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**The Characteristics of Electronic Communications Traffic
in Office Buildings**

by

Alan D. McKinley, P. Eng.

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

Master of Engineering

**Ottawa-Carleton Institute for Electrical Engineering
Faculty of Engineering
Department of Systems and Computer Engineering**

**Carleton University
Ottawa, Ontario**

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submitted by Alan D. McKinley, B. Eng.,

in partial fulfillment of the requirements for the degree of
Master of Engineering

Thesis supervisor

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Abstract

The main objective of this thesis is to determine the present and 10 year future states of electronic communications traffic in office buildings. This is done by examining the level of traffic for each device, the use of broadband communications, the use of wireless communications including Personal Communications Networks (PCN) and the potential for in-building network integration. All devices are considered, including present telecommunications, office automation and building service equipment as well as new systems under development such as multimedia, HDTV and PCN's. Based on current trends, it is concluded that traffic growth will vary from zero for terminals, to 4-9% for telephones, to 20-25% for workstations, and to 25-30% for facsimile machines. Device transfer rates for personal computers, may increase from an average of 200 kbits/s to 500 kbits/s, and for powerful workstations from 2.2 mbits/s to 10 mbits/s over the next 5 years. High Definition Television (HDTV) will likely adopt a digital standard in North America with average speeds of 22 mbits/s. It will begin production in 1996 in parallel with broadcast TV which will begin to be phased out in 2008. Multimedia workstations may require speeds of 2.3-7 mbits/s and could represent 30-40% of office workstations within 10 years. PCN systems are expected to be in common use within the same period and the PCN infrastructure and communications modules could be used to support data devices such as portable computers. Calculations of the future requirements of the large 775,500 sq. ft. office building studied suggest that a fully integrated building network (IBN) may see about 148 Mbits/s traffic on each floor and that the backbone system could be required to support about 1.3 Gbits/s. The Sonet ISDN system with speeds to 2.488 Gbits/s could be used today or the B-ISDN asynchronous transfer mode being defined by the CCITT which will be available soon.

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Chapter 1 Introduction

This thesis was undertaken to determine the characteristics of office building electronic communications systems over the next ten years. In particular it examines the present and future states of the following five characteristics:

- 1. the level of traffic**
- 2. the use of broadband communications**
- 3. the use of wireless communications**
- 4. the use of personal communications networks (PCN's)**
- 5. the potential for in-building network integration**

The methodology used is to first identify the possible states for each of the characteristics, then to examine the present status of communications systems and to evaluate the traffic demanded by devices now and in the future and finally, based on this examination and evaluation, to determine which states can and need to be achieved to support these requirements over the next ten years.

The level of traffic is fundamentally determined by the devices and applications in use and therefore these are examined in detail rather than attempting to project the level of use from higher level studies of present network installations. The level of traffic is dependent upon several sub factors such as the required device speeds, the application's response time and the desired error rate. The study of device and application development will determine the status for the level of traffic and the possible requirements for broadband traffic.

The two characteristics relating to wireless communications and, in particular, the possible use of personal communications networks to provide the final link between the in-building network and some devices is both a technical question and a marketing one. The thesis therefore examines the technical developments of this technology to determine its feasibility and reviews the market trends to determine its desirability. The feasibility and desirability will therefore determine the state of the two wireless characteristics.

Determination of the in-building network integration characteristic's state is dependent upon the states of the first four variables, the traffic volume and possible use of broadband, wireless in general and PCN in particular and also upon the network products and standards available to support those characteristics.

Table 1 shows possible states for each of the five characteristics under investigation. The objective of the thesis is to predict the state of each within a ten year horizon.

This study does not consider the requirements of the fire protection systems as the National Fire Code in Canada requires that it be kept separate at this time. The characteristics of this system however are not dissimilar from those of other building services and the devices could utilize a common building network if the level of security and dependability were such that the code requirements could be altered.

