransmission delay, this reduces the collision probability and eliminates a possible instability.

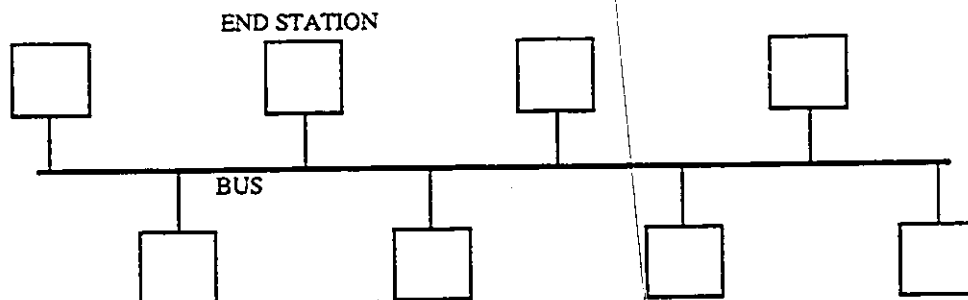


Figure 2.1: CSMA/CD bus topology.

The CSMA/CD protocol defines a slot time which largely determines the dynamics of collision handling. The single parameter describes three important aspects of collision handling:

1. It is an upper bound on the acquisition time of the medium.
2. It is an upper bound on the length of a frame fragment generated by a collision.
3. It is the scheduling quantum for retransmission.

The first aspect represents the minimum allowed length of a CSMA/CD PDU queued for transmission. If the initial CSMA/CD PDU does not have the length required for proper operation of the protocol, a pad field must then be added. In fact, the minimum frame length (equivalent to the slot time) shall be long enough in order to get reasonable system performance [BUX81] (this is discussed below). The second aspect illustrates the maximum possible length of the frame fragment generated by a collision involving the stations situated at each end of the bus. The third aspect refers to the slot time used as a scheduling quantum for the retransmission of frames. To fulfill all these aspects, the slot time shall be larger than the sum of the physical layer round-trip propagation time and the jam time generated by the stations having detected a collision.

Performance of IEEE 802.3 CSMA/CD

In evaluating the CSMA/CD performance, the parameter $a = \tau/m \ll 1$ has been found to have the most important influence, τ being the end-to-end propagation delay along the bus while m being the frame transmission time [BUXS1]. In fact, it has been shown that the parameter a must be kept low in order to get acceptable system throughput. More precisely, the only way to improve the performance of CSMA/CD scheme is to reduce the parameter a . If a decreases, collisions are more readily detected. On the contrary, if a increases towards 1, which means that the propagation delay tends to be as long as the frame transmission time, the probability of collision is increased which will cause system degradation. Thus, the parameter a explains the fact that CSMA/CD implementations like Ethernet must be limited to low speeds, short bus length and use a minimum frame length. In the case of Ethernet, the speed has been fixed to 10 Mbps while the bus length has been bound to 1.5 km and the slot time fixed to 512 bits [SCHW]. Finally, it must be pointed out that one of the most important advantage of CSMA/CD on other types of access method is the short access time under low traffic intensity in the system (as it is equal to the waiting time to detect an idle period).

2.1.3 IEEE 802.5 Token-Passing Ring

The IEEE 802.5 token passing on a ring [ANSI85D] is mostly based on work on the token ring technique developed by researchers at the IBM Research Laboratory in Zurich, Switzerland [BUXS1]. Its concept is quite simple and similar to the token-passing bus, but now a physical ring is used instead of a bus (see Fig. 2.2). In this configuration all stations operate in a decentralized mode. Each station, having packets queued for transmission, has to capture the token passing on the ring before performing packet transmission. When the packet transmission is completed, the station passes the token to the next station on the ring. Hence, each station is either in transmit or repeat state. In transmit state, it sends out its own frame after receiving the permission to do so. It transmits until it has completed transmission of all frames queued or until the transmission of another frame cannot be completed before the

token holding timer (THT) expires. In repeat state, it outputs a received frame bit by bit back onto the ring. It may copy the frame while repeating it if it recognizes its own address. It may also modify some control bits to indicate that the frame was correctly received.

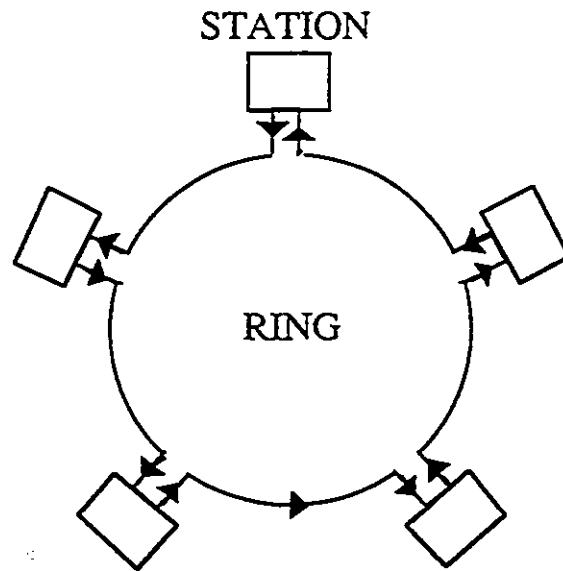


Figure 2.2: Token ring topology.

The IEEE 802.5 standard defines a priority mechanism which comprises eight levels of priorities. However, the IEEE 802.5 priority mechanism is centralized. In fact, there is only one priority level recognized on the ring at a given time, and this is indicated in the token exchanged between the stations. When stations grab the token, they can only send frames having the same or a greater priority level than the one of the token. In addition to indicate the ring priority in the token, the token ring priority mechanism is based on the use of reservation bits contained in each token ring frame header and on the use of stack registers present in each station. The reservation bits are used by the stations requesting for higher token priority. This may force the next station generating the token to increase the token ring priority. The stack registers are used by the station generating the token to store the new and old priority levels in order to bring back or reset the ring to the original service priority, at a later stage. The term stacked is utilized, since multiple new and old priority level values may be stored if

a given station raises the service priority of the ring more than once before the service priority is returned to a lower priority level.

Furthermore, the IEEE 802.5 committee is currently defining the text of the standard for the "16 Mbps Token Ring" [GLASS]. In addition to this increase in speed, a new early token release which allows multiple frames to be on the ring at a given time (but only one free token) is also proposed. Indeed, workstations will be authorized to transmit a token immediately after sending a frame, without having to wait for the frame to return (which is not the case in the present IEEE 802.5 standard). Efficiency of 95 % is guaranteed for a user sending data frames larger than 128 bytes, regardless of ring length [IBM88].

Performance of IEEE 802.5

Performance studies [BUX81] have showed that better performance is obtained by using the token ring access method compared to the CSMA/CD method, since the latter, under heavy traffic, leads to inefficient operation (increase of the number of collisions). The difference between them is amplified if the ratio of propagation delay to packet transmission time (parameter α) is increased, such as in the case of increasing the network speed. Nevertheless, the CSMA/CD strategy is simpler and was implemented much earlier commercially. It appears to be a good practical solution to the local area network problem for small networks that operate at relatively moderate bit rates with many highly bursty stations connected.

2.1.4 AppleTalk

AppleTalk is a recent LAN announced by Apple Computer Inc [APPLE]. It uses CSMA/CA (Carrier Sense Multiple Access Collision Avoidance) [BERT] over a twisted pair of wires (300 m maximum length) and its data transfer rate is 230.4 kbps. It can interconnect up to 32 stations. Its interfaces are very inexpensive, and the medium access control (MAC) protocol is implemented in software.

The transmission node uses the physical layer's ability to sense if the channel is idle. If the channel is busy, the node waits until it becomes idle. Upon sensing an idle channel, the transmitter waits for a time equal to the minimum Inter-Dialogue Gap ($400\ \mu\text{s}$), plus a randomly generated period. During this "wait", the transmitter continues to monitor the channel. If the channel remains idle throughout the wait period, then the node sends a Request-to-Send (RTS) short frame (9 bytes) to the intended receiver. The receiver must return, within the maximum Inter-Frame Gap ($200\ \mu$), a Clear-to-Send (CTS) frame to the transmitting node. Upon receiving this frame, the transmitter must send out, within $200\ \mu\text{s}$, the data frame (578 bytes of data information at most, plus 25 bytes of overhead). Figure 2.3 depicts the timing diagrams of the AppleTalk link access protocol (ALAP) .

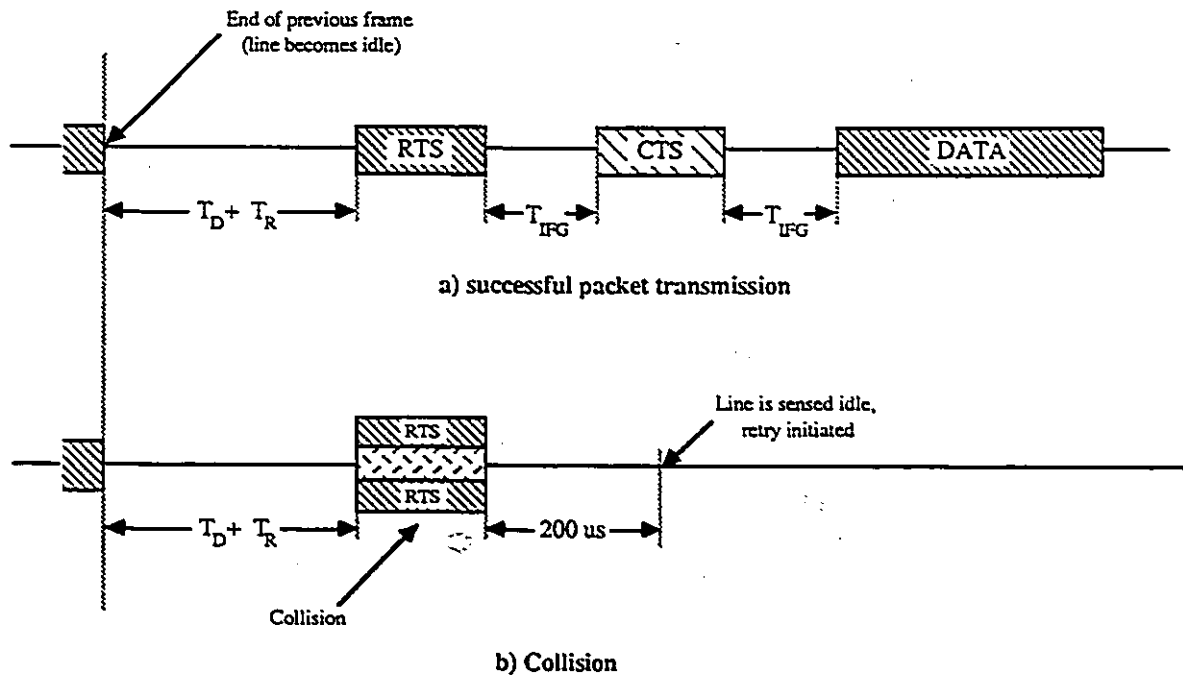
Since there is no collision detection, as in Ethernet (CSMA/CD), the transmitting node learns of a collision from the RTS/CTS exchange. If no CTS is received, after transmission of RTS, a collision is assumed, and the RTS is retried after adjusting the random time interval. This adjustment follows a linear algorithm that changes the back-off distribution dynamically in response to recent network traffic history.

2.2 Public Networks

2.2.1 Datapath - A 56 kbps Link

Datapath is capable of transmitting data at 64 kbps over the standard two-wire subscriber loops already installed in the outside plant and in most office buildings [CHIA]. Due to constraints in the existing digital transmission network, this transmission capability, however, is currently limited to 56 kbps. As ISDN moves from concept to reality, Datapath has been designed to interwork with it to provide 64 kbps transmission and to extend data services to areas where ISDN may not become immediately available.

Businesses - the main users of such data services - can send their intersite data through the public switched telephone network (PSTN) or via private lines; for data transmission within



$T_{IFG} \longrightarrow$ Inter-Frame Gap ($< 200 \mu s$)
 $T_D \longrightarrow$ Inter-Dialogue Gap ($> 400 \mu s$)
 $T_R \longrightarrow$ randomly generated time interval

Figure 2.3: Timing diagram in AppleTalk.

their location, they may use private branch exchanges (PBXs). Datapath opens up the public circuit-switched network for high-speed digital service, thus increasing connectivity for users of high-speed digital circuit-switched capability between PBXs.

2.2.2 T1

T1 is a TDM (time division multiplexing) carrier which multiplexes 24 channels of 64 kbps. It is based on the use of a frame periodically generated at intervals of $125\ \mu\text{s}$. With a frame length of 193 bits ($24 \times 8 + 1 = 193$) per $125\ \mu\text{s}$, we have a data rate of 1.544 Mbps (1.536 Mbps for data). The structure of the T1 frame is shown in Fig. 2.4. Each 8-bits word in a channel is also referred to as a time slot in the time-multiplexed signal stream.

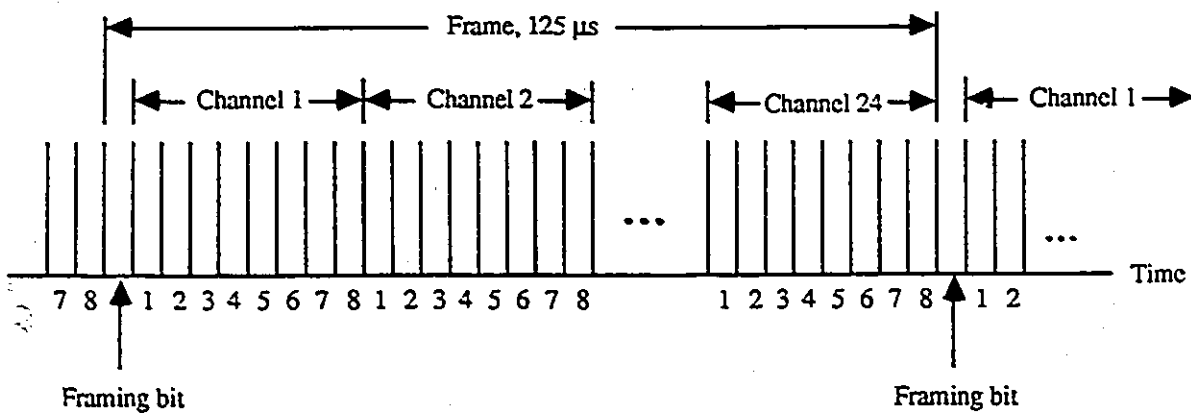


Figure 2.4: T1 frame structure.

In the last few years, T1 has appeared as the main carrier to provide high bandwidth between remote locations. Indeed, by combining all the 24 channels, a bandwidth of 1.536 Mbps can be provided. Thus, such bandwidth can be used to support applications involving transfer of large volumes of voice and data traffic over long distances. One of these applications is the use of T1 as a backbone network for interconnecting LANs situated in remote location.

In parallel to the bandwidth offered by T1 links, there are the services which have been

proposed by the ISDN standard. Indeed, the ISDN standard defines an equivalent of the T1 carrier. This is the primary rate interface defining 23 B-channels and one D-channel where each channel offers a bandwidth of 64 kbps. However, B-channels can be grouped to provide higher data rate channels (H0 - 384 kbps, H11 - 1.536 Mbps).

2.3 Interconnection Devices

As the need arises to provide full connectivity between systems located at different buildings or organizations, computer communications systems comprising several LANs are being deployed. In fact, the "networking of networks" takes place within single buildings and across continents as corporations attempt to provide company-wide access to electronic files, services and resources.

The interconnection of multiple LANs can be done by using three different types of devices, namely bridges, routers and gateways [STALL].

2.3.1 Bridges

The simplest of the internetworking devices is the bridge. Early versions of the bridge were designed for use between LANs that use identical protocols for the physical and medium-access control (MAC) layers. More recently, the term "bridge" has been broadened to include devices that link networks (local or wide area) of the same MAC service interface to higher levels. Figure 2.5 shows the layers implied in the scenario when two LANs are linked by a bridge.

To describe the main functions of a bridge, consider the connection between LAN1 and LAN2 of figure 2.5. The bridge must do the following:

- Read all frames transmitted on LAN1 and accept those addressed to LAN2.
- Using the medium access control protocol for LAN2, retransmit the frames to LAN2.

- Do the same for LAN2-to-LAN1 traffic.

In addition to these basic functions, the bridge makes no modifications to the content or format of the frames it receives, nor does it encapsulate them with an additional header. A bridge may connect another bridge by a point-to-point link, which might be an HDLC link, a T1 link or any other type of public links. Also, it must contain addressing and routing intelligence and should have enough buffer space to meet peak demands.

Depending on the circumstances, there are several reasons for using multiple LANs connected by bridges.

- *Performance:* A number of smaller LANs will often give improved performance if devices can be clustered so that intranetwork traffic exceeds internetwork traffic.
- *Security:* The establishment of multiple LANs may improve security of communications by keeping different types of traffic on physically separate LANs.
- *Geography:* Separate LANs are needed to support devices clustered in distant locations.

2.3.2 Routers

A general purpose device that can be used to connect dissimilar networks and that operates at layer 3 of the Open System Interconnection model is known as a router. The router must be able to cope with a variety of differences among networks, such as:

- *Addressing Schemes:* the networks may use different schemes for assigning addresses to devices.
- *Maximum Packet Length:* packets from one network may have to be broken into smaller pieces to be transmitted on another network.
- *Interfaces:* the hardware and software interfaces to various networks may differ.

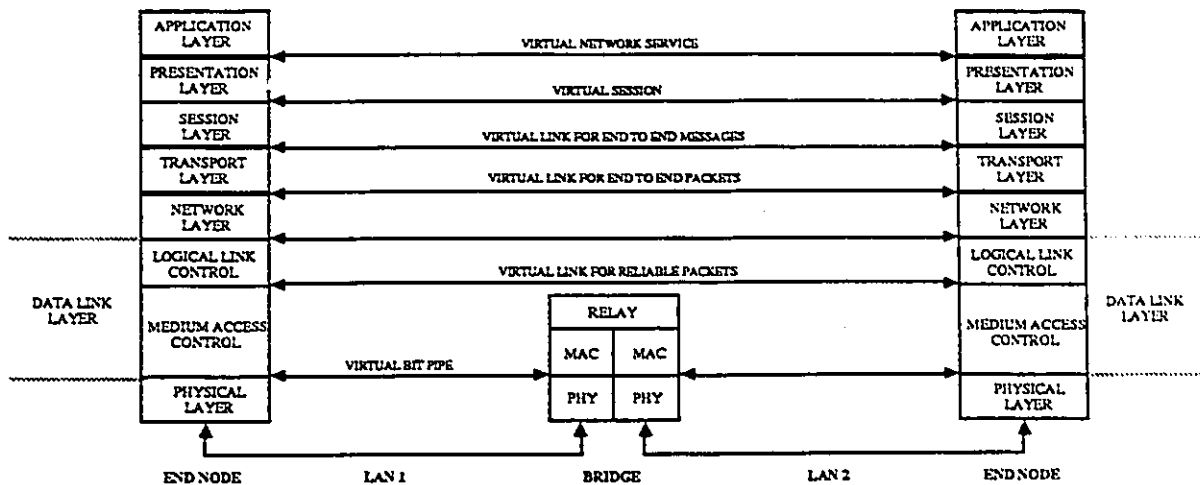


Figure 2.5: Data transfer procedures in frame relaying links.

- **Reliability:** various network services may provide anything from a reliable end-to-end virtual circuit to an unreliable service.

There is a place for both bridges and routers in planning the development of an internet. Bridges are simple, easy to configure, and have no impact on the host software. In an environment in which all of the communicating devices are on similar LANs, bridges are the appropriate solution. In a mixed environment, more complex routers are needed. However, even then, bridges may be used to interconnect some of the LANs.

2.3.3 Gateways

Bridges and routers can be used to solve internetwork problems in an environment when all of the devices implement compatible protocols from the OSI Model. The gateway operates at layer 7 and provides a link between dissimilar architectures, e.g., OSI and IBM's System Network Architecture (SNA) on either the same network or different networks. A gateway is a device that connects different network architectures by performing a conversion at the application level. The gateway itself must use all seven layers of the OSI model, plus all layers

of the proprietary architecture.

2.4 Evolution in CCITT

The evolution in system concepts and progress of technology have greatly influenced the ideas of CCITT [DEPRY]. The first solution is called step 1 in the discussions on packet mode within CCITT. It involved the transport of X.25 over ISDN, which allows an overlay of X.25 access onto ISDN. The next step is called step 2: in this solution all bearer channel control functions are supported by the control plane of the ISDN protocol stack. This allowed the Q.931 to have full call control functionality and the level 3 protocol, which evolved from the existing X.25, will only be responsible for the user information transfer. In a next step, step 3, the sole functions to be supported on a link-by-link basis are the so-called LAPD core functions: bit transparency, CRC calculation, and frame delimiting. Other LAPD functions only performed end-to-end, are flow control and packet retransmission. This step is referred to as frame relaying. A fourth step, step 4, is the evolution towards broadband for packet transfer. In 1987 (Hamburg, study group XVIII), it was decided that ATM would be the ultimate solution for Broadband ISDN. However, a large number of options remain open, such as the size of the cell, the header, the information field, the functionality of the header, the interface to be used at the User Network Interface (UNI), etc. Currently an ATM experiment is being carried out by five Belgian telecommunication manufacturers: Bell telephone, Atea, Siemens, Acec and Philips. This project will last for five years and the goal is to set up a complete experiment, including terminals and transmission equipment, to show the viability of ATM [DEPRY].

2.4.1 Concept Implementation

Concept changes have been made all throughout ISDN, BISDN and ATM. The basic idea behind the concept changes is the fact that functions must not be repeated in the network several times if the required service can still be guaranteed, if these functions are only once implemented at the boundary of the network [DEPRY].

In the initial packet switched networks the quality of transmission media was not too good, so in order to guarantee an acceptable end-to-end quality, error control was performed on every link. This error control is supported by a High-level Data Link Control (HDLC) protocol (Link Access Protocol (LAP) B and D) which includes core functions such as frame delimiting, bit transparency, CRC, error recovery (retransmission) and other functions.

With the advent of ISDN for narrowband services, the quality of the transmission and switching systems is increased, thus reducing the errors within the network. In such a high-quality network it is proposed to implement only the core functions of the HDLC protocol (frame delimiting, bit transparency and error checking) on a link-by-link basis, and other functions such as error recovery on an end-to-end basis: hence the birth of frame relaying concept. Figure 2.6 shows that in frame relaying layer 2 of the OSI model is divided in two sublayers: one supporting only the core functions of layer 2, and the other supporting the additional or optional functions.

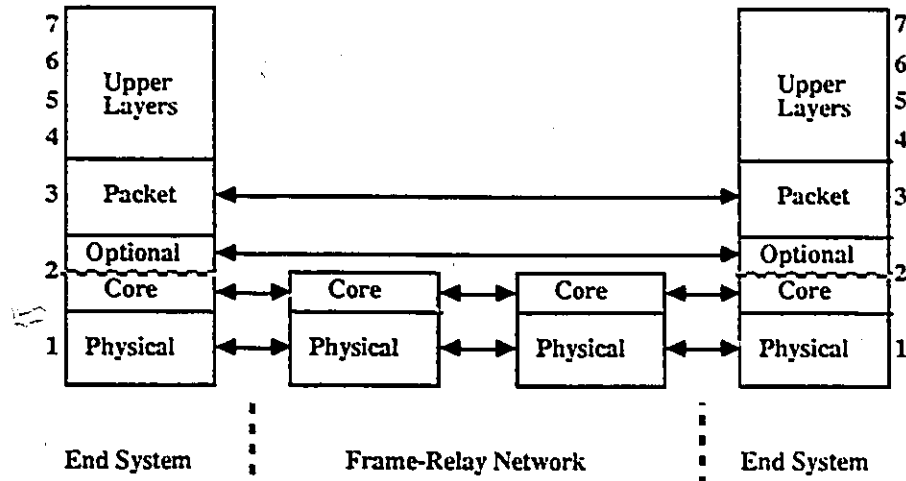


Figure 2.6: Frame-Relay Network with reference to the OSI model.

For Broadband ISDN this idea is further extended. In this case, packets or cells are still used, but the core functions of layer 2 have also been removed to the edges of the network. This concept is called ATM.

As can be observed, the functions performed in the network are reduced from full error control in X.25 to a strict minimum in ATM (cell switching). This is also reflected in the complexity of the nodes inside the network: X.25 nodes have large complexity, frame relaying nodes have a smaller complexity, and therefore allows higher speeds; whereas ATM nodes have minimal complexity and thus allow very high speeds (e.g. 600 Mbits).

2.5 Flow Control Protocols

2.5.1 IEEE 802.2 Logical Link Control

General Overview

The IEEE 802.2 Logical Link Control (LLC) standard [ANSI85A] describes the functions of the upper part of the the Data Link Layer (DLL), and is common to the various medium access methods that are defined and supported by the IEEE 802 activities (see Fig. 2.7). It provides peer-to-peer protocol procedures that are defined for the transfer of information and control between any pair of logical service access points (L-SAPs) on a network (one LLC entity can support one or several L-SAPs).

To satisfy a broad range of potential applications, three types of data link control operations are presently defined. The first one, called type 1, provides a data link connectionless service across a data link with a minimum protocol complexity. This type of operation is useful when higher layers provide any essential recovery and sequencing services. In addition, it can prove useful when it is not essential to guarantee the delivery of every data unit. The second type of operation, called type 2, provides a data link connection-oriented, where setting up, maintaining and disconnecting operations of a link are performed. For this type, sequence numbered information frames and supervisory frames are used to provide acknowledgement, retransmission and flow control actions. A window mechanism is also defined to detect and recover lost data units without any higher layer intervention. Hence it is suitable for supporting higher layer protocols that assume error free service except for rare signalled failures.

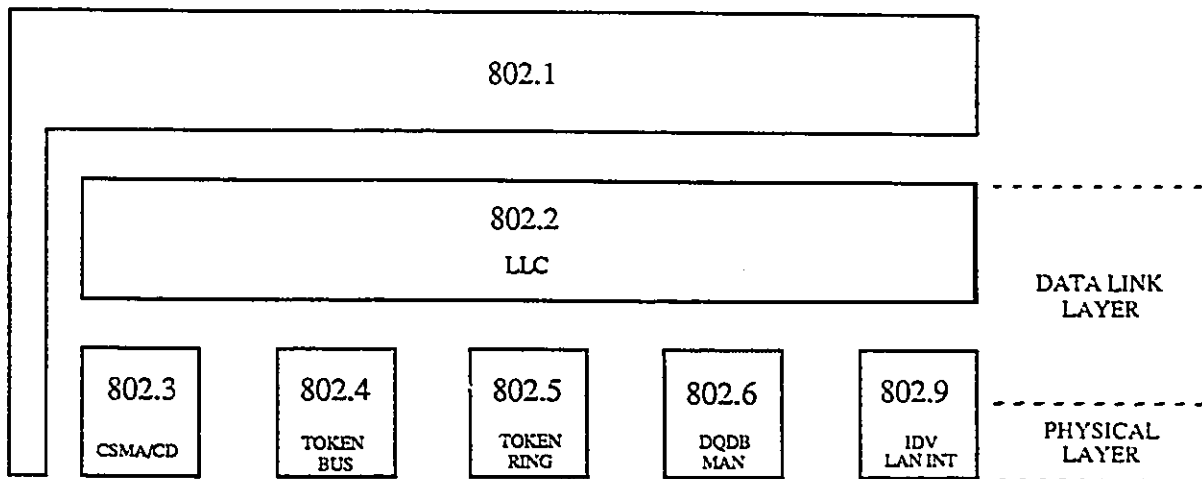


Figure 2.7: IEEE 802 family of standards.

Such protocols are simpler and more efficient than those that must perform all error recovery services. A third type of operation, called type 3, has been recently proposed [ISO]. This type of operation is also called “Acknowledgement Connectionless Service”, since it provides acknowledgement with minimum protocol complexity, therefore it requires the minimum implementation. In cases where higher layer protocols (usually transport) provide end-to-end error controls and flow control, this minimum service is all that is needed. A major application for this service will be in process control to obtain information from sensor equipment containing very little processing capacity. In the next sections, the LLC PDU frame format is presented and a detailed description of the LLC type 2 operation is given.

LLC PDU Frame Format and Functions

Figures 2.8 and 2.9 show respectively the frame format and control field of the LLC PDU. Three control fields are defined to identify three types of frames (Fig. 2.9): I-frames supporting numbered information transfer; S-frames supporting numbered supervisory transfer; and U-frames supporting unnumbered information transfer. The I- and S-frames are only used by the LLC type 2 operation while the U-frames can be used by all three LLC types of operations.

The I-frame control field, in order to identify numbered information transfer, contains a send sequence number $N(S)$. Both I- and S-frames also contain a receive sequence number $N(R)$ which is interpreted by the receiving LLC as being the number of the next expected I-frame to be received by the remote LLC. The S-frame shall be used to perform data link supervisory and control functions. In fact, there are three types of S-frames distinguished by the SS bits: RR-frame (receive ready), RNR-frame (receive not ready), and REJ-frame (reject). In each case, $N(R)$ acknowledges all I-frames up to and including $N(R)-1$. The RNR-frame also provides the flow control for a temporary suspension of I-frame transmissions while the REJ-frame contains a $N(R)$ which rejects all I-frames from $N(R)$. The U-frame is used for initialization and termination of a data link connection (for LLC type 2), and for transferring unnumbered information and diverse control messages (for type 1 and 3). Its control field is shorter than the other ones since it does not contain any sequence number.

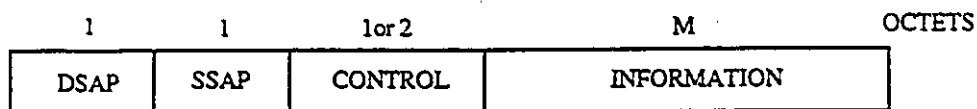


Figure 2.8: Logical Link Control Protocol Data Unit (LLC PDU) frame format.

In each control field, there is also the P/F (poll/final) bit. The poll (P) bit shall be used to solicit (poll) a response from a remote LLC. Then the final (F) bit shall be used to indicate the response frame sent as a result of the soliciting (poll) command. This polling/response function of the P/F bit can be used for checking if the data link is operating properly, for forcing an early acknowledgement of an I-frame or an early REJ-frame, or for preparing to take a link down.

LLC Type 2

LLC type 2 provides connection-oriented data transfer for two LLC entities. Compared to LLC type 1, a logical link must be established between SAPs before exchanging I-frames.

	1	2	3	4	5	6	7	8	9	10		16	BITS
INFORMATION TRANSFER (I-FRAME)	0	N(S)							P/F	N(R)			
SUPERVISORY (S-FRAME)	1	0	S	S	X	X	X	X	P/F	N(R)			
UNNUMBERED (U-FRAME)	1	1	M	M	P/F	M	M	M					

N(S): TRANSMITTER SEND SEQUENCE NUMBER
 N(R): TRANSMITTER RECEIVE SEQUENCE NUMBER
 S: SUPERVISORY BIT
 M: MODIFIER FUNCTION BIT
 X: RESERVED AND SET TO ZERO
 P/F: POLL FINAL BIT

Figure 2.9: LLC PDU control field.

By using N(S) and N(R) in I- and S-frames, the type 2 protocol can provide an in-sequence information transfer without loss or duplication of data. As previously mentioned, S-frames are used for acknowledgement, retransmission and flow control purposes. Besides, the “Go back n ” protocol [BERT] is used as a retransmission and flow control strategy. The idea of the “Go back n ” protocol is that the sending station can send up to a number of n I-frames without having to wait for the acknowledgement of the first sent I-frame. The expression “window of size n ” is used to represent the physical environment containing the unacknowledged frames. When the first frame in the window is acknowledged, the window is slid by one, and another frame can be sent. By using the sequence number N(S) with a modulus M , a window of at most M minus 1 frames can be employed for preventing any ambiguity in the association of sent I-frames with sequence numbers during normal operation and/or error recovery action. The case where $n = 1$ is called the Stop-and-Wait protocol [BERT].

Figure 2.10 presents an example of “Go back n ” protocol where $n = 4$. An example of the use of REJ-frame is also depicted. The REJ-frame forces the retransmission of I-frames having a send sequence number equal and greater to N(R) (N(R) = 2 for the example). The send state variable V(S) denotes the sequence number of the next in-sequence I-frame to be

sent, and the receive state variable $V(R)$ denotes the sequence number of the next in-sequence I-frame to be received. These variables shall take on a value between 0 and M minus 1. $V(S)$ is incremented by one with each successive I-frame transmission, but shall not exceed $N(R)$ of the last received I- or S-frame by more than the window size n minus one. However, $V(S)$ may be set to the value contained in $N(R)$ if a REJ-frame is received (see example in Fig. 2.10). $V(R)$ is incremented by one whenever an error-free in sequence I-frame is received whose send sequence number $N(S)$ equals $V(R)$.

Furthermore, the LLC type 2 uses four timers:

- *acknowledge timer*: used to define the time interval during which the LLC shall wait for an acknowledgement of an I-frame.
- *P-bit timer*: used to define the time interval during which the LLC shall wait for a reply to a previous poll command.
- *REJ-timer*: used to define the time interval during which the LLC shall expect to receive a reply to the sent REJ-frame.
- *busy-state timer*: used to define the time interval during which the LLC shall wait for an indication of the clearance of a busy condition at the remote LLC (used when the LLC has received a RNR-frame).

2.5.2 Applebus Transaction Protocol

At the transport layer, AppleTalk proposes the Applebus Transaction Protocols. This protocol provides similar services to those of the IEEE 802.2 LLC protocol, e.g. error recovery and flow control. Figure 2.11 shows an example of an ATP transaction.

The requester issues a request for the transfer of data from a remote file. At the requester end, the ATP protocol procedures build the request packet (TREQ) and set the least significant six bits in the bitmap (for six packets to be received). Upon receiving this request,

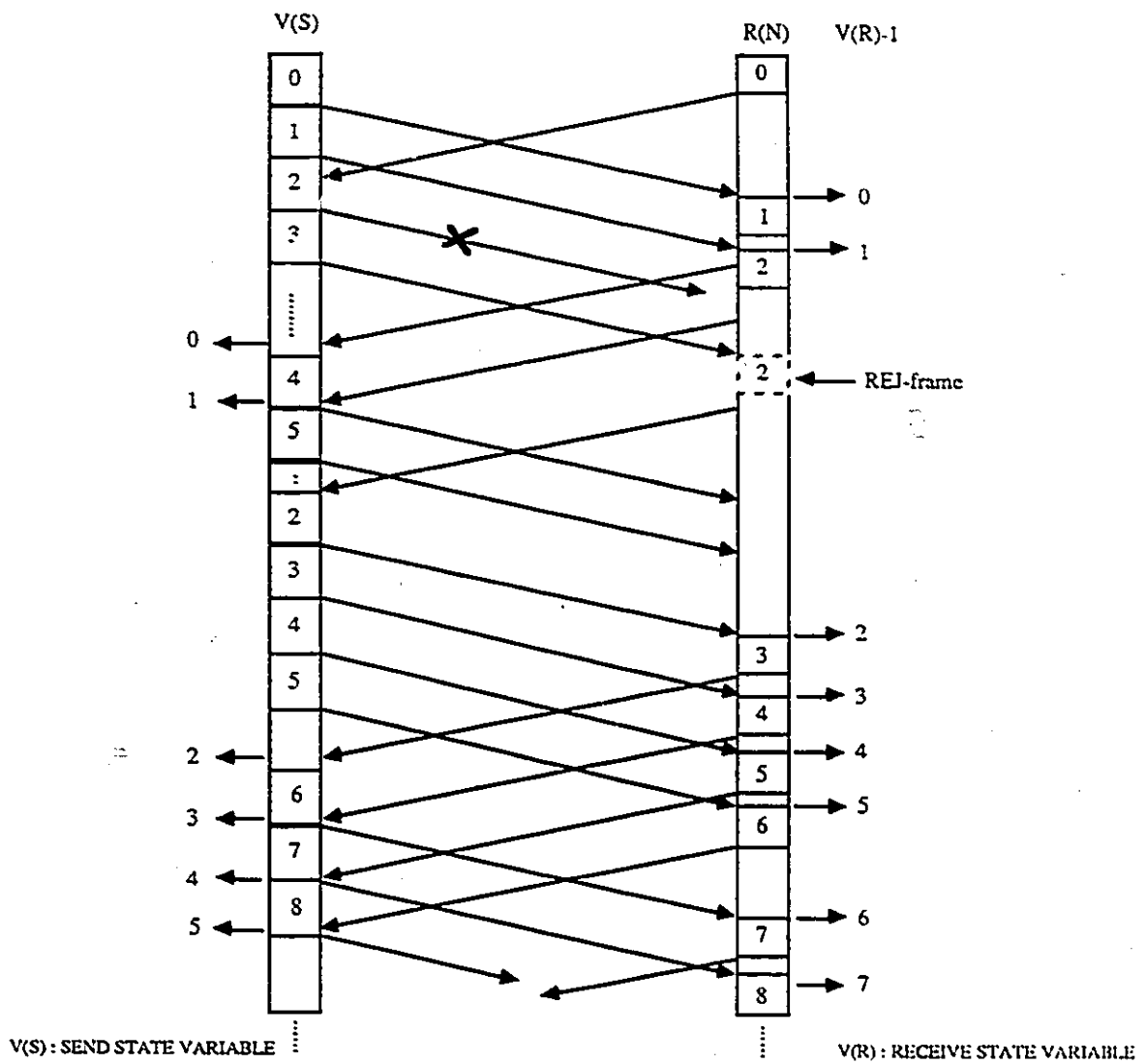


Figure 2.10: Example of the "Go back n " protocol with $n = 4$.

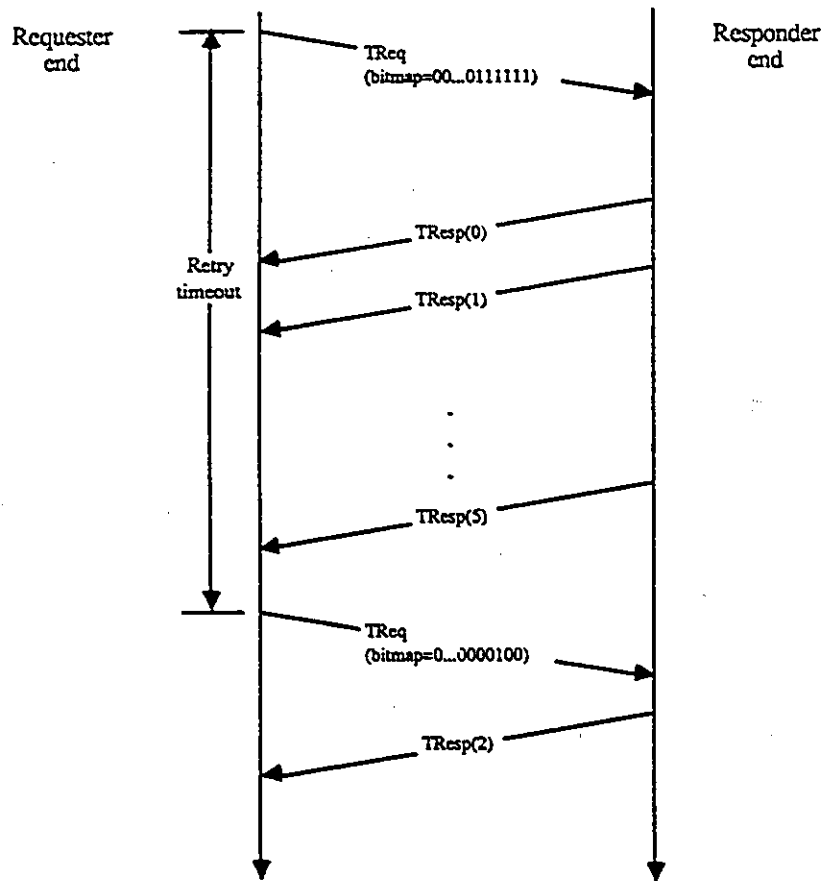


Figure 2.11: Example of the AppleTalk Transaction Protocol.

the responder examines the bitmap and thus determines the range of the host's request to be serviced. Once the proper information retrieved from the disk, it is passed to the ATP layer in the device node which sends it to the host, a block per packet. ATP identifies each packet by using a sequential numbering scheme.

The example in the figure assumes that the third response packet is lost in the network. Thus the retry timeout expires in the requesting end, which then retransmits the original request (transparently to the ATP requesting client) but with a bitmap reflecting only the missing third response packet. The ATP protocol allows the transfer of up to 12 packets per response.

Chapter 3

System Description and Configurations

In this chapter, a detailed description of the communications systems that have been used as well as the different configurations that were considered in the work of this thesis are presented. The main characteristics of the frame relay protocol are discussed in section five. Section six presents the queueing models of the communications and computer systems that have been considered in this thesis. These models have been built by using QNAP2 which has been summarized in appendix A. It successively presents the models of the LANs, the one of the bridge interconnecting LANs and public communications link (Datapath or T1), and the ones of the workstation and the database server which are connected to the LANs.

3.1 Office Communications

The large growth in the use of office information systems (OIS) over the last years has in turn significantly increased the demand for electronic communications in offices. Many office systems today, whether created from a set of personal computers or workstations, are being interconnected to constitute office automation systems (OAS). Via data communications networks, each personal computer and workstation has access to many specialized information handling services such as remote database systems, printers, mailing systems, etc. In the automated office environment, all workers have easy access to powerful workstations or personal

computers.

The evaluation of the current communications services requires an estimation of the volumes of information handled within a typical office system. The activities that are generated in an office are of interest in determining the quantities of information that are handled (transmitted to and processed) daily by individuals, and in determining the time over which the communication activities take place. Several studies have been done towards this end [ENGEL,MCCA,SMIT]. A more detailed description on the amount of information that is handled by an office worker is presented in chapter 4.

3.2 File Transfer Applications

In an office environment, any user may choose to login at a remote site and may ask the system to transfer files from one LAN to the other. This generation of file transfers between LANs has a considerable effect on the throughput of data exchanged between them. Therefore, performance evaluation of office automation on any Local Area Networks technologies must take into consideration file transfer activities.

In a typical application, consider the case where a hospital LAN is interconnected to another hospital LAN. The LAN could be any of the ones discussed earlier (Ethernet, Token Ring or AppleTalk). Consider also that the hospital database system, where all patients' files are stored or archived, is at one specific LAN. Therefore one expects a daily transfer of digitized X-RAY images as well as text and voice annotations to the archiving center at the remote site. Since file transfers can be lengthy processes, particularly if performed in background mode, this activity can take place at night when the LANs are expected to be less busy and a great number of files need to be transferred to the remote LAN.

In another application, consider a company that distributes a weekly or daily newsletter or report to its employees, within the organization, who are located at different sites and are interconnected by high speed links such as T1. Typical newsletter size varies from three to

ten pages which could include graphics and text.

One of the objectives in this thesis is to study the effect of file transfer activities on different Local Area Networks. In doing so, this study considers file transfers between two Ethernets (CSMA/CD), two Token Rings and two AppleTalks LANs. The interconnection medium between each type of these LANs is the T1 link that has been described in chapter 2 and which has a maximum transmission bandwidth of 1.544 Mbps. The results of this study are presented in chapter 5.

3.3 System Description

Figure 3.1 shows the architecture of the office system to be evaluated. A 56 kbps link and T1 are considered for connecting two remote LANs. Each LAN consists of a number of workstations which generate flow of information through the interwork system. Therefore information flows between local as well as remote workstations (workstations situated on different LANs). It is assumed that workstations exchange various kinds of files, such as publications, documents, messages, financial forms [MCCA] which are described in chapter 4.

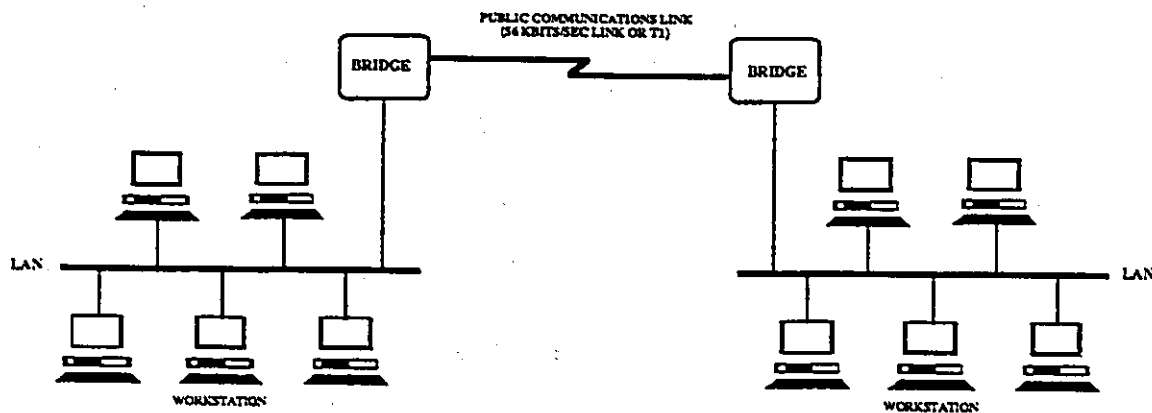


Figure 3.1: Public communications-link interconnecting LANs supporting office worker activities.

We are particularly interested in evaluating the number of workstations that the system can support, the required delay for transferring files between LANs as well as the utilization of the link used for interconnecting LANs.

The internetwork considered in the present case involves two remote LANs interconnected by a link (56 kbps link or T1). The connection between the LANs and the public link is provided by a bridge able to process an important number of packets per second. In the present case, the bridge will have to connect various types of LANs with the public link. Currently there are many bridges available on the market. The choice has been made on the Vitalink bridge [THIE] which is one of the fastest bridges available, and which is capable of interconnecting various LANs and public links. The Vitalink bridge is able to process up to 5000 packets/sec. Figure 3.2 shows the simplified structure of the Vitalink bridge. For instance, the bridge can be used to receive and transmit frames from/into the LAN/T1 and T1/LAN. Their main function is to direct data to their destinations. Frames are forwarded when their destination address is recognized as corresponding to a station situated on the remote LAN accessible through the public link. Further since T1 service provides raw bandwidth, no segmentation or reassembly of packets was necessary for transmission purpose.

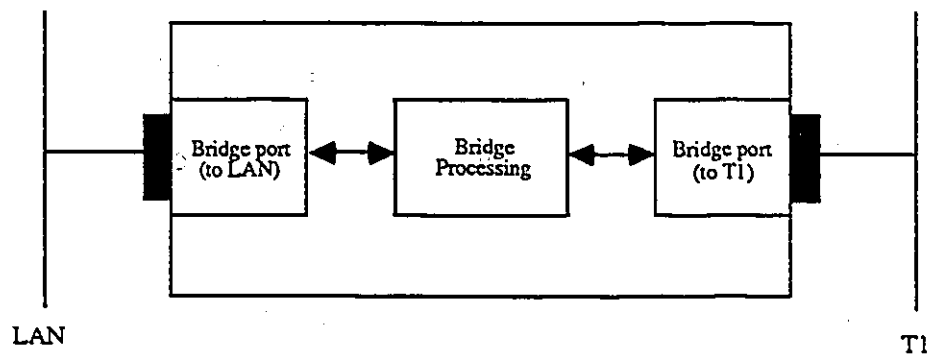


Figure 3.2: Abstract bridge implementation.

Connected to each LAN, PC-based and highly powerful workstations such as the COMPAQ DESKPRO 386/20 line of computer are considered in this study. This kind of computers is

currently employed in applications, such as medical applications requiring powerful processors and memory unit sizes of several Mbytes [GEOR89]. Figure 3.3 shows the model of the PC based workstation. A common bus is used for connecting the CPU, the memory, the disk controller, the network interface unit and the image and graphics processor.

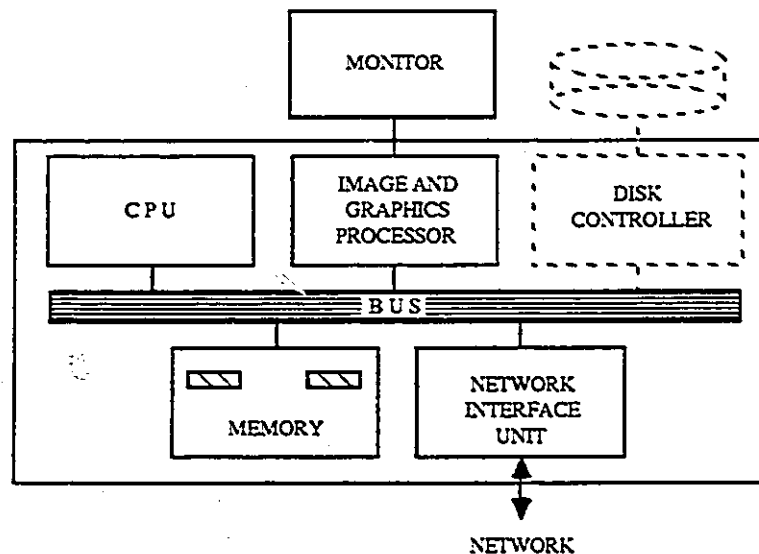


Figure 3.3: The PC-based workstation.

The workstations are equipped with a Network Interface Unit (NIU) that ensures compatibility between the workstation and the LAN. The NIU does not have a local processor therefore all the processing is done at the workstation main CPU. The transmission of frames between end-stations (workstation and remote file server) has the following properties, as implied by frame relaying characteristics:

- Frames must not be discarded (i.e. minimal frame loss).
- Frames cannot be duplicated.
- Frames cannot be misordered.

In this study, connection oriented protocols will be assumed for data transfer. In the case of CSMA/CD or token rings LANs, the LLC protocol is used for performing end to end frame recovery and flow control. In the case of AppleTalk, the AppleTalk Transaction Protocol (ATP) is used at the layer 4 of the OSI Reference Model in order to perform similar tasks.

3.4 System Configurations

The LAN configurations that have been adopted for this study are shown in the following figures.

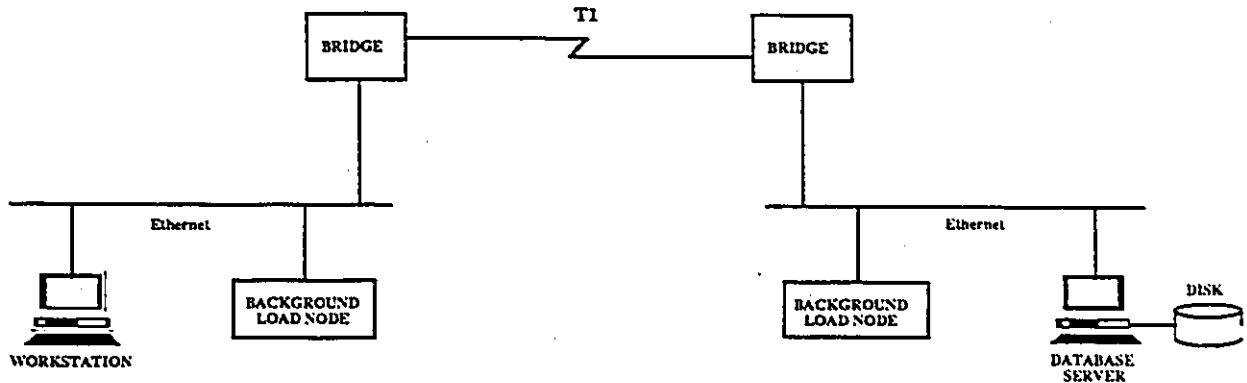


Figure 3.4: T1 interconnecting Ethernet based LANs

Figure 5.1 shows two Ethernet Local Area Networks interconnected by T1 link and Fig. 5.2 shows two token rings LANs interconnected by T1. The AppleTalk configuration is the same as the Ethernet with the Apple Bus used instead of CSMA/CD.

In all three configurations, file transfer and office exchange activities are done between the two LANs. In the case of file transfer, a workstation may request a file from a remote file server and vice versa. The file transfer is done on both LANs with equal request from one LAN or the other. Consequently the system is *homogeneous* and the number of file requests from LAN A to LAN B is equal to the number of requests from LAN B to LAN A. This is

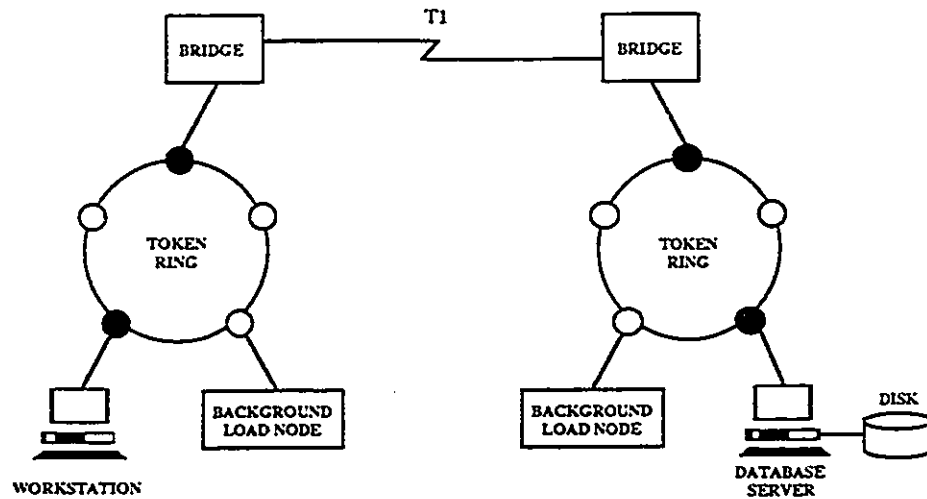


Figure 3.5: T1 interconnecting token rings

assumed throughout the study.

Now once a request is made to the remote file server, the server processes this request by reading the file block by block from the disk and by sending the file, also block by block at a time to the requesting workstations. The number of blocks depends on the file size. The size of the block is assumed to be 64 kbytes. This is due to the fact that many file servers are equipped with a buffer of size 64 or 128 kbytes. The role of this buffer is to hold data temporarily, while the disk is still reading other data, before transmitting them to the internal memory of the file server. In taking into account the multimedia document, a file of size 1.2 Mbytes (the size of an X-RAY image) have been considered.

The background loads shown in the configurations are used to generate data and requests to their local and remote LAN. These background loads are used to simulate the LAN behavior under different traffic, mainly low and heavy traffic. They represent the overall load that a number of workstations generates while performing data exchange locally between them, or between the remote stations i.e. represent intra and inter LANs traffic.

3.5 Frame Relay Protocol

Frame relay is a packet-switching technique that takes advantage of the characteristics of the ISDN environment as well as the capacity of the frame structure employed by the ISDN D-channel Link Access Protocol (LAPD) to support multiplexing within layer 2 [CHERU]. Frame relay is one of several so-called "additional packet-mode bearer services" defined in CCITT recommendation I.122. Standards for frame relay are being developed by the CCITT, ANSI and ECMA.

Frame relay is based on partitioning of the link layer into a frame-level sub-layer, consisting of the so-called *core functions* such as frame delimiting and error detection that are associated with the LAPD frame structure and an upper, procedural sub-layer consisting of the data link control (DLC) elements of the procedure including such functions as error recovery and flow control.

As defined by CCITT, "frame relaying 1" service allows users to select the DLC procedures, while "frame relaying 2" service specifies that the DLC procedures be those of the LAPD with appropriate extensions. In providing a frame relay service, the network terminates only the frame-level sub-layer, so that only the core functions are performed in frame-relay network nodes.

3.5.1 Data Transfer in Frame Relay

The LAPD is defined as a link access protocol to be used at layer 2 on D channels. D-channels are physical channels whose primary function is to transport connection-control messages accross ISDN user-interfaces. LAPD is a version of asynchronous-balanced mode HDLC. Its definition includes elements of procedure, an HDLC frame format, a mechanism for dynamic assignment of layer 2 addresses, and the capability for several independent logical links to be multiplexed within a single physical element using layer 2 addresses. Frame relay takes advantage of the capability of LAPD for multiplexing at the core functions sub-layer.

Figure 3.6 shows a pictorial representation of frame relay protocol layers and their functional definitions [BHUSH].

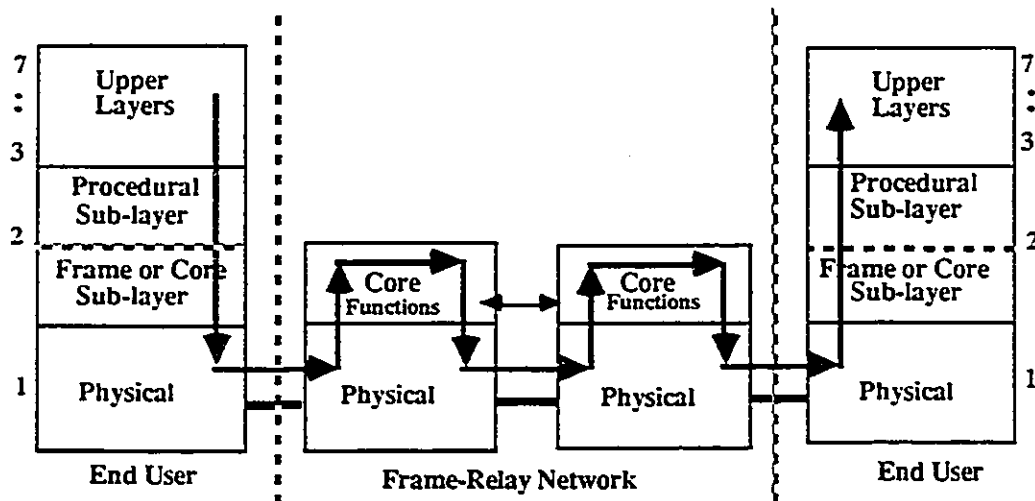


Figure 3.6: Implementation of frame relay service.

The Frame Sub-layer

The functions associated with the frame sub-layer, referred to as core functions in CCITT Recommendation I.122 are:

- Frame delimiting, alignment, and transparency
- Frame multiplexing/demultiplexing using the address field
- Inspection of the frame to ensure that it consists of an integer number of octets.
- Inspection of the frame to ensure that it is not too long or too short
- Detection of transmission errors

All user data streams, which are also called DLCs, are assigned an identifier (named DLCI) at the call establishment time. Subsequent to call establishment, data frames carry this DLCI

in all data streams. This DLCI address information is unique and defines a logical channel within the underlying physical channel. All frames carried in a given physical channel that contain a particular DLCI value, say $DLCI = n$, will be said to flow in logical channel n within the given physical channel. A logical channel within a D-channel is identified by a (SAPI,TEI) pair. The 6-bit Service Access Point Identifier (SAPI) and the 7-bit Terminal Endpoint Identifier (TEI) constitute the DLCI field on the D-channels. The SAPI value is used to indicate the nature of the logical channel (e.g. SAPI = 0 for signaling, SAPI = 1 for frame relay, SAPI = 16 for X.25), and the TEI value indicates the particular logical entity on the user side of the interface that terminates the logical channel [CHERU]. At the network nodes, additional functions may be needed for throughput monitoring and enforcement.

The Procedural Sub-layer

The procedural sub-layer consists of the DLC elements of procedure, which may include:

- Mode selection
- Maintaining sequence counts
- Acknowledgements
- Error recovery
- Flow control

Since the frame-relay network is transparent to the procedural sub-layer, users may select protocols for this sub-layer that are most appropriate for the traffic to be carried by any particular connection. For example, as extensions to the logical link control (LLC), the user may include a dynamic window algorithm. Additional requirements may be placed on terminals depending on the congestion control and throughput enforcement used.

The frame-relaying process essentially consists of the routing of frames based on their DLCI values. The entity that performs frame relaying is referred to as frame handler. The routing of the frames is controlled by entries in a connection table which resides within the frame handler.

3.6 System Models

The overall system is modeled by a closed queueing network as shown in Fig. 5.3. Every workstation can exchange information with any other workstation(s) situated either on the same LAN or on the remote LAN via the public communications link. As public communications facilities, the 56 kbps link or a T1 (1.544 Mbps) link have been considered in each direction of data flow. The solid lines show the direction of the traffic that is generated from LAN1 to LAN2 and the dotted lines represent the incoming traffic that is generated from the opposite direction. In the next subsections, the simulation models of CSMA/CD, token ring, AppleTalk, as well as the one of the bridges and the workstations are presented.

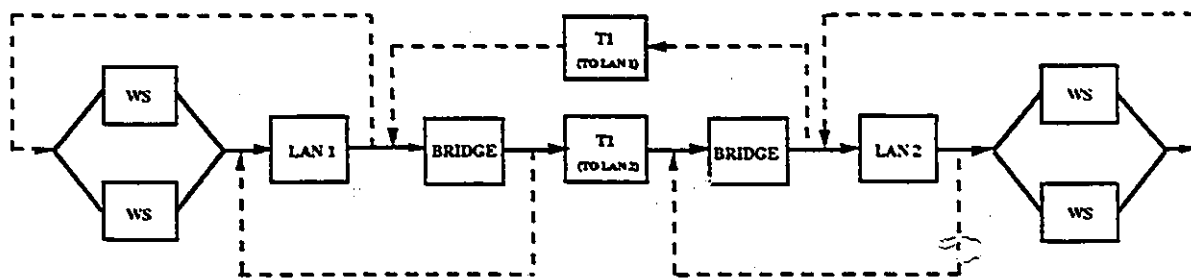


Figure 3.7: The system model.

The model of Ethernet, AppleTalk and token rings are successively described. In the case of Ethernet and AppleTalk, the model is limited to an algorithm simulating the protocol for accessing the medium. In all cases, the queueing model is collectively incorporated in the models of the stations which are connected on the LAN (as discussed in section 3.6.5).

3.6.1 Ethernet

Figure 3.8 shows the algorithm for simulating the medium access protocol defined for Ethernet. In QNAP, this is a macro which is called in the part of the program simulating the stations connected to the LAN (see section 3.6.5).

3.6.2 AppleTalk

Similarly as for Ethernet, the AppleTalk medium access protocol is simulated by a macro. The algorithm of this macro is presented in Fig. 3.9.

3.6.3 Token ring

Figure 3.10 shows the simulation model of the token ring operation. The exchange of the token within the ring is represented by a flag. Only one token may be circulating through each token ring network at any time, since the token ring has a short rotation time compared to the transmission time of the packets sent on it. A monitor is responsible for passing successively the token from one station to the other [BUXS1]. In the case of the priority mode, the monitor, before passing the token to the next station, verifies if the bridge MAC has a packet queued for transmission. If so, the monitor passes it the token. After the bridge MAC has emptied its queue, the monitor returns the token to the next station downstream from the one which last transmitted before the bridge MAC.

3.6.4 The model of the bridge

As it has been discussed in section 3.3, the bridge architecture comprises a bridge processor and two ports. One port is used for sending packets on the LAN, while the other one is used for sending packets on the public communications link (see Fig. 3.2). These three components have been represented in the queueing model of the bridge (see Fig. 3.11).

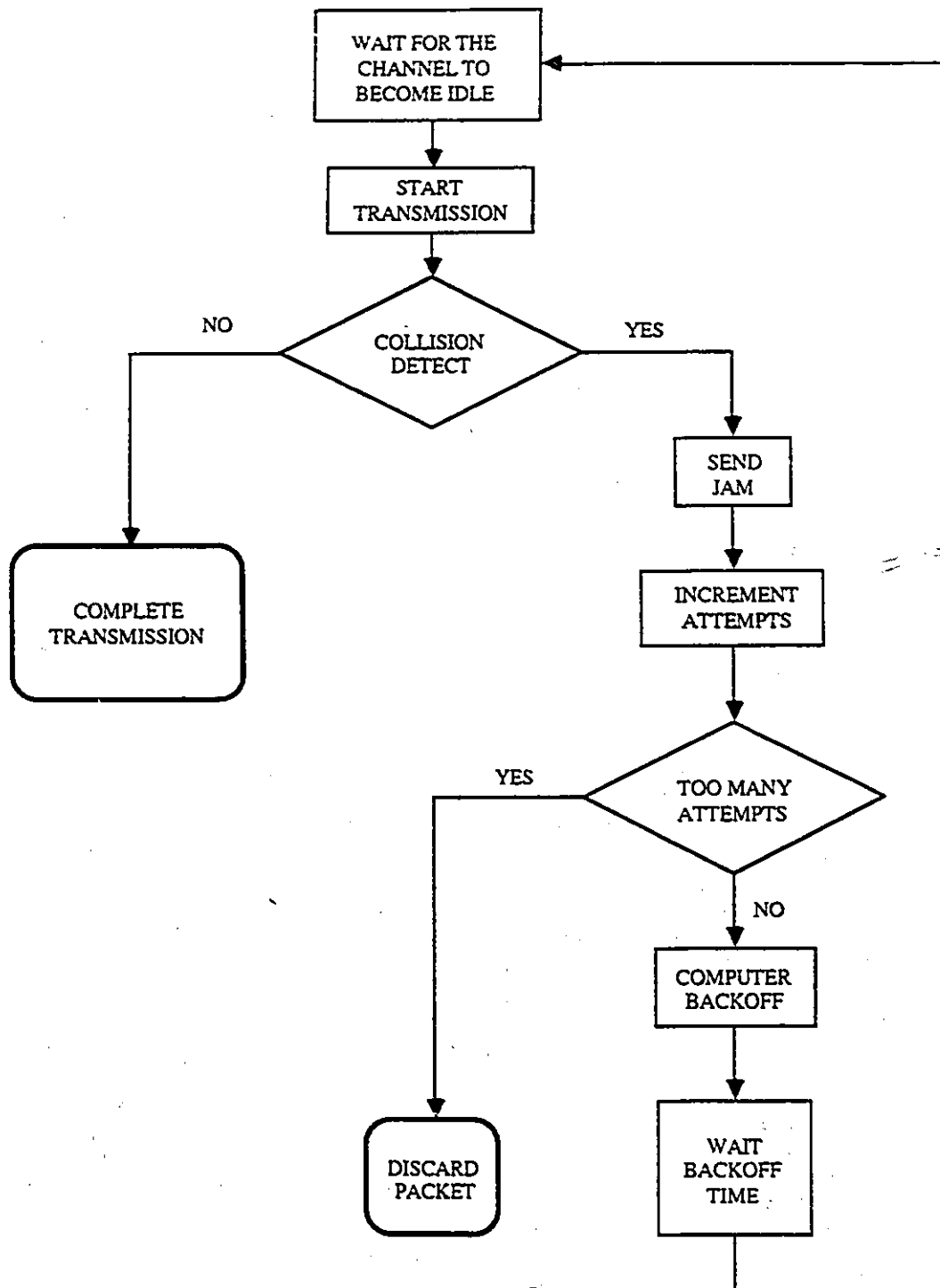


Figure 3.8: Algorithm used for simulating the Ethernet protocol.

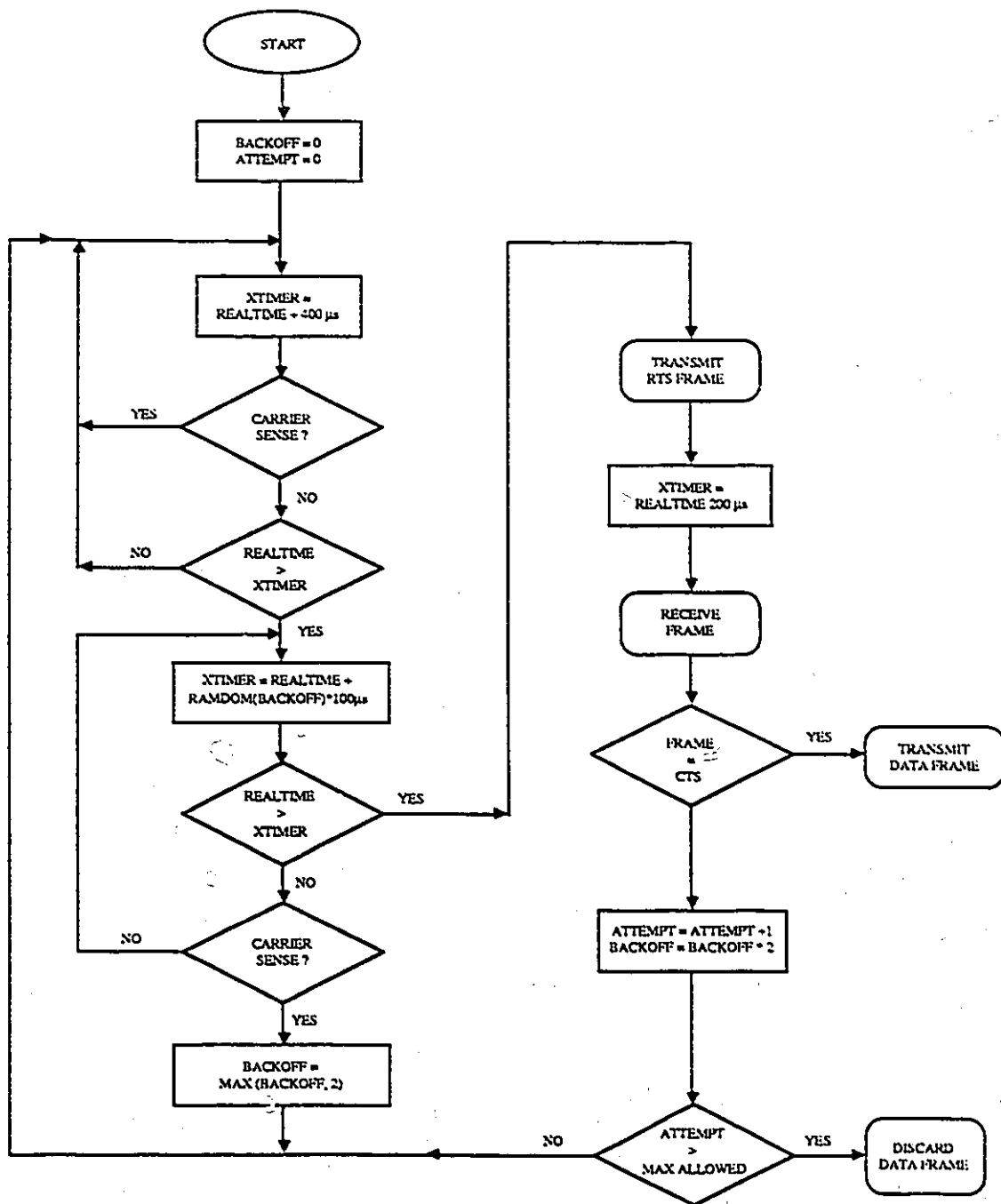


Figure 3.9: Algorithm used for simulating the AppleTalk medium access protocol.

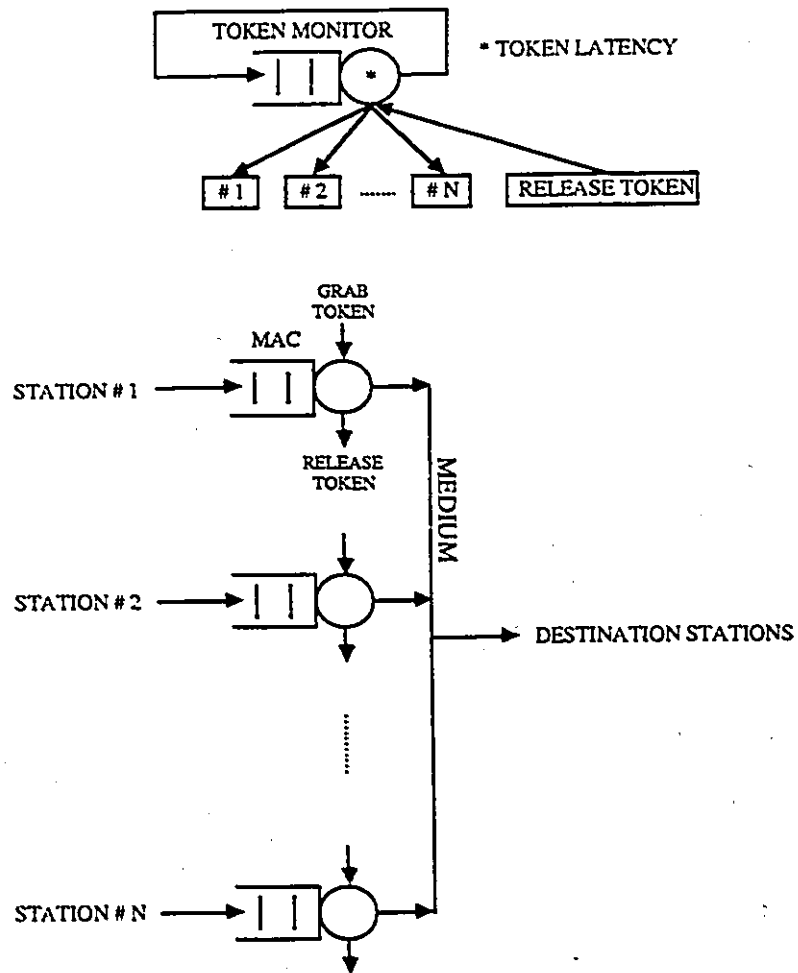


Figure 3.10: The model to simulate the token ring.

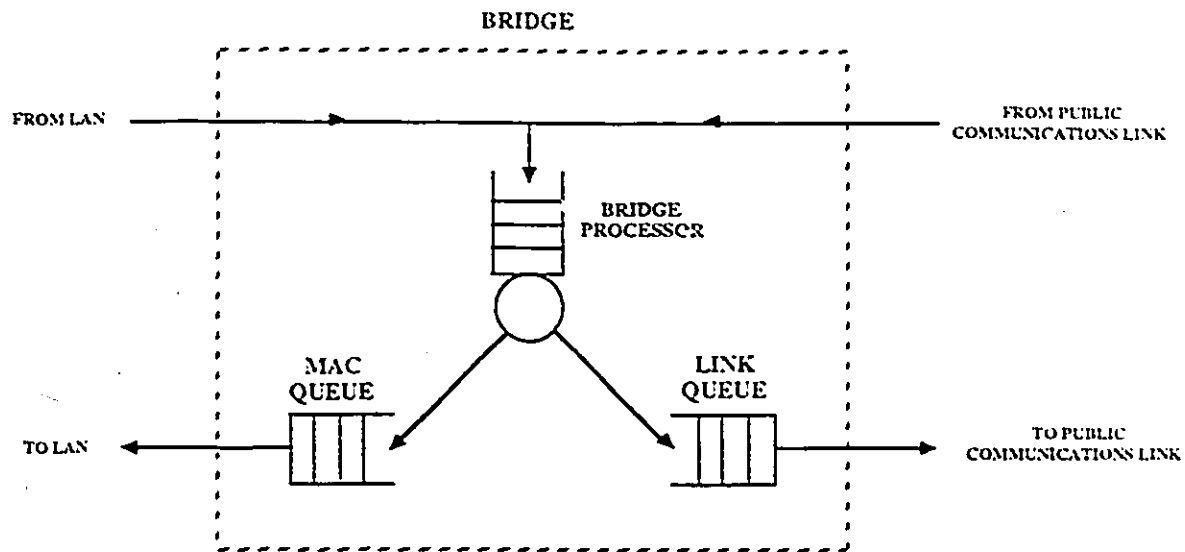


Figure 3.11: The model to simulate the bridge.

3.6.5 Models of the stations connected to the LANs

In this thesis two types of stations, which are used for supporting various types of applications, have been considered. Thus, in order to serve the end users, the study considers the use of PC-based workstations. In some applications, we also looked at the use of multimedia database servers for storing information which can then be retrieved by any users at a remote workstation.

Figure 3.12 presents the queueing model of the workstation. It comprises servers simulating the medium access control (MAC), the logical link protocol (LLC) or the AppleTalk transaction protocol (ATP), the central processing unit (CPU), the disk and the terminal behavior. The server representing the "terminal" behavior does not contain a waiting room since it is used for representing the user thinking time. Indeed, this is only a "pure delay". On the other hand, one customer generated from the CPU to the disk can cause the generation of an important number of customers at the disk. These customers will represent packets generated from the segmentation of a file which is read from the disk and intended to be transferred to

the remote station which has requested the file. Finally, as it has been mentioned in section 3.6, the MAC server is concerned about the medium access protocol of the LAN which is used. In fact, among the MAC server procedures, there is one which is calling a macro which served for simulating the LAN access protocol.

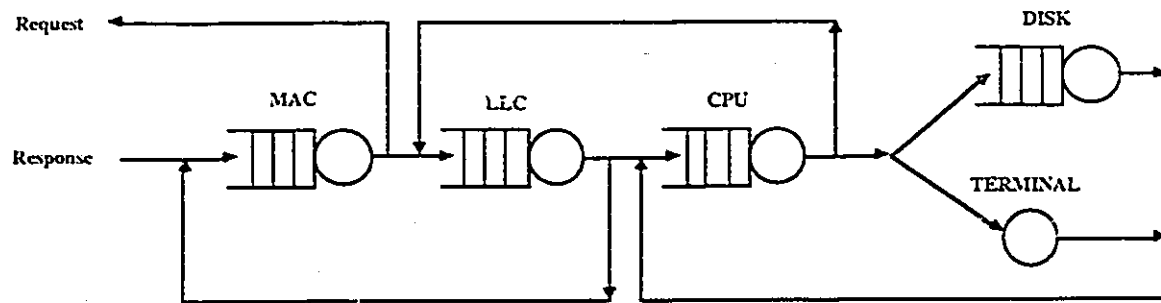


Figure 3.12: The model to simulate the PC-based workstation.

The queueing model of the database server is quite similar as the one of the workstation (see Fig. 3.13). However, in this case, there is no server representing the user thinking time and the actual server activity process is shown in more details.



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Chapter 4

Office Communications Performance Analysis and Results

This chapter analyzes the performance of office communications systems consisting of workstations and servers on LANs, which are interconnected by either 56 kbps or T1 links. The primary intention of this study is to provide useful planning estimates of communications demand for providers of intersite communications services.

In studying the performance of an office environment, one requires an estimation of the volumes of information that are handled and exchanged within a typical office system. The activities that are generated in an office are of interest in determining the quantities of information that are transmitted to and processed daily by individuals, and in determining the time over which the communication activities take place. The next section presents the amount of information that is handled by an office worker.

4.1 Information Volumes per Office Worker

The amount of information handled by an individual in an office depends on many factors, such as the size of the office, the categories of workers, etc. The time usage for different categories of workers in offices has been studied by several investigators [ENGEL,MCCA,SMIT]. Obviously, the studies have not produced identical results, because offices vary significantly.

Table 4.1 shows the time usage breakdown of different categories of office workers. More detailed breakdowns of time usage are given in the original studies.

Categories of office workers	Percentage of time by activity					
	man	prof	tech	secr	clerk	all
Interpersonal communications	34.2	26.7	20.8	17.5	13.5	24.3
Document creation	13.0	18.6	7.2	7.3	16.2	13.4
Information analysis	28.4	28.2	34.9	23.8	27.3	27.6
Using equipment	2.3	10.9	18.6	36.2	19.3	14.7
Less productive time	20.4	11.2	18.6	12.4	19.5	17.0
Other	1.8	4.4	0.0	2.9	4.3	3.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.1: Distribution of average time use by managers, professionals, technicians, secretaries, clerks, and for all office workers (McCallum and Yap 1989).

The time distribution in the table shows that communication tasks are dominant at higher levels of the hierarchy. Furthermore, it has been shown that voice communications use most of the bandwidth today. Voice usage dominates the requirements and is increasing at a slow rate [UHLIG]. However, the results of these studies do not show when the communication activities are performed.

Normally, communication traffic rates are based on peak hour rates. It is well known that low traffic periods occur during the early working hours, the lunch period and just before quitting time. A good approximation to this activity is to say that the activity is uniformly distributed over a 5 hour period. This is represented in Fig 4.1.

The form of unstructured information that passes through the office has also been studied by several investigators [MCCA,SMIT,UHLIG]. Table 4.2 gives the average paperwork that passes through a typical office desk. Table 4.3 gives quantities of information which are associated with different types of documents. In this table, publications include newspapers, books, magazines and catalogues. Documents include general types of documents, including computer forms. Messages include letters, telex and facsimile messages. Financial forms

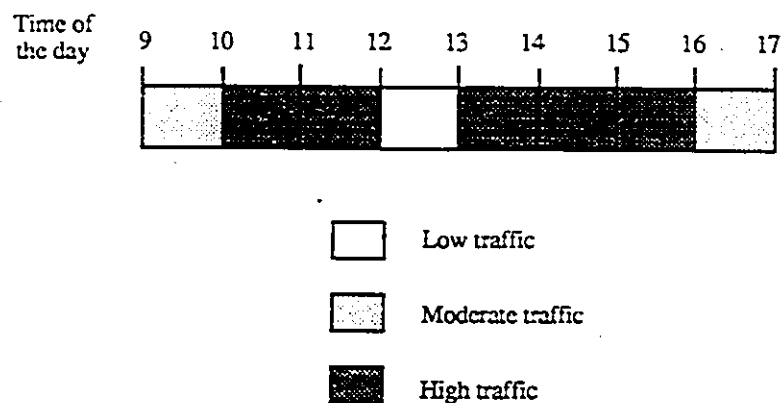


Figure 4.1: Office day.

include bills, receipts, invoices and similar financial documents.

Type of document	Number per day		Average pages per document
	pages	items	
publications	151	5	30.2
documents	105	17	6.2
messages	52	22.3	2.3
financial forms	31	22.5	1.4
Total	339	66.8	5.1

Table 4.2: Mean number of documents across an office worker's desk per day (McCallum and Yap 1989).

Item	Information in documents	
	quantity	in bits
preprinted form	200 chars	1600
typed page	2479 chars	19832
small B & W photo	48 cm ²	480000
large colour photo	139 cm ²	5560000
diagram (plot)	100 points	3000

Table 4.3: Typical quantities of information per document types (McCallum and Yap 1989).

An estimate of the daily information flow across an average desk can be obtained from

tables 4.2 and 4.3. Financial forms were assumed to consist of standard forms. Messages and documents were assumed to consist of standard typed pages and an average publication page is assumed to consist of standard text (2479 characters or equivalents) plus a 6.3 cm^2 black and white image, and a 0.4 cm^2 colour image per page. Normally, photographs contain a significant amount of information. A typical black and white photograph has a resolution that corresponds to about 10000 bits/cm^2 . A colour photograph, printed in four colours where each colour of the pixel can have about 256 values, has a resolution of about $40\,000 \text{ bits/cm}^2$ [MCCA]. The resulting information quantities are listed in table 4.4.

Item	Information quantities			
	pages/day	Info/page in bits	documents/day	Info/doc in bits
Publication	151	98123	5	2^{21}
Document	105	19832	17	2^{17}
Message	52	19832	22.3	2^{15}
Financial form	31	1600	22.5	2^{11}
Total	339		66.8	
Average		53038		2^{18}

Table 4.4: The quantity of information in different forms through an office worker (values are calculated from the two previous tables).

From table 4.4, it is also obtained that an average of $66.8 \text{ documents/worker_day} \times 2^{18} \text{ bits/document} \simeq 18 \text{ Mbits/worker_day}$ pass through an office worker's desk.

4.2 Performance Study

Figure 3.1 showed the architecture of the system to be evaluated. A 56 kbps link and T1 are considered for connecting two remote LANs. Each LAN consists of a number of workstations which generate flow of information through the interwork system. Therefore information flows between local as well as remote workstations. It is assumed that workstations exchange various kinds of files, such as publications, documents, messages, financial forms [MCCA] which have

been presented in the previous section.

One of the objectives of this thesis is to determine the maximum number of workstations that the system can support, the required delay for transferring files between LANs as well as the utilization of the link used for interconnecting LANs.

4.2.1 Modeling and Simulation Assumptions

The system is modeled by a closed queueing network as was shown in Fig. 5.3. Every workstation can exchange information with any other workstation(s) situated either on the same LAN or on the remote LAN via the public communications link. As public communications facilities, the 56 kbps link or a T1 (1.544 Mbps) link were considered in each direction of data flow.

In carrying out this study, the following assumptions are made:

1. Four different types of information are considered to be exchanged between workstations.

These types are (cf. tables 4.2 and 4.4):

- publications.
 - documents.
 - messages.
 - financial forms.
2. Each workstation is sending or receiving 18 Mbits of information per working day (5 hours). This scenario corresponds to a fully electronic office of the future having traffic data as in table 4.4. Evidently the office of today will evolve to the above over several years.
 3. For each file transferred from one workstation to another workstation a logical link is established.