Variables	Possible states within a ten year horizon
- the level of traffic (speed & volume)	<ul style="list-style-type: none"> - Level I: no growth in number of devices (1992 levels) <ul style="list-style-type: none"> - terminals @ 2.4 kbits/s, workstations @ 200 kbits/s-2.2 Mbits/s - telephones @ 64 kbits/s, fax @ 9.6 kbits/s - Level II: - terminals unchanged, zero growth <ul style="list-style-type: none"> - workstations @ 300 Kbits/s-5 Mbits/s, 10% growth - telephones @ 64 Kbits/s, 5% growth - fax @ 19.2 Kbits/s, 10% growth - Level III - terminals unchanged, zero growth <ul style="list-style-type: none"> - workstations 500 Kbits/s to 10 Mbits/s, growth 20-25% - telephones @ 64 Kbits/s, 4-9% growth - fax @ 64 Kbits/s, 25-30% growth <p>Note: % growth is the change in the overall traffic</p>
the use of broadband communications	<ul style="list-style-type: none"> - no HDTV, limited multimedia (5%) - 30 - 40% of workstations are multimedia, limited HDTV, moderate imaging - all workstations are multimedia, HDTV for all video, heavy imaging
the use of wireless communications	<ul style="list-style-type: none"> - infrequent (< 5% of devices) - frequent but not universally (20 - 50% of devices) - universally (> 50% of devices)
the use of PCN	<ul style="list-style-type: none"> - will not be implemented or won't be used for other devices - will be implemented and can be used for voice and data only devices - will be implemented and can be used for voice, data and possible video
in-building network integration	<ul style="list-style-type: none"> - Level I: Status quo at 1992 level with no further integration. - Level II: 1 PBX, multiple LANS, CT-2Plus, separate broadband, several BS LAN's and some direct wiring - Level III: 1 PBX, CT-2Plus and PCN, OA LAN, 1 BS LAN, broadband LAN - Level IV: Integrated voice/data LAN for all services, Integrated broadband LAN - Level V: One Integrated Building Network

Table 1: Possible states of communications variables

Office buildings use more than a dozen separate but technically similar communications networks and wiring systems to operate the various electrical and electronic systems which support either the building or its tenants and there are a number of efforts underway to develop standards for the implementation of combined networks.

Communications systems used in office buildings have developed in parallel in three separate fields; telecommunications for voice, facsimile and video, computers for data and graphics and control systems for building equipment control and monitoring. Each have developed separate standards and rarely have network designers nor equipment manufacturers looked beyond their field of interest. Integration of all communications over one network requires a broader look at the applications and devices used and at the characteristics and anticipated levels of traffic. Although there have been studies of the PBX and computer network traffic, there is little information available about the traffic generated by evolving and new computer applications such as multimedia or about the traffic generated by building services. There also have not been many studies that evaluate the total traffic that can be expected over a combined system. It is estimated that 35% of the cost of communications wiring may be saved by combining telephone, data, lighting, climate controls and security systems into a single integrated system [1].

Table 2 summarizes the types of traffic found in office buildings and illustrates the levels of integration of networks set out as states of the first characteristic. Each of the three disciplines; telecommunications, office automation and building services have requirements for voice, data and video communications. The table therefore illustrates the parallel development of these disciplines and shows how network integration could serve all three.

	Voice				Data				Video			
	Telecom.	O.A.	B.S.	Telecom.	O.A.	B.S.	Telecom.	O.A.	B.S.			
examples of some of the services	- telephones - fax - voice messaging	- voice e-mail - multimedia audio	- intercoms - audio distribution - paging	- modems - network gateways	- workstations - terminals - printers - file servers	- device control - sensors - workstations - printers	- television - CCTV - video conferencing	- multimedia - tele-conferencing	- security cameras - equipment monitoring			
Level I (1992)	- direct lines - voice PBX	- direct lines - voice PBX	- direct lines - voice PBX	- direct lines	- direct lines - LANs	- direct lines	- direct lines - CATV	- direct lines - CATV	- direct lines			
Level II	- voice PBX - CT-2Plus	- OA LAN - voice PBX	- voice PBX - BS LAN	- voice PBX	- O.A. LAN	- B.S. LANs - direct lines	- B-LAN	- B-LAN	- direct lines			
Level III	Voice PBX with sepcarac CT-2Plus and PCN systems			Data LAN			Tenant B-LAN			B.S. B-LAN		
Level IV	Integrated voice & data LAN with wireless drops									Integrated broadband LAN		
Level V	Integrated Building Network (IBN)											

Table 2: Levels of Office Building Network Integration

where:

Telecom. = Telecommunications

O.A. = Office Automation

B.S. = Building Services

CCTV = closed circuit television

PBX = private branch exchange

LAN = local area network

B-LAN = broadband LAN

CATV = community access television

PCN = personal communications network

Chapter 2 examines the use of communications in today's office buildings. It first describes the types of applications found in Building and Tenant services and then reviews the state of the art of the communications technologies used to support these services. Finally it examines some of the problems and opportunities that presently exist.

Chapter 3 examines in detail the traffic generated by each of the specific devices in each of the services. The devices considered include the tenant service telecommunication devices such as telephones, facsimile machines, voice messaging and video conferencing and office automation devices such as workstations, computer terminals and word processors. Building service devices such as sensors, thermostats, security systems and elevators are also considered. It also looks at new devices and applications such as HDTV and multimedia to project their future requirements.

Chapter 4 considers the combined traffic levels generated within an office. To illustrate the present level of communications traffic, a case study is presented showing the characteristics and total traffic for a large, open office concept floor of a modern office. In addition, a hypothetical office of the future is examined through the presentation of several model scenarios made up of the more communications intensive equipment and a projection of the future requirements for the open office concept case study.

Chapter 5 reviews the opportunities for the use of wireless communications and in particular looks at personal communications networks.

Chapter 6 reviews some of the present network integration projects to evaluate the feasibility of further integration. A complete evaluation would require a full modeling and simulation program which is beyond the scope of this thesis. However a preliminary traffic estimate of the total building traffic is presented based on projected developments of the case study presented in chapter 4.

The final conclusions about the states of each of the five characteristics under consideration are contained in chapter 7.

The thesis examines the type of usage expected these systems and discusses the variables and driving factors that affect the communications loads. This information would also provide the data necessary to construct a comprehensive office building communications modeling and simulation program which would be very useful to industries designing, manufacturing and installing integrated networks and to in-building network managers. Such a system should be able to model any office building given specific physical dimensions and the applications and equipment to be installed.

The movement towards Personal Communications Networks (PCN's) which propose the use of small wireless telephones would involve the installation of antenna systems throughout all office buildings. This opens up the possibility of using this same antenna network to support the other devices requiring communications. As Hardy [2] points out, the question now is how much bandwidth will be required for these services and this thesis addresses that question.

In summary, this thesis presents a review and analysis of communications traffic of all devices found in office buildings. In particular, it evaluates the level of traffic expected over the next 10 years, the use of broadband and wireless communications and the possibilities for integration of the in-building networks. Predictions of future uses and traffic levels are dependent both on technology developments and on market acceptance. While it has been possible to project technical advancements and to speculate on how technologies such as multimedia, HDTV and PCN might be used there are widely varying opinions on how readily and to what extent the market will adopt these systems. The thesis does attempt to estimate the future level of implementation. However there are few reliable market estimates on which to base these projections. There is also considerable caution among manufacturers as a result of the initial failure of video text and slow response to pay-per-view video on demand.

Chapter 2 Today's Office Building Communications

2.1 A Brief Review of Building and Tenant Services

There have been a number of advances in the use of automated technologies in modern office buildings which have resulted in large, and complex communication systems and requirements. Building designers often fail to realize that the cost of modern telecommunications has risen to about \$8/sq. ft. compared to \$3/sq. ft. for lighting and \$5/sq. ft. for electrical services. The Intelligent Building Institute says that telecommunications costs may represent 10% or more of new building construction [3]. To understand the communications problem, it is first necessary to understand the requirements of all of the devices within the building.

There are two categories of services in modern buildings, Tenant Services as shown in Figure 1 and Building Services shown in Figure 2. Tenant Services are those systems installed and (usually) paid for by the tenant renting or occupying the space. Building Services are the systems installed in the building structure by the builder to operate the building and to serve all of the occupants, and often (though not always) are included by the owner in the rent to a tenant. Appendix A describes some of the tenant and building service systems being installed today. The communications requirements of their devices will be examined in chapter 3.

Telecommunications Services

Office Automation

Figure 1: Tenant Service Systems

Figure 2: Building Service Systems

At present, most building services use their own separate networks. Office Automation service networks are being integrated into various types of local area networks (LANs). Telecommunications services are typically supported by Private Branch Exchanges (PBX's) and cable TV networks. Of particular significance is the similarity between the technologies of telecommunications, office automation and building services as they all are progressively basing their new networks on digital communications.