4. The three different LANs under study are:

- CSMA/CD: 10 Mbps.
- Token Ring: 4 Mbps.
- AppleTalk: 230.4 kbps.

5. The maximum number of stations which can access a LAN is:

- 1024 for CSMA/CD [SCHW].
- 260 for token ring [IBM86].
- 32 for AppleTalk [APPLE].

6. The bridge interconnecting the LANs and the public link is assumed to require a time of $120\ \mu\text{s}$ to process the overhead of each frame. An additional time of $0.16\ \mu\text{s}/\text{byte}$ is also assumed for manipulating a packet in the bridge.

7. When the token rings are used, two priority modes are considered:

- *Non bridge priority mode*: every station on the ring has the same access priority and is allowed to send only one packet per token possession.
- *Bridge priority mode*: higher access priority service is allocated to the bridge in the ring. The others stations on the ring have the same characteristics as in the previous mode.

8. Execution of the LLC protocol at the end stations is assumed to require the following processing times:

- a) transmit I-frame (first-time): $250\ \mu\text{s}$
- b) receive in-sequence I-frame and transmit RR-frame: $300\ \mu\text{s}$
- c) receive RR-frame and delete I-frame(s): $100\ \mu\text{s}$.

9. A very small probability of frame loss. Frames are rarely corrupted by transmission errors.

10. Although bridges may have to discard frames for various reasons, this should be minimized and adequate memory space should be available.
11. Only one packet size of 1 kbytes is considered, since workstations are running under XENIX which allocates memory partitions per segment of 1 kbytes (in the case of AppleTalk, a maximum packet size of 512 bytes is defined).
12. A 56 kbps link and T1 (1.544 Mbps) are considered as public communications links for interconnecting LANs.
13. Two different ratios between remote and local traffic in the interwork system are considered (remote/local):
 - 20/80
 - 50/50

4.2.2 Results and Analysis

Analysis versus Simulation

An analytical solution that takes into account workstations, servers, LANs, bridges, priorities and protocol layers such as application, frame relay and medium access control is practically not possible. This is due to the great dimension of the problem involved and the many parameters that must be taking into considerations, at the same time, during the analysis. Therefore simulation is needed. Results of this study has been obtained using QNAP2 Discrete Event Simulator. The spectral method has been chosen to estimate a confidence interval of 95%. Accuracy on these results is obtained within $\pm 5\%$.

Simulation results are shown in Fig. 4.2 to 4.17. We successively present the results for the configuration where a 56 kbps link is interconnecting Ethernets, token rings or AppleTalks. Then we compare the obtained results with the ones obtained for configurations where T1 is used instead of the 56 kbps link.

56 kbps Link Interconnecting Ethernet LANs

In this subsection, we present the results obtained from the simulation of two Ethernet LANs interconnected by 56 kbps link.

First, we consider the case where the ratio between the remote and local traffic is 20/80 (see Fig. 4.2 to 4.3). The same is repeated for a ratio of 50/50 (Fig. 4.4 and 4.5).

Results show that more the traffic generated by each workstation is inter-LAN, less is the number of workstations which can be supported by the interwork system. For a ratio of 20/80 between the traffic sent to remote workstations and the one sent to local workstations, the maximum number of workstations is around 375. For a ratio of 50/50, this value is reduced to 175. These results are due to the fact that, for a specific number of workstations, the more the inter-LAN traffic is high, the more the 56 kbps link becomes saturated.

Figure 4.2 and 4.4 show the delay required for transferring one page of various types of information between workstations situated on remote LANs. Higher transfer delay is then obtained for a remote/local traffic ratio of 50/50. Indeed, most of the delay is due to the fact that the public link is only running at 56 kbps. The 56 kbps link and Ethernet utilization is shown in Fig. 4.3 and 4.5. While the Ethernet utilization has never been more than 2%, the utilization of the 56 kbps link increases rapidly. As it should be expected, the utilization of the 56 kbps link increases more rapidly when the remote/local traffic ratio is 50/50.

Under heavy load, it can be observed that the mean delay for transferring one page of a financial form increases sharply compared to the other types of information. This is mainly due to the fact that a financial form is usually sent over one data packet (< 1 kbytes) compared to the other types of information which can be sent over 10 to 300 data packet having a length of 1 kbytes. Then, since the use of window flow control protocols is considered at the workstations (with window sizes larger than one), the transfer of a larger file appears more efficient under heavy load compared to the case where one packet file has to be transmitted.

From Fig. 4.3 and 4.5, it can be also observed that the utilization of the 56 kbps link is quite proportional with the number of workstations connected to the LAN. In fact, when the 56 kbps link utilization reaches 80%, congestion problems appear so important in the bridge that the system cannot accept more workstations in the system.

56 kbps Link Interconnecting Token Rings

In this subsection, we present the results obtained from the simulation of two token rings interconnected by the 56 kbps link. As previously mentioned, we consider two priority modes: 1) non bridge priority; and 2) bridge priority in the token rings.

We first look the case where there is no bridge priority in the rings (see Fig. 4.6 to Fig. 4.9).

Figures 4.6 and 4.7 present the situation where the ratio between the remote and local traffic is 20/80. Under such scenario, it appears that the system capacity is mainly limited by the fact that each token ring cannot connect more than 260 stations [IBMS6]. Thus, where there are 260 stations on each token ring, the utilization of the 56 kbps link is approximately 50%. The corresponding delay per page of document appears to be between 1 and 4 seconds, depending of the kind of information which has to be transferred.

As expected, higher delays are measured when the ratio between the remote and local traffic is 50/50 (see Fig. 4.8). Similarly as we have observed in the case of Ethernet, the delay for transferring one page of financial form increases sharply under heavy load. However, the overall delays are higher than the case of Ethernet. This is due to the fact that under low traffic conditions in the LANs, Ethernet performs better than token ring [BUX81].

On the other hand, the interwork system can now support up to 185 workstations per LAN when the ratio remote/local traffic is 50/50. After that point, congestion problems related to the speed of the 56 kbps link occurs. Thus, the maximum utilization of the 56 kbps link appears to be around 83%.

Now, we examine the case where higher access priority is allocated to the bridge in each token ring (see Fig. 4.10 to 4.13).

The results obtained for the bridge priority configuration are quite the same as the ones for the non bridge priority configuration. Then, there is no advantage for providing higher ring access priority for the bridge in the present applications. This is mainly due to the fact that the utilization of the token rings is maintained low.

56 kbps Link Interconnecting AppleTalk LANs

Here, we consider the scenario where the 56 kbps link is interconnecting AppleTalk LANs. As previously mentioned, AppleTalk is running at 230.4 kbps, and cannot interconnect more than 32 stations. Thus, from the previous results we should expect that the delay for transferring page of information types will remain low as well as the utilization of the 56 kbps link. This is represented in Fig. 4.14 to 4.17.

Since the utilization of the overall system is kept low, the page transfer for any types of information does not increase significantly with an increase of the number of workstations. This behavior appears particularly important when the remote/local traffic ratio is 20/80 (see Fig. 4.14).

Thus, considering the present application, it clearly appears that the 56 kbps link, although it offers a low bit rate, can provide sufficient bandwidth when this network is used to interconnect AppleTalk LANs.

Comparison of LANs Performance

Figures 4.18 to 4.21 allow us to compare the results we have previously obtained for different LAN configurations. Thus, there is no significant difference between the results obtained for each LAN configuration. This is particular true for the case where the remote/local traffic is

20/80. These results are due to the fact that the system performance (throughput and delay) is quite related to the speed of the 56 kbps link.

Figures 4.19 and 4.21 show that the utilization of the 56 kbps link is slightly higher when this network is interconnecting Ethernet. This is due to the fact that, for Ethernet, the minimum packet size is 64 bytes. In the present case, such packets are mostly control packets used to acknowledge information frames.

Table 4.5 summarizes the measures reflecting the interwork system capacity under different LAN configurations. Under the configuration where the interconnected LANs are Ethernet, the system limitation is related to the speed of the 56 kbps link. However, under other configurations, the system limitation will rather depend on the ratio between the remote and local traffic. If the inter-LAN traffic is quite low, the system limitation will be directly related to the maximum number of stations which can be supported by the interconnected LANs.

LAN Configuration	Remote/Local traffic	Maximum number of workstations per LAN	Corresponding 56 kbps link utilization (%)	System limitation
Ethernet	20/80	375	75.7	56 kbps link
	50/50	175	81.2	56 kbps link
Token ring (non bridge priority)	20/80	260	49.9	rings
	50/50	185	82.9	56 kbps link
Token ring (bridge priority)	20/80	260	50.1	rings
	50/50	185	83.8	56 kbps link
AppleTalk	20/80	32	6.56	AppleTalk
	50/50	32	15.4	AppleTalk

Table 4.5: Interwork system supporting office communications.

Comparison of the 56 kbps link and T1 for supporting Office Communications

In the present study, we have been mainly interested to find the maximum number of workstations that can be supported by the interwork system involving public communications links interconnecting LANs. We did not place emphasis on the delays which result. The reason has been that, in many occasions, office automation applications do not require low transfer

delay. For example, we can mention the cases where files are sent to a printer facility or where electronic mail is exchanged between users. Thus, the use of a 56 kbps link for supporting such environment can appear to be sufficient. However, it can be interesting to compare what will be the results by considering the use of T1 instead of a 56 kbps link. Some are presented in table 4.6.

LAN Configuration	Remote/Local traffic	56 kbps link			T1 link		
		Max no. of WS per LAN	Link utilization (%)	Publi. page trans. delay (sec)	Max no. of WS per LAN	Link utilization (%)	Publi. page trans. delay (sec)
Ethernet	20/80	375	75.7	8.43	1024	7.15	0.083
	50/50	175	81.2	13.55	1024	17.72	0.084
Token ring (non bridge priority)	20/80	260	49.9	4.162	260	1.80	0.070
	50/50	185	82.9	16.92	260	4.43	0.077
Token ring (bridge priority)	20/80	260	50.1	4.222	260	1.80	0.070
	50/50	185	83.8	16.90	260	4.39	0.076
AppleTalk	20/80	32	6.56	1.974	32	0.22	0.030
	50/50	32	15.4	2.138	32	0.57	0.030

Table 4.6: Comparison between interwork systems supported by a 56 kbps link and T1.

Under configurations based on the use of T1, the system limitation is now directly related to the maximum number of stations which can have access to the interconnected LANs (1024 for Ethernet, 260 for token ring, and 32 for AppleTalk). In most of the cases, the use of T1 allows us to get a significant reduction of the delay required for transferring information types. However, this does not really apply for the configuration where T1 is interconnecting AppleTalk. Indeed, for such configuration, AppleTalk LANs are now the main source of delay in the system. Furthermore, in this case, the T1 bandwidth (1.544 Mbps) appears to be underused since AppleTalk cannot support more than 32 workstations per LAN. Thus, the use of a 56 kbps link may be preferred in such configuration.

The decision to use T1 or a 56 kbps link can be then dependent the service demand. However, in the present applications, it must be pointed that the T1 utilization is generally low. Consequently a significant amount of bandwidth remains unused. If low transfer delays are necessary then T1 should be used, however, the use of a 56 kbps link should be considered especially in the case where Appletalk and Token rings LANs are configured.

4.2.3 Other Useful Results

The previous section has analyzed the performance of office communications systems with a scenario that corresponds to a fully electronic office of the future. It was assumed that an average of 18 Mbits of information passes through an office worker's desk per working day (Wd). Evidently the office of today is not fully automated. A substantial fraction of the 18 Mbits traffic still flows manually. For this reason, this section considers more realistic scenarios, by lowering the data exchange rate, for each station, from 18 Mbits to 12 Mbits and to 6 Mbits per working day. These rates are chosen in order to simulate the current volumes that flow electronically between offices nowadays. Consequently, these rates might vary from one organization to another. Therefore the 6 Mb/Wd rate is aimed to be a lower bound on the minimal amount of information that flows electronically in an office environment.

This section presents the simulation results for the configuration where a 56 kbps link is interconnecting two Ethernets, two Token rings, and two AppleTalk LANs. Each LAN configuration is considered separately. As it was recommended in the previous section, the use of the 56 kbps link for supporting such an environment, and at the mentioned rates, can be more than sufficient. As a matter of fact, with these low exchange rates we expect the 56 kbps to perform better, in terms of transfer delays and link utilization, than at the data exchange rate of 18 Mbits per working day. The modeling and simulation assumptions which are given in the previous section, are still valid with the following slight modifications:

- Each workstation is sending or receiving 6 Mbits of information per working day (Wd). As mentioned previously, a working day is assumed to be 5 hours long.
- Each workstation is sending or receiving 12 Mbits of information per working day.
- When the Token rings are used, only the non bridge priority mode is considered. Since there was no significant difference between the bridge priority and the non bridge priority modes in terms of page transfer delay or network utilizations.

56 kbps Link Interconnecting Ethernet LANs

First we consider the case where the exchange rate of information between the workstations is equal to 6 Mb/Wd with the ratios between the remote and local traffic is 20/80 and 50/50. The 20% remote traffic is considered as the normal percentage of traffic that is generated outside any organization environment. Whereas the 50% remote traffic is considered as the upper bound on the percentage of traffic that an organization should send to a remote site, or environment. The same is repeated when the exchange rate of information between the workstation is equal to 12 Mb/Wd. Results show that there are two major factors which contribute to the maximum number of workstations which can be supported by each LAN. The first factor is the inter-LAN traffic ratio. It can be observed that as the remote/local traffic ratio is increased, the number of workstations which can be supported is decreased. The second factor is the amount of information that each workstation sends or receives per working day. Results indicate that as the data exchange rate increases, it will have a negative effect on the maximum number of workstations which can be supported by each LAN.

At a data exchange rate of 6 Mb/Wd and for a ratio of 20/80 between the traffic sent to remote workstations and the one sent to local workstations, the maximum number of workstations reaches the maximum limit allowed by Ethernet which is 1024. However this number is reduced to 500 workstations per LAN at the data exchange rate of 12 Mb/Wd, (see figure 4.22 and 4.26). For a remote/local traffic ratio of 50/50 these values are reduced to 460 at data exchange rate of 6 Mb/Wd and to 225 workstations at data exchange rate of 12 Mb/Wd. This represents a significant increase in the number of workstations as compared to the values obtained at 18 Mb/Wd.

Figures 4.22, 4.24, 4.26 and 4.28 show the delay for transferring one page of various types of information between workstations situated on remote LANs. For a given number of workstations and for a remote/local traffic ratio of 50/50, we obtained a higher transfer delay than the one for a remote/local traffic ratio of 20/80. This delay is caused by the fact that the link is running at 56 Kbps. Hence more the inter LAN traffic increases more the link will

be busy and frames have to wait longer at the bridges. We also observe that the utilization of 56 kbps link increases more rapidly when the remote/local traffic ratio is 50/50. From figures 4.23, 4.25, 4.27 and 4.29, it can be observed that the utilization of the 56 kbps link is still quite proportional to the number of workstations connected to the LAN. This was also observed at 18 Mb/Wd. Furthermore the utilization of the 56 kbps link almost doubles, when comparing the results obtained at the data exchange rate of 12 Mb/Wd to the one obtained at 6 Mb/Wd. This observation holds for both ratios of remote/local traffics, the 20/80 and 50/50.

Next we present the results obtained from simulation of two token rings interconnected by the 56 kbps link. We only consider the non bridge priority mode.

56 kbps Link Interconnecting Token Rings LANs

Results show that the page transfer delay for each type of information transferred is greatly decreased. The curves tend to become flatter than the ones obtained for the results at the data exchange rate of 18 Mb/Wd. The maximum number of workstations that can be supported, per LAN, is increased up to the maximum allowed limit by the token ring which is 260. This is true for both ratios of remote/local traffics and at both data exchange rates, the 6 Mb/Wd and 12 Mb/Wd.

Figures 4.30, 4.32, 4.34 and 4.36 show that the page transfer delay at 260 WS/LAN ranges between 0.3 and 4 seconds at 6 Mb/Wd. However at 12 Mb/Wd, the page transfer delay ranges between 0.5 and 3 seconds at a remote/local ratio of 20/80, and between 12.9 and 49.7 seconds at remote/local ratio of 50/50, depending on the kind of information which has to be transferred. From these figures, one can observe that the delay for transferring one page of a financial form increases sharply under heavy load, (see figure 4.36). As it was previously observed at 18 Mb/Wd.

The overall delays are higher or equal than the case of Ethernet. This, as it was mentioned

earlier, is due to the fact that under low traffic conditions, Ethernet performs better than token ring.

Figures 4.31, 4.33, 4.35, and 4.37 show that, compared to the results obtained at 18 Mb/Wd, the link utilization decreases by a factor of about three at the 6 Mb/Wd and a factor of 2/3 at 12 Mb/Wd. The utilization of the 56 kbps link approximately doubles when increasing the data exchange rate from 6 Mb/Wd to 12 Mb/Wd for the same remote/local traffic ratio. The highest utilization of the 56 kbps link appears to be around 82% at the data exchange rate of 12 Mb/Wd and at a remote/local traffic ratio of 50/50.

In the next subsection, we present the results from simulation of two AppleTalk LANs interconnected by the 56 kbps link.

56 kbps Link Interconnecting Appletalk LANs

Figures 4.38 to 4.45, show the results obtained at data exchange rate of 6 Mb/Wd and 12 Mb/Wd and for the remote/local traffic ratios of 20/80 and 50/50. Since AppleTalk cannot interconnect more than 32 workstations per LAN, there is no substantial difference in the page transfer delay or in the overall network utilization. However we observe that as the data exchange rate decreases the page transfer delay decreases for any type of the transferred information. At 32 workstations per LAN, most of the delay encountered will be caused by the processing time rather than the access to the Applebus. This can be observed from the very low utilization of the Applebus as shown in the network utilization graphs. Compared to the results obtained at 18 Mb/Wd and for ratio of remote/local equal to 20/80 or 50/50, the link utilization decreases by a factor of approximately three at 6 Mb/Wd and 2/3 at 12 Mb/Wd.

Comparison of LANs Performance

Tables 4.7 and 4.8 summarize the measures reflecting the interwork system capacity under different LAN configurations, for the data exchange rate of 6 Mbits and 12 Mbits per working day respectively.

Under the data exchange rate of 6 Mbits per working day, the system limitation, for the Ethernet configuration, depend on the ratio between the remote and local traffic. If inter-LAN traffic is low, the system limitation will be directly related to the maximum number of stations which can be supported by the Ethernet LAN (1024 stations). At heavy traffic (remote/local ratio of 50/50), the system limitation appears to be the 56 kbps link and can support a maximum of 450 workstations per LAN. However, under the Token ring and Appletalk configurations, the system limitation is uniquely related to the maximum allowed number of stations which can be supported by the interconnected LANs irrespective of the remote to local traffic ratio.

As we increased the data exchange rate to 12 Mbits per working day, the system limitation for the Ethernet configuration became the 56 kbps link rather than the maximum allowed number of stations that it can support. In the case of the Token ring and Appletalk configurations, the system limitation has not changed from the one found at 6 Mbits per working day.

Finally, by lowering the data exchange rate, for each station, from 18 Mbits per working day to 12 Mbits and 6 Mbits per day, we were able to obtain a greater number of workstations per LAN (see Table 4.7 and 4.8) and lower transfer delays (refer to graphs). Also the use of the 56 kbps link for supporting such environment, at the mentioned rates, has proven to be the most adequate for the configurations under consideration.

In the next chapter, we will look at applications where the T1 bandwidth will be required in order to provide low delays for transferring high volume files.

LAN Configuration	Remote/Local traffic	Maximum number of workstations per LAN	Corresponding 56 kbps link utilization (%)	System limitation
Ethernet	20/80	1024	66.0	Ethernet 56 kbps link
	50/50	450	74.3	
Token ring (non bridge priority)	20/80	260	16.2	Rings Rings
	50/50	260	41.0	
AppleTalk	20/80	32	1.98	AppleTalk AppleTalk
	50/50	32	5.18	

Table 4.7: Interwork system supporting office communications at data rate of 6 Mb/Wd.

LAN Configuration	Remote/Local traffic	Maximum number of workstations per LAN	Corresponding 56 kbps link utilization (%)	System limitation
Ethernet	20/80	500	64.4	— 56 kbps link
	50/50	225	73.3	
Token ring (non bridge priority)	20/80	260	33.2	Rings Rings
	50/50	260	82.0	
AppleTalk	20/80	32	3.85	AppleTalk AppleTalk
	50/50	32	10.1	

Table 4.8: Interwork system supporting office communications at data rate of 12 Mb/Wd.

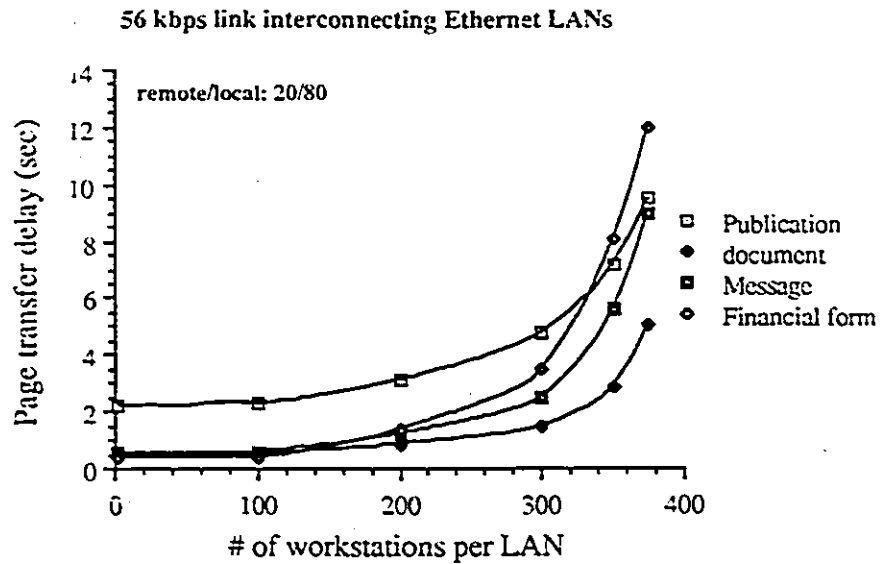


Figure 4.2: Page transfer delay versus the number of workstations per LAN.

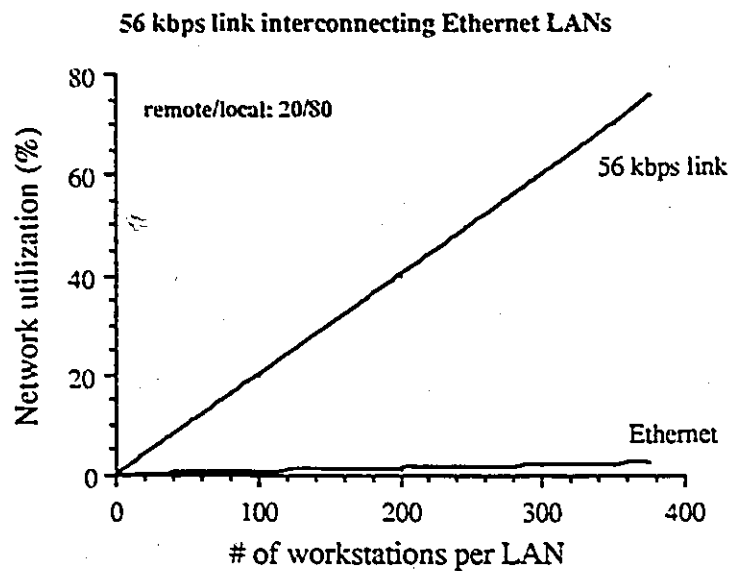


Figure 4.3: Network utilization versus the number of workstations per LAN.

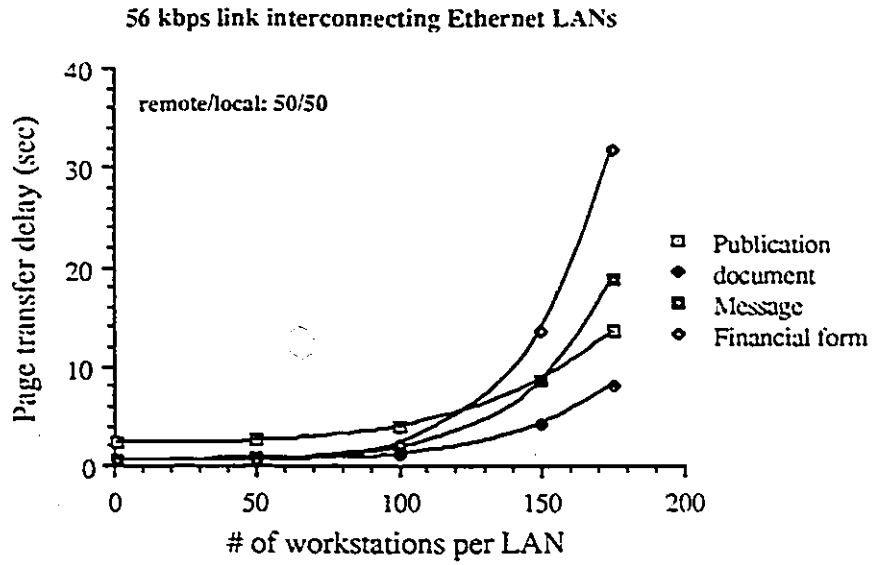


Figure 4.4: Page transfer delay versus the number of workstations per LAN.

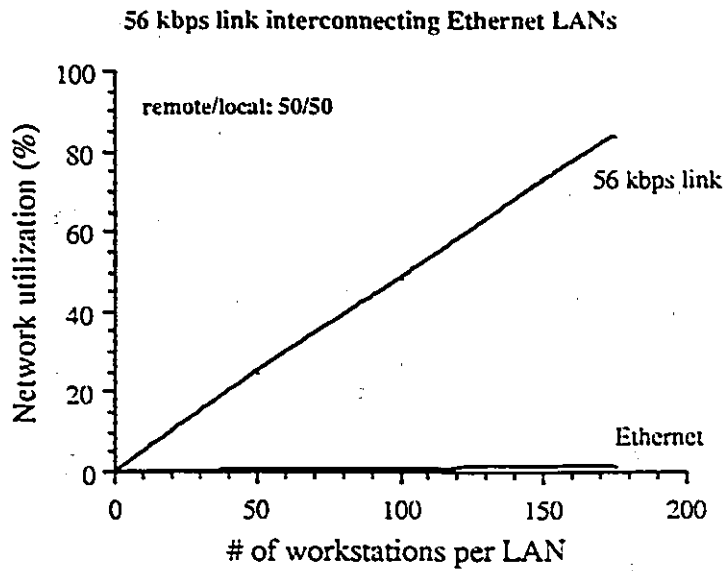


Figure 4.5: Network utilization versus the number of workstations per LAN.

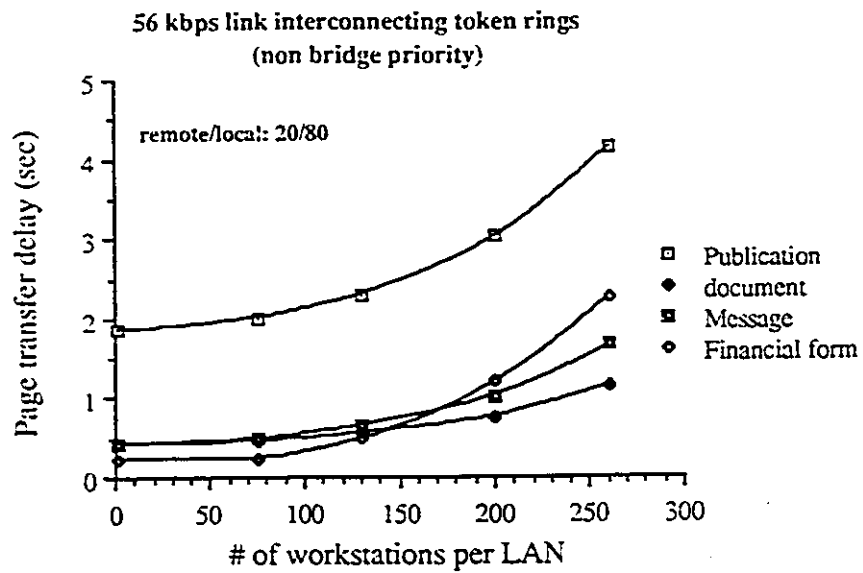


Figure 4.6: Page transfer delay versus the number of workstations per LAN.

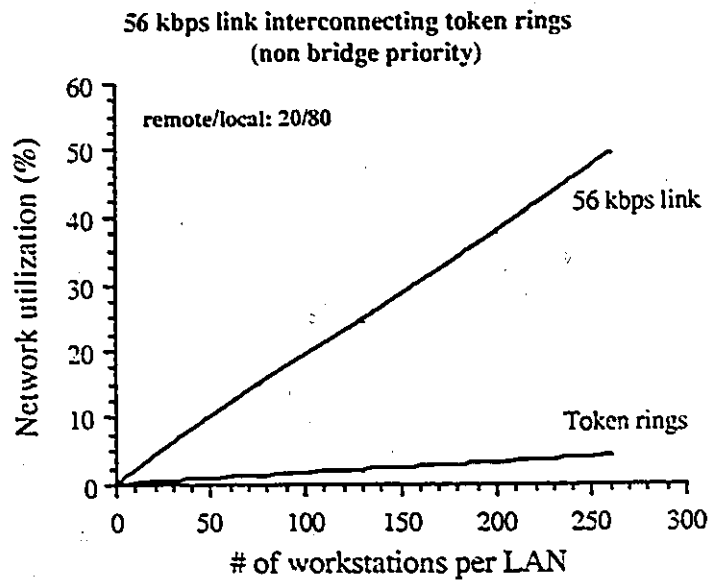


Figure 4.7: Network utilization versus the number of workstations per LAN.

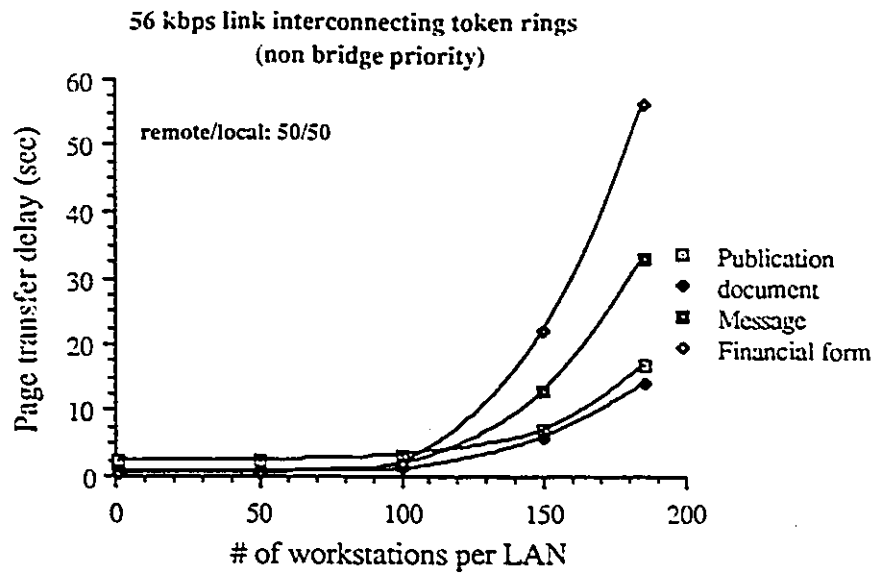


Figure 4.8: Page transfer delay versus the number of workstations per LAN.

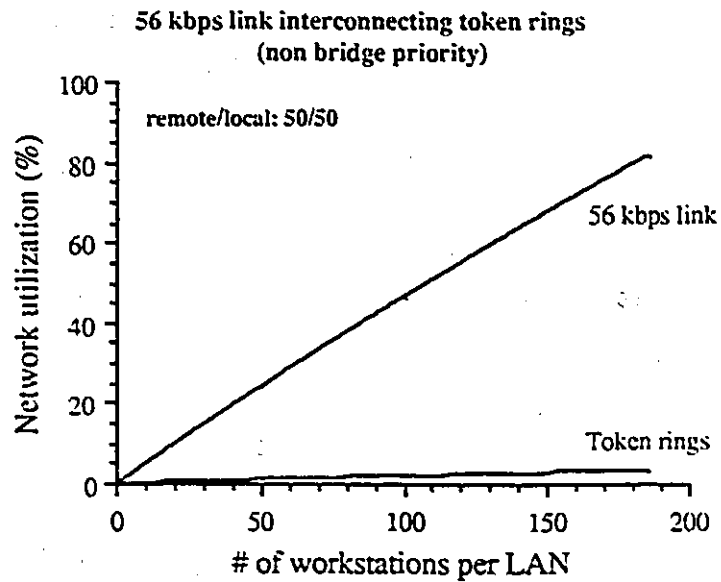


Figure 4.9: Network utilization versus the number of workstations per LAN.

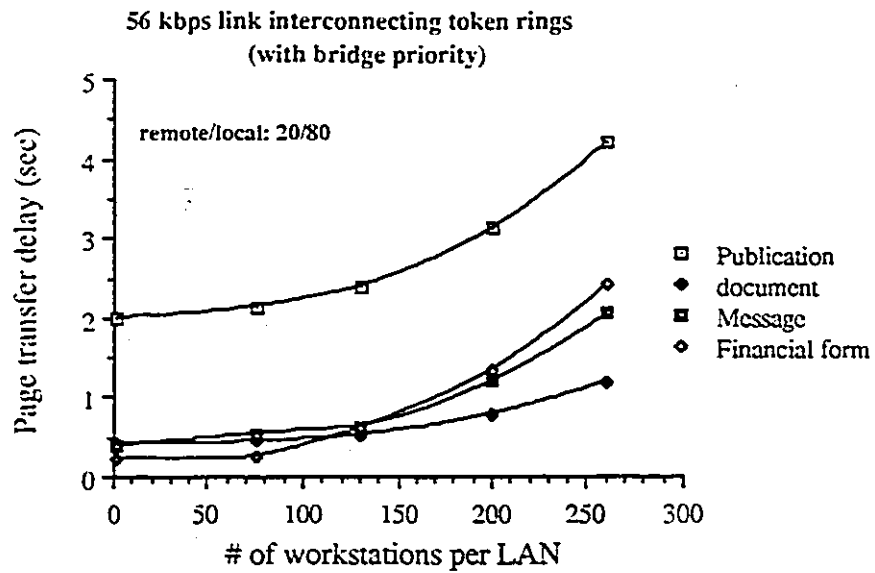


Figure 4.10: Page transfer delay versus the number of workstations per LAN.

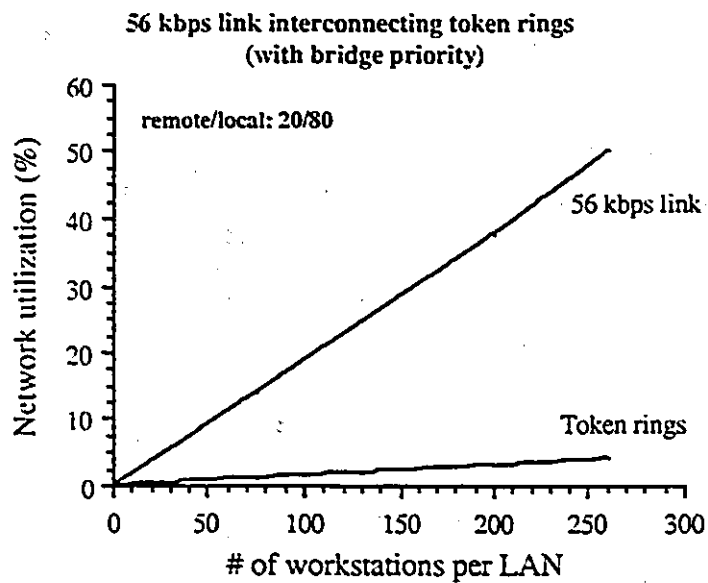


Figure 4.11: Network utilization versus the number of workstations per LAN.

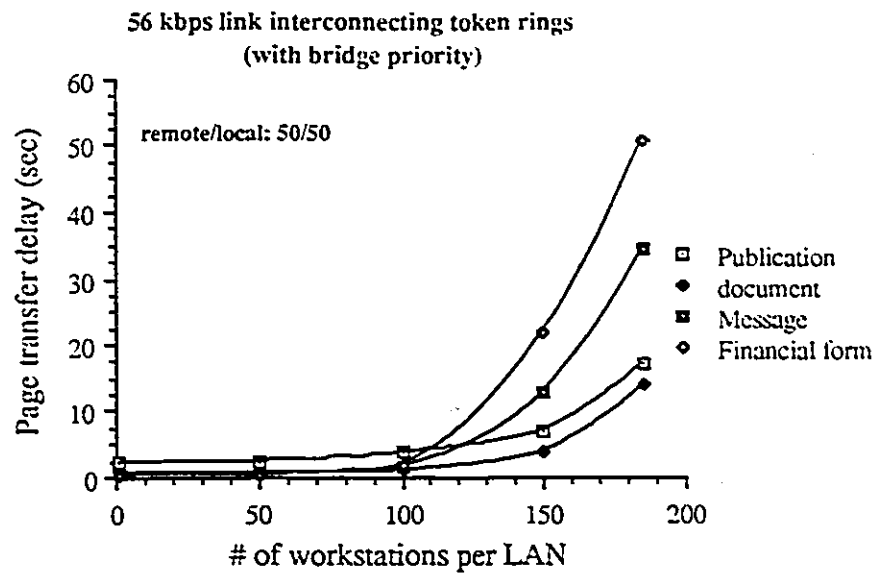


Figure 4.12: Page transfer delay versus the number of workstations per LAN.

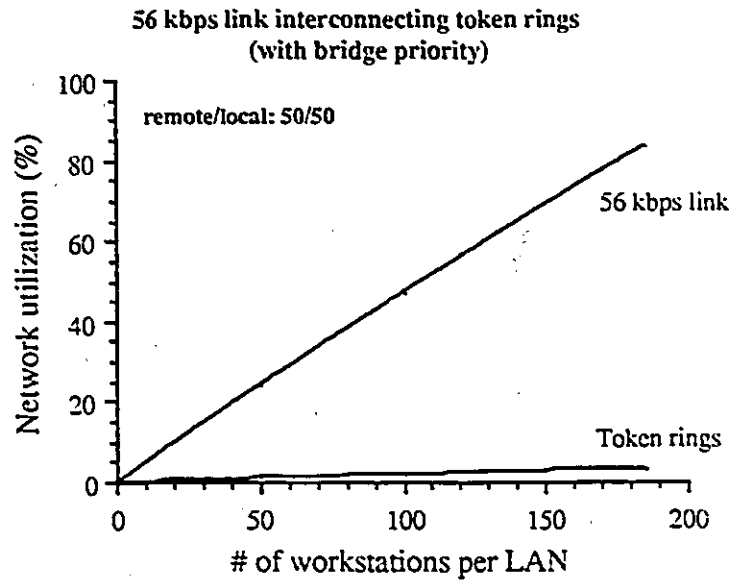


Figure 4.13: Network utilization versus the number of workstations per LAN.

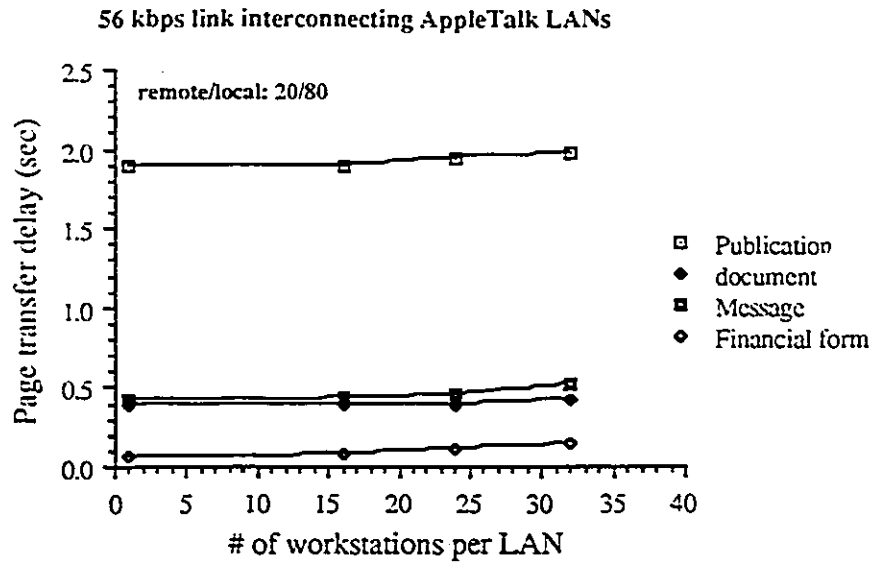


Figure 4.14: Page transfer delay versus the number of workstations per LAN.

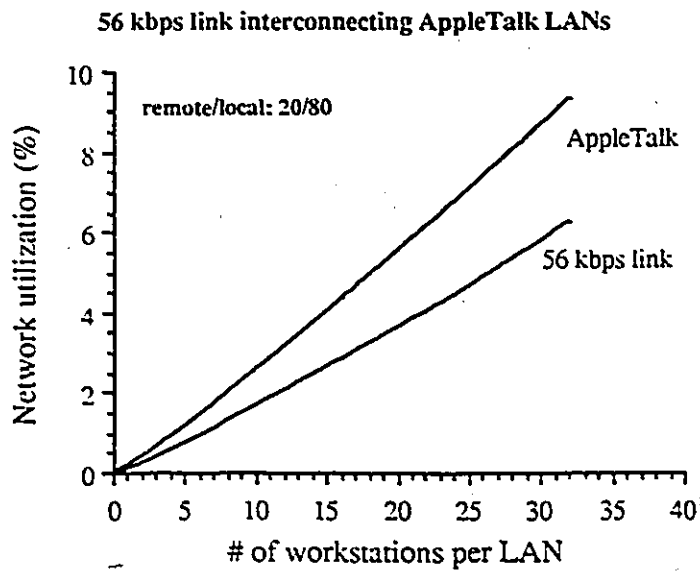


Figure 4.15: Network utilization versus the number of workstations per LAN.