The service requirements of different building types as categorized by Mizukura [4] are shown in Table 3.

Building	Main Purpose	Air Cond.	Lights	Power	Security	Fire	PBX	Office Auto.	Audio Visual	Area Service
Own bldgs.	info. & OA oriented	V	V	S	V	V	V	V	M	M
Rental bldgs.	efficiency, lower labour \$	V	V	V	V	V	S	S	M	V
Hospitals	improved med. service	V	M	S	M	V	S	S	S	S
Schools	higher academic stds.	V	M	M	M	M	M	M	V	S
Hotels	improved customer serv.	V	M	M	M	V	V	V	V	V
Apt. blocks	privacy & communication	S	S	V	V	V	M	M	S	V
Gov. bldgs.	guard public interest	V	V	S	V	V	V	V	S	V

Table 3: The Functional Requirements of Different Building Types

where: V = very strong need

S = strong need

M = moderate need

Modern buildings that adequately address the communications needs of their tenant and building services have recently been termed Intelligent Buildings, a term that, despite initial uncertainty, has become an accepted label in the industry [5] [6] [7]. The term "intelligent" implies that the building systems are able to dynamically adapt themselves to varying conditions in pre-programmed ways. The term, and its synonym "smart" are

used for many modern devices such as "Intelligent Time Division Multiplexers" (ITDM's) which perform data compression, "Smart Cards" which are security access cards that contain information about the user and lighting and temperature controls that adjust automatically based upon the occupancy requirements and the local conditions.

In addition to Building Service systems that dynamically adjust to a variety of sensed conditions, it has been suggested that an Intelligent Building Network (IBN) might also be installed and operated by the building owner and provide integrated building network communications support for all of the services operating in the building.

Building service systems change far less frequently than tenant services and they are more difficult and costly to alter as they are built into the structure. There are two reasons for changing a building service system. One is to upgrade it to a newer and more efficient technology. Given that new generations of electronics based services appear about every five years over the fifty year life of the average building, difficulty in upgrading has recently become a serious concern. The other is the pressure from the office space rental market that forces the owner to provide competitive office space and services and to renovate office layouts to suit new tenants or the changing needs of existing ones.

There are significantly more building service devices than tenant service devices installed in the average building as shown in Table 4 which gives the ratio of the number of Tenant Service Video and Data devices to the number of devices required by the Building Services.

	Device Ratio V & D : Bldg. Serv.
Office Buildings	1:3.5
Service Buildings	1:4.5
Manufacturing	1:2.5
School/Higher Education	1:2.5
Hospital/Health Care	1:2.0
Hotels & Convention	1:2.5

Table 4: Ratio Video & Data Devices to Building Service Devices [8]

Modern office buildings have few interior load bearing walls which allows the owner to re-configure the floor space to suit the tenant by moving walls and partitions. Unfortunately this same flexibility has not been built into the services with the result that frequently lighting, HVAC, fire and security systems are not modified during a retrofit resulting in light switches or thermostats in one room controlling the space in another room. More critically safety and security systems may be compromised by improperly placed sensors. It is also not uncommon during the installation of wiring for installers to knock holes in fire walls to route cables and not to seal the opening afterwards as required by the National Fire Code. While these problems should be corrected as part of the renovation, they often are not properly addressed due to the cost and difficulty in moving devices that are hardwired.

There are many new ideas yet to be explored in the development of building services, such as energy conservation and the quality of the indoor environment, which will evolve over the next five years given the public's present concerns about the

environment, health and energy conservation. Each of these will add to the communications requirements and make the continued safe operation of the building even more critical. Presently in Canada there are over 10 million lost work days annually relating to indoor environmental problems in buildings [9].

Tenant services are experiencing a much higher rate of change for two reasons. Firstly, business and staff are still discovering ways that workstations, networks and information systems can be used in their operations. The availability of low cost personal computers and reliable networks is resulting in a ratio of one workstation for each staff member, primarily for word processing, electronic mail, spreadsheet or drawing purposes. Once these systems are installed, the availability of additional applications for communications or organizational databases is often discovered. Secondly, the hardware and software technologies themselves are developing at an increasing rate providing new business software, multimedia and broadband capabilities and network speeds to support them.