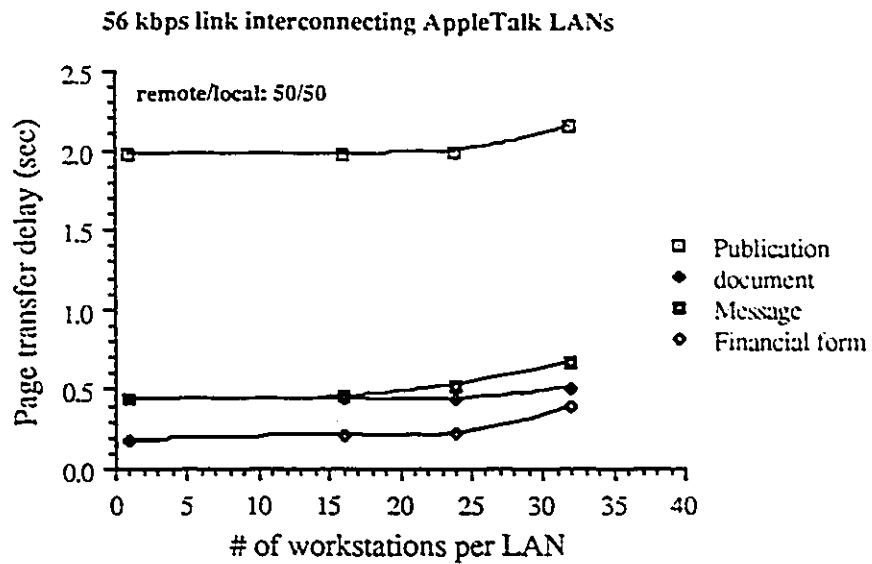


Figure 4.16: Page transfer delay versus the number of workstations per LAN.

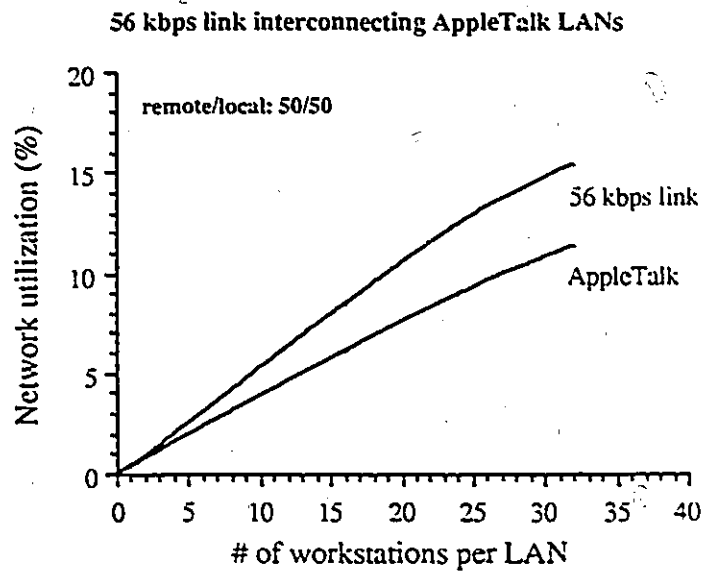


Figure 4.17: Network utilization versus the number of workstations per LAN.

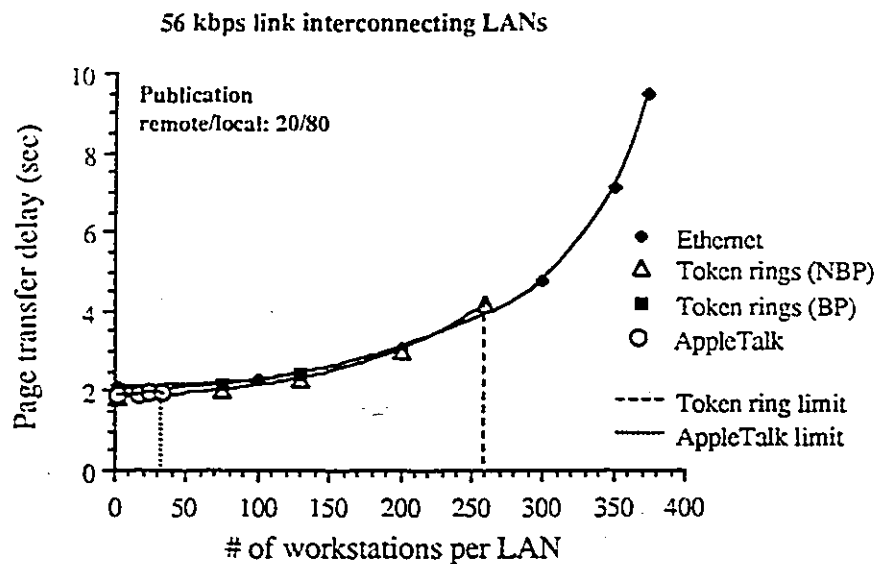


Figure 4.18: Publication page transfer delay versus the number of workstations per LAN.

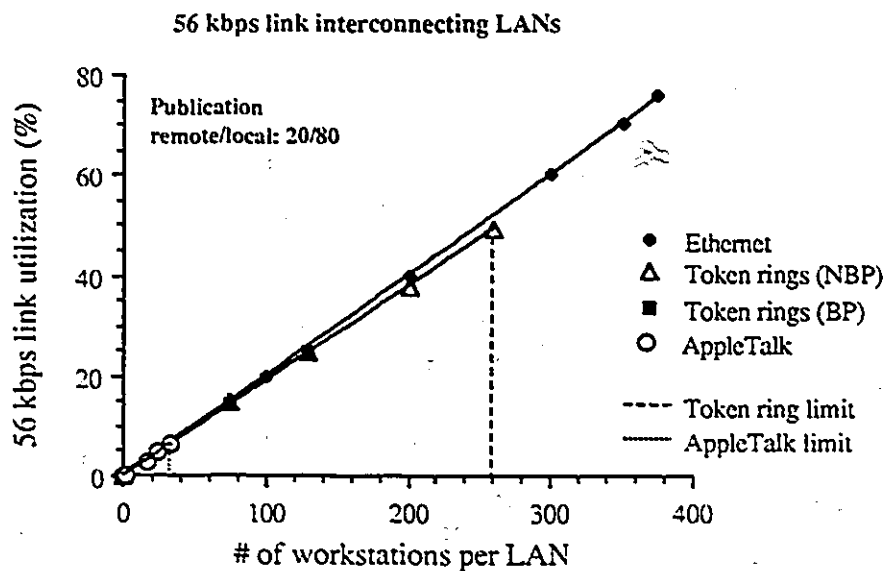


Figure 4.19: Network utilization versus the number of workstations per LAN.

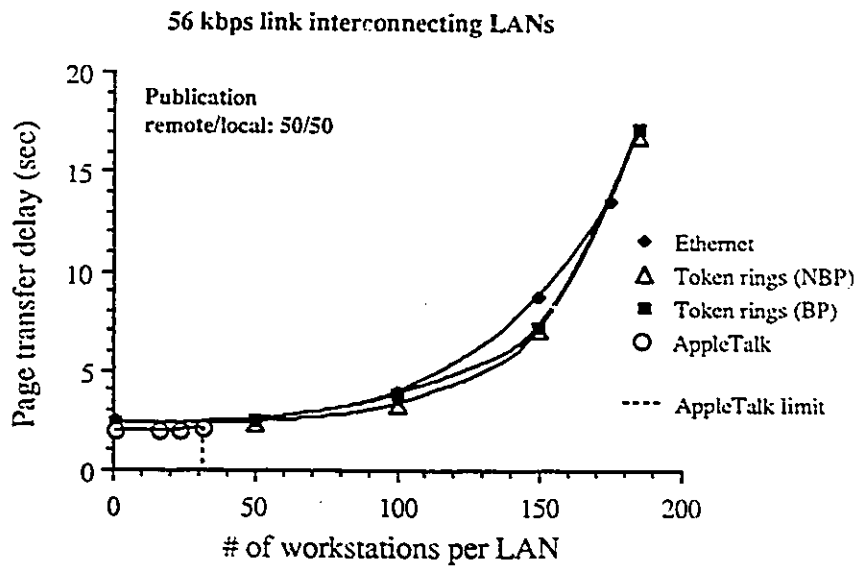


Figure 4.20: Publication page transfer delay versus the number of workstations per LAN.

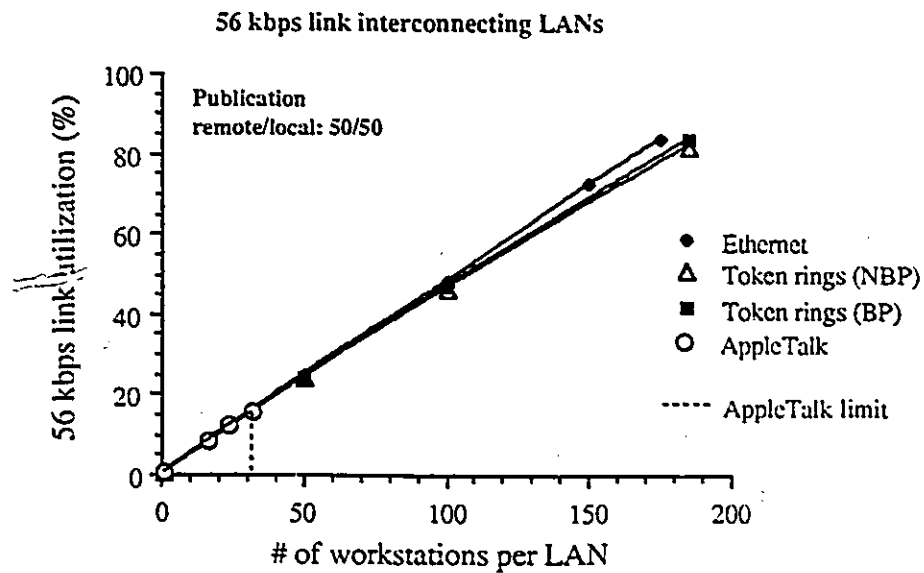


Figure 4.21: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

(Exchange Data Rate = 6 Mb/Wd)

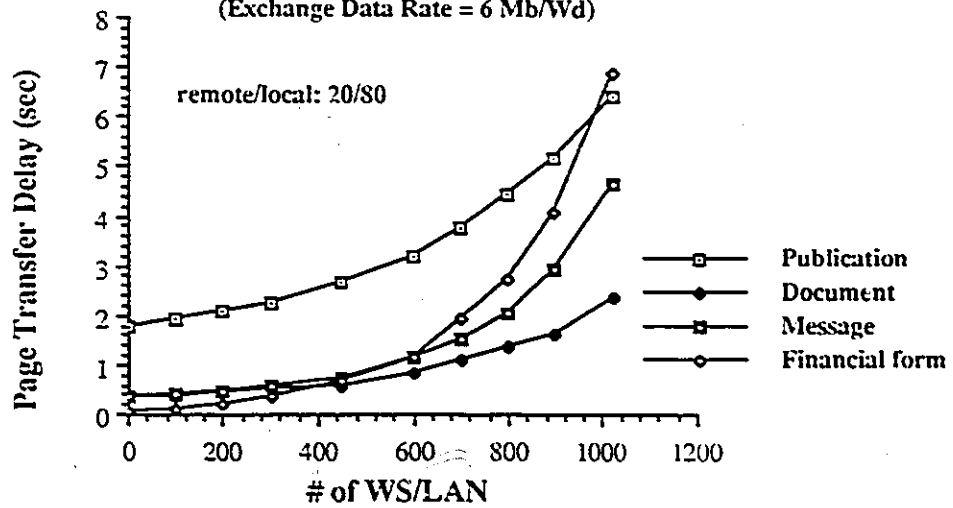


Figure 4.22: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

(Exchange Data Rate = 6 Mb/Wd)

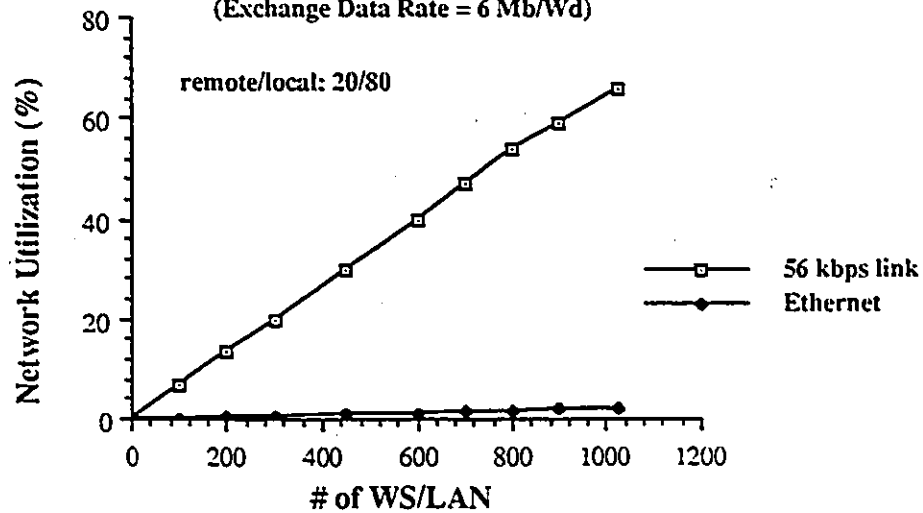


Figure 4.23: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

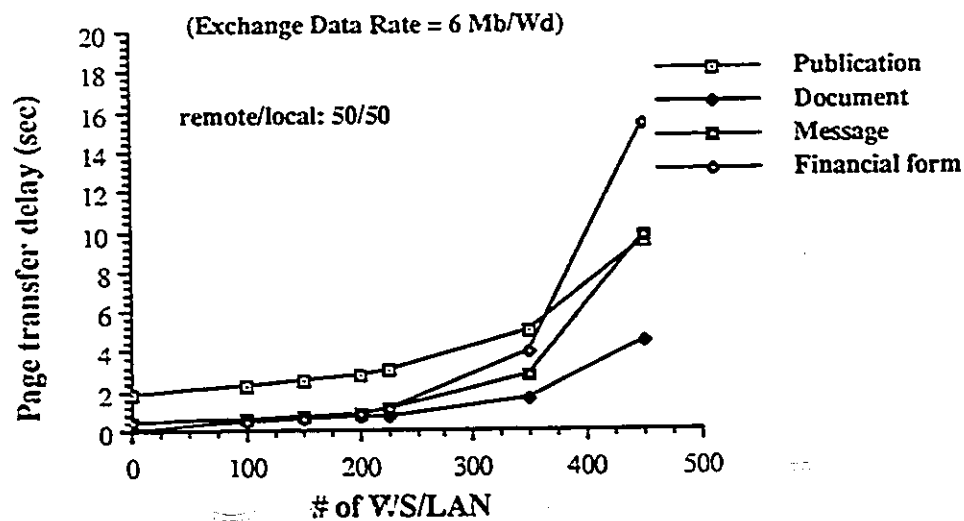


Figure 4.24: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

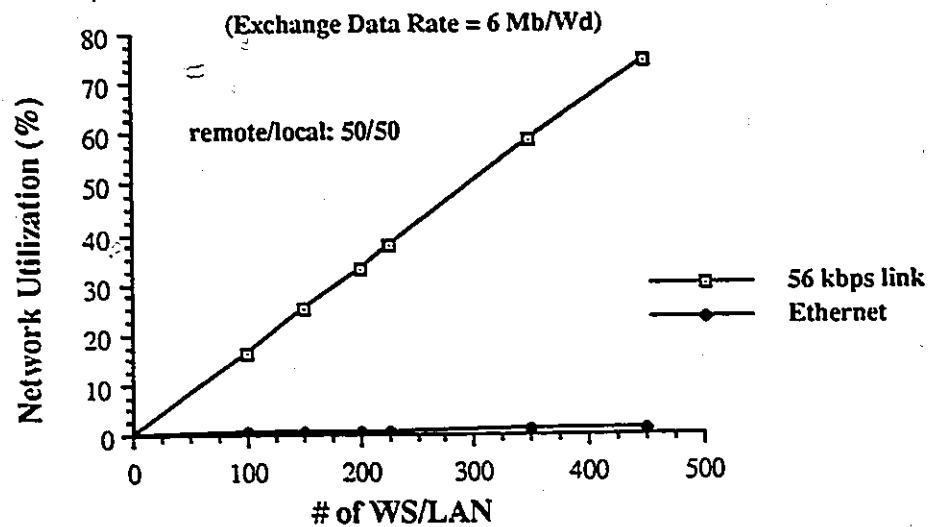


Figure 4.25: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

(Exchange Data Rate = 12 Mb/Wd)

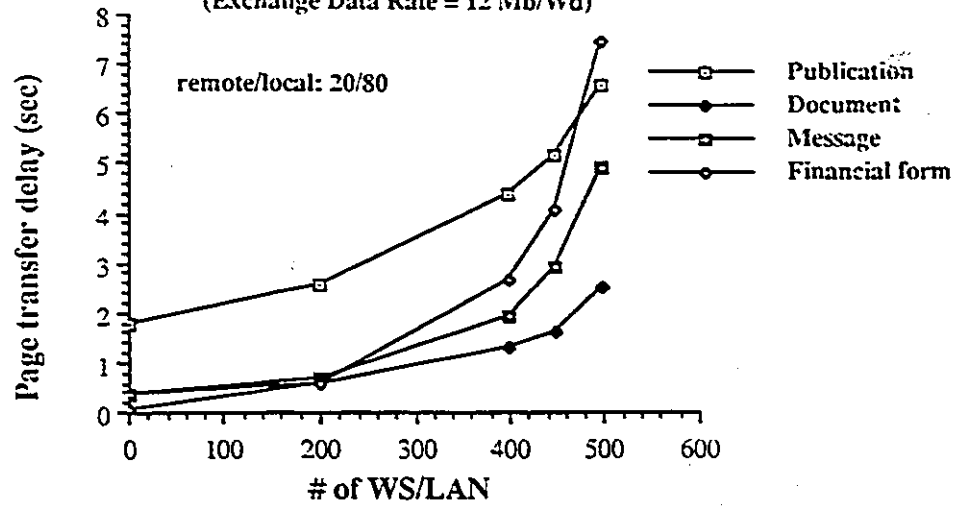


Figure 4.26: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs

(Exchange Data Rate = 12 Mb/Wd)

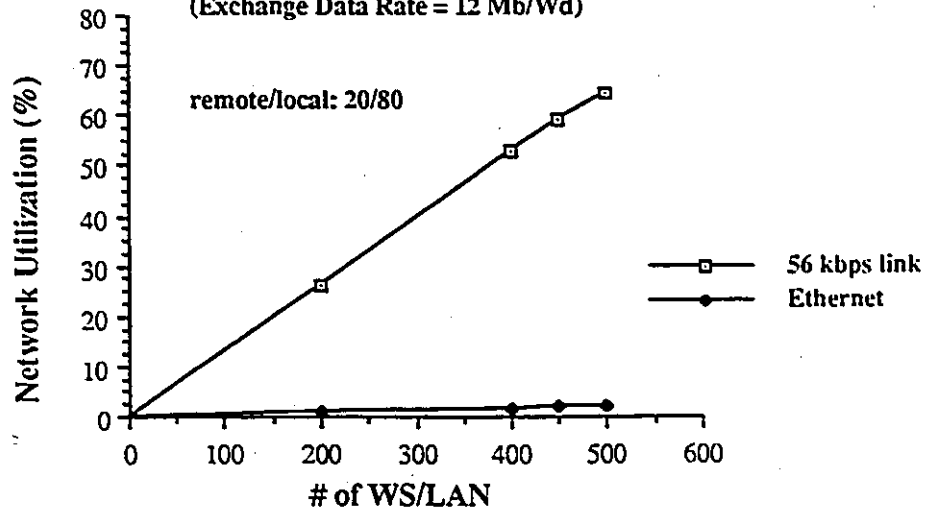


Figure 4.27: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs (Exchange Data Rate = 12 Mb/Wd)

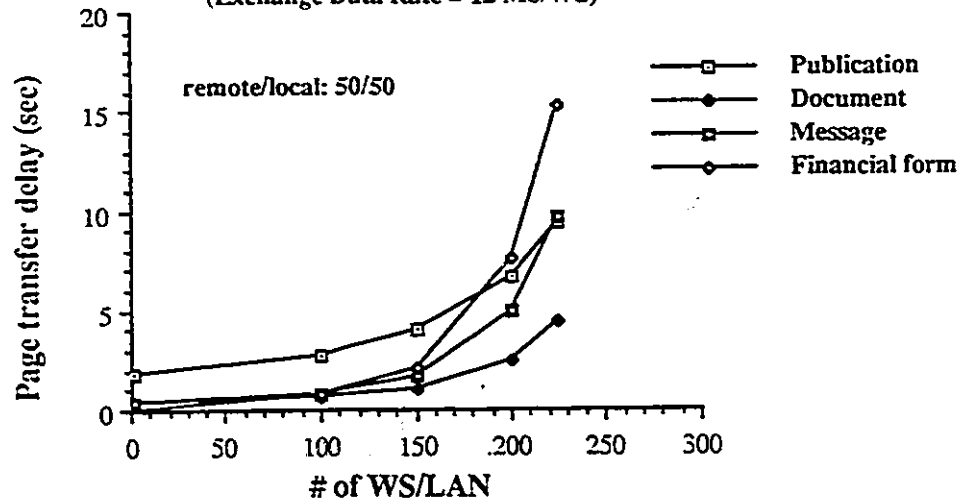


Figure 4.28: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Ethernet LANs (Exchange Data Rate = 12 Mb/Wd)

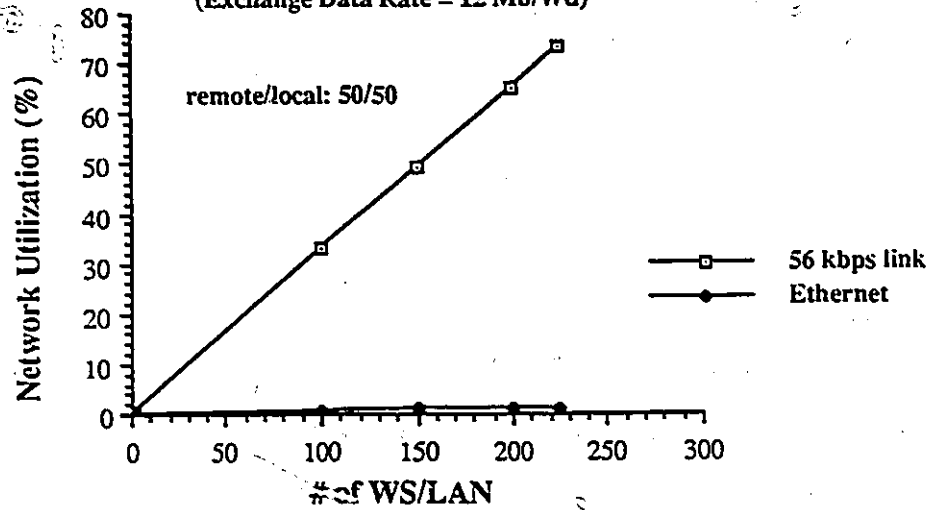


Figure 4.29: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs

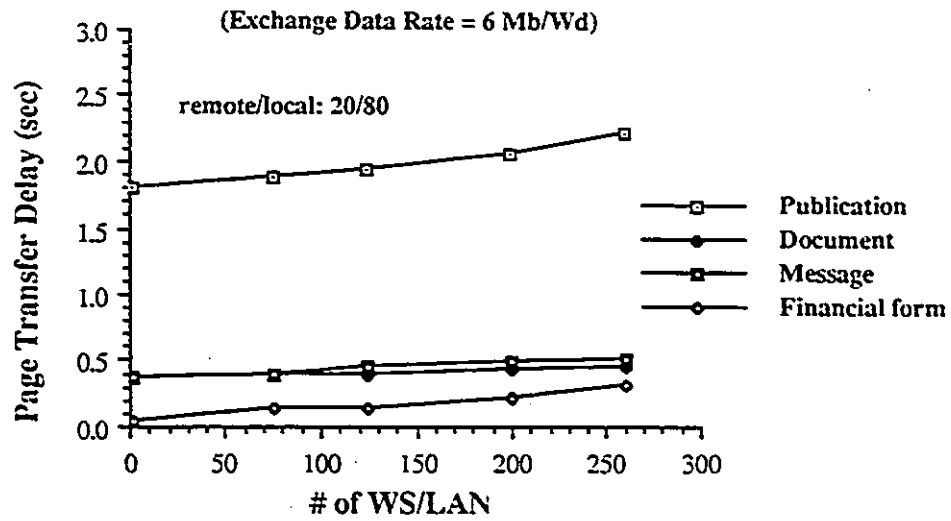


Figure 4.30: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs

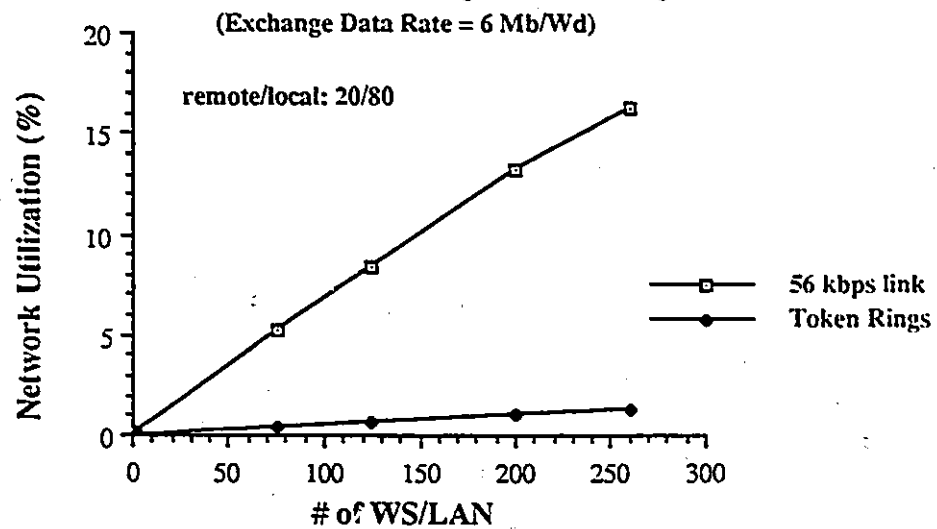


Figure 4.31: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs (Exchange Data Rate = 6 Mb/Wd)

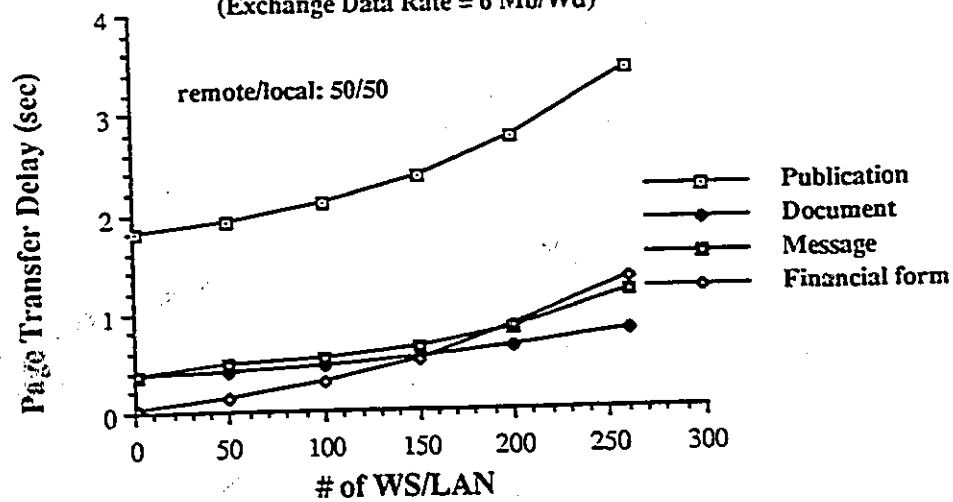


Figure 4.32: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs (Exchange Data Rate = 6 Mb/Wd)

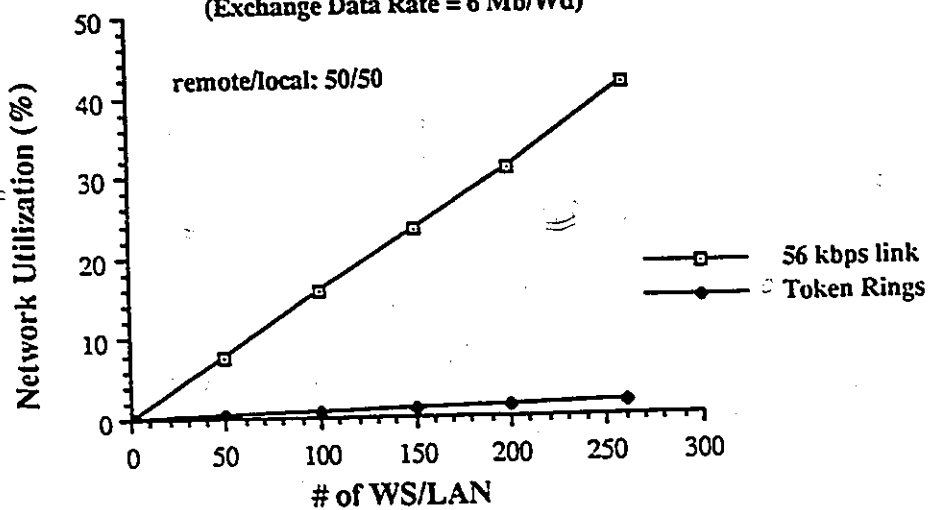


Figure 4.33: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs

(Exchange Data Rate = 12 Mb/Wd)

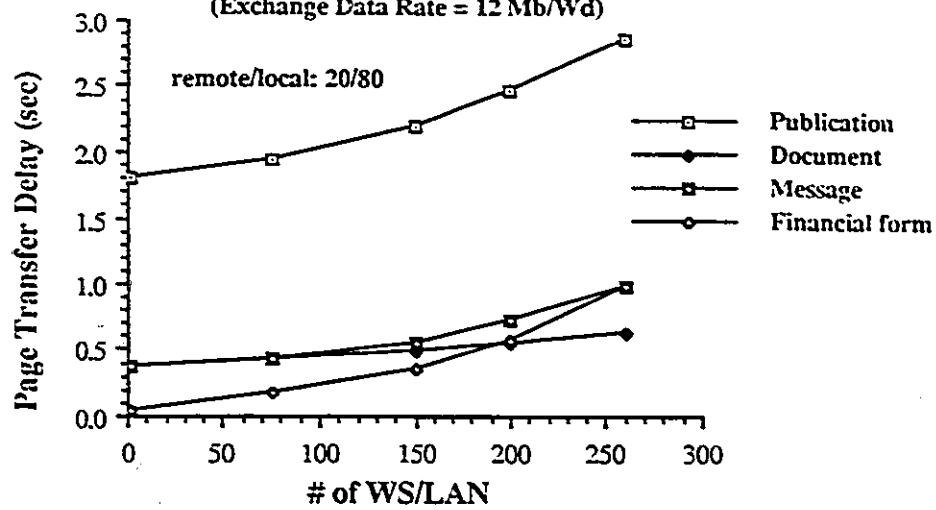


Figure 4.34: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs

(Exchange Data Rate = 12 Mb/Wd)

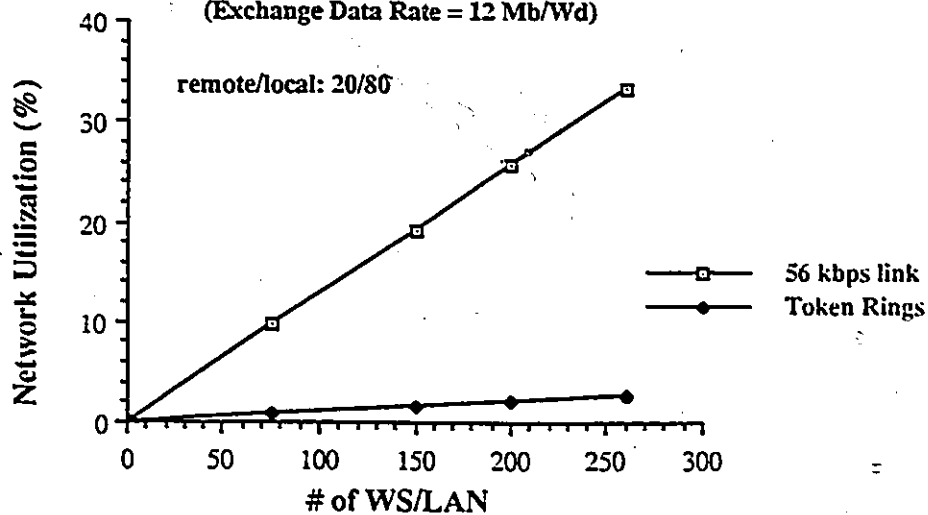


Figure 4.35: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs (Exchange Data Rate = 12 Mb/Wd)

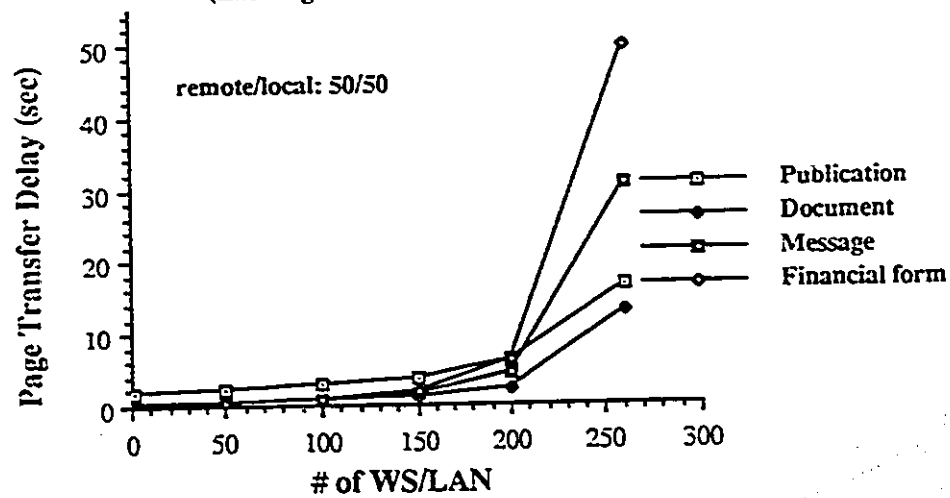


Figure 4.36: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting Token Ring LANs (Exchange Data Rate = 12 Mb/Wd)

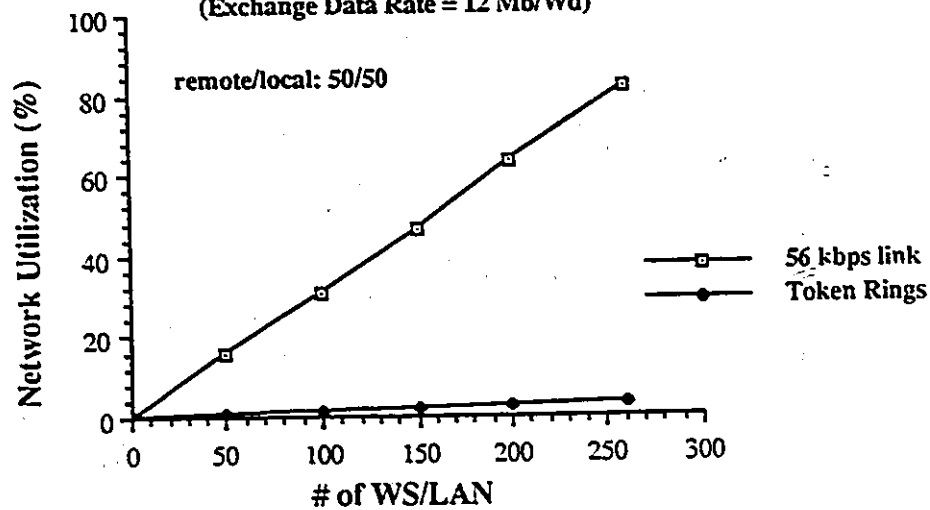


Figure 4.37: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANS

(Exchange Data Rate = 6 Mb/Wd)

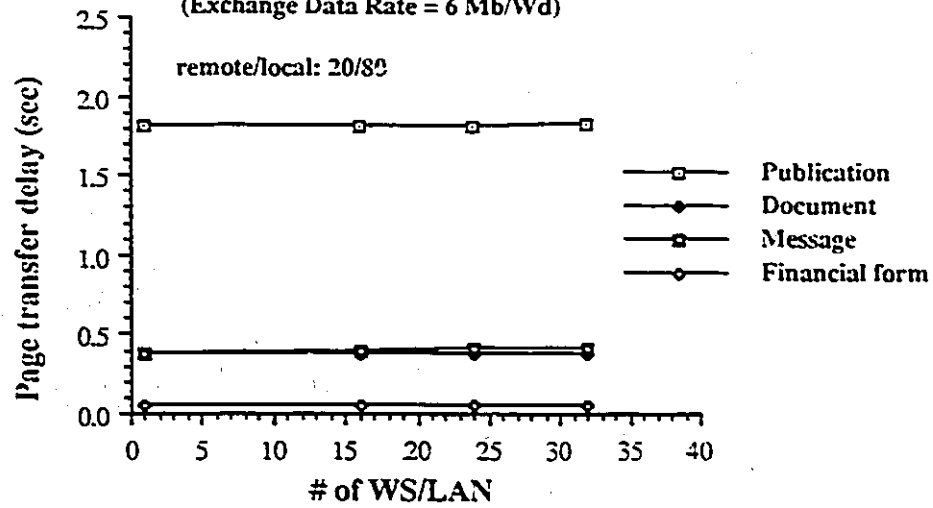


Figure 4.38: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANS

(Exchange Data Rate = 6 Mb/Wd)

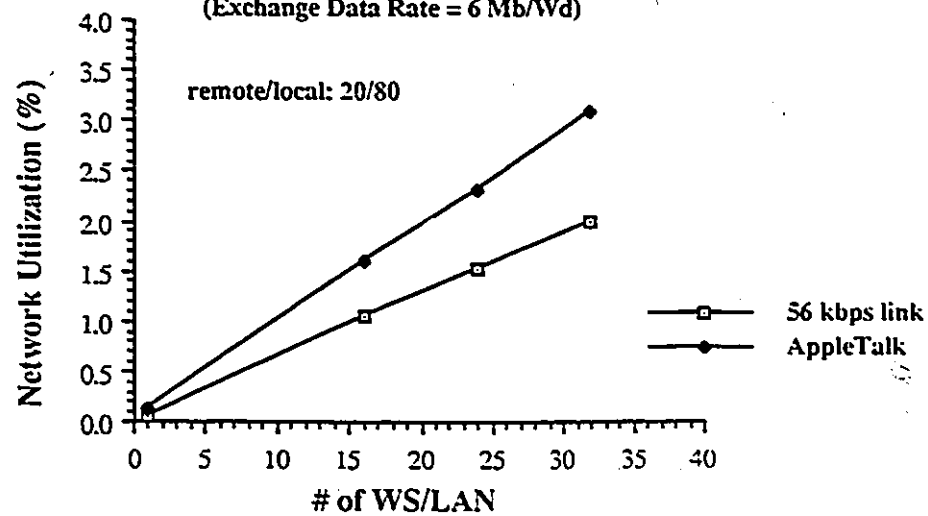


Figure 4.39: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANs (Exchange Data Rate = 6 Mb/Wd)

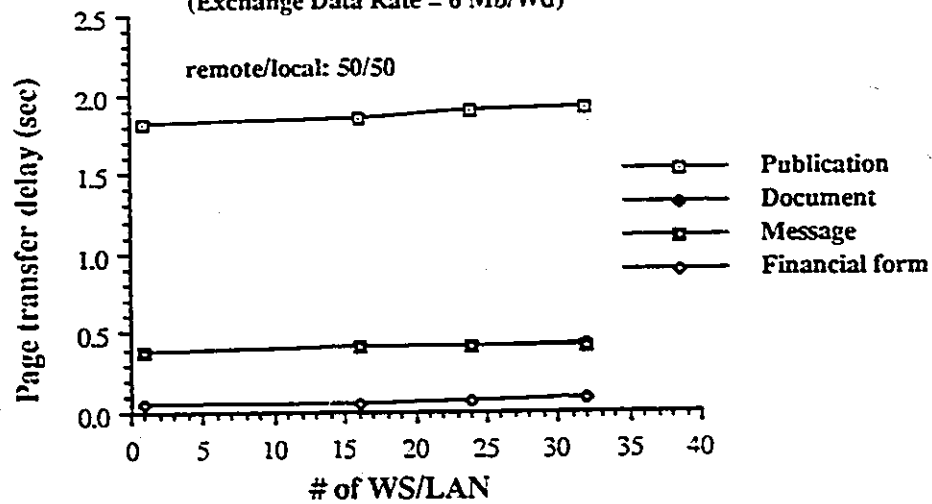


Figure 4.40: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANs (Exchange Data Rate = 6 Mb/Wd)

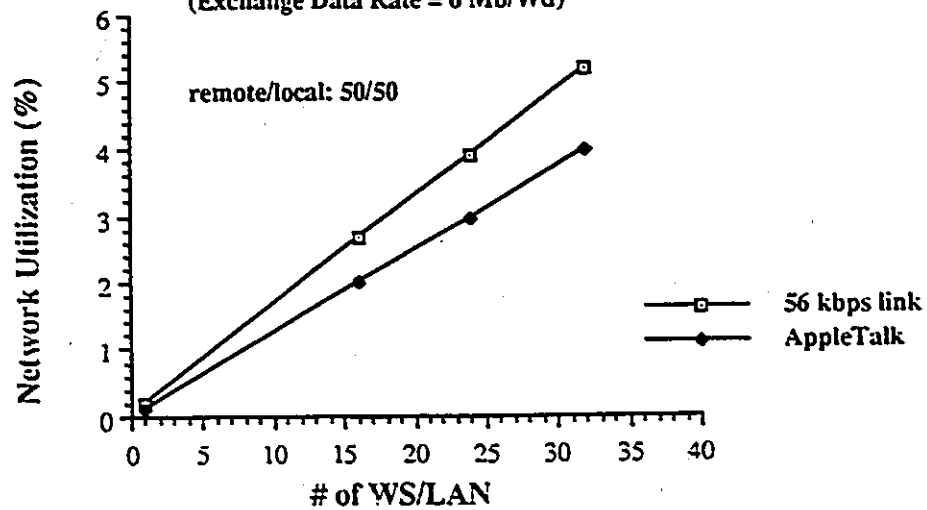


Figure 4.41: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANS

(Exchange Data Rate = 12 Mb/Wd)

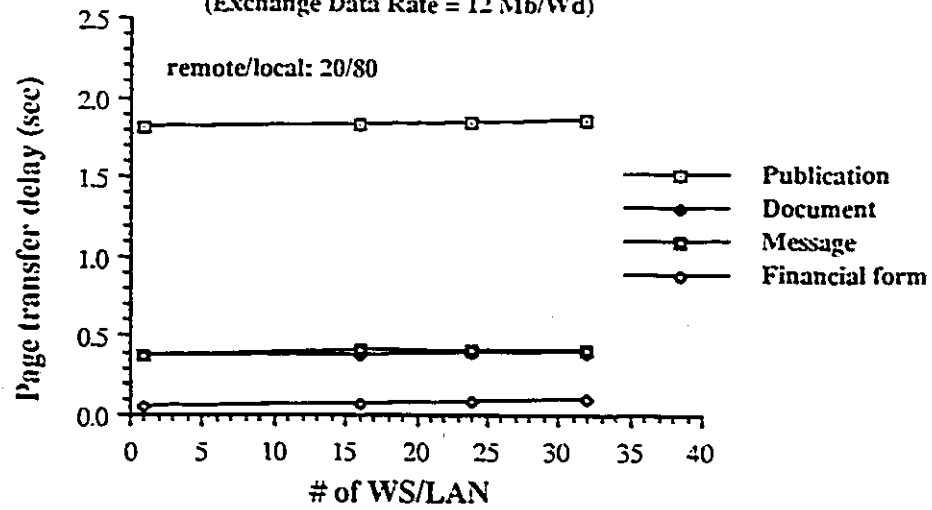


Figure 4.42: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANS

(Exchange Data Rate = 12 Mb/Wd)

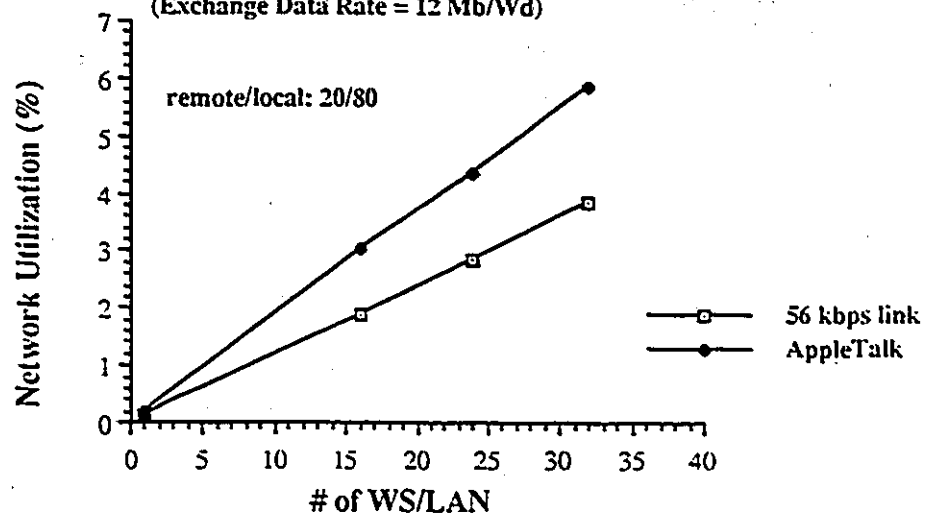


Figure 4.43: Network utilization versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANs (Exchange Data Rate = 12 Mb/Wd)

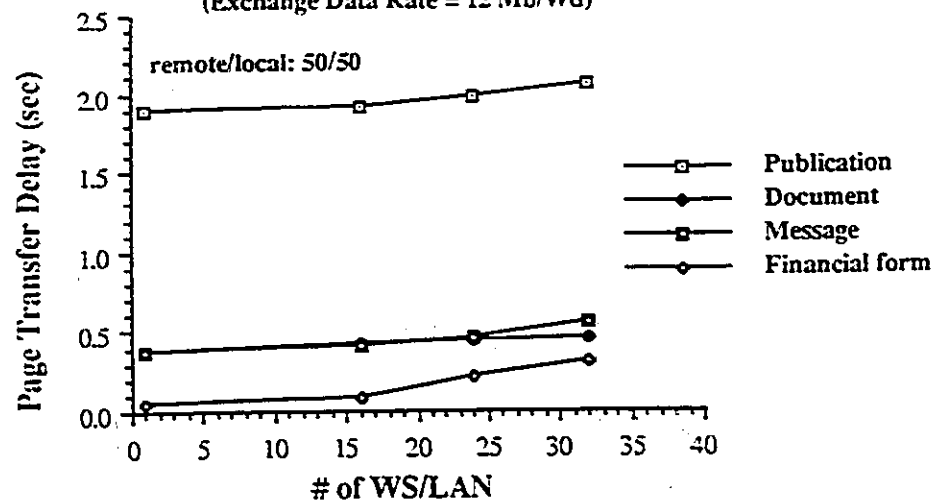


Figure 4.44: Page transfer delay versus the number of workstations per LAN.

56 kbps Link Interconnecting AppleTalk LANs (Exchange Data Rate = 12 Mb/Wd)

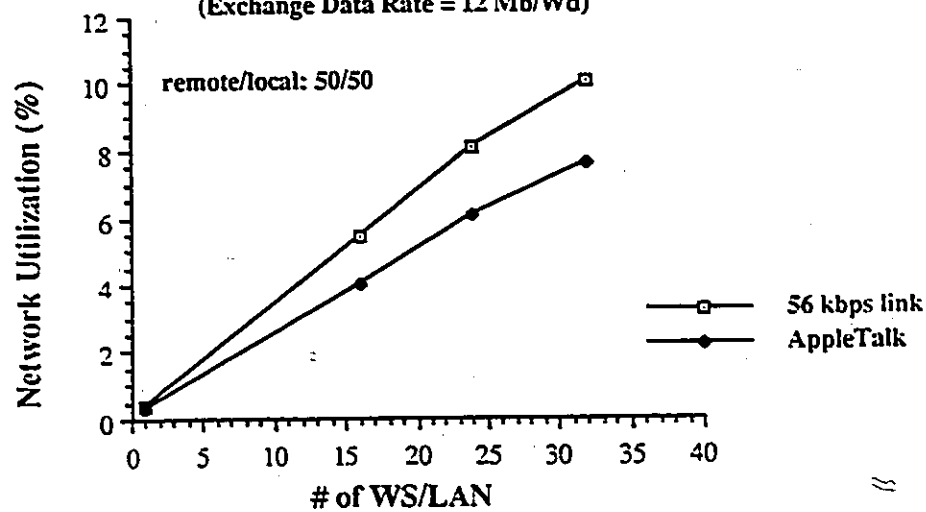


Figure 4.45: Network utilization versus the number of workstations per LAN.

Chapter 5

File Transfer Applications

5.1 Motivation

Some of the most important sources of traffic generated and exchanged in an office or any company's environment today are Virtual terminal, Electronic Mail and most importantly File Transfers. Any user may login at one LAN and start sending electronic mail to his fellow users on the same LAN or on a remote site. This is done by using the electronic mail facility that is offered to the user at the operating system level.

On the other hand, a user may choose to login at a remote site and may ask the system to transfer files from one LAN to the other. This generation of file transfers between LANs has a considerable effect on the throughput of data exchanged between them. Therefore, performance evaluation of office automation on any Local Area Networks technologies must take into consideration file transfer activities. Our objective is to study the effect of file transfer activities on different Local Area Networks. In doing so, we consider file transfers between two Ethernets (CSMA/CD), two Token Rings and two AppleTalks LANs. The interconnection medium between each type of these LANs is the T1 link that has been described in chapter 2 and which has a maximum transmission bandwidth of 1.544 Mbps. Furthermore we would like to examine closely the following parameters: The mean file transfer delay, the T1 utilization i.e. how much of the bandwidth is used, and the number of file transfer sessions that can be supported by the link and its effect on the link utilization and file transfer delay. These

factors are of interest to the user and to the analyst of the LAN. It is of interest to the user to know how long it takes to transfer a file from one site to the other. To the provider, the T1 utilization, file transfer delay and the number of file transfers sessions across the two LANs are the major parameters in the decision making in terms of costs, customer's (users') satisfaction, and LAN reliability and efficiency.

In a typical application, consider the case where a hospital LAN is interconnected to another hospital LAN. The LAN could be any of the ones discussed earlier. Consider also that the hospital archiving center, where all patients' files are permanently stored, is located at one specific LAN. Therefore, depending on the size of the hospital, one expects a daily or weekly transfer of digitized X-RAY images as well as text and voice annotations to the archiving center at the remote site. Since file transfers can be lengthy processes, particularly if performed in background mode, this activity can take place at night when the LANs are expected to be less busy and a great number of files need to be transferred to the remote LAN. This huge data transfer activity can be carried out continuously and need not be interrupted until all files have been transferred.

In another application, consider a company that distributes a weekly or daily newsletter or report to its employees, within the organization, who are located at different sites and are interconnected by high speed links such as T1. Typical newsletter size varies from three to ten pages which could include graphics and text. This small size file transfer activity uses a considerable amount of the provided bandwidth. It would be interesting to measure exactly how much of this bandwidth had been utilized by such activity and at what cost, in terms of money and transfer delays.

5.2 LAN Configurations

The LAN configurations that we have adopted for this study are shown in the following figures.

Figure 5.1 shows two Ethernet Local Area Networks interconnected by T1 link and Fig. 5.2

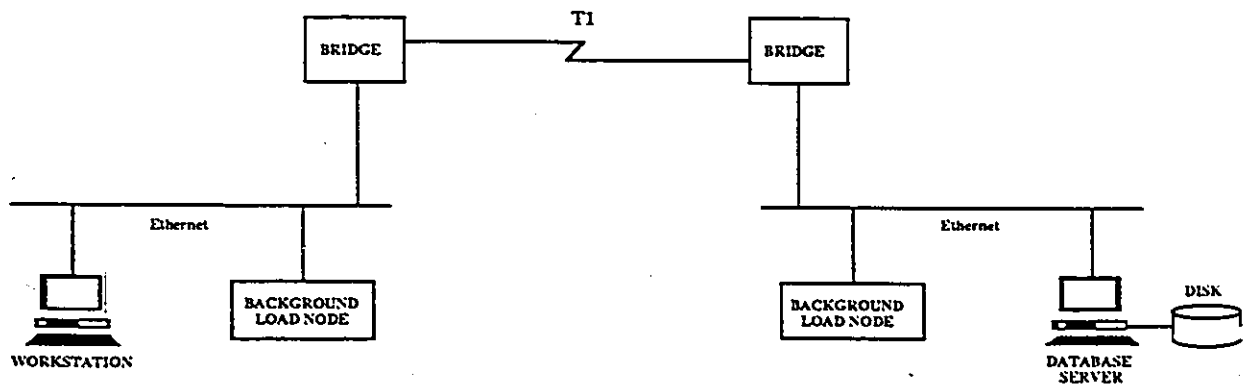


Figure 5.1: T1 interconnecting Ethernet based LANs

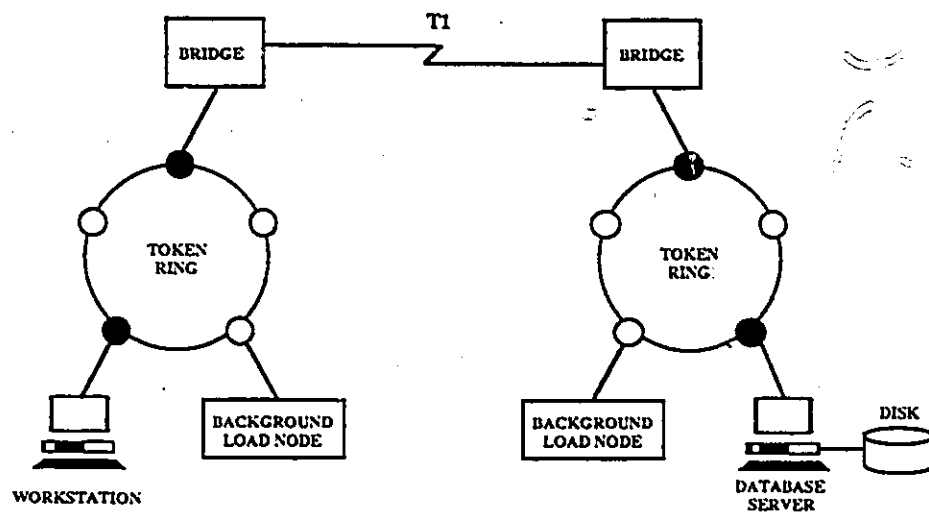


Figure 5.2: T1 interconnecting token rings

shows two token rings LANs interconnected by T1. The AppleTalk configuration is the same as the Ethernet with the Apple Bus used instead of CSMA/CD.

Many studies have been carried out on these type of LANs and many results have been published. However when interconnection is considered very few results or analysis are published. One experiment was conducted by BNR on the interconnection of three token rings with remote bridges using frame relay services [BNR]. Messages and files are sent and received as well as some applications such as LOTUS 123. The link used was the 56 kbps digital connection. Results of the experiment showed that the status and statistics of every other bridge in the network. For a large network, this could be a significant benefit.

As it was described in chapter 3, that in all three configurations file transfer is done between the two LANs. A workstation may requests a file from a remote file server and vice versa. The file transfer is done on both LANs with equal request from one LAN or the other. Consequently the system is *homogeneous* and the number of file requests from LAN A to LAN B is equal to the number of requests from LAN B to LAN A. This is assumed throughout the study.

The bridges, as explained in earlier chapters, are used to connect the two independent Local Area Networks (see Chapter 3). Their main function is to direct the data to their destinations. The background loads shown in the configurations are used simulate the LAN behavior under different traffic, mainly low and heavy traffic. The transmission of frames between end-stations (workstation and remote file server) has the following properties, as implied by frame relaying characteristics:

- Frames must not be discarded (i.e. minimal frame loss).
- Frames cannot be duplicated.
- Frames cannot be misordered.

5.3 Performance Analysis and Results

The following scenarios have been considered in order to evaluate file transfer applications between a workstation and a remote database server. Figure 5.3 shows the model of the system under study. The arrows' directions show how traffic flows from one LAN to the other between the workstations and the remote file servers.

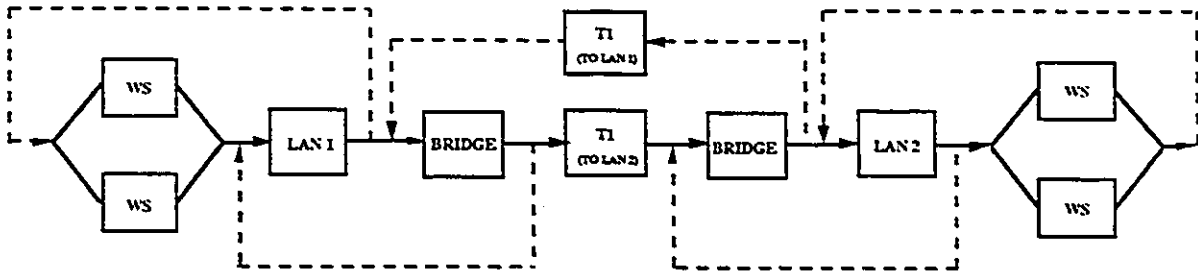


Figure 5.3: The system model

Here we have considered two extreme cases where the LAN is not locally busy in one case, and the LAN is 50% busy locally on the other. i.e. only inter-LAN traffic is allowed in the first case and 50% intra-LAN plus inter-LAN traffic is added in the second case. After a session was established between the workstation and remote file server, we fixed the intra-LAN traffic and we varied the inter-LAN traffic in order to see its effect on the networks. Two file sizes were chosen for this study. A typical X-RAY image file of 1.2 Mbytes and a newsletter, or any other file, of size 64 kbytes. Also we have examined the effect of packet length on the file transfers.

In the next section, we present all the assumptions made for the performance evaluation study.

5.3.1 Simulation Assumptions

The following are the modeling assumptions made for the different Local Area Networks Performance Evaluation.

1. Assumptions 4 to 10, made in section 4.2.1, are still valid.
2. We consider two file sizes: 64 kbytes and 1.2 Mbytes.
3. Different packet lengths (64 bytes, 1 kbytes, and 1.5 kbytes) are examined in the case of Ethernet. In the case of Token ring only the results for a packet length of 1 kbytes are presented and in the case of AppleTalk only one packet size of 512 bytes is examined.
4. Intra-LAN traffic of 0 and 50% is considered. While intra-LAN traffic is set at a specific rate, we vary the inter-LAN traffic.
5. The worst case scenario has been assumed, where files are pumped continuously from one LAN to the other. (only one connection is established between the two LANs)

5.3.2 T1 Interconnecting two Ethernet LANs

In this section we present the results obtained from the simulation of two Ethernet LANs interconnected by T1.

First we consider 64 kbytes file transfers between the LANs under two cases. Zero local traffic is present in one case and 50% local traffic in the other. The same is repeated for the 1.2 Mbytes files.

The effect of packet lengths was studied for the file size of 64 kbytes. In this regard, we have examined the worst cases in terms of maximum and minimum packet lengths allowed by Ethernet and which are 1.5 kbytes and 64 bytes respectively.

Figures 5.4 and 5.5 show the T1 utilization and the file transfer delay as a function of

the number of simultaneous file transfer that can occur between the two LANs. For the 64 kbytes file and a packet length of 1 kbytes, we see that T1 starts saturating after exceeding 11 simultaneous file transfers at 0% intra-LAN traffic and 13 simultaneous file transfers at 50% intra-LAN traffic with their corresponding delay are 2 and 2.4 seconds respectively.

A slightly less number of simultaneous file transfers was obtained for the same T1 utilization when a packet length of 1526 bytes was used. However a slightly smaller delay was also obtained in this case (see Fig. 5.6 and 5.7).

We observe a big difference in results when a 64 bytes packet length was used (see Fig. 5.8 and 5.9). First we can see that the file transfer delay is much higher than the delay obtained in the case of 1.5K and 1Kbytes packet length for the same number of simultaneous file transfers. To explain this delay difference one can observe that the number of 64 bytes packets generated for the transfer of the 64 Kbytes file are much greater than the one with packet lengths of 1 K and 1.5 Kbytes. The generation of additional packets to make the transfer of 64 kbytes file comes with the cost of additional processing and waiting time at the servers, bridges and accessing the LAN's medium. We see also that a greater number of simultaneous file transfers can be supported but at a very high delay cost. In all cases the T1 utilization is the limiting factor. From the graphs we observe that as the number of simultaneous file transfer increases T1 gets more and more saturated (close to 100%). The difference between the 0% and the 50% intra-LAN traffic is measured by the greater delay imposed at 50% intra-LAN traffic. This delay can be explained by the fact that we are likely to have more collisions when competing for the bus access at 50% intra-LAN traffic.

Figures 5.4 to fig. 5.9 suggest that the 1 kbytes packet length is the optimum packet size to be chosen for the data transfer. For a given number of simultaneous file transfers, the packet length of 1 kbytes gave us the lowest delays.

Now we look at a different file size namely 1.2 Mbytes and a fixed packet length of 1 kbytes. Fig. 5.10 and 5.11 show the graph of file transfer delay versus the number of simultaneous file transfers (or Inter-LAN sessions) and the corresponding T1 utilization versus number of

file sessions. From Fig. 5.11 we see that T1 starts to saturate when about 9 simultaneous file transfers are established in the case of 0% local traffic and 10 sessions in the case of 50% intra-LAN traffic. The corresponding delays are 31.8 and 37.2 seconds. Higher delays occur at 50% intra-LAN traffic than at 0% local traffic. This is normal since the LANs are more busy in the 50% intra-LAN traffic. We observe also that the T1 utilization is less at 50% intra-LAN. This, as explained earlier, is due to the fact that more collisions are likely to happen at 50% intra-LAN traffic hence a retry to get access to the medium occurs more frequently which implies higher delay. When compared to the results obtained for the 64 kbytes file, we can observe that less number of simultaneous file transfer is obtained in the case of 1.2 Mbytes file.

In the next section we examine the same parameters used for Ethernet but under Token Ring topology.

5.3.3 T1 Interconnecting Token Ring LANs

In this section we present the results obtained from the simulation of two token ring LANs interconnected by T1. Since token ring offers priority to its users, we have examined the case where higher priority was allocated to the bridge. Throughout this study we shall present results with and without priority allocated to the bridge.

Consider the 64 kbytes file transfers, where Figs. 5.12, 5.13 and 5.14 show the results for a 1 kbyte packet length with no bridge priority. Figures 5.15, 5.16 and 5.17 show the corresponding results when a priority was allocated to the bridge. Comparing these two sets of graphs we observe that there is an insignificant difference in the delay per number of simultaneous file transfers sessions and the T1 utilization changes only slightly with or without priority.

At 0% intra-LAN traffic, T1 saturates and becomes the bottleneck in both cases. Whereas at 50% intra-LAN traffic the T1 is no longer the bottleneck. The Ring becomes the bottleneck.

(see Fig. 5.14 and 5.17).

At 50% intra-LAN traffic the number of simultaneous file transfers is limited by the Ring. The use of priority at the bridge did not improve the results. On the contrary, we obtained lesser number of simultaneous file transfer. This comes from the fact that, with or without priority, the bridge is capable to process a fixed number of packets per second. By providing priority to the bridge, the processor queue gets longer and packets awaits longer therefore less file transfer sessions could be opened simultaneously.

Different packet lengths were not studied in detail, but a few simulation runs were taken and gave us the same observation as in the case of Ethernet. i.e. in the case of 64 bytes packet length, we have a very high delay as compared to the case of packet lengths of 1.5 kbytes and 1 kbytes, for the same number of file transfer sessions. As an example, considering 16 simultaneous file transfers (0% intra-LAN traffic) we observe delays of 3, 3, and 11.3 seconds at packet length of 1.5 k, 1 k and 64 kbytes respectively. Results suggest that there exists an optimum packet length which is about 1 kbytes, that provides maximum data throughput.

The 1.2 Mbytes file size was studied with and without bridge priority (see Fig. 5.18, 5.19 and 5.20 for results with no bridge priority, and Fig. 5.21, 5.22 and 5.23 for results with bridge priority). Again we observe that with or without bridge priority there is no significant difference in terms of delays for a given number of simultaneous file transfers. However fewer file transfer sessions are obtained when bridge priority is allocated.

The number of simultaneous file transfers was limited by the T1 link at 0% intra-LAN traffic and by the ring utilization at 50% intra-LAN traffic.

We next present the results obtained for AppleTalk LANs.

5.3.4 T1 Interconnecting AppleTalk LANs

Here we employ a bus topology as in the case of Ethernet. The maximum LAN speed for the Apple Bus is 230.4 Kbps. Since the packet cannot exceed 512 bytes, we have used this maximum packet length throughout the simulation. Also for reasons due to the LAN protocol one cannot exceed . in practice, more than 32 simultaneous file transfers between the two LANs. Figures 5.24 and 5.25 show the results obtained for 64 Kbytes files and a packet length of 512 bytes and for the different intra-LAN traffics (0% and 50%). From these results we can see that, there is a significant difference in terms of delays when compared to Ethernet or Token Ring results. This is due to fact that the Applebus runs at much lower rates than Ethernet (10 Mbps) or Token Ring (4 Mbps). A comparison of the three LANs is done in section 5.3.5. Furthermore the bus utilization is the limiting factor in both cases, i.e. 0% and 50% intra-LAN traffic, the T1 can never be a bottleneck in this case since it runs at a speed of 1.544 Mbps i.e. faster than the speed of the LAN.

The same observations can be made when transferring a file of 1.2 Mbytes. Figures 5.26 and 5.27 show the results. One should mention that these delays can be intolerable in some applications. Thus either a limit to the simultaneous file transfers must be imposed or a change of LAN technology has to be made. As a typical example, from these results, consider the case where the LANs have 50% local traffic and about 27 simultaneous file transfer sessions are opened, then a user experiences a delay of about 45 minutes (2700 seconds) for the transfer of a 1.2 Mbytes file.

5.3.5 Comparison of LAN Performance

In all the three different Local Area Networks we have studied, we observe the following general behaviors:

- As the number of simultaneous file transfers increases the file transfer delay increases.

- At 50% Intra-LAN traffic, the number of simultaneous file transfers is limited by the T1 link in the case of Ethernet, the Ring Bus utilization in the case of Token ring and the Apple Bus in the case of AppleTalk configurations.
- At 0% Intra-LAN traffic, T1 was the limiting factor in the case of Ethernet and Token Ring. However only a small fraction of the T1 bandwidth was used when Appletalk was used. This is due to the fact that the offered bandwidth by Appletalk is 230.4 kbps which is much smaller than the T1 capacity (1.544 Mbps).
- Ethernet appears to be a better candidate than the token ring or Appletalk as it gives the lowest delays for a given number of simultaneous file transfers (see table 5.1 and 5.2).
- From this study, it is apparent that if the packet length is small, the system is operating inefficiently. In this case, the link is transmitting control bits rather than real data. On the other hand, if the packet length is made too long, after a certain length the resulting data throughput is reduced, since longer delays arise at the bridge. Analysis of Ethernet and token ring indicates that packet length of 1 kbyte provides maximum data throughput. Such length is in fact typical of packet lengths used in practice.

Now, with the above mentioned packet length in mind, we attempt to compare the results for the three different LANs technologies. This is done in the case of file size of 64 kbytes and a packet length of 1 kbytes for Ethernet and Token Ring and 512 bytes for Appletalk. The priority at the bridge is not considered in the case of Token Ring.

Table 5.1 shows, for a given number of simultaneous file transfers, the corresponding delay for each type of LAN used. Also it shows the entity on the overall system that gets saturated or starts to saturate mostly. The same is done for the 1.2 Mbytes file (see table 5.2).

We note a negligible difference in the file transfer delays between Ethernet and Token Ring at small number of file transfer sessions. However Ethernet outperforms Token Ring (4Mbps)

Intra-LAN traffic (%)	Number of file transfer sessions	File transfer delay (sec)			System bottleneck		
		Ethernet	token ring	AppleTalk	Ethernet	token ring	AppleTalk
0	2	1.0	1.0	5.5	T1	T1	bus
	6	1.3	1.4	15.2			
	10	1.8	2.0	25			
50	2	1.0	1.1	12.3	T1	ring	bus
	6	1.4	1.85	33			
	10	2.0	2.9	55			

Table 5.1: LAN Comparison for 64 kbytes files.

Intra-LAN traffic (%)	Number of file transfer sessions	File transfer delay (sec)			System bottleneck		
		Ethernet	token ring	AppleTalk	Ethernet	token ring	AppleTalk
0	2	11.5	11.5	99	T1	T1	bus
	6	22.5	23	286			
	10	34.5	37	480			
50	2	11.7	12.2	222	T1	ring	bus
	6	23.5	31.9	635			
	10	36	52.6	1023			

Table 5.2: LAN Comparison for 1.2 Mbytes files.

as the number of simultaneous file transfers is increased. On the other hand AppleTalk gives a very high transfer delay.

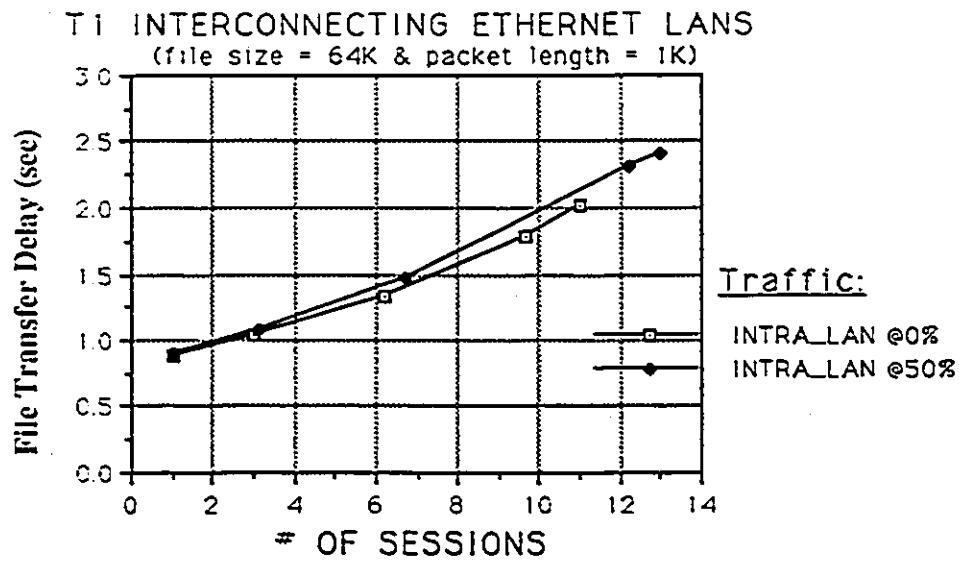


Figure 5.4: Mean file transfer delay versus the number of inter-LAN file transfers sessions.

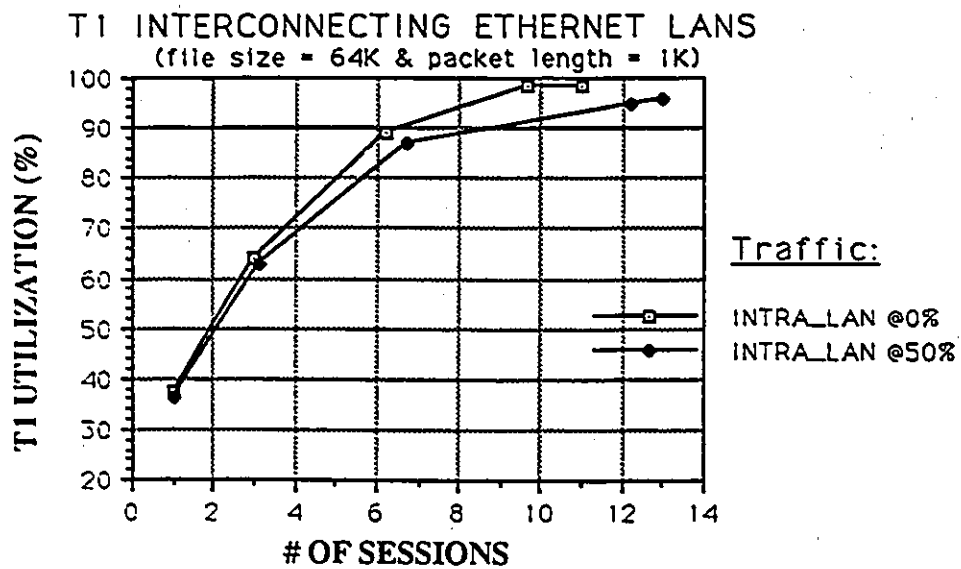


Figure 5.5: T1 utilization versus the number of inter-LAN file transfers sessions.

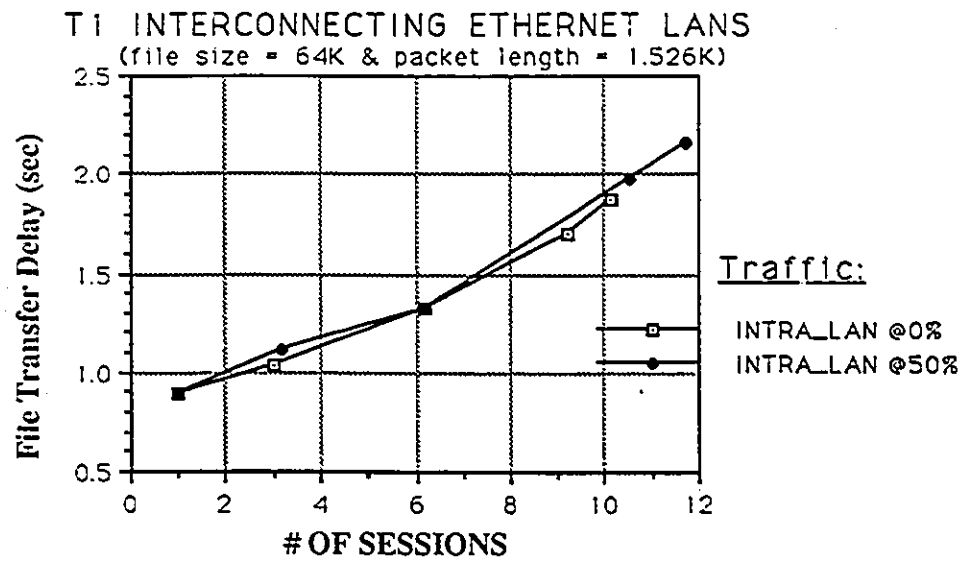


Figure 5.6: Mean file transfer delay versus the number of inter-LAN file transfers sessions.

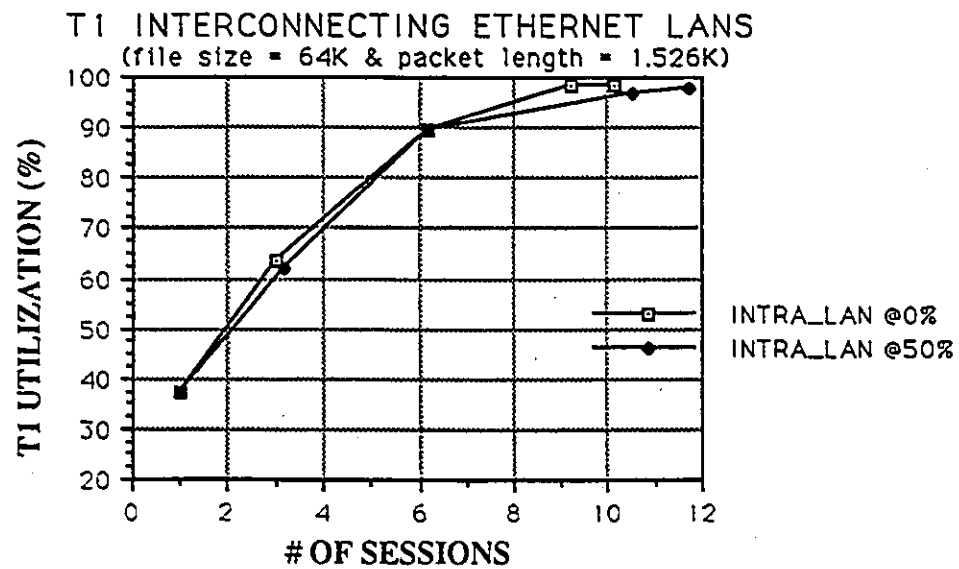


Figure 5.7: T1 utilization versus the number of inter-LAN file transfers sessions.

T1 INTERCONNECTING ETHERNET LANS

File size= 64K & packet length= 64bytes

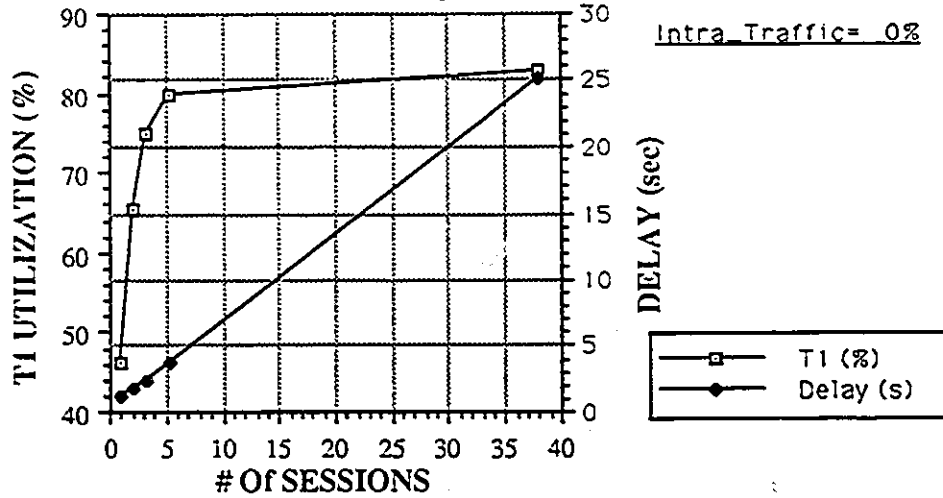


Figure 5.8: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING ETHERNET LANS

File size= 64K & packet length= 64bytes

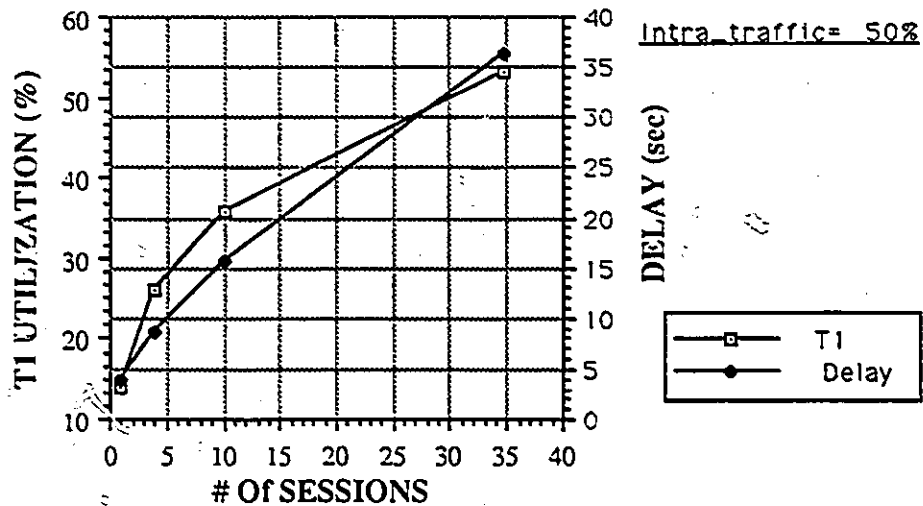


Figure 5.9: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

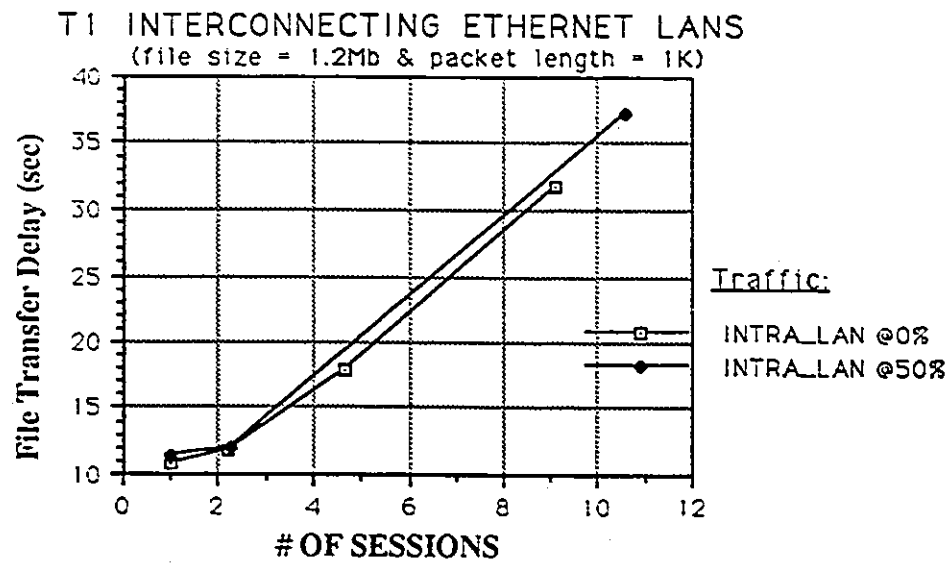


Figure 5.10: Mean file transfer delay versus the number of inter-LAN file transfers sessions.

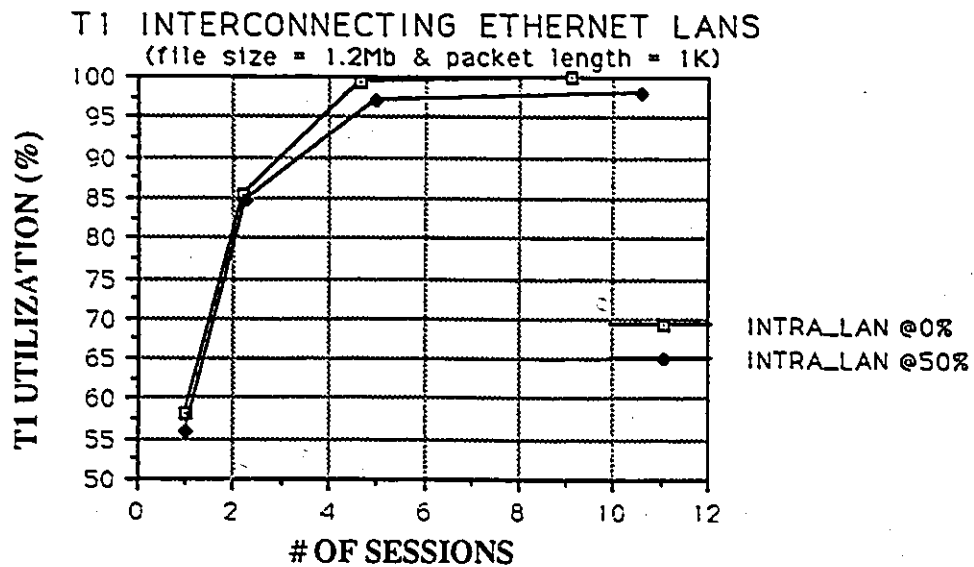


Figure 5.11: T1 utilization versus the number of inter-LAN file transfers sessions.