The first IBM Personal Computer, the XT, was introduced in 1981. In the 11 year period since then, personal computers have gone through three generations of hardware development with orders of magnitude increases in power. More importantly, they have found practical applications in most businesses and, with the advent of the laser printer, virtually all typing is now done on personal computers. Much of the design work for presentations and publications is now done on these systems and development continues at a high rate on network based information systems for both administrative and production support.

Our society has moved from an industrial base to an information base in the last decade with the result that modern offices and businesses have developed an operational reliance on information systems. In many offices, the workstations are networked together to provide electronic mail and/or database access capabilities. The telecommunications requirements have similarly evolved with the requirement for personal telephone access and voice messaging systems. Most offices also average at least one facsimile machine per floor. Some of the pressure towards technology stems from the increased cost of labour that causes businesses to reduce support staff sizes, particularly secretarial, clerical and receptionist staff, by replacing them with distributed electronic devices operated directly by the administrative, technical or even executive staff.

This increasing requirement for communications is quickly exceeding the abilities of present networks and the requirement to relocate devices, coupled with a reluctance to remove old wiring quickly fills the available cable raceways in buildings creating a serious wire management problem.

2.2 The State of the Art in Building Communications

Both building and tenant services now employ the same basic electronic control technologies (digital microcomputers and networks), although some services do still rely on analogue signaling.

The most significant growth in demand for communications is in the computer network field where there are few, if any, computer network installations whose growth has stabilized. The 10 megabit per second office building networks, which were installed

with extra capacity two years ago are becoming saturated and network managers are looking towards 100 megabit per second technologies to support the number of devices being installed in some of the larger organizations such as university campuses and large clerical firms such as insurance companies.

Communications links between buildings and the outside world fall into three categories; the telephone companies and their public switched telephone networks (PSTN's), the cable companies and their networks and to a lesser extent, satellite communications. The first two have the highest penetration and are very active in developing broadband systems suitable for supporting all external office building communications. Developments in satellite broadcasting such as Digital Direct Satellite Broadcasting (D-DBS) however will make this link more viable in the future [10]. Information rates of 40 Mbits/s will be possible for home and business applications and will require a dish antenna of only 60 cm. The systems accommodate services such as data/fixed image broadcasting (teletext, news distribution, mailboxes, enhanced facsimile and personal computers), conditional access services (pay-TV or pay-sound), digital TV and high definition TV. For businesses, a low-data-rate up-link capability might allow tailored program scheduling for business and educational services.

2.2.1 Integration of Networks

The goal of a common building communications service has not been reached. However there is some activity towards this end. Structured distribution systems (SDS), which are single physical networks based on twisted pair and fiber optic media, have recently become available. They support a limited set of logical networks for voice, data, video and building services. Companies installing these SDS estimate the traffic

in a qualitative manner by considering the logical networks to be carried rather than the traffic generated by the individual devices. This results in over design of the system and is not valid if the networks are to be logically integrated as well.

Telecommunications manufacturers are moving towards universal adoption of the ISDN and broadband ISDN (B-ISDN) standards while computer communications tend to be based upon the seven layer ISO and IEEE communications standards, although the market is still composed of proprietary systems. ISDN defines the following channels:

- B channel - 64 Kbits/s
- D channel - either 16 Kbits/s or 64 Kbits/s
- H0 channel - 384 Kbits/s
- H11 channel - 1,536 Kbits/s
- H12 channel - 1,920 Kbits/s
- H4 channel - 135,168 Kbits/s

The D channel is used for signalling and the rest for general data. B-ISDN promises the capability of supporting a wide range of services from voice and low speed data to high speed image and video. Asynchronous transfer mode (ATM), based on statistical time division multiplexing is a promising technology for broadband transmission due to its ability to accommodate different traffic at high bandwidth. The Consultative Committee on International Telephony and Telegraphy (CCITT) has agreed that B-ISDN will be implemented using Asynchronous Transfer Mode (ATM). They are also developing video and audio standards as well as the X.400 standard for message handling.