T1 INTERCONNECTING TOKEN RING LANS

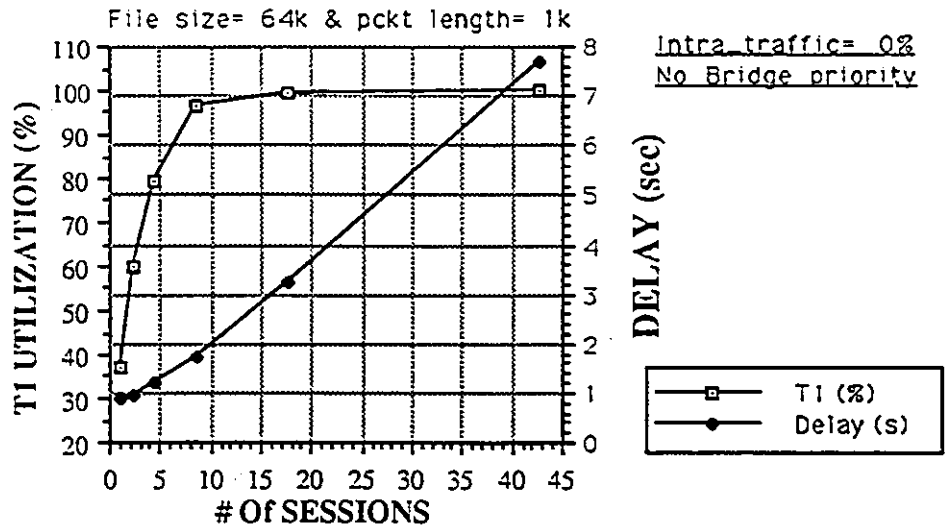


Figure 5.12: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING TOKEN RINGS

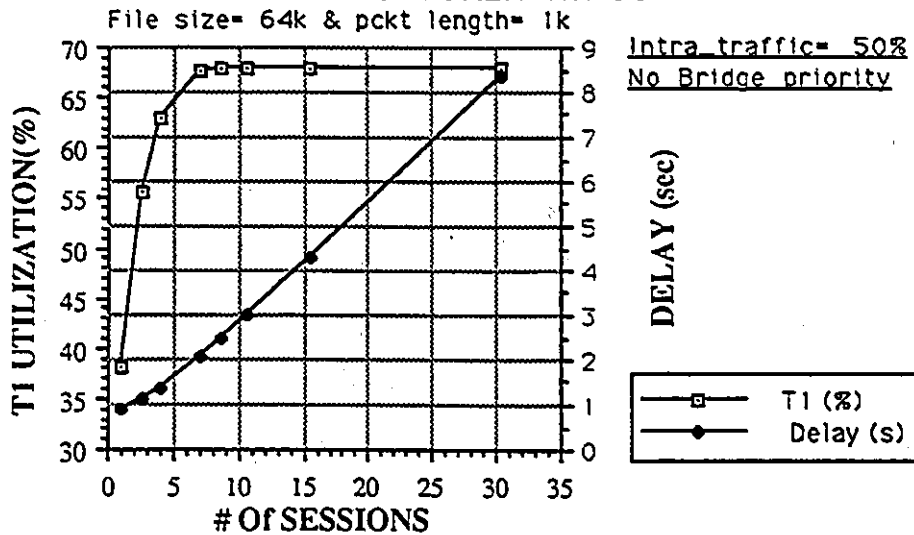


Figure 5.13: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

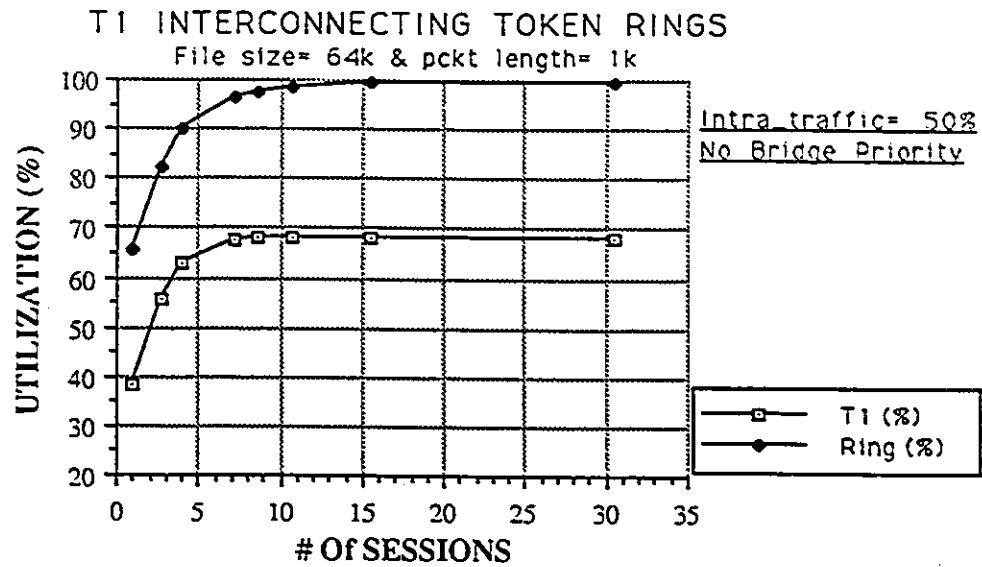


Figure 5.14: T1 & Ring utilizations versus the number of inter-LAN file transfer sessions.

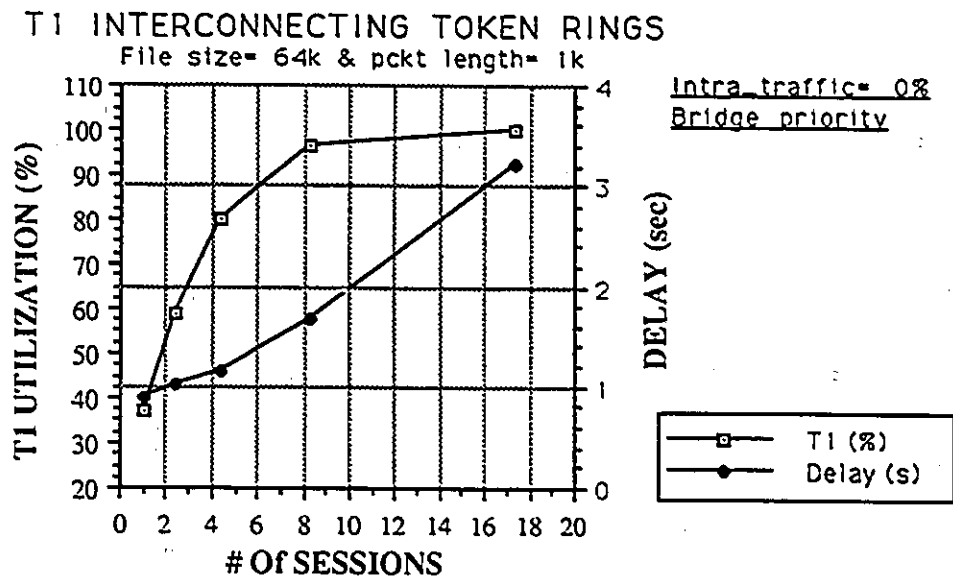


Figure 5.15: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING TOKEN RINGS

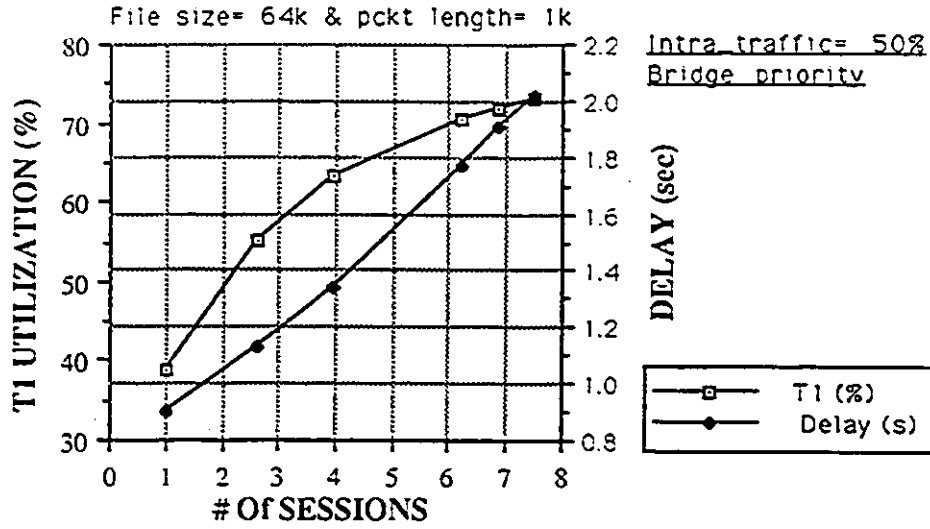


Figure 5.16: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

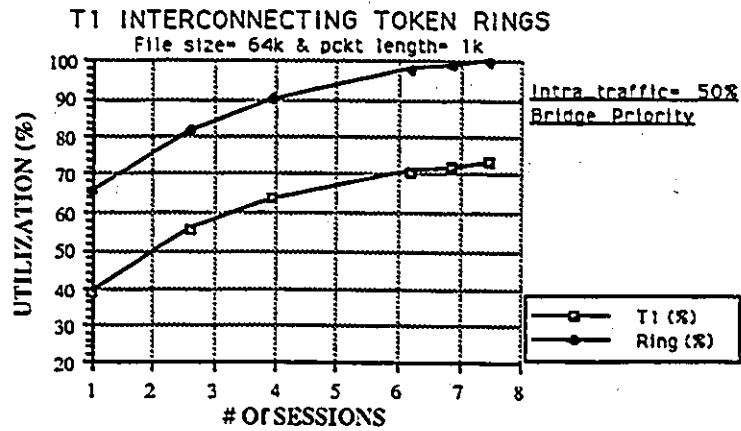


Figure 5.17: T1 & Ring utilizations versus the number of inter-LAN file transfer sessions.

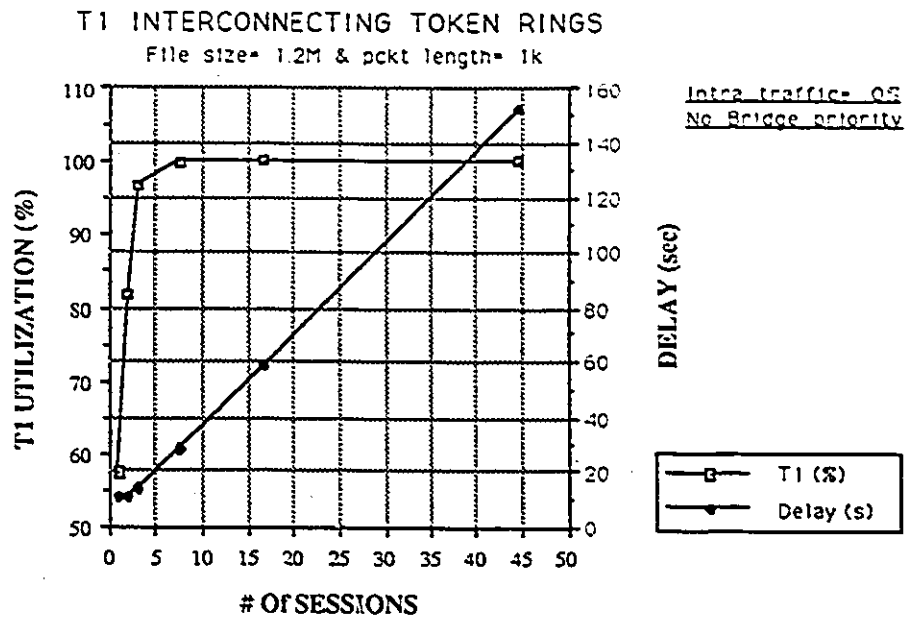


Figure 5.18: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

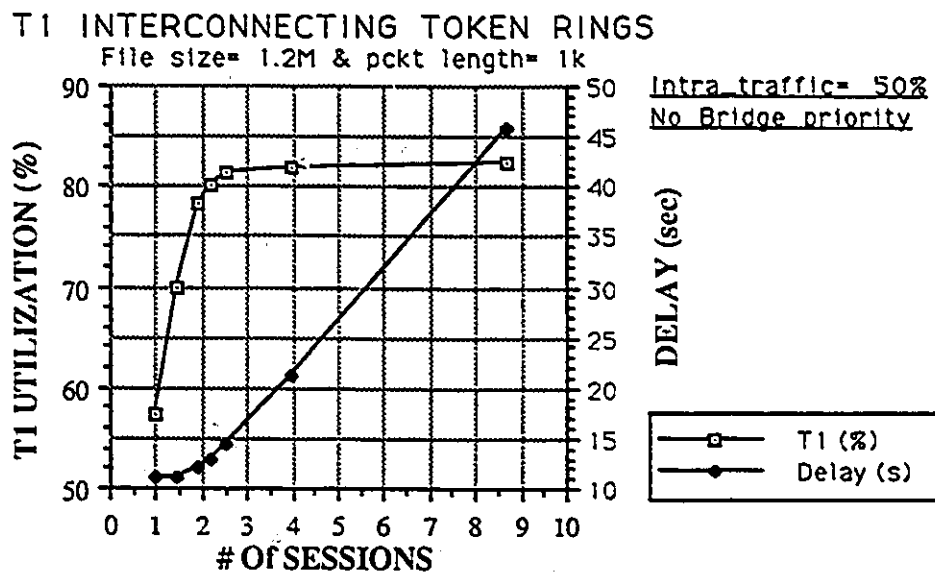


Figure 5.19: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

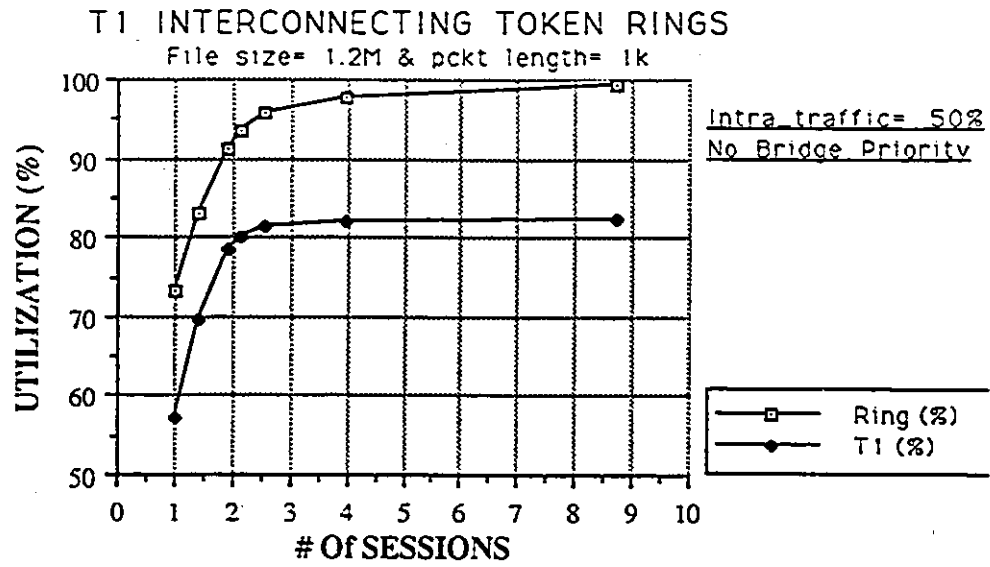


Figure 5.20: T1 & Ring utilizations versus the number of inter-LAN file transfer sessions.

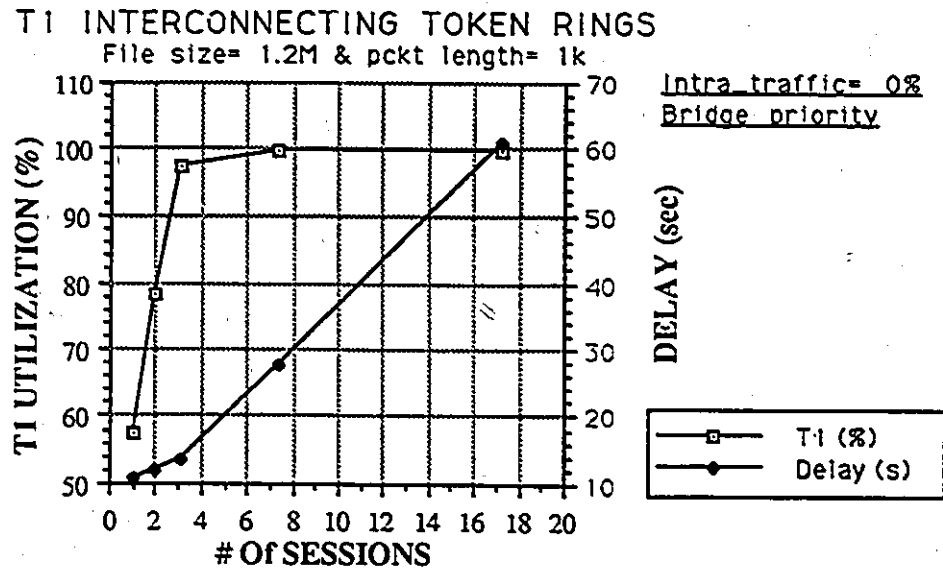


Figure 5.21: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING TOKEN RINGS

File size= 1.2M & pkt length= 1k

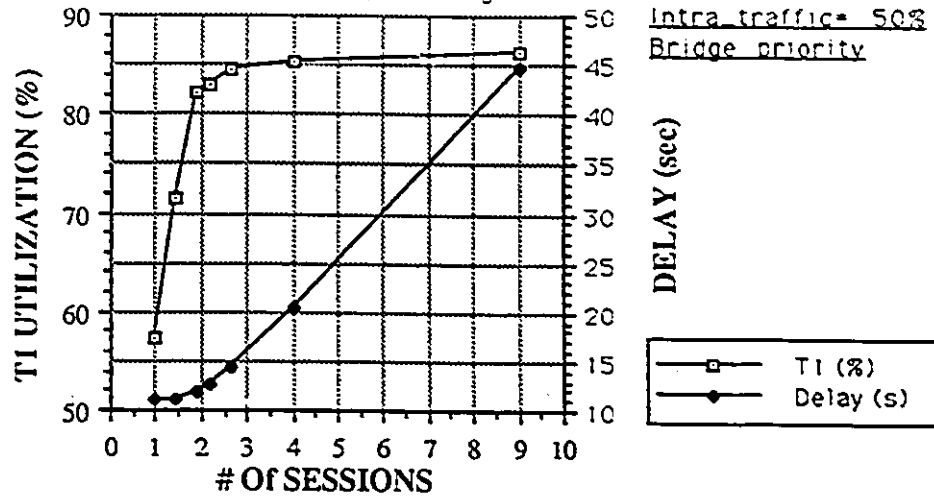


Figure 5.22: T1 utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING TOKEN RINGS

File size= 1.2M & pkt length= 1k

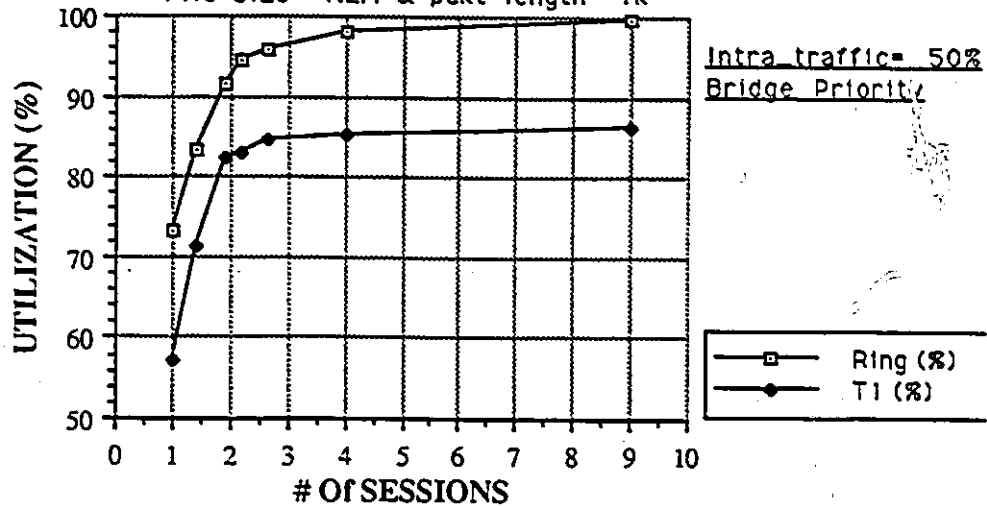


Figure 5.23: T1 & Ring utilizations versus the number of inter-LAN file transfer sessions.

T1 INTERCONNECTING AppleTalk LANS

(File size = 64K & pkt length = 518 bytes)

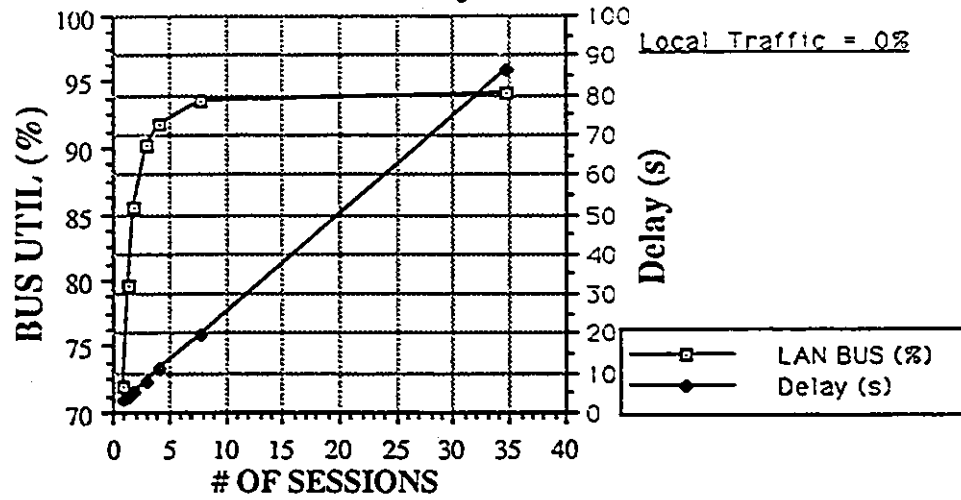


Figure 5.24: AppleBus utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING AppleTalk LANS

(File size = 64K & pkt length = 518 bytes)

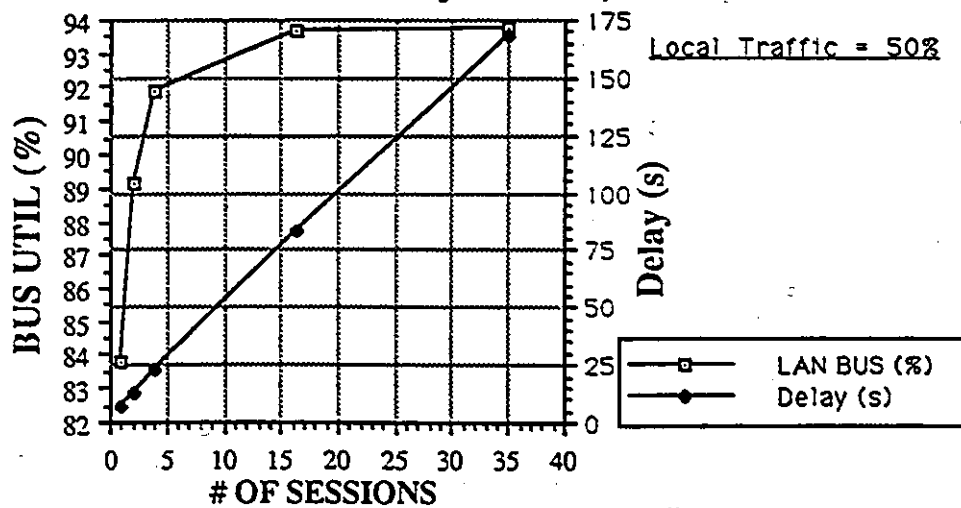


Figure 5.25: AppleBus utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING AppleTalk LANS

(File size = 1.2M & pkt length = 518 bytes)

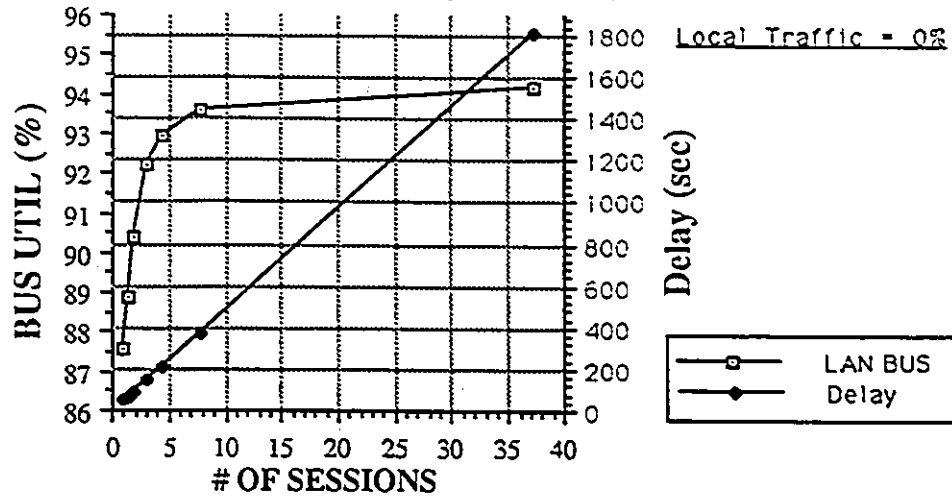


Figure 5.26: AppleBus utilization & file transfer delay versus the number of inter-LAN sessions.

T1 INTERCONNECTING AppleTalk LANS

(File size = 1.2M & pkt length = 518 bytes)

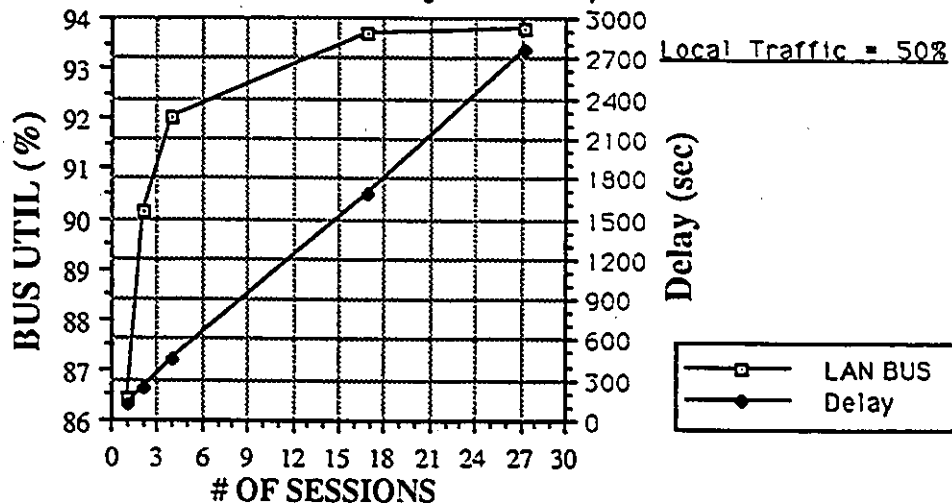


Figure 5.27: AppleBus utilization & file transfer delay versus the number of inter-LAN sessions.

Chapter 6

Conclusions and Suggestions for Further Research

The rapid growth in the use of office information systems (OIS) over the last years has significantly increased the demand for electronic communications in offices. In this thesis, we have analyzed the performance of office communications consisting of both local and intersite communications facilities. Three different LAN technologies have been considered, namely Ethernet, Token Ring and AppleTalk, and two different bit rates of 56 kbps and 1.544 Mbps (T1) for intersite communications links.

The main aim of our study was the evaluation of intersite office communications needs. Therefore, the general architecture of the communications systems considered consisted of a pair of LANs linked by a public communications link.

6.1 Office Communications

We started our analysis, by considering the communications needs in a fully automated office of the future. In a first instance, we considered the use of an intersite link of 56 kbps. From our results we have observed that a link of 56 kbps can adequately provide the level of service required by the typical future office communications needs. For example, we have obtained the maximum number of workstations which can be supported by the interwork system under

different LAN configurations (see 4.2.2).

For the situations where the interconnected LANs are token rings or AppleTalk based, if we consider that the inter-LAN traffic is 20% of the total generated traffic, the maximum number of workstations which can be supported by the system is restricted to the maximum number of workstations which can be physically supported by each LAN [APPLE,IBM86]. If the inter-LAN traffic is brought up to 50% of the total traffic, the above remark only applies to the case of AppleTalk LANs. Ethernet based LANs and token rings support in this case less workstations than their maximum limit.

It is important to note here that we have assumed that the current office applications are not time constrained. Despite this fact, we have also considered the use of a T1 link as the intersite communications link. As expected, we have obtained better results for this second system configuration. However, we have noticed that the T1 link is underused (less than 18% utilization over all the configurations examined). Other useful and more realistic results were presented in order to simulate the current volumes that flow electronically between offices nowadays. It was found that two major factors contribute to the maximum number of workstations which can be supported by each LAN: the remote/local traffic ratio and the data exchange rate that each workstation sends or receives per working day.

From these results we have been able to assess the utilization of the intersite link, as well as the transfer delays for different types of documents and different conditions. These results can be used for estimating the expected level of service to be provided by such kind of systems.

6.2 File Transfer Applications

Finally, in this thesis, we have examined one of the most important sources of traffic in an office environment: file transfers. As for the previous studies, we have considered an intersite architecture of the underlying communications system. However, in this part of our study we have analyzed the interwork system capacity for supporting "continuous" file transfers.

Clearly this is a worst-case traffic scenario. In this case, we have compared the results for different LAN configurations by assuming different numbers of inter-LAN file transfers in the system. Only T1 utilization has been considered since large volumes have been assumed to be exchanged between remote stations. The simulation results have shown that for the configuration based on Ethernet or token ring, the potential bottleneck of the system is the T1 link.

6.3 Suggestions for Further Research

In this study we have evaluated office information systems supported by both local and intersite communications facilities. From the results, we have been able to assess the level of services provided by different system configurations. Both, current and future office applications have been taken into account. Further research can be conducted on the system. For example: studying the behavior of the system when congestion problems arise. By introducing some losses due to errored frames or limited space at the bridge, frame relaying can then be compared to packet switching in terms of system throughput and delays. Furthermore, if system delays can be found for low probabilities of Bit Error Rates (BER), then results can be extrapolated to obtain delays for higher probabilities of BER (10^{-9}). As for the file transfer applications one can introduce some thinking times during the file transfer activities which could be relevant to some applications.

Finally, the results obtained in this thesis will be useful to organizations, such as Bell Canada or any other telephony company, which provide services such as the T1 link or the 56 kbps link.

References

- [ANSI85A] ANSI/IEEE Standard 802.2, "Logical Link Control", IEEE Project 802. IEEE, New York, 1985.
- [ANSI85B] ANSI/IEEE Standard 802.3, "CSMA/CD Access Method and Physical Layer Specification", IEEE Project 802, Local Area Network Standards, IEEE, New York, 1985.
- [ANSI85D] ANSI/IEEE Standard 802.5, "Token Ring Access Method and Physical Layer Specification", IEEE Project 802, Local Area Network Standards, IEEE, New York, 1985.
- [APPLE] Apple Computer Inc., "Inside AppleTalk", 1985.
- [BELL] Nicholas D. Georganas, Luis Orozco Barbosa, Richard Vallee and Bilal Awada, "Local Area Network Performance Analysis", *Bell Canada*, Report written for Bell Canada under Research Contract, Dec. 1989.
- [BERT] D. Bertsekas and R. Gallager, Data Networks, *Prentice Hall Inc.*, New Jersey, 1987.
- [BHUSH] B. Bhushan, "A User's Guide to Frame Relay", *Telecommunications*, North American Edition, pp. 39-43, Jul. 1990.
- [BNR] J. Lamont, J. Doak and M. Lui, "LAN Interconnection via Frame Relaying", *Bell Northern Research*, Ottawa, CANADA, Dec. 1990.
- [BUX81] W. Bux, "Local-Area Subnetworks: A Performance Comparison", *IEEE Trans. on Comm.*, vol. COM-29, no. 10, pp. 1465-1473, Oct. 1981.
- [BVAG] Luis Orozco Barbosa, Richard Vallee, Bilal Awada and Nicholas D. Georganas, "Communications Services for Real-Time Multimedia Office Applications", to be presented at *GLOBECOM'90*, Dec. 1990.
- [CHERU] Rao J. Cherukuri and Jeffrey H. Derby, "Frame Relay: Protocols and Private Network Applications", *Proc. INFOCOM'89*, Ottawa, CANADA, pp. 676-684, April 1989.
- [CHIA] C. Chiang, B. Han and L. Hinz, "Datapath - End-to-end Digital Connectivity-Now", *Telesis*, vol. 15, no. 1, pp. 37-43, 1988.

- [DEPRY] M. De Prycker, "Evolution from ISDN to BISDN: a logical step towards ATM", *Computer Comm.*, vol. 12, no. 3, pp. 141-146, June 1989.
- [ENGEL] G.H. Engel, J. Gropusso, R.A. Lowenstein and W.G. Traub, "An Office Communications System", *IBM Systems Journal*, vol. 18, no. 3, pp. 402-431, 1979.
- [GEOR87] N. D. Georganas and N. Naffah, "Integrated office systems over LANs - a performance study", *Computer Communications*, vol. 10, no. 6, pp. 291-296, Dec. 1987.
- [GEOR89] N. D. Georganas, M. Goldberg, L. Orozco-Barbosa and J. Mastronardi, "A Multimedia Communications System for Medical Applications", *Proc. ICC'89*, Boston, USA, pp. 1496-1500, June 1989.
- [GLASS] B. Glass, "Under the Hood: The Token Ring", *Byte*, vol. 14, no. 1, pp. 363-376, Jan. 1989.
- [IBMS6] IBM Token Ring Network PC Adapter, *Reference Manual*, Ref Lib 69X7830, Boca Raton, Fl., U.S.A., June 1986.
- [IBMS8] IBM Canada Ltee, "New LAN Technology Quadruples Speed of Token Ring Data Transmissions", *IBM Solutions*, no. 5, pp. 14-15, 1988.
- [ISO] ISO/TC97/SC6/WG1, "Draft Proposed Addendum to ISO DIS 8802/2 Logical Link Control-Acknowledgement Connectionless Service", 14th Draft, June 1986.
- [LIEB] M. A. Lieberman, G.J. Selig and J.J. Walsh, *Office Automation - A Manager's Guide for Improved Productivity*, John Wiley & Sons, 1982.
- [MCCA] J.C. McCallum and C.S. Yap, "A Survey of Singapore Offices", Technical Report TRB3/89, DISCS, National University of Singapore, Dec. 1988.
- [MOUF] H.T. Mouftah and S.E. Tavares, *Information Networking: A Ten Year Forecast*, Research Report submitted to Bell Canada under contract #ORS-88-001, Kingston, Ont., June 1988.
- [MOWS] A. Mowshowitz, "The Social Dimensions of Office Automation", *Advances in Computers*, Vol. 25, pp. 363-399, 1986.
- [QNAP2] QNAP2. Reference Manuel, Version V03, Bull and INRIA. May 1984.
- [SCHM] B. Schmidt, "AppleTalk Performance Investigation (or How Many Macs on a LAN?)", *Proceedings Macintosh Business Conference & Exposition*, New York, USA, pp. 1-37, April 1989.
- [SCHO] J.F. Schoch and J.A. Hupp, "Measured Performance of an Ethernet Local Network", *Communications of the ACM*, vol. 23, no. 12, pp. 711-721, Dec. 1980.
- [SCHW] M. Schwartz, *Telecommunication Networks*, Addison-Wesley Publishing Company, 1987.

- [SMIT] S.A. Smith and R.I. Benjamin, "Projecting Demand for Electronic Communications in Automated Offices", *ACM Transactions on Office Information Systems*, vol. 1, no. 3, pp. 211-229, July 1983.
- [STAL] W. Stallings, *Data and Computer Communications*, Macmillan Publishing Company, Second Edition, New York, 1988.
- [STALL] W. Stallings, "When One LAN Is Not Enough", *Byte*, vol. 14, no. 1, pp. 293-298, Jan. 1989.
- [THIE] E. Thiele, "Charting the Bridges", *LAN Magazine*, March 1989.
- [UHLIG] R.P. Uhlig and R.S. Emerson, "Architectural Implications of Office Systems", *Information Network and Data Communication 1*, D. Khakhar (Editor), Elsevier Science Publishers B.V. (North Holland), IFIP, pp. 59-88, 1987.
- [WATA87] K. Watanabe, "Integrated Office Systems: 1985 and Beyond", *IEEE Communications Magazine*, vol. 25, no. 12, pp. 74-80, 1987.

Appendix A

Overview of QNAP2

This appendix is intended as a fast overview of QNAP2 (Queueing Network Analysis Package, version 2) [QNAP2] by presenting the objective and illustrating the main features of this software package. For a detailed and complete description of the package the reader should refer to the QNAP2 Reference manual.

A.1 QNAP2 Objective

Research efforts in the field of modelling and evaluation of computer systems performance have contributed to major theoretical advances in methods and tools, and to the elaboration of a general methodology for the performance modelling of computer architectures and installations. This methodology is based on the representation of a computer system as a network of queues and servers. From these research efforts, a wide spectrum of efficient resolution techniques for queueing network models having complementary ranges of utilization has resulted. These methods differ by their cost of operation and by the limitations they impose on the generality of the model being studied.

Each method realizes a certain compromise between cost, accuracy and applicability. Therefore it is important to be able to have access to these different techniques in order to select the one which represents the best compromise for the problem to be analysed. The

main objective of QNAP2 is to provide computer systems analysts and users with a tool which facilitates the practical use of these methods.

Hence QNAP2 can be defined as a system for describing, handling and solving queueing network models. QNAP2 is comprised of a specification language (based on Pascal) which is used for the description of the models under study and the control of their resolution, and of several resolution modules, or solvers, implementing the different algorithms currently available.

A.2 QNAP2 Main Features

QNAP2 consists of:

- A collection of resolution algorithms, including discrete event simulation, exact and approximate mathematical methods.
- A common user interface for model description, analysis control, and result presentation.

The QNAP2 package provides the analyst with a framework for modelling computer systems and with the techniques for solving the models. In QNAP2, a queueing network consists of a set of stations through which customers circulate according to given rules. The processing done by each station may be described by a simple time duration or by a complex algorithm which may include synchronization operations.

The results of the simulation are represented in a form of a table. For each station, the results give the mean service time, the utilization, the mean number of customers queued and in service, the mean response time and the number of customers served from the beginning of the simulation.

The solvers implemented in QNAP2 can be classified into three categories:

1. discrete event simulation

2. exact analytical solvers:

- analytical results based on the theorem developed by Baskett et al.
- convolution algorithm
- mean value analysis algorithm

3. approximate analytical solvers:

- iterative methods
- diffusion approximations
- heuristic approaches

When an analytical solution is required, for any problem under study, QNAP2 selects the most appropriate solver from the set of the analytical solvers presented above. If the exact solution to the model cannot be found by the analytical solvers then one can use simulation techniques. However one must provide some additional information to define the simulation run. This information concerns:

- the simulation length
- the confidence interval estimation
- the tracing options

The definition of the simulation length is mandatory. The other definitions are optional. Three different methods are implemented in QNAP2 for the derivation of confidence intervals: the replication method, the regeneration method and the spectral method.

- The replication method which consists of generating several sample paths of the model studied, so that these sample paths are statistically independent and identical. This is achieved by resetting the original initial state of the model at the beginning of each replication, and by using a different random number stream for each replication.

- The **regeneration method** which consists of splitting the the simulation run into several successive intervals, so that the model behavior in these intervals be statistically equivalent and independent. The length of the intervals should be large enough so that within an interval the behavior of the model be as independent as possible of its behavior in the previous interval. On the other hand, the number of intervals should be large enough to ensure an accurate estimation of the confidence intervals.
- The **spectral method** which applies to correlated samples provided that the identical distribution property is satisfied. The main advantage of the spectral method over the two previous methods is that the user needs not bother with the choice of specific parameters. The method applies to the analysis of the stationary behaviour of any simulated model. It does not rely on the independence of the subintervals. The correlation of the variance and covariance is explicitly taken into account in the estimation of the confidence intervals. Further the confidence intervals produced by this method are larger than those of other methods.

In the thesis, the analysis of the systems has been carried by simulation using the spectral method to estimate the confidence intervals for the results. The confidence intervals are produced with a confidence level of 95%. The confidence intervals are themselves estimates because the computation of exact confidence intervals would require an a-priori knowledge of the estimated characteristics.