Networks based on Synchronous Digital Hierarchy (SDH) using Synchronous Transfer Mode (STM) are being introduced in several countries. Called SONET (Synchronous Optical Network) in North America, these systems will allow broadband services to be introduced much earlier than ATM networks. The basic STS-1 frame speed is 51.84 Mbits/s for a payload rate of 49.5 Mbits/s [11]. The basic frames can be used in multiples to achieve higher transfer rates such as the STS-3, STS-12 and STS-48 systems available now from Northern Telecom with line rates of 155.52, 622.08 and 2488.32 Mbits/s respectively.

The Fiber Distributed Data Interface (FDDI) is an ANSI standard for high speed (100 Mbit/sec) LANS using optical fiber to support synchronous and asynchronous traffic. FDDI-II also supports circuit-switched (isochronous) communications such as voice and video. One study [12] estimates that a single FDDI-II ring can support 9000 voice only lines or 500-2000 low and medium quality image traffic stations or 240 video stations.

The building services as yet have no single standard and tend to be comprised of individual proprietary networks. Each manufacturer of each building service provides their own communications network. If two HVAC control companies provide equipment in the same building, they each provide their own separate, incompatible, network. There are, however, several efforts underway in North America to standardize building service communications so they will be able to use a single network. Public Works Canada has completed their Canadian Automated Building (CAB) protocol, an energy management control system (EMCS) gateway standard to permit the interconnection of equipment produced by different manufacturers. The American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc (ASHRAE) is

developing a complete EMCS protocol (BACnet) that, if adopted by the manufacturers, will allow for interconnection of system components regardless of manufacturer. The Canadian Institute for Broadband and Information Network Technologies (CIBINT) at the University of Regina is also working on a fiber optic based network that would support not only office automation but the building services as well [1]. Their fiber optic system has an effective 100 Mbps channel capacity from 125 Mbps theoretical bandwidth.

The Echelon Corporation introduced its LONworks communications technology in December of 1990. This technology is optimized for 64 byte messages or less and is intended for control systems. Their target market therefore includes building operational systems as well as cars, aircraft and appliances. Several hundred companies are working with the technology, Solus Technologies has recently announced an integrated building control system and there is a prototype apartment building project underway in France.

Over the past 12 years, LAN communications rates have increased by less than two orders of magnitude while processing power and memory size have increased by three orders of magnitude. There is significant pressure and resulting activity to produce networks capable of tens of gigabits per second to replace our megabit systems [13]. FDDI's 100 Mbit/s capacity allows many workstations to operate at megabit speeds however there are two activities that promise to eclipse this. The high-performance parallel interface (Hippi) standard is being developed by ANSI's Task Group X3T9.3 under the leadership of the Los Alamos National Laboratory in New Mexico to run parallel interfaces between 800-1600 Mbits/s. IBM Corporation and Lawrence

Livermore National Laboratory are developing the Fiber Channel, also standardized within ANSI's Task Group X3T9.3, to provide data rates of 132.8, 265.6, 531.2 and 1062.4 Mbits/s up to several kilometers. The Scalable Coherent Interface (SCI) standard, recently introduced, has the potential for LAN speeds of 8 Gbits/s.

Wide Area Network (WAN) development lags behind that of LAN's however Nippon Telegraph and Telephone (NTT) Corporation intends to support B-ISDN services as high as 622 Mbits/s by 1996 and expects to have switching and transmission equipment commercially available with capacities of 10 Gbits/s at that time.

Integration of communications at the lower levels of the ISO model is logical however this does not necessarily imply integration of functionality at the higher levels, nor does it imply a single central control computer. In the early 1980's several attempts were made to install one big computer to run all building services and to provide tenant computer and telecommunications services as well. These systems failed due to the complexity and inflexibility of their central systems. After having reverted back to the stand alone systems with separate networks, we are now seeing building service manufacturers providing some integration by expanding their product lines to include more than one building service. It is still not generally possible for a building owner to install a mixture of suppliers' equipment nor is it possible to interconnect one supplier's lighting system with another's security system so that an alarm might sound if a light is turned on in what supposedly is an unoccupied, secure area. These are examples of limited higher levels of integration that will be achieved in the future. The introduction of distributed processing has presented a new approach that allows the systems and their

individual devices to contain their own stand alone intelligence while supporting inter-system information sharing.

2.2.2 Wireless Communications in Office Buildings

Most wireless systems available today or under development are based on Radio Frequency (RF) and this will be the primary wireless technology examined by this thesis. However a study done at the University of California at Berkeley [14] suggests that Infrared Radiation (IR) technology may play a role as well. Present IR systems achieve speeds up to 1 Mbits/s and the study indicates that speeds up to 100 Mbits/s should be practical. The advantages of IR include an abundance of bandwidth which is free of Federal Communications Commission regulation, immunity to radio interference, low power requirements and small inexpensive components. Disadvantages include problems of shadowing and limited range which result in cells of about 5m radius and therefore little reduction in the amount of wire required to support the system. IR systems, although used extensively in the remote controls of consumer products, are not common in higher speed devices and it is expected that they will not play a significant role in office building communications in the near future.

Wireless RF communications have recently become available for computer networks such as;

- National Cash Register (NCR) Corporation sells the WaveLAN system with speeds up to 2 Mbits/s using spread spectrum technology and is compatible with Novell's Netware system. The WaveLAN card, driver and antenna are listed at \$1390 (U.S.) per node.

- O'Neill Communication's Local Area Wireless Network (LAWN) operates in the band from 902-928 Mhz at relatively low speeds with unit costs per computer of about \$500 (U.S.).
- Telesystem's ARLAN 450 system, at a cost per computer node of about \$1500 (U.S.) operates at 915 Mhz with a signalling rate of 230 kbits/s using Carrier Sense Multiple Access (CSMA) and is compatible with Novell's Advanced Netware LAN system.
- Motorola is developing a 15 Mbits/s Wireless In-Building Network (WIN) based on 18 GHz microwave technology using a special six-sector microwave antenna, high performance RF digital processor, GaAs monolithic microwave integrated circuit modules and a high speed data handling and switching chip. The microcell would have a maximum range of 200 feet, the ability to achieve one million connections per second, would be based on Time Division Multiplexing (TDM) architecture, and allow up to ten 10 Mhz channels per cell. A microcell would support approximately 30 LAN devices with a combined traffic of about 3 Mbits/s [15]. The system is also compatible with existing Ethernet LANs. The control module lists for \$3995 (U.S.) plus a \$995 (U.S.) user module for up to six devices.

One study [16], recognizing the potential for continuous networking of portable computers over a wireless LAN, built, used and studied a portable computer system based on a spread-spectrum LAN. This was based on the results of the Student Electronic Notebook (SEN) project carried out at Colombia University's Centre for telecommunications Research as a joint project with IBM. It concluded that wireless LANs offer great promise, however changes to existing network addressing and routing

are required to allow transparent movement of the devices from cell to cell. They forecast that systems software design to support wireless portables will be a much more active field in a year or two.

Although a number of installations have implemented these systems successfully, there remain questions about performance, costs and standards [17]. The installation costs of the systems are still higher than wire based solutions (where the cost per node, including wiring, ranges from \$300 to \$1000), however the cost to rewire for subsequent office moves is approximately the same again (less the network hardware) indicating that wireless installations may pay off in the long run.

There presently is no single standard for wireless communications and therefore current systems operate in different modes on a variety of frequencies. The Institute of Electrical and Electronics Engineers (IEEE) is developing the IEEE 802.11 standard radio frequency protocol, the final draft of which is scheduled for July 1993 with submission to the ISO/IEC by November 1993 [18]. Indications are that spread spectrum will be used in the 1 to 2 GHz frequency range.

Telephone manufacturers have implemented simple frequency modulated (FM) wireless telephones, and cellular telephone networks are available in most major centers. Both of these systems have performance and cost drawbacks that prevent their use as a wireless replacement for the majority of hardwired office telephones.

Second generation cordless telephones, based on the CT-2 and CT-2 Plus standards, are under development. The compact, pocket sized handsets weighing only 170 grams (6

oz) will sell initially for \$250 and drop eventually to \$150. One recent forecast estimates that the U.S. market for integrated wireless office systems, non-existent today, will grow to \$1.36 billion by 1997 [19]. Another industry study predicts that the cordless market will be \$3 billion by 1997, serving 5 million users [20]. Some analysts expect the North American market to be worth \$12 billion by the year 2000. In Canada, the Canadian Department of Communications has specified the CT-2 Plus standard for Canada, has allocated spectrum and is taking applications now for licenses to be issued by the end of 1992. The CT-2 Plus module could eventually be installed into portable computers, notebook computers and facsimile machines to permit access to the building networks.