Appendix B

Program listings

B.1 Simulation Program of Office Communications

```

/CONTROL/OPTION=NSOURCE;
CLASS=ALL QUEUE;

```

```

&
& *****
& ---->>>> OFFICE AUTOMATION
& *****
&
& *****
& LAN INTERCONNECTION VIA T1
& This program simulates the communication between two office sites
& each working on an ETHERNET LAN and are interconnected by either
& a T1 link of 1.544Mbps or a 56Kbps link. The Logical Link Control
& (LLC) is used to control the End-to-End transmission of data
&
& *****
&
&
&

```

```

/DECLARE/
INTEGER

```

```

1 = 2, & number of interconnected LANs
bg = 30, & of background nodes per LAN
node=bg+1, & number of nodes on each LAN
info=1024, & info data length
slot=64, & length of a slot in bytes
s_frame=slot, & MAC control data
i_frame=25+info, & I-frame length
byte=8, & 1 byte --> 8 bits
jam=4, & jamming signal length
window = 8, & window size.
ind=3,
nb_typ=4, & four different types of documents
last_len(nb_typ), & last page length of a document
nb_seg(nb_typ), & number of segments per type
ws, & number of workstations
&***** Ethernet parameters *****
br(1)=0, COLLI(1), discard(1),
i, j;
&***** bridge parameters *****
t_bridge=120E-6, & processing time in bridges
t_ram=160E-9, & processing time per byte
tI_rate=56E3/8.0, & 56 kbps/byte rate
&***** Ethernet parameters *****
lan_spd=10E6/byte, & LAN speed
lan_len=1.0, & LAN length in km
prog=5.0E-6, & propagation delay per KM
t_prg=prog*lan_len, & prop. time of the packet thru the net
t_jam=jam/lan_spd, & jam time
t_slot=slot/lan_spd, & slot time
t_del=9.6E-6, & inter gap time
&***** workstation parameters *****
pr_publi, & probability for getting a publicat.
pr_docu, & probability for getting a document
pr_mess, & prob. for getting a message
pr_finan, & prob. for getting a financial form
size(nb_typ),
tdelay(nb_typ), num(nb_typ, ind),
mdelay(nb_typ, ind), & intermediate measured delay
cdelay(nb_typ),
mfile,
page(nb_typ), & number of pages per type
load, rate, & load on the network
inter, & inter LAN traffic probability
&***** simulation parameters *****
tperiod; & time interval between results
no_idle(1, node);
icI;

```

```

REAL

```

```

BOOLEAN
CLASS INTEGER

```

```

CLASS          ack,seg1(nb_typ),seg2(nb_typ),
               one;
QUEUE INTEGER  il,is,active,type,          & IDs for LANs and stations
               cnt,y,inext,
               rem_lan;                    & holds address of remote LAN
QUEUE          &***** T1 + Token rings parameters *****
               T1(1),bridge(1),mac1(node),mac2(node),initial,bus(1),
               &***** background load nodes parameters *****
               bg1(bg),bg2(bg),llc1(bg),llc2(bg),
               buf1(bg),buf2(bg),wind1(bg),wind2(bg),time;
               &***** workstation parameters *****
FLAG          net(1),fl(1,node),poll(1);
CUSTOMER INTEGER in,c,
               last,                      & last image packet ?
               length,                    & packet length
               attempt(1),backoff(1),E(1),
               sour_llc,dest_llc,
               sour_lan,dest_lan;         & source and destination LAN
CUSTOMER REAL  start;
REF CUSTOMER   pack(1),
               tok(1);

&*****
& This macro simulates the behaviour of the packet processing in the bridges.
&*****
$MACRO bridges(mac)
SERVICE = BEGIN
    CST(t_bridge+length*t_ram);    & processig time at the bridges
    IF dest_lan = il
    THEN TRANSIT(mac(node))
    ELSE TRANSIT(T1(il));
END;
$END

/STATION/NAME = bridge(1);          & bridge on LAN1
$bridges(mac1)

/STATION/NAME = bridge(2);          & bridge on LAN2
$bridges(mac2)

&*****
& This station simulates the behaviour of the T1 link access queue
&*****
/STATION/NAME = T1;
SERVICE = BEGIN
    CST(length/t1_rate);            & transmission time on T1 or 56kbps
    TRANSIT(bridge(rem_lan));
END;

/STATION/NAME=initial;
SERVICE=BEGIN
    SET(net(1));                    & set flag for ethernet on LAN1
    SET(net(2));                    & set flag for ethernet on LAN2
    TRANSIT(OUT);
END;
INIT(one)=1;

/STATION/NAME = bus;
TYPE=RESOURCE,INFINITE;
SERVICE = BEGIN
    CST(length/t1_rate);
    TRANSIT(bridge(rem_lan));
END;

&*****
& This macro simulates the behaviour of the ethernet protocol that is used *

```

```

& on the ethernet LAN medium.
& *****
$MACRO ethernet(n)
& ETHERNET protocol
& *****
    attempt(n) := 0;
    & CARRIER SENSING
    & *****
    WAIT(net(n));
    attempt(n) := attempt(n) + 1;
    & CHANNEL ALLOCATION
    & *****
    P(bus(n));
    CST(t_prg);
    br(n) := br(n) + 1;
    RESET(net(n));
    & COLLISION DETECTION
    & *****
    CST(t_prg);
    V(bus(n));
    WHILE br(n) > 1 DO
        BEGIN
            COLLI(n) := COLLI(n) + 1;
            P(bus(n));
            CST(t_jam);
            V(bus(n));
            & BACKOFF CALCULATION
            IF attempt(n) = 1
            THEN backoff(n) := 2
            ELSE backoff(n) := backoff(n) * 2;
            E(n) := RINT(0, backoff(n) - 1);
            br(n) := br(n) - 1;
            IF br(n) = 0
            THEN SET(net(n));
            & BACKOFF
            IF attempt(n) > 15
            THEN
                BEGIN
                    & DISCARD INACTIVE
                    discard(n) := discard(n) + 1;
                    CST(t_slot * RINT(0, 1023));
                    WAIT(net(n));
                    attempt(n) := attempt(n) + 1;
                    CST(t_prg);
                    br(n) := br(n) + 1;
                    RESET(net(n));
                    CST(t_prg);
                END
            ELSE
                BEGIN
                    IF attempt(n) > 10
                    THEN
                        BEGIN
                            CST(t_slot * RINT(0, 1023));
                            WAIT(net(n));
                            attempt(n) := attempt(n) + 1;
                            CST(t_prg);
                            br(n) := br(n) + 1;
                            RESET(net(n));
                            CST(t_prg);
                        END
                    ELSE
                        BEGIN
                            CST(t_slot * E(n));
                            WAIT(net(n));
                            attempt(n) := attempt(n) + 1;

```

```

        CST(t_prg);
        br(n):=br(n)+1;
        RESET(net(n));
        CST(t_prg);
    END;
END;
END;
& NO COLLISION
&*****
& END OF TRANSMISSION
P(bus(n));
CST(length/lan_spd-2*t_prg);
V(bus(n));
br(n):=br(n)-1;
CST(t_del);
SET(net(n));
&*****
&TRANSFER OF THE PACKET THROUGH ETHERNET
$END

&*****
& These stations simulate the behaviour of the MAC sublayer queue responsible
& for sending packet through the LAN.
&*****
/STATION/NAME = mac1(1 STEP 1 UNTIL bg);
SERVICE = BEGIN
    $ethernet(il)                & call ethernet medium for the
    IF dest_lan=rem_lan          & background nodes on LAN1
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc1(dest_llc));
END;

/STATION/NAME = mac1(node);      & calling ethernet medium from
SERVICE=BEGIN                  & bridge on LAN1
    $ethernet(il)
    TRANSIT(llc1(dest_llc));
END;

/STATION/NAME = mac2(1 STEP 1 UNTIL bg);
SERVICE = BEGIN
    $ethernet(il)                & call ethernet medium for the
    IF dest_lan=rem_lan          & background nodes on LAN2
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc2(dest_llc));
END;

/STATION/NAME = mac2(node);      & calling ethernet medium from
SERVICE=BEGIN                  & bridge on LAN2
    $ethernet(il)
    TRANSIT(llc2(dest_llc));
END;

&*****
& This part simulates the background nodes situated on each LAN.
&*****
$MACRO bgnode(buffer,seg)
TYPE = SOURCE;
SERVICE = BEGIN
    EXP(1/rate);
    IF DRAW(pr_publi)
    THEN type:=1                & if publication then assign type1
    ELSE
        BEGIN
            IF DRAW(pr_docu/(pr_docu+pr_mess+pr_finan))
            THEN type:=2        & if document then assign type2
            ELSE

```

```

        BEGIN
            IF DRAW(pr_mess/(pr_mess+pr_finan))
                THEN type:=3;          & if message then assign type3
                ELSE type:=4;          & if financial form then assign type4
            END;
        END;
    IF DRAW(inter)
        THEN
            BEGIN
                dest_lan:=rem_lan;      & if inter traffic then assign remote
                P(time,seg(type));      & LAN address
                last:=1;
            END
            ELSE dest_lan:=il;
    IF DRAW(REALINT(is-1)/REALINT(bg-1))
        THEN dest_llc:=RINT(1,is-1)
        ELSE dest_llc:=RINT(is+1,bg);
    sour_lan:=il;
    sour_llc:=is;
    length:=last_len(type)+s_frame;   & length of the frame
    IF nb_seg(type)>1
        THEN
            FOR cnt:=1 STEP 1 UNTIL nb_seg(type)-1
                DO
                    BEGIN
                        pack(il):=NEW(CUSTOMER);
                        pack(il).length:=i_frame;
                        pack(il).sour_lan:=sour_lan;
                        pack(il).dest_lan:=dest_lan;
                        pack(il).sour_llc:=sour_llc;
                        pack(il).dest_llc:=dest_llc;
                        TRANSIT(pack(il),buffer(is),seg(type));
                    END;
                TRANSIT(buffer(is),seg(type));
            END;
    SEND

/STATION/NAME=time;                  & used to time the data transfer
TYPE=RESOURCE,INFINITE;

/STATION/ NAME = bg1;
    $bgnode(buf1,seg1)

/STATION/ NAME = bg2;
    $bgnode(buf2,seg2)

$MACRO buff(macc,windo)
SERVICE=BEGIN
    P(windo(is));
    TRANSIT(macc(is));
END;
$END

/STATION/ NAME = buf1;
    $buff(mac1,wind1)

/STATION/ NAME = buf2;
    $buff(mac2,wind2)

$MACRO llc(macc,windo)                & logical link control used on ETHERNET
SERVICE(ack)=BEGIN
    V(windo(is));
    TRANSIT(OUT);
END;
SERVICE=BEGIN
    IF last=1

```

```

        THEN
            BEGIN
                V(time);
            END;
        length:=s_frame;
        dest_lan:=sour_lan;
        dest_llc:=sour_llc;
        TRANSIT(macc(is),ack);
    END;
$END

/STATION/NAME = llc1;                                & LLC on LAN1
    $llc(mac1,wind1)

/STATION/NAME = llc2;                                & LLC on LAN2
    $llc(mac2,wind2)

/STATION/NAME = wind1;                                & window resources (8 frames)
TYPE=RESOURCE,MULTIPLE(window);

/STATION/NAME = wind2;
TYPE=RESOURCE,MULTIPLE(window);

$MACRO print_out                                        & printout format
    BEGIN
        PRINT(" ");
        PRINT("TIME =",TIME);
        PRINTF("(1H,'Inter-LAN traffic                : ',F4.1,' %')",inter*100);
        PRINTF("(1H,'Number of WS/LAN                : ',F6.1)",ws);
        PRINT(" ");
        PRINT(" ");
        PRINT("-----");
        FOR i:=1 STEP 1 UNTIL nb_typ
            DO
                BEGIN
                    FOR j:=2 STEP 1 UNTIL ind
                        DO
                            BEGIN
                                mdelay(i,j-1):=mdelay(i,j);
                            END;
                            mdelay(i,ind):=(MRESPONSE(time,seg1(i))+MRESPONSE(time,seg2(i)))/2;
                            PRINT("Delay for file",i,"      : ",mdelay(i,ind));
                            PRINT("Delay per page for file",i,"    : ",mdelay(i,ind)/page(i));
                            PRINT(" ");
                        END;
                    PRINT("-----");
                    PRINT("-----");
                    PRINT("56 kbps utilization          : ",
                        100*(MBUSYPCT(T1(1))+MBUSYPCT(T1(2)))/2," %");
                    PRINT("Ethernet utilization         : ",
                        100*(MCUSTNB(bus(1))+MCUSTNB(bus(2)))/2," %");
                    PRINT("-----");
                    PRINT(" ");
                    PRINT(" ");
                END;
            END;
$END

/CONTROL/TMAX=200E3;                                & total simulation time
PERIOD=tperiod;
ACCURACY=time,seg1,time,seg2,T1,bus;
TEST=BEGIN
    $print out
    IF ((ABS(mdelay(1,ind)-mdelay(1,ind-1)/mdelay(1,ind)) < 5.0E-2) AND
        (ABS(mdelay(1,ind)-mdelay(1,ind-2)/mdelay(1,ind)) < 5.0E-2) AND
        (ABS(mdelay(2,ind)-mdelay(2,ind-1)/mdelay(2,ind)) < 5.0E-2) AND

```

```

        (ABS(mdelay(2,ind)-mdelay(2,ind-2)/mdelay(2,ind)) < 5.0E-2) AND
        (ABS(mdelay(3,ind)-mdelay(3,ind-1)/mdelay(3,ind)) < 5.0E-2) AND
        (ABS(mdelay(3,ind)-mdelay(3,ind-2)/mdelay(3,ind)) < 5.0E-2) AND
        (ABS(mdelay(4,ind)-mdelay(4,ind-1)/mdelay(4,ind)) < 5.0E-2) AND
        (ABS(mdelay(4,ind)-mdelay(4,ind-2)/mdelay(4,ind)) < 5.0E-2))
    THEN STOP;    & Stop the simulation if results converge
END;

```

```

ENTRY=BEGIN
    PRINT("56 kbps INTERCONNECTING ETHERNET");
    PRINT("-----");
    PRINT(" ");
    PRINT(" ");
    PRINT("OFFICE AUTOMATION");
    PRINT("-----");
    PRINT(" ");
    PRINT(" ");
    PRINT("INPUT PARAMETER --> FILES");
    PRINT("Publication           : ",size(1)/info," kbytes");
    PRINT("Document                 : ",size(2)/info," kbytes");
    PRINT("Message                   : ",size(3)/info," kbytes");
    PRINT("Financial form           : ",size(4)/info," kbytes");
    PRINT(" ");
    PRINT("INPUT PARAMETER --> DataPath AND Ethernet");
    PRINT("DATAPATH bit rate        : ",byte*t1_rate);
    PRINT("Ethernet                  : ",byte*lan_spd);
    PRINTF("(1H,'Nb of nodes per LAN      : ',F3.0)",node);
    PRINT(" ");
    PRINTF("(1H,'Inter-LAN traffic          : ',F4.1,' %')",inter*100);
    PRINTF("(1H,'Number of WS/LAN           : ',F7.1)",ws);
    PRINT(" ");
END;

```

```

EXIT=BEGIN
    $print_out
END;

```

/EXEC/

```

BEGIN
    FOR i:=1 STEP 1 UNTIL 2
    DO
        BEGIN
            FOR j:=1 STEP 1 UNTIL ind
            DO mdelay(i,j):=1E-15;
            END;
        FOR i:=1 STEP 1 UNTIL 1 DO          & assign local and remote IDs to
        BEGIN                             & of the following stations
            T1(i).rem_lan:=i+1-INTREAL(i/1)*1;
            bridge(i).il:=i;
            bridge(i).rem_lan:=i+1-INTREAL(i/1)*1;
        END;
    
```

```

    FOR i:=1 STEP 1 UNTIL nb_typ DO
    BEGIN
        seg1(i).icl:=i;
        seg2(i).icl:=i;
    END;

```

```

    FOR i:=1 STEP 1 UNTIL node DO          & assign local and remote address to
    BEGIN                                  & the MACs on every LAN
        mac1(i).il:=1;
        mac2(i).il:=2;
        mac1(i).is:=i;
        mac2(i).is:=i;
        mac1(i).rem_lan:=2;
        mac2(i).rem_lan:=1;
    
```

```

END;

FOR i:=1 STEP 1 UNTIL bg DO
  BEGIN
    bg1(i).il:=1;
    bg2(i).il:=2;
    bg1(i).is:=i;
    bg2(i).is:=i;
    bg1(i).rem_lan:=2;
    bg2(i).rem_lan:=1;
    llc1(i).is:=i;
    llc2(i).is:=i;
    buf1(i).is:=i;
    buf2(i).is:=i;
  END;
  & assign local and remote address to
  & the background nodes on every LAN

pr_publi:=0.0749;
pr_docu:=0.2545;
pr_mess:=0.3338;
pr_finan:=0.3368;
  & prob. for each type of document

nb_seg(1):=362;
nb_seg(2):=15;
nb_seg(3):=6;
nb_seg(4):=1;
  & number of segments per type

last_len(1):=info;
last_len(2):=info;
last_len(3):=582;
last_len(4):=280;
  & last page length for every type

FOR I:=1 STEP 1 UNTIL nb_typ
  DO size(i):=(nb_seg(i)-I)*info+last_len(i);
  & size of each type

page(1):=30.2;
page(2):=6.2;
page(3):=2.3;
page(4):=1.4;
  & number of pages per type

& Ethernet

*****
inter:=0.2;
  & % of traffic transferred to the remote LAN
*****

*****
ws:=550;
  & number of workstations per LAN
*****

tperiod:=2000;
  & show intermediate results every 2000 sec.
mfile:=pr_publi*size(1)+pr_docu*size(2)+pr_mess*size(3)+pr_finan*size(4);

*****
rate:=(66.8*2/3)*ws/2/18000;
  & Offered Load (18*2/3 Mbps per working day)
*****

rate:=rate/bg;
  & background rate for every background station

SIMUL;

END;
/END/

```

```

/CONTROL/OPTION=NSOURCE;
CLASS=ALL QUEUE;

```

```

&
& *****
& ---->>>> OFFICE AUTOMATION
& *****
&
& *****
& LAN INTERCONNECTION VIA T1
& This program simulates the communication between two office sites
& each working on a token ring LAN and are interconnected by either
& a T1 link of 1.544Mbps or a 56 kbps link. The Logical Link Control
& (LLC) is used to control the End-to-End transmission of data.
&
& *****
&
&
& /DECLARE/
INTEGER
    l = 2, & number of interconnected LANs
    bg = 30, & number of background nodes per LAN
    node=bg+1, & number of nodes on each LAN
    info=1024, & info data length
    s_frame=25, & MAC control frame
    i_frame=s_frame+info, & I-frame length
    byte=8, & 1 byte --> 8 bits
    window = 8, & window size.
    ind=3,
    nb_typ=4, & 4 different type of documents
    last_len(nb_typ), & last page length of a document
    nb_seg(nb_typ), & number of segments per type
    ws, & workstation
    ask(l,node), & flag
    i,j;
REAL
    & ***** bridge parameters *****
    t_bridge=120E-6, & processing time in bridges
    t_ram=160E-9, & processing time per byte
    tI_rate=56E3/8.0, & 56 kbps/byte rate
    & ***** Token rings parameters *****
    lan_spd=4.0E6/byte, & LAN speed
    dusty=1E-6,
    & ***** workstation parameters *****
    pr_publi, & probability for getting a publicat.
    pr_docu, & prob. for getting a document
    pr_mess, & prob. for getting a message
    pr_finan, & prob. for getting a financial form
    size(nb_typ), & size of each document type
    tdelay(nb_typ),num(nb_typ,ind),
    mdelay(nb_typ,ind), & intermediate measured delays
    cdelay(nb_typ),
    mfile,
    page(nb_typ), & number of pages per type of doc.
    load,rate, & load on the network
    inter, & inter traffic probability
    & ***** simulation parameters *****
    tperiod; & time interval between results
    no_idle(l,node); & check to see if idle
    icl;
    ack,seg1(nb_typ),seg2(nb_typ),
    token(l); & token flag on each LAN
    il,is,active,type, & IDs for LANs and stations on LANs
    cnt,y,inext,
    rem_lan; & hold address of remote LAN
    & ***** T1 + Token rings parameters *****
    T1(l),bridge(l),mac1(node),mac2(node),ring(l),
    & ***** background load nodes parameters *****

```

```

                                bg1(bg),bg2(bg),llc1(bg),llc2(bg),
                                buf1(bg),buf2(bg),wind1(bg),wind2(bg),time;
                                &***** workstation parameters *****
FLAG                            fl(1,node),poll(1);
CUSTOMER INTEGER               in,c,
                                last,                                & last image packet ?
                                length,                              & packet length
                                sour_llc,dest_llc,
                                sour_lan,dest_lan;                    & source and destination LAN
CUSTOMER REAL                  start;
REF CUSTOMER                   pack(1),
                                tok(1);

```

```

&*****
& This macro simulates the behaviour of the packet processing in the bridges.
&*****
$MACRO bridges(mac)
SERVICE = BEGIN

```

```

    CST(t_bridge+length*t_ram);    & processing time at the bridge
    IF dest_lan = il
    THEN TRANSIT(mac(node))
    ELSE TRANSIT(T1(il));
END;

```

```

$END

```

```

/STATION/NAME = bridge(1);        & Bridge station calling macro
$bridges(mac1)

```

```

/STATION/NAME = bridge(2);        & the other bridge on LAN2
$bridges(mac2)

```

```

&*****
& This station simulates the behaviour of the T1 link access queue
&*****
/STATION/NAME = T1;
SERVICE = BEGIN

```

```

    CST(length/t1_rate);          & transmission time on T1
    TRANSIT(bridge(rem_lan));
END;

```

```

&*****
& This part simulates the behaviour of the Token rings protocol (non-prty).
&*****
/STATION/ NAME = ring;
SERVICE = BEGIN

```

```

    active:=1;
    y:=RINT(1,node);
    WHILE is >= 0 DO
    BEGIN
        cnt:=cnt+1;
        is:=is+1-INTREAL(is/node)*node;
        IF ask(il,is)=1
        THEN
            BEGIN
                cnt:=0;
                SET(fl(il,is));
                WAIT(poll(il));
                RESET(poll(il));
                CST(dusty);
            END;

```

```

    && WHILE ask(il,node)=1 DO    & procedure that assigns higher
    && BEGIN                      & priority to the bridge
    &&     cnt:=0;
    &&     SET(fl(il,node));
    &&     WAIT(poll(il));
    &&     RESET(poll(il));

```

```

        &&          CST(dusty);
        &&          END;
        IF cnt > node+y
        THEN
            BEGIN
                cnt:=0;
                active:=0;
                TRANSIT(OUT);
            END;
        END;
    END;
TRANSIT = ring(il);
INIT(token) = IF il=icl THEN 1
                ELSE 0;

*****
& These stations simulate the behaviour of the MAC sublayer queue responsible
& for sending packet through the LAN.
*****
$MACRO med acc
    ask(il, is):=1;
    IF ring(il).active=0
    THEN
        BEGIN
            tok(il):=NEW(CUSTOMER);
            TRANSIT(tok(il), ring(il));
        END;
    WAIT(fl(il, is));
    RESET(fl(il, is));
    CST(length/lan_spd);
    ask(il, is):=0;
    SET(poll(il));
$END

*****
& These stations simulate the behaviour of the MAC sublayer queue responsible
& for sending packet through the LAN.
*****
/STATION/NAME = mac1(1 STEP 1 UNTIL bg);
SERVICE = BEGIN
    $med acc
    IF dest_lan=rem_lan
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc1(dest_llc));
    END;

/STATION/NAME = mac1(node);
SERVICE=BEGIN
    $med acc
    TRANSIT(llc1(dest_llc));
    END;

/STATION/NAME = mac2(1 STEP 1 UNTIL bg);
SERVICE = BEGIN
    $med acc
    IF dest_lan=rem_lan
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc2(dest_llc));
    END;

/STATION/NAME = mac2(node);
SERVICE=BEGIN
    $med acc
    TRANSIT(llc2(dest_llc));
    END;

```

```

&*****
& This part simulates the background nodes situated on each LAN.
&*****
$MACRO bgnode(buffer,seg)
TYPE = SOURCE;
SERVICE = BEGIN
    EXP(1/rate);
    IF DRAW(pr_publi)
        THEN type:=1 & if publication then assign type1
    ELSE
        BEGIN
            IF DRAW(pr_docu/(pr_docu+pr_mess+pr_finan))
                THEN type:=2 & if document then assign type2
            ELSE
                BEGIN
                    IF DRAW(pr_mess/(pr_mess+pr_finan))
                        THEN type:=3 & if message the assign type3
                    ELSE type:=4; & if financial form then type4
                END;
            END;
        END;
    IF DRAW(inter)
        THEN
            BEGIN & assign address of remote LAN
                dest_lan:=rem_lan;
                P(time,seg(type));
                last:=1;
            END
        ELSE dest_lan:=il;
        IF DRAW(REALINT(is-1)/REALINT(bg-1))
            THEN dest_llc:=RINT(1,is-1)
            ELSE dest_llc:=RINT(is+1,bg);
        sour_lan:=il;
        sour_llc:=is;
        length:=last_len(type)+s_frame; & length of the frame
        IF nb_seg(type)>1
            THEN
                FOR cnt:=1 STEP 1 UNTIL nb_seg(type)-1
                    DO
                        BEGIN
                            pack(il):=NEW(CUSTOMER);
                            pack(il).length:=i_frame;
                            pack(il).sour_lan:=sour_lan;
                            pack(il).dest_lan:=dest_lan;
                            pack(il).sour_llc:=sour_llc;
                            pack(il).dest_llc:=dest_llc;
                            TRANSIT(pack(il),buffer(is),seg(type));
                        END;
                    TRANSIT(buffer(is),seg(type));
                END;
            END;
$END

/STATION/NAME=time; & used to time data transfer
TYPE=RESOURCE, INFINITE;

/STATION/ NAME = bg1;
$bgnode(buf1,seg1)

/STATION/ NAME = bg2;
$bgnode(buf2,seg2)

$MACRO buff(macc,windo)
SERVICE=BEGIN
    P(windo(is));
    TRANSIT(macc(is));
END;
$END

```

```

/STATION/ NAME = buf1;
$buff(mac1,wind1)

/STATION/ NAME = buf2;
$buff(mac2,wind2)

$MACRO llc(macc,windo)
SERVICE(ack)=BEGIN
    V(windo(is));
    TRANSIT(OUT);
END;
SERVICE=BEGIN
    IF last=1
    THEN
        BEGIN
            V(time);
        END;
        length:=s_frame;
        dest_lan:=sour_lan;
        dest_llc:=sour_llc;
        TRANSIT(macc(is),ack);
    END;
$END

/STATION/NAME = llc1;
$llc(mac1,wind1)

/STATION/NAME = llc2;
$llc(mac2,wind2)

/STATION/NAME = wind1;
TYPE=RESOURCE,MULTIPLE(window);

/STATION/NAME = wind2;
TYPE=RESOURCE,MULTIPLE(window);

$MACRO print_out                                & printing format
BEGIN
    PRINT(" ");
    PRINT("TIME =",TIME);
    PRINTF("(1H,'Inter-LAN traffic           : ',F4.1,' %')",inter*100);
    PRINTF("(1H,'Number of WS/LAN           : ',F6.1)",ws);
    PRINT("non bridge priority");
    PRINT(" ");
    PRINT(" ");
    PRINT("-----");
    FOR i:=1 STEP 1 UNTIL nb_typ
    DO
        BEGIN
            FOR j:=2 STEP 1 UNTIL ind
            DO
                BEGIN
                    mdelay(i,j-1):=mdelay(i,j);
                END;
                mdelay(i,ind):=(MRESPONSE(time,seg1(i))+MRESPONSE(time,seg2(i)))/2;
                PRINT("Delay for file",i,"      : ",mdelay(i,ind));
                PRINT("Delay per page for file",i,"    : ",mdelay(i,ind)/page(i));
                PRINT(" ");
            END;
        END;
    PRINT("-----");
    PRINT("-----");
    PRINT("56 kbps utilization           : ",
        100*(MBUSYPCT(T1(1))+MBUSYPCT(T1(2)))/2," %");
    PRINT("Token ring utilization        : ",
        100*(MBUSYPCT(ring(1))+MBUSYPCT(ring(2)))/2," %");

```



```

    ring(i).il:=i;
    token(i).icl:=i;
END;

FOR i:=1 STEP 1 UNTIL nb_typ DO
    BEGIN
        seg1(i).icl:=i;
        seg2(i).icl:=i;
    END;

FOR i:=1 STEP 1 UNTIL node DO
    BEGIN
        mac1(i).il:=1;
        mac2(i).il:=2;
        mac1(i).is:=i;
        mac2(i).is:=i;
        mac1(i).rem_lan:=2;
        mac2(i).rem_lan:=1;
    END;
    & assign local and remote address to
    & MACs on every LAN

FOR i:=1 STEP 1 UNTIL bg DO
    BEGIN
        bg1(i).il:=1;
        bg2(i).il:=2;
        bg1(i).is:=i;
        bg2(i).is:=i;
        bg1(i).rem_lan:=2;
        bg2(i).rem_lan:=1;
        llc1(i).is:=i;
        llc2(i).is:=i;
        buf1(i).is:=i;
        buf2(i).is:=i;
    END;
    & assign local and remote address to
    & the background nodes on every LAN

pr_publi:=0.0749;
pr_docu:=0.2545;
pr_mess:=0.3338;
pr_finan:=0.3368;
    & assign probability to each type

nb_seg(1):=362;
nb_seg(2):=15;
nb_seg(3):=6;
nb_seg(4):=1;
    & number of segments per type

last_len(1):=info;
last_len(2):=info;
last_len(3):=582;
last_len(4):=280;
    & last page length for every type
FOR i:=1 STEP 1 UNTIL nb_typ
    DO size(i):=(nb_seg(i)-1)*info+last_len(i);

page(1):=30.2;
page(2):=6.2;
page(3):=2.3;
page(4):=1.4;
    & number of pages per type

& non priority mode in token rings
&*****
inter:=0.2;
    & % of traffic transferred to the remote LAN
&*****

&*****
ws:=260;
    & Number of workstation per LAN
&*****

tperiod:=2000;
    & show results every 2000 seconds
mfile:=pr_publi*size(1)+pr_docu*size(2)+pr_mess*size(3)+pr_finan*size(4);

```

```

&*****
rate:=(66.8/3)*ws/2/18000; & offered load (18/3 Mbps per working day)
&*****
rate:=rate/bg;           & background rate for every background station
SIMUL;
END;
/END/

```

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```

/CONTROL/OPTION=NSOURCE;
      CLASS=ALL QUEUE;
&
&*****
& --->>> OFFICE AUTOMATION
&*****
&
&*****
& LAN INTERCONNECTION VIA 56 kbps
& This program simulates the communication between two office sites
& working on APPLETALK LANs and interconnected by a 56 kbps link.
& The AppleTalk Transaction Protocol (ATP) is used to control the
& End-to-End transmission of data.
&*****
&
&
&
/DECLARE/
INTEGER
    l = 2,                & number of interconnected LANs
    bg = 15,              & of background nodes per LAN
    node=bg+1,            & number of nodes on each LAN
    info=512,             & info data length
    s_frame=18,           & MAC control data
    i_frame=s_frame+info, & I-frame length
    byte=8,               & 1 byte --> 8 bits
    window = 8,           & window size.
    inc=3,
    nb_typ=4,             & number of types of documents.
    last_len(nb_typ),     & last page length
    nb_seg(nb_typ),       & number of segments per type
    ws,
    &***** AppleTalk parameters *****
    colli,counter(1),     & measure the number of collisions
    active(1),online(1),
    nb(1,node),nbout(1,node),
    i,j;
REAL
    &***** bridge parameters *****
    t_bridge=120E-6,      & processing time in bridges
    t_ram=160E-9,         & additional processing per byte
    t_rate=56.0E3/byte,   & 56 kbps rate
    &***** AppleTalk parameters *****
    backoff(1,node),     & backoff time
    lan_spd=230.4E3/byte, & LAN speed
    t_proc=100E-6,       & processing time
    t_prop=5E-6,         & propagation time
    &***** workstation parameters *****
    pr_publi,            & probability of getting a publication
    pr_docu,             & probability of getting a document
    pr_mess,             & probability of getting a message
    pr_finan,            & prob. of getting a financial form
    size(nb_typ),        & size of each type of document
    tdelay(nb_typ),num(nb_typ,ind),
    mdelay(nb_typ,ind),  & intermediate delays
    cdelay(nb_typ),
    mfile,
    page(nb_typ),        & number of pages per type
    load,rate,           & rate at each background load
    inter,               & probability of inter-LAN traffic
    &***** simulation parameters *****
    tperiod;             & show simulation result every tperiod
    no_idle(1,node);
    icl;                 & integer number for each class
    ack,seg1(nb_typ),seg2(nb_typ),
    one,rts,cts;
    il,is,type,attempt,  142 parameters for LAN id., WS id.

```

```

cnt,y,inext,          & # of attempts etc..
rem_lan;
QUEUE
&***** T1 + AppleTalk parameters *****
T1(1),bridge(1),mac1(node),mac2(node),initial,link(1),
timer1(node),timer2(node),
&***** background load nodes parameters *****
bg1(bg),bg2(bg),llc1(bg),llc2(bg),
buf1(bg),buf2(bg),wind1(bg),wind2(bg),time;
FLAG
send(1,node),stop(1,node),idle(1);
CUSTOMER INTEGER in,c,          & used when creating a new cust.
last,          & last image packet ?
length,          & packet length
sour_llc,dest_llc,          & source and dest. LLC id.
sour_lan,dest_lan;          & destination LAN
CUSTOMER REAL
start;
REF CUSTOMER
pack(1),
tok(1),ctl(1,node),tic(1);

&*****
& This macro simulates the behaviour of the packet processing in the bridges.
&*****
$MACRO bridges(mac)
SERVICE = BEGIN
    CST(t_bridge+length*t_ram);          & processing time at the bridge
    IF dest_lan = il
    THEN TRANSIT(mac(node))
    ELSE TRANSIT(T1(il));
END;
$END

/STATION/NAME = bridge(1);          & Bridge on LAN1
$bridges(mac1)

/STATION/NAME = bridge(2);          & Bridge on LAN2
$bridges(mac2)

&*****
& This station simulates the behaviour of the T1 link access queue
&*****
/STATION/NAME = T1;          & either T1 or 56 kbps
SERVICE = BEGIN
    CST(length/t1_rate);          & time to send packet on T1
    TRANSIT(bridge(rem_lan));
END;

&*****
& This part simulates the behaviour of the AppleTalk protocol.
&*****

/STATION/NAME=initial;          & initialization procedure
SERVICE=BEGIN
    FOR cnt:=1 STEP 1 UNTIL 1
    DO SET(idle(cnt));          & set idle flag on for both LANs
    TRANSIT(OUT);
END;
INIT(one)=1;

$MACRO bus(timer)
TYPE=INFINITE;
SERVICE(rts,cts)=BEGIN
    online(il):=online(il)+1;          & if incoming frame is of class
    nb(il,in):=online(il);          & rts or cts then go through
    nbout(il,in):=counter(il);          & the checking procedure
    CST(t_prop);
    active(il):=active(il)+1;
    FOR c:=1 STEP 1 UNTIL 48;

```

```

DO
  BEGIN
    IF timer(c).cnt=1
      THEN
        BEGIN
          MOVE(timer(c),OUT);
          no_idle(il,c):=TRUE;
          SET(stop(il,c));
        END;
      END;
    RESET(idle(il));
    CST(length/lan_spd);
    nb(il,in):=ABS(nb(il,in)-online(il));
    nb(il,in):=nb(il,in)+counter(il)-nbout(il,in);
    IF (nb(il,in)>0) OR (CLASS=rts)
      THEN
        BEGIN
          IF active(il)=1
            THEN SET(idle(il));
          END;
          online(il):=online(il)-1;
          active(il):=active(il)-1;
          counter(il):=counter(il)+1;
          SET(send(il,in));
          TRANSIT(OUT);
        END;
    SERVICE=BEGIN
      active(il):=active(il)+1;
      FOR c:=1 STEP 1 UNTIL node
        DO
          BEGIN
            IF timer(c).cnt=1
              THEN
                BEGIN
                  MOVE(timer(c),OUT);
                  no_idle(il,c):=TRUE;
                  SET(stop(il,c));
                END;
              END;
            CST(length/lan_spd);
            active(il):=active(il)-1;
            counter(il):=counter(il)+1;
            SET(send(il,in));
            SET(idle(il));
            TRANSIT(OUT);
          END;
        $END
      & if class is different than
      & rts and cts
    /STATION/NAME=link(1);
    $bus(timer1)
    /STATION/NAME=link(2);
    $bus(timer2)

$MACRO clock
SERVICE=BEGIN
  cnt:=1;
  CST(backoff(il,is));
  SET(stop(il,is));
  TRANSIT(OUT);
END;
$END

/STATION/NAME=timer1;

```

\$clock

/STATION/NAME=timer2;

\$clock

```
$MACRO apple(timer)                                & Apple LAN protocol
attempt:=0;
nb(il,is):=1;
WHILE nb(il,is)>0
DO
BEGIN
  attempt:=attempt+1;
  WHILE (((active(il)+nb(il,is))>0) OR (no_idle(il,is)))
  DO
  BEGIN
    WAIT(idle(il));
    nb(il,is):=active(il);
    nbout(il,is):=counter(il);
    no_idle(il,is):=FALSE;
    backoff(il,is):=UNIFORM(400E-6,1.0E-3+100E-6*(attempt-1));
    RESET(stop(il,is));
    tic(il):=NEW(CUSTOMER);
    TRANSIT(tic(il),timer(is));
    WAIT(stop(il,is));
    timer(is).cnt:=0;
    nb(il,is):=ABS(nb(il,is)-active(il))+counter(il)-nbout(il,is);
  END;
  & SEND RTS
  CST(t_proc);
  ctl(il,is):=NEW(CUSTOMER);
  ctl(il,is).in:=is;
  ctl(il,is).length:=3;
  TRANSIT(ctl(il,is),link(il),rts);
  WAIT(send(il,is));
  RESET(send(il,is));
  IF nb(il,is)>0
  THEN
  BEGIN
    colli:=colli+1;
    CST(2*t_proc);
  END
  ELSE
  BEGIN
    &SEND CTS
    CST(t_proc);
    ctl(il,is):=NEW(CUSTOMER);
    ctl(il,is).in:=is;
    ctl(il,is).length:=3;
    TRANSIT(ctl(il,is),link(il),cts);
    WAIT(send(il,is));
    RESET(send(il,is));
    IF nb(il,is)>0
    THEN
    BEGIN
      colli:=colli+1;
      CST(t_proc);
    END
    ELSE
    BEGIN
      &NO COLLISION --> PACKET TRANSMISSION
      ctl(il,is):=NEW(CUSTOMER);
      ctl(il,is).in:=is;
      ctl(il,is).length:=length;
      TRANSIT(ctl(il,is),link(il));
      WAIT(send(il,is));
      RESET(send(il,is)); 145
    END
  END
END
```

```

        END;
    END;
END;
$END

&*****
& These stations simulate the behaviour of the MAC sublayer queue responsible
& for sending packet through the LAN.
&*****
/STATION/NAME = mac1(1 STEP 1 UNTIL bg);    & MAC of the Background
SERVICE = BEGIN                            & Workstations situated on LAN1
    $apple(timer1)
    IF dest_lan=rem_lan
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc1(dest_llc));
END;

/STATION/NAME = mac1(node);                & MAC of the bridge situated
SERVICE=BEGIN                             & on LAN1
    $apple(timer1)
    TRANSIT(llc1(dest_llc));
END;

/STATION/NAME = mac2(1 STEP 1 UNTIL bg);    & MAC of all the Background
SERVICE = BEGIN                           & Workstations situated on LAN2
    $apple(timer2)
    IF dest_lan=rem_lan
    THEN TRANSIT(bridge(il))
    ELSE TRANSIT(llc2(dest_llc));
END;

/STATION/NAME = mac2(node);                & MAC of the bridge situated
SERVICE=BEGIN                             & on LAN2
    $apple(timer2)
    TRANSIT(llc2(dest_llc));
END;

&*****
& This part simulates the background nodes situated on each LAN.
&*****
$MACRO bgnode(buffer,seg)
TYPE = SOURCE;
SERVICE = BEGIN
    EXP(1/rate);                            & exponential service time
    IF DRAW(pr_publi)
    THEN type:=1                            & publications are assigned type1
    ELSE
    BEGIN
        IF DRAW(pr_docu/(pr_docu+pr_mess+pr_finan))
        THEN type:=2                        & documents are assigned type2
        ELSE
        BEGIN
            IF DRAW(pr_mess/(pr_mess+pr_finan))
            THEN type:=3                    & messages are assigned type3
            ELSE type:=4;                   & financial forms are of type4
        END;
    END;
    END;
    IF DRAW(inter)
    THEN
    BEGIN
        dest_lan:=rem_lan;                 & if inter traffic then
        P(time,seg(type));                 & destination add. equal remote LAN
        last:=1;
    END
    ELSE dest_lan:=il;                       & else destination add. is local
    IF DRAW(REALINT(is-1)/REALINT(bg-1))

```

```

        THEN dest_llc:=RINT(1,is-1)
        ELSE dest_llc:=RINT(is+1,bg);
sour_lan:=11;
sour_llc:=is;
length:=last_len(type)+s_frame;
IF nb_seg(type)>1
    THEN
        & generate as many packet as the number of segments
        FOR cnt:=1 STEP 1 UNTIL nb_seg(type)-1
            DO
                BEGIN
                    pack(il):=NEW(CUSTOMER);
                    pack(il).length:=i_frame;
                    pack(il).sour_lan:=sour_lan;
                    pack(il).dest_lan:=dest_lan;
                    pack(il).sour_llc:=sour_llc;
                    pack(il).dest_llc:=dest_llc;
                    TRANSIT(pack(il),buffer(is),seg(type));
                END;
            TRANSIT(buffer(is),seg(type));
        END;
$END

/STATION/NAME=time;
TYPE=RESOURCE,INFINITE;
& used to measure the time

/STATION/ NAME = bg1;
    $bgnode(buf1,seg1)

/STATION/ NAME = bg2;
    $bgnode(buf2,seg2)

$MACRO buff(macc,windo)
SERVICE=BEGIN
    P(windo(is));
    TRANSIT(macc(is));
END;
$END

/STATION/ NAME = buf1;
    $buff(mac1,wind1)

/STATION/ NAME = buf2;
    $buff(mac2,wind2)

$MACRO llc(macc,windo)
SERVICE(ack)=BEGIN
    V(windo(is));
    TRANSIT(OUT);
END;
SERVICE=BEGIN
    IF last=1
        THEN
            BEGIN
                V(time);
            END;
            length:=s_frame;
            dest_lan:=sour_lan;
            dest_llc:=sour_llc;
            TRANSIT(macc(is),ack);
        END;
$END

/STATION/NAME = llc1;
    $llc(mac1,wind1)
& LLC called on LAN1

/STATION/NAME = llc2;
    147 & LLC called on LAN2

```

```

$llc(mac2,wind2)

/STATION/NAME = wind1;                                & resources for the number of
TYPE=RESOURCE,MULTIPLE(window);                        & packets send at window size

/STATION/NAME = wind2;
TYPE=RESOURCE,MULTIPLE(window);

$MACRO print_out                                         & printout format of the results
BEGIN
  PRINT(" ");
  PRINT("TIME =",TIME);
  PRINTF("(1H,'Inter-LAN traffic           : ',F4.1,' %')",inter*100);
  PRINTF("(1H,'Number of WS/LAN         : ',F6.1)",ws);
  PRINT(" ");
  PRINT(" ");
  PRINT("-----");
  FOR i:=1 STEP 1 UNTIL nb_typ
  DO
    BEGIN
      FOR j:=2 STEP 1 UNTIL ind
      DO
        BEGIN
          mdelay(i,j-1):=mdelay(i,j);
        END;
        mdelay(i,ind):=(MRESPONSE(time,seg1(i))+MRESPONSE(time,seg2(i)))/2;
        PRINT("Delay for file",i,"      : ",mdelay(i,ind));
        PRINT("Delay per page for file",i," : ",mdelay(i,ind)/page(i));
        PRINT(" ");
      END;
    END;
  PRINT("-----");
  PRINT("-----");
  PRINT("56 Kbps link utilization           : ",
        100*(MBUSYPCT(T1(1))+MBUSYPCT(T1(2)))/2," %");
  PRINT("AppleTalk utilization           : ",
        100*(MCUSTNB(link(1))+MCUSTNB(link(2)))/2," %");
  PRINT("Collisions rate per sec           : ",colli/TIME/2);
  PRINT("-----");
  PRINT(" ");
  PRINT(" ");
END;
$END

/CONTROL/TMAX=200E3;                                & total simulation time
PERIOD=tperiod;                                       & show results every tperiod
ACCURACY=time,seg1,time,seg2,T1,link;
TEST=BEGIN
  $print out
  IF ((ABS(mdelay(1,ind)-mdelay(1,ind-1)/mdelay(1,ind)) < 5.0E-2) AND
      (ABS(mdelay(1,ind)-mdelay(1,ind-2)/mdelay(1,ind)) < 5.0E-2) AND
      (ABS(mdelay(2,ind)-mdelay(2,ind-1)/mdelay(2,ind)) < 5.0E-2) AND
      (ABS(mdelay(2,ind)-mdelay(2,ind-2)/mdelay(2,ind)) < 5.0E-2) AND
      (ABS(mdelay(3,ind)-mdelay(3,ind-1)/mdelay(3,ind)) < 5.0E-2) AND
      (ABS(mdelay(3,ind)-mdelay(3,ind-2)/mdelay(3,ind)) < 5.0E-2) AND
      (ABS(mdelay(4,ind)-mdelay(4,ind-1)/mdelay(4,ind)) < 5.0E-2) AND
      (ABS(mdelay(4,ind)-mdelay(4,ind-2)/mdelay(4,ind)) < 5.0E-2))
  THEN STOP;    & Stop the simulation if results converge
END;

ENTRY=BEGIN
  PRINT("DATAPATH INTERCONNECTING APPLETALK");
  PRINT("-----");
  PRINT(" ");
  PRINT(" ");
  PRINT("OFFICE AUTOMATION");
  PRINT("-----");

```

```

PRINT(" ");
PRINT(" ");
PRINT("INPUT PARAMETER --> FILES");
PRINT("Publication      : ",size(1)/1024," kbytes");
PRINT("Document          : ",size(2)/1024," kbytes");
PRINT("Message            : ",size(3)/1024," kbytes");
PRINT("Financial form     : ",size(4)/1024," kbytes");
PRINT(" ");
PRINT("INPUT PARAMETER --> DataPath AND AppleTalk");
PRINT("DataPath bit rate    : ",byte*tl_rate);
PRINT("AppleTalk bit rate    : ",byte*lan_spd);
PRINTF("(1H,'Nb of nodes per LAN      : ',F3.0)",node);
PRINT(" ");
PRINTF("(1H,'Inter-LAN traffic          : ',F4.1,' %')",inter*100);
PRINTF("(1H,'Number of WS/LAN          : ',F7.1)",ws);
PRINT(" ");
END;

EXIT=BEGIN
  $print_out
END;

/EXEC/
BEGIN
  FOR i:=1 STEP 1 UNTIL 2
  DO
    BEGIN
      FOR j:=1 STEP 1 UNTIL ind
      DO mdelay(i,j):=1E-15;
    END;
    FOR i:=1 STEP 1 UNTIL 1 DO
      BEGIN
        T1(i).rem_lan:=i+1-INTREAL(i/1)*1;
        bridge(i).il:=i;
        bridge(i).rem_lan:=i+1-INTREAL(i/1)*1;
        link(i).il:=i;
      END;
    END;

    FOR i:=1 STEP 1 UNTIL nb_typ DO
      BEGIN
        seg1(i).icl:=i;
        seg2(i).icl:=i;
      END;

    FOR i:=1 STEP 1 UNTIL node DO
      BEGIN
        mac1(i).il:=1;
        mac2(i).il:=2;
        mac1(i).is:=i;
        mac2(i).is:=i;
        mac1(i).rem_lan:=2;
        mac2(i).rem_lan:=1;
        timer1(i).il:=1;
        timer2(i).il:=2;
        timer1(i).is:=i;
        timer2(i).is:=i;
      END;

    FOR i:=1 STEP 1 UNTIL bg DO
      BEGIN
        bg1(i).il:=1;
        bg2(i).il:=2;
        bg1(i).is:=i;
        bg2(i).is:=i;
        bg1(i).rem_lan:=2;
        bg2(i).rem_lan:=1;

```

```

    llc1(i).is:=i;
    llc2(i).is:=i;
    buf1(i).is:=i;
    buf2(i).is:=i;
END;

pr_publi:=0.0749;           & assign probability to each document type
pr_docu:=0.2545;
pr_mess:=0.3338;
pr_finan:=0.3368;
nb_seg(1):=724;           & number of segment in each type
nb_seg(2):=30;
nb_seg(3):=12;
nb_seg(4):=1;
last_len(1):=238;         & last page length for every type
last_len(2):=info;
last_len(3):=69;
last_len(4):=280;
FOR I:=1 STEP 1 UNTIL nb_typ & find the size for each type
    DO size(i):=(nb_seg(i)-I)*info+last_len(i);

page(1):=30.2;             & give the number of pages for every type
page(2):=6.2;
page(3):=2.3;
page(4):=1.4;

& AppleTalk
*****
inter:=0.5;                & % of traffic transferred to the remote LAN
*****
ws:=24;                    & Number of workstations per LAN
*****

tperiod:=1000;
mfile:=pr_publi*size(1)+pr_docu*size(2)+pr_mess*size(3)+pr_finan*size(4);

*****
rate:=66.8*ws/2/18000;     & Offered load (18 Mbps per working day)
*****

rate:=rate/bg;             & final load rate at every background node

SIMUL;

END;
/END/

```

B.2 Simulation Program of File Transfer Activities (only token ring program is given)

```

/CONTROL/OPTION=NSOURCE;
      CLASS=ALL QUEUE;
&
&*****
&      LAN INTERCONNECTION VIA T1
&      This program simulates the file transfer activities between a
&      workstation and a file server each located on a different token
&      ring LAN. The Logical Link Control (LLC) is used to control the
&      End-to-End communication between the two stations.
&*****
&
&
/DECLARE/
INTEGER
&***** token ring parameters *****
l = 2,          & number of interconnected LANs
bg = 10,        & number of background nodes per LAN
stat=bg+1,      & number of station on each LAN
node=stat+1,    & number of nodes on each LAN
byte = 8,       & 1 byte --> 8 bits
ask(l,node),
&***** file server parameters *****
memsize = 400,cntr,
&***** llc parameters *****
maxseq = 8,      & the maximum sequence number. ( 0..7)
window = 9,      & window size. meaning of maxseq and window
                  is exchanged. It should be maxseq <--> window
&                  all throughout the program
&
&      gatenb = 2,          & number of gates or LANs.
&      nxtfrsnd(gatenb),   & next frame to be sent.
&      frmexpct(gatenb),   & next expected frame.
&      outstand(gatenb),   & outstanding frames.
&      timeout(gatenb),    & this occurs when the timer expires.
&      running(gatenb),    & running status of the timers.
&      sttimer(gatenb),    & start timer 1 and 2 of LAN#1 and #2 respcet.
&      counter = 0,jj,     & indeces for lan number
&      dumlgth,totpkt,     & length of the frame of class dummy.
&      nb_reqts,cntr,      & no. of disk requests per file size.
&      x,yy,i,j=0;        & counter for the timers.

&
&
&      BOOLEAN rejflag(gatenb), & this flag is set when a rej_frame is received.
&      cksumerr(gatenb);        & this is set when a cheksum error occurs.
&
&      CUSTOMER INTEGER kind,    & kind of frame (data, RRframe or REJframe).
&      ack,dest,                & acknowledgment number and destination.
&      seq,                    & sequence number of a particular frame.
&      p,f;                    & P and F bit used in the RRframe.
&
&      CLASS INTEGER lpack,      & packet length
&      icl;
&
&      CLASS
&      token(l),
&      request,response,dummy,
&      data,                & frame that contains data.
&      RRframe,             & frame that carries the acknowledgement.
&      REJframe;            & Reject frame.
&
&
&      QUEUE INTEGER
&      active,il,is,cnt,y;
&
&      QUEUE &***** llc parameters *****
&      LLC1,LLC2,timer1,timer2,filesrvr,
&      lan(gatenb),bridgel,bridge2,bdgleth,bdg2eth,
&      bdglt1,bdg2t1,ring(l),
&      &***** workstation parameters *****
&      ws_niu,niu_bws,ws_cpu,img_proc,time2

```

```

lanlws1,lanlws2,lanlws3,lanlws4,lanlws5,lanlws6,lanlws7,lanlws8,lanlws9,
lanlws10,
mac1,mac2,mac3,mac4,mac5,mac6,mac7,mac8,mac9,mac10,
lan2ws1,lan2ws2,lan2ws3,lan2ws4,lan2ws5,lan2ws6,lan2ws7,lan2ws8,lan2ws9,
lan2ws10,
ws1mac,ws2mac,ws3mac,ws4mac,ws5mac,ws6mac,ws7mac,ws8mac,ws9mac,ws10mac,
***** file server parameters *****
fs_niu,niu_buff,fs_cpu,fs_disk,BUS,buffer;

&
FLAG notoutsd,fl(1,node),poll(1);
&
REAL
***** token ring parameter *****
lan_spd = 4E6,           & LAN speed
dusty   = 1E-6,         & dusty variable
***** llc parameters *****
t_convrt,t_prop,t_tlprop,t_timer,clock,
***** workstation parameters *****
t_detect,t_proc,
low_ld,mod_ld,hvy_ld,x_hvy_ld,s_hvy_ld,inter,intra,
***** file server parameters *****
t_query,t_disk,t_visit,t_dbuff,t_bmem,t_trans;

&
REF CUSTOMER C1,C2,visit,gen,gen1,c,cws,temps,tok,req_d;
REF QUEUE r_q;
&
&
&
&-----
&
&
*****
& This part simulates the behaviour of the token ring monitor.
*****
$MACRO tok_ring
  SERVICE = BEGIN
    active:=1;
    y:=RINT(1,node);
    WHILE is >= 0 DO
      BEGIN
        cnt:=cnt+1;
        is:=is+1-INTREAL(is/node)*node;
        IF ask(il,is)=1
          THEN
            BEGIN
              cnt:=0;
              SET(fl(il,is));
              WAIT(poll(il));
              RESET(poll(il));
              CST(dusty);
            END;
        WHILE ask(il,node)=1 DO
          BEGIN
            cnt:=0;
            SET(fl(il,node));
            WAIT(poll(il));
            RESET(poll(il));
            CST(dusty);
          END;
        IF cnt > node+y
          THEN
            BEGIN
              cnt:=0;
              active:=0;
              TRANSIT(OUT);
            END;
      END;
    END;
  END;

```

```

        END;
    END;
    TRANSIT = ring(il);
    INIT(token) = IF il=icl THEN 1
                  ELSE 0;
$END

/STATION/ NAME = ring(1);
$tok_ring

/STATION/ NAME = ring(2);
$tok_ring

*****
& These stations simulate the behaviour of the MAC sublayer queue responsible
& for sending packet through Token Ring NET.
*****
$MACRO med_acc
    ask(il, is) := 1;
    IF ring(il).active = 0
    THEN
        BEGIN
            tok := NEW(CUSTOMER);
            TRANSIT(tok, ring(il));
        END;
    WAIT(fl(il, is));
    RESET(fl(il, is));
    CST(lpck*byte/lan_spd);
    ask(il, is) := 0;
    SET(poll(il));
$END
&
&
$MACRO eventsone
    IF cksumerr(1) = TRUE THEN
        BEGIN
            cksumerr(1) := FALSE;
            C1 := NEW(CUSTOMER);
            C1.seq := frmexpct(1);
            C1.dest := 2;
            CST(0.000125);
            P(C1, niu_bws);
            TRANSIT(C1, ws_niu, REJframe);
            TRANSIT(OUT);
        END;
    IF timeout(1) = 1 THEN
        BEGIN
            timeout(1) := 0;
            C1 := NEW(CUSTOMER);
            C1.p := 1;
            C1.f := 0;
            C1.seq := frmexpct(1);
            C1.dest := 2;
            CST(0.000125);
            P(C1, niu_bws);
            TRANSIT(C1, ws_niu, RRframe);
            TRANSIT(OUT);
        END;
$END
&
&
$MACRO eventstwo
    IF cksumerr(2) = TRUE THEN
        BEGIN
            cksumerr(2) := FALSE;

```

```

C2 := NEW(CUSTOMER);
C2.seq := frmexpct(2);
C2.dest := 1;
CST(0.000125);
P(C2,niu buff);
TRANSIT(C2,fs_niu,REJframe);
TRANSIT(OUT);
END;
IF timeout(2) = 1 THEN
BEGIN
  timeout(2) := 0;
  C2 := NEW(CUSTOMER);
  C2.p := 1;
  C2.f := 0;
  C2.seq := frmexpct(2);
  C2.dest := 1;
  CST(0.000125);
  P(C2,niu buff);
  TRANSIT(C2,fs_niu,RRframe);
  TRANSIT(OUT);
END;

```

```

$SEND
&
$MACRO genfrm1                                & generate the lost frames
                                              & from LAN1
  WHILE seq <> nxtfrsnd(1) DO
  BEGIN
    gen1 := NEW(CUSTOMER);
    gen1.seq := seq;
    gen1.p := 0;
    gen1.f := 0;
    gen1.dest := 2;
    gen1.ack := frmexpct(1);
    IF seq < maxseq THEN
      seq := seq + 1
    ELSE
      seq := 0;
    outstand(1) := outstand(1) + 1;
    CST(t trans);
    P(gen1,niu_bws);
    TRANSIT(gen1,ws_niu,data);
    IF running(1) = 0 THEN
      BEGIN
        gen1 := NEW(CUSTOMER);
        gen1.dest := 1;
        TRANSIT(gen1,timer1,request);
      END
    ELSE sttimer(1) := 1;
  END;
  TRANSIT(OUT);

```

```

$SEND
&
$MACRO genfrm2                                & generate the lost frames
                                              & from LAN2
  WHILE seq <> nxtfrsnd(2) DO
  BEGIN
    gen := NEW(CUSTOMER);
    gen.seq := seq;
    gen.dest := 1;
    gen.p := 0;
    gen.f := 0;
    gen.ack := frmexpct(2);
    IF seq < maxseq THEN
      seq := seq + 1
    ELSE
      seq := 0;
    outstand(2) := outstand(2) + 1;
    CST(t_trans);

```

```

P(gen,niu_buff);
TRANSIT(gen,fs_niu,data);
IF running(2) = 0 THEN
  BEGIN
    gen := NEW(CUSTOMER);
    gen.dest := 2;
    TRANSIT(gen,timer2,request);
  END
ELSE sttimer(2) := 1;
END;
IF outstand(2) < maxseq THEN
  SET(notoutsd)
ELSE
  RESET(notoutsd);
TRANSIT(OUT);
$END
&
/STATION/NAME = LLC1 ;                                & LLC macro on LAN1
SCHED= PRIOR,PREEMPT;
PRIOR(data) = 1;
PRIOR = 2;
SERVICE(request) = BEGIN
  $seventsone                                & see if there is a cksumerr
  CST(t_trans);                                & or a timeout error.
  IF nextfrsnd(1) < maxseq THEN
    nextfrsnd(1) := nextfrsnd(1) + 1
  ELSE
    nextfrsnd(1) := 0;
  C1 := NEW(CUSTOMER);
  p := 0;
  f := 0;
  dest := 2;
  P(niu bws);
  TRANSIT(C1,timer1);                                & send to ws_niu
  TRANSIT(ws_niu);                                & start timer
END;
SERVICE(data) = BEGIN
  $seventsone                                & see if there is a cksumerr
  IF seq = frmexpct(1) THEN                                & or a timeout error.
    BEGIN
      CST(t_trans);
      IF nextfrsnd(1) < maxseq THEN
        nextfrsnd(1) := nextfrsnd(1) + 1
      ELSE
        nextfrsnd(1) := 0;
      IF frmexpct(1) < maxseq THEN
        frmexpct(1) := frmexpct(1) + 1
      ELSE
        frmexpct(1) := 0;
      ack := frmexpct(1);
      rejflag(1) := FALSE;
      j := j + 1;
      IF j = totpckt THEN
        BEGIN
          j := 0;
          V(time);
          cws := NEW(CUSTOMER);                                & send the packets
          cws.dest := 1;                                & to the workstation
          TRANSIT(cws,ws_cpu,response);
          END;
          dest := 2;
          P(niu bws);
          TRANSIT(ws_niu,RRframe);                                & send ack
        END
      ELSE BEGIN
        IF rejflag(1) = FALSE THEN

```

```

        BEGIN
            seq := frmexpct(1);
            CST(0.000125);
            dest := 2;
            rejflag(1) := TRUE;
            P(niu bws);
            TRANSIT(ws_niu, REJframe);
        END
    ELSE TRANSIT(OUT);
END;
END;

SERVICE(RRframe) = BEGIN
    $seventsone           & see if there is a cksumerr
    IF (p = 1) AND (f = 1) THEN & or a timeout error.
        BEGIN
            outstand(1) := 0;
            $genfrml
        END;
    IF (p = 1) AND (f <> 1) THEN
        BEGIN
            f := 1;
            CST(0.000125);
            seq := frmexpct(1);
            dest := 2;
            P(niu bws);
            TRANSIT(ws_niu);
        END
    ELSE BEGIN
        CST(t_trans);
        frmexpct(1) := ack;
        IF ack > nxtfrsnd(1) THEN
            outstand(1) := window - ack + nxtfrsnd(1)
        ELSE
            outstand(1) := nxtfrsnd(1) - ack;
        IF outstand(1) = 0 THEN
            running(1) := 0 & stop timer one
        ELSE sttimer(1) := 1; & restart timer 1
        TRANSIT(OUT);
    END;
END;

SERVICE(REJframe) = BEGIN
    CST(0.000125);
    $seventsone           & see if there is a cksumerr
    outstand(1) := 0;      & or a timeout error.
    $genfrml
END;

&
&
&
/STATION/NAME = LLC2;
SCHED= PRIOR, PREEMPT;
PRIOR(data) = 1;
PRIOR = 2;
SERVICE(request) = BEGIN
    $seventstwo           & check if events had occurred
    CST(t_trans);         & convert it to a LAN frame
    IF nxtfrsnd(2) < maxseq THEN
        nxtfrsnd(2) := nxtfrsnd(2) + 1
    ELSE
        nxtfrsnd(2) := 0;
        C2 := NEW(CUSTOMER);
        C2.ack := nxtfrsnd(2);
        C2.p := 0;
        C2.f := 0;
        C2.dest := 157

```

```

C2.seq:= nxtfrsnd(2);
P(C2,niu buff);
TRANSIT(C2,fs_niu,RRframe);
TRANSIT(fs_cpū);
END;

SERVICE(data) = BEGIN
  $eventstwo
  IF outstand(2) < maxseq THEN
    SET(notoutsd)
  ELSE RESET(notoutsd);
  WAIT(notoutsd);
  seq := nxtfrsnd(2);
  dest := 1;
  p := 0;
  f := 0;
  IF nxtfrsnd(2) < maxseq THEN
    nxtfrsnd(2) := nxtfrsnd(2) + 1
  ELSE
    nxtfrsnd(2) := 0;
    outstand(2) := outstand(2) + 1;
    IF running(2) = 0 THEN
      BEGIN
        C2 := NEW(CUSTOMER);
        TRANSIT(C2,timer2,request);
      END
    ELSE
      sttimer(2) := 1;
      dest := 1;
      P(niu buff);
      TRANSIT(fs_niu);
    END;
  END;

SERVICE(RRframe) = BEGIN
  $eventstwo
  IF (p = 1) AND (f = 1) THEN
    BEGIN
      outstand(2) := 0;
      $genfrm2
    END;
  IF (p = 1) AND (f <> 1) THEN
    BEGIN
      f := 1;
      CST(0.000125);
      dest := 1;
      seq := frmexpct(2);
      P(niu buff);
      TRANSIT(fs_niu);
    END
  ELSE BEGIN
    CST(t_trans); &receive RRframe
    frmexpct(2) := ack;
    IF ack > nxtfrsnd(2) THEN
      outstand(2) := window - ack + nxtfrsnd(2)
    ELSE
      outstand(2) := nxtfrsnd(2) - ack;
    IF outstand(2) = 0 THEN
      running(2) := 0 & stop timer 2
    ELSE sttimer(2) := 1; & restart timer 2
    IF outstand(2) < maxseq THEN
      SET(notoutsd)
    ELSE RESET(notoutsd);
    TRANSIT(OUT);
  END;
END;

```

```

SERVICE(REJframe) = BEGIN
    CST(0.000125);
    $eventstwo
    outstand(2) := 0;
    $genfrm2
    END;

&
&
/STATION/NAME=timer1;                                & timer on LAN1
    SERVICE= BEGIN
        sttimer(1) := 0;
        running(1) := 1;
    TRANSIT(OUT);
        FOR x:= 1 STEP 1 UNTIL INTREAL(t_timer/clock) DO
            BEGIN
                IF sttimer(1) = 1 THEN
                    BEGIN
                        sttimer(1) := 0;    & reset timer
                        x := 1;
                    END;
                IF running(1) = 0 THEN
                    TRANSIT(OUT);          & stop timer
                    CST(clock);
                END;
                IF running(1) = 0 THEN
                    TRANSIT(OUT)
                ELSE
                    timeout(1) := 1;      & signal timeout
                    running(1) := 0;
                    TRANSIT(LLC1,request);
                END;                        & end of timer service.
            END;
        END;

&
&
/STATION/NAME=timer2;                                & timer on LAN2
    SERVICE= BEGIN
        sttimer(2) := 0;
        running(2) := 1;
    TRANSIT(OUT);
        FOR yy:= 1 STEP 1 UNTIL INTREAL(t_timer/clock) DO
            BEGIN
                IF sttimer(2) = 1 THEN
                    BEGIN
                        sttimer(2) := 0;    & reset timer
                        yy := 1;
                    END;
                IF running(2) = 0 THEN
                    TRANSIT(OUT);          & stop timer
                    CST(clock);
                END;
                IF running(2) = 0 THEN
                    TRANSIT(OUT)
                ELSE
                    timeout(2) := 1;      & signal timeout
                    running(2) := 0;
                    TRANSIT(LLC2,request);
                END;                        & end of timer service.
            END;
        END;

&
&
/STATION/ NAME = lan(1);                                & LAN1 queue for Applebus
    SERVICE= BEGIN
        $med acc
        TRANSIT(bridgel);
    END;

&
/STATION/ NAME = lan(2);                                & LAN2 queue for Applebus
    SERVICE= BEGIN

```

```

$med acc
TRANSIT(bridge2);
END;

```

```

-----
LAN ONE BACKGROUND LOAD (STATION 1..10)
-----

```

```

/STATION/ NAME      = lanlws1;           & this is just a loading
          TYPE      = SOURCE;           & station. It is there in
          SERVICE   = BEGIN             & order to provide local loads
                                EXP(intra); & on the network.
                                dest := 2;
                                lpack := dumlgth;
                                TRANSIT(mac1,dummy);
                                END;

```

```

/STATION/ NAME      = mac1;
          SERVICE   = BEGIN
                                $med acc
                                TRANSIT(CUT,dummy);
                                END;

```

```

/STATION/ NAME      = lanlws2;           & its purpose is the same
          TYPE      = SOURCE;           & as lanlws1.
          SERVICE   = BEGIN
                                EXP(intra);
                                dest := 2;
                                lpack := dumlgth;
                                TRANSIT(mac2,dummy);
                                END;

```

```

/STATION/ NAME      = mac2;
          SERVICE   = BEGIN
                                $med acc
                                TRANSIT(OUT,dummy);
                                END;

```

```

/STATION/ NAME      = lanlws3;           & its purpose is the same
          TYPE      = SOURCE;           & as lanlws1.
          SERVICE   = BEGIN
                                EXP(intra);
                                dest := 2;
                                lpack := dumlgth;
                                TRANSIT(mac3,dummy);
                                END;

```

```

/STATION/ NAME      = mac3;
          SERVICE   = BEGIN
                                $med acc
                                TRANSIT(OUT,dummy);
                                END;

```

```

/STATION/ NAME      = lanlws4;           & its purpose is the same
          TYPE      = SOURCE;           & as lanlws1.
          SERVICE   = BEGIN
                                EXP(intra);
                                dest := 2;
                                lpack := dumlgth;
                                TRANSIT(mac4,dummy);
                                END;

```

```

/STATION/ NAME      = mac4;
          SERVICE   = BEGIN
                                $med acc
                                TRANSIT(OUT,dummy);
                                END;

```

```

/STATION/ NAME      = lanlws5;           & its purpose is the same
          TYPE      = SOURCE;           & as lanlws1.
          SERVICE   = BEGIN

```

```

EXP(intra);
dest := 2;
lpack := dumlgth;
TRANSIT(mac5,dummy);
END;
/STATION/ NAME    = mac5;
SERVICE = BEGIN
    $med acc
    TRANSIT(OUT,dummy);
END;

/STATION/ NAME    = lanlws6;           & its purpose is the same
TYPE           = SOURCE;              & as lanlws1. However traffic is
SERVICE = BEGIN                      & generated inter LAN
    EXP(inter);
    dest := 2;
    lpack := dumlgth;
    TRANSIT(mac6,dummy);
END;
/STATION/ NAME    = mac6;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridgel,dummy);
END;

/STATION/ NAME    = lanlws7;           & its purpose is the same
TYPE           = SOURCE;              & as lanlws1. However traffic is
SERVICE = BEGIN                      & send inter LAN
    EXP(inter);
    dest := 2;
    lpack := dumlgth;
    TRANSIT(mac7,dummy);
END;
/STATION/ NAME    = mac7;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridgel,dummy);
END;

/STATION/ NAME    = lanlws8;           & its purpose is the same
TYPE           = SOURCE;              & as lanlws1. However traffic is
SERVICE = BEGIN                      & send interLAN
    EXP(inter);
    dest := 2;
    lpack := dumlgth;
    TRANSIT(mac8,dummy);
END;
/STATION/ NAME    = mac8;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridgel,dummy);
END;

/STATION/ NAME    = lanlws9;           & its purpose is the same
TYPE           = SOURCE;              & as lanlws1. However traffic is
SERVICE = BEGIN                      & send inter LAN
    EXP(inter);
    dest := 2;
    lpack := dumlgth;
    TRANSIT(mac9,dummy);
END;
/STATION/ NAME    = mac9;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridgel,dummy);
END;

```

```

/STATION/ NAME      = lanlws1;           & its purpose is the same
          TYPE       = SOURCE;           & as lanlws1. However traffic is
          SERVICE    = BEGIN              & send inter LAN
                        EXP(inter);
                        dest := 2;
                        lpack := dumlgth;
                        TRANSIT(mac10,dummy);
                        END;
/STATION/ NAME      = mac10;
          SERVICE    = BEGIN
                        $med acc
                        TRANSIT(bridge1,dummy);
                        END;
&-----
& LAN TWO BACKGROUND LOAD (STATION 1..10)
&-----
&
/STATION/ NAME      = lan2ws1;           & this is just a loading
          TYPE       = SOURCE;           & station. It is there in
          SERVICE    = BEGIN              & order to provide local loads
                        EXP(intra);        & on the network.
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(wslmac,dummy);
                        END;
/STATION/ NAME      = wslmac;
          SERVICE    = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME      = lan2ws2;           & its purpose is the same
          TYPE       = SOURCE;           & as lanlws1.
          SERVICE    = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(ws2mac,dummy);
                        END;
/STATION/ NAME      = ws2mac;
          SERVICE    = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME      = lan2ws3;           & its purpose is the same
          TYPE       = SOURCE;           & as lanlws1.
          SERVICE    = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(ws3mac,dummy);
                        END;
/STATION/ NAME      = ws3mac;
          SERVICE    = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME      = lan2ws4;           & its purpose is the same
          TYPE       = SOURCE;           & as lanlws1.
          SERVICE    = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth; 162

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```

/STATION/ NAME    = lan1ws10;           & its purpose is the same
          TYPE     = SOURCE;             & as lan1ws1. However traffic is
          SERVICE  = BEGIN                & send inter LAN
                        EXP(inter);
                        dest := 2;
                        lpack := dumlgth;
                        TRANSIT(mac10,dummy);
                        END;
/STATION/ NAME    = mac10;
          SERVICE  = BEGIN
                        $med acc
                        TRANSIT(bridge1,dummy);
                        END;
&-----
& LAN TWO BACKGROUND LOAD (STATION 1..10)
&-----
&
/STATION/ NAME    = lan2ws1;           & this is just a loading
          TYPE     = SOURCE;             & station. It is there in
          SERVICE  = BEGIN                & order to provide local loads
                        EXP(intra);         & on the network.
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(wslmac,dummy);
                        END;
/STATION/ NAME    = wslmac;
          SERVICE  = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME    = lan2ws2;           & its purpose is the same
          TYPE     = SOURCE;             & as lan1ws1.
          SERVICE  = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(ws2mac,dummy);
                        END;
/STATION/ NAME    = ws2mac;
          SERVICE  = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME    = lan2ws3;           & its purpose is the same
          TYPE     = SOURCE;             & as lan1ws1.
          SERVICE  = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth;
                        TRANSIT(ws3mac,dummy);
                        END;
/STATION/ NAME    = ws3mac;
          SERVICE  = BEGIN
                        $med acc
                        TRANSIT(OUT,dummy);
                        END;

/STATION/ NAME    = lan2ws4;           & its purpose is the same
          TYPE     = SOURCE;             & as lan1ws1.
          SERVICE  = BEGIN
                        EXP(intra);
                        dest := 1;
                        lpack := dumlgth;

```

```

SERVICE = BEGIN                                & send inter LAN
    EXP(inter);
    dest := 1;
    lpack := dumlgth;
    TRANSIT(ws9mac, dummy);
END;
/STATION/ NAME = ws9mac;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridge2, dummy);
END;

/STATION/ NAME = lan2ws10;                        & its purpose is the same
TYPE = SOURCE;                                    & as lan1ws1. However traffic is
SERVICE = BEGIN                                & send inter LAN
    EXP(inter);
    dest := 1;
    lpack := dumlgth;
    TRANSIT(ws10mac, dummy);
END;
/STATION/ NAME = ws10mac;
SERVICE = BEGIN
    $med acc
    TRANSIT(bridge2, dummy);
END;

&-----
&
/STATION/NAME = bridge1;
SERVICE = BEGIN
    CST(0.000200);    & proc. time at the bridge
    IF dest = 1 THEN
        TRANSIT(bdg1eth)
    ELSE
        TRANSIT(bdg1t1);
    END;

/STATION/NAME = bdg1eth;    & bridge at lan 1 to ethernet MAC layer
SERVICE = BEGIN
    $med acc
    IF CLASS = dummy THEN
        TRANSIT(OUT)
    ELSE BEGIN
        IF ws_niu.NB > memsize THEN
            TRANSIT(OUT)
        ELSE BEGIN
            P(niu bws);
            TRANSIT(ws_niu);
        END;
    END;
END;

/STATION/NAME = bdg1t1;    & bridge at lan1 to T1 link MAC layer
SERVICE = BEGIN
    CST(lpack*8.0/1544000);    & time to TX packet over T1
    TRANSIT(bridge2);
END;

&
/STATION/NAME = bridge2;
SERVICE = BEGIN
    CST(0.000200);    & processing time at the bridge
    IF dest = 2 THEN
        TRANSIT(bdg2eth)
    ELSE
        TRANSIT(bdg2t1); 164

```

```

TRANSIT (ws4mac, dummy);
END;
/STATION/ NAME    = ws4mac;
SERVICE = BEGIN
$med acc
TRANSIT (OUT, dummy);
END;

/STATION/ NAME    = lan2ws5;           & its purpose is the same
TYPE             = SOURCE;           & as lanlws1.
SERVICE = BEGIN
EXP (intra);
dest := 1;
lpack := dumlgth;
TRANSIT (ws5mac, dummy);
END;

/STATION/ NAME    = ws5mac;
SERVICE = BEGIN
$med acc
TRANSIT (OUT, dummy);
END;

/STATION/ NAME    = lan2ws6;           & its purpose is the same
TYPE             = SOURCE;           & as lanlws1. However traffic is
SERVICE = BEGIN                     & send inter LAN
EXP (inter);
dest := 1;
lpack := dumlgth;
TRANSIT (ws6mac, dummy);
END;

/STATION/ NAME    = ws6mac;
SERVICE = BEGIN
$med acc
TRANSIT (bridge2, dummy);
END;

/STATION/ NAME    = lan2ws7;           & its purpose is the same
TYPE             = SOURCE;           & as lanlws1. However traffic is
SERVICE = BEGIN                     & send inter LAN
EXP (inter);
dest := 1;
lpack := dumlgth;
TRANSIT (ws7mac, dummy);
END;

/STATION/ NAME    = ws7mac;
SERVICE = BEGIN
$med acc
TRANSIT (bridge2, dummy);
END;

/STATION/ NAME    = lan2ws8;           & its purpose is the same
TYPE             = SOURCE;           & as lanlws1. However traffic is
SERVICE = BEGIN                     & send inter LAN
EXP (inter);
dest := 1;
lpack := dumlgth;
TRANSIT (ws8mac, dummy);
END;

/STATION/ NAME    = ws8mac;
SERVICE = BEGIN
$med acc
TRANSIT (bridge2, dummy);
END;

/STATION/ NAME    = lan2ws9;           & its purpose is the same
TYPE             = SOURCE;           & as lanlws1. However traffic is

```

```

        END;

/STATION/NAME = bdg2eth;           & bridge at lan 2 to ethernet MAC layer
SERVICE = BEGIN
    $med acc
    IF CLASS = dummy THEN
        TRANSIT(OUT)
    ELSE BEGIN
        IF fs_niu.NB > memsize THEN
            TRANSIT(OUT)
        ELSE BEGIN
            P(niu buff);
            TRANSIT(fs_niu);
        END;
    END;
END;

        END;
/STATION/NAME = bdg2t1;           & bridge at lan 2 to T1 link MAC layer
SERVICE= BEGIN
    CST(lpack*8.0/1544000);      & time to TX packet over T1
    TRANSIT(bridg1);
END;

&
&
&-----
&
&
&*****
&   This procedure simulates the workstation model. It also      *
&   has a network interface unit with internal memory of size memsize.*
&*****
&
&
&
/STATION/NAME= niu bws;
TYPE= RESOURCE, MULTIPLE(memsize);

/STATION/NAME= time;              & used to time the transfer of data
TYPE= RESOURCE;

/STATION/NAME= ws_niu;
SERVICE= BEGIN                  & this response releases one buffer
    V(niu bws);                  & of size 1K from the NIU memory
    IF deSt = 1 THEN
        TRANSIT(LLC1)
    ELSE
        TRANSIT(lan(1));
    END;

/STATION/NAME= ws_cpu;
SERVICE(request)= BEGIN
    EXP(t_convrt);               & req. processing time
    P(time);
    lpack := 64;                 & set packet length
    TRANSIT(LLC1);               & start timing the request
    END;
SERVICE(response)= BEGIN
    EXP(t_detect);               & detect response packet
    TRANSIT(img_proc);           & and transit to img_proc.
    END;

/STATION/NAME= img_proc;
INIT(request) = 1;
SERVICE= BEGIN
    EXP(t_proc);                 & time to display the image.
    TRANSIT(ws_cpu,request);     & change class to request

```

```

END;

&
&-----
&
&*****
&   This program simulates the file server model. It also      *
&   has a network interface unit with internal memory of size memsize.*
&*****
&
&
&
/STATION/NAME= BUS;                      & file server BUS resource
      TYPE= RESOURCE, MULTIPLE(1);

/STATION/NAME= buffer;                   & file server buffer resource
      TYPE= RESOURCE, MULTIPLE(1);

/STATION/NAME= niu buff;                 & NIU resurces
      TYPE= RESOURCE, MULTIPLE(memsize);

/STATION/NAME= fs niu;
      SERVICE= BEGIN
          V(niu_buff);                      & release one niu_buffer;
          IF dest = 2 THEN
              TRANSIT(LLC2)
          ELSE
              TRANSIT(lan(2));
          END;

/STATION/NAME= fs cpu;                   & file server CPU
      SCHED= QUANTUM(1E-3);
      SERVICE(request)= BEGIN
          EXP(t_query);                      & req. processing time
          FOR cnter := 1 STEP 1 UNTIL (nb_reqts - 1) DO
              BEGIN
                  req_d := NEW(CUSTOMER);
                  TRANSIT(req_d,fs_disk);
              END;
          TRANSIT(fs_disk);
          END;
      SERVICE(response)= BEGIN
          FOR cntr := 1 STEP 1 UNTIL 63 DO
              BEGIN
                  P(BUS);
                  c := NEW(CUSTOMER); & convert the 64K data into
                  CST(t_convrt);      & 64 packets of size 1K
                  V(BUS);
                  TRANSIT(c,LLC2,data); & station and transit.
              END;
          P(BUS);
          CST(t_convrt);
          V(BUS);
          TRANSIT(LLC2,data);
          END;

/STATION/NAME= fs disk;                  & disk station
      SERVICE= BEGIN
          P(buffer);                        & ask for the buffer
          EXP(t_disk);                      & time to read from disk
          P(BUS);
          CST(t_dbuff);                    & time to transfer from disk to buffer
          V(BUS);
          P(BUS);
          CST(t_bmem);                    & time to transfer from buffer to memory
          V(BUS);
          V(buffer);

```

```

TRANSIT(fs_cpu,response); & change class to response
END;

&
&-----
&                (Background load on both Token Ring LANs)
&                (***** NO BRIDGE PRIORITY *****)
& 50% INTRA & 18% INTER LAN TRAFFIC WITH FILE SIZE 1.216Mbyte,lpack=1.0Kbyte
& =====
&
/CONTROL/TMAX=10000;                & total simulation time
    PERIOD = 2000; TEST = OUTPUT;
    ACCURACY=ALL QUEUE;
/EXEC/BEGIN

& ----- ethernet parameters -----
FOR jj:=1 STEP 1 UNTIL 1 DO
    BEGIN
        ring(jj).il:=jj;
        token(jj).icl:=jj;
    END;

mac1.il:=1;                & assigning local address and position to
mac1.is:=1;                & the background nodes on LAN1
mac2.il:=1;
mac2.is:=2;
mac3.il:=1;
mac3.is:=3;
mac4.il:=1;
mac4.is:=4;
mac5.il:=1;
mac5.is:=5;
mac6.il:=1;
mac6.is:=6;
mac7.il:=1;
mac7.is:=7;
mac8.il:=1;
mac8.is:=8;
mac9.il:=1;
mac9.is:=9;
mac10.il:=1;
mac10.is:=10;
&
ws1mac.il:=2;                & assigning local address and position to
ws1mac.is:=1;                & the background nodes on LAN2
ws2mac.il:=2;
ws2mac.is:=2;
ws3mac.il:=2;
ws3mac.is:=3;
ws4mac.il:=2;
ws4mac.is:=4;
ws5mac.il:=2;
ws5mac.is:=5;
ws6mac.il:=2;
ws6mac.is:=6;
ws7mac.il:=2;
ws7mac.is:=7;
ws8mac.il:=2;
ws8mac.is:=8;
ws9mac.il:=2;
ws9mac.is:=9;
ws10mac.il:=2;
ws10mac.is:=10;
&
lan(1).il:=1;
lan(1).is:=stat;

```

```

lan(2).il:=2;
lan(2).is:=stat;
&
bdgleth.il:=1;
bdgleth.is:=node;
bdg2eth.il:=2;
bdg2eth.is:=node;

&***** LLC INITIALIZATION *****
nxtfrsnd(1) := 0;           & next frame to send
frmexpct(1) := 0;           & frame expected
outstand(1) := 1;           & outstanding frames on LAN1
nxtfrsnd(2) := 0;
frmexpct(2) := 0;
outstand(2) := 0;
cksumerr(1) := FALSE;
cksumerr(2) := FALSE;
timeout(1) := 0;
timeout(2) := 0;
rejflag(1) := FALSE;
rejflag(2) := FALSE;
& ----- SET THE PACKET LENGTH OF THE FRAMES -----
dumlgth := 1000 ;           & frame length of the dummy classes of customers
request.lpack := 64;
response.lpack := 64;
REJframe.lpack := 64;      & length of different control frames
RRframe.lpack := 64;
data.lpack := 1000;
dummy.lpack := dumlgth;
nb_reqts := 19;
totpkt := 1216;           & (1.216Mbyte/1.0Kbyte)
&
&*****
&
& ----- llc protocol parameters -----
t_tlprop:= 5.4E-3;
t_prop := 100E-6;           & propagation time of a packet thru ISDN net
t_trans:= 200E-6;
t_timer := 500E-3;          & timer expiration time
clock := 50E-6;             & clock pulse or tick time
& ----- file server parameters -----
t_disk:= 0.4;               & time to access 64Kbytes fro disk
t_query := 0.00011;         & to analyze the request
t_convrt := 0.000100;       & to packetize the data
t_visit := 8;               & inter_request's time
t_dbuff := 0.08;            & transfer time from disk to buffer
t_bmem := 0.08;             & transfer time from buffer to memory
& ----- workstation parameters -----
t_proc := 0.001; &6.4;      & thinking and display time.
t_detect := 0.000100;       & to analyze the request
low_ld := (8.0*1000/880000); & rate for 22% utilization of network
mod_ld := (8.0*1000/2000000); & rate for 50% utilization of network
hvy_ld := (8.0*1000/720000); & rate for 18% util. of the network
x_hvy_ld := (8.0*1000/1200000); & rate for 30% util. of the network
s_hvy_ld := (8.0*1000/1400000); & rate for 35% util. of the network
&
intra := mod_ld*5.0;         & load applied to ring network
inter := hvy_ld*5.0;        & intertraffic probability
&
PRINT(" (Background load on both Token Ring LANs) ");
PRINT(" (***** NO BRIDGE PRIORITY *****) ");
PRINT("50% INTRA & 18% INTER TRAFFIC & FSIZE 1.216Mbyte,lpack=1.0Kbyte");
PRINT("=====");
PRINT(" ");
&
SIMUL;

```

END;

&

&

/END/

\$EOD