There are developments underway to create personal communications networks (PCN's) with the objective that everyone would have their own pocket sized wireless telephone that would work anywhere. One study suggests that worldwide, high-capacity PCN capability will not occur until the late 1990's or the turn of the century [21], another [22] however predicts 100 million subscribers worldwide by the year 2000 and 450 million by 2010.

Arthur D. Little, Inc. carried out a national (U.S.) market study, canvassing 600 households and 400 businesses, about the potential for PCN services [2]. The study showed significant demand with up to 40% of all households indicating that they were likely to subscribe to PCN services. Little characterized this demand level as "astonishing" for an as-yet undeveloped service and predicted that there would be 13 million Personal Communications System (PCS) subscribers within five years of the initial licensure of PCS and more than 60 million within fifteen years.

The consumer trends in subscribing to cellular phones reflect the demand for PCN services. In 1984 there were 91,000 cellular subscribers in the U.S. representing industry revenue of \$178 million which grew to 5.3 million subscribers by 1992. The Cellular Telecommunications Industry Association statistics show that 1.8 million customers were added in 1990 alone.

PCN's will require a great deal of development work, standardization and the installation of a significant infrastructure before they can be put into general use, although limited sized trials are underway. The cellular system, comprised of a great many microcells and picocells, will require the development of cellular packet switches, the establishment of metropolitan area networks (MAN's) and the re-allocation of radio frequencies by both the Federal Communications Commission (FCC) and the Canadian Department of Communications [23]. The cable television industry is very interested in PCN service as they believe that their industry could provide the backbone transmission media in terms of coax, fiber, and access to poles and easements in order to locate PCN base stations. This infrastructure represents a large portion of the expense associated with the construction of a PCN system.

The 1992 World Administrative Radio Conference (WARC92) of the International Telecommunications Union (ITU) resulted in worldwide allocation for mobile services, which includes PCS, in the 1.7 to 2.69 GHz band [24]. It also allocated spectrum for low-Earth orbit (LEO) satellite service that may provide PCS type service to remote areas worldwide.

The United Kingdom has been the world leader in adopting PCS although not without problems. Initially they divided up too little spectrum among too many licensees, each of whom had too small a market. Users had to look for signs to determine where they could place a call. The two surviving licensees (of four) are expected to begin service in 1992. The allocation was 170 MHz in the 1710 to 1880 MHz band.

The European Community (EC) has issued a directive (which supersedes any inconsistent national laws) requiring a pan-European frequency allocation for PCS from 1.88 to 1.9 GHz and is working to complete a PCS technical standard by the end of 1992. Existing users may continue to use the band but have a secondary status to PCS. The U.K., France and Germany have already taken steps to implement this. France had indicated its intent to establish a PCS network in the 1.8 GHz band as has Germany. LM Ericsson of Sweden is working on systems based on a single office building while Millicom is planning city wide networks based on spread spectrum technology [25].

The Canadian Department of Communications (DOC) is also studying a PCS allocation in the 1.8 to 1.9 GHz band. Carleton University is studying, as part of a Canadian Institute for Telecommunications Research (CITR) project, a PCN implementation in the 20-60 GHz band [26] using Time Division Multiple Access (TDMA) with Time Division Duplex (TDD). The model provides coverage of a 40m x 30m (133.3' x 100') office building floor using 19 antennas (one per room or hall) by dividing the band into four 10 GHz channels, each capable of supporting 25 users. Voice, at 64 Kbits/s and three different types of data traffic were modeled, assuming between one voice plus one data device for every 10 sq.m. (107 sq. ft.) and one each per square meter. A simulator was used to quantitatively study the blocking

probability, traffic offered, portable density and call congestion. The results indicated that the system offered 99% availability even if all portables (240) were active all the time (one erlang per portable). System utilization under this maximum load condition was 68.21% for a 20 dB signal to interference plus noise ratio (SINR) and 83.37% for 10 dB SINR.

In the United States, the FCC adopted a "notice of inquiry" in July 1990 to look into the development and implementation of PCS. In October 1991, the Commission explained that it intended to broadly define PCS and "to make available adequate amount of spectrum to foster the development of innovative and competitive markets for these services". This definition includes a proposal by Apple Computer Incorporated for a data PCS. The FCC is exploring the dedication of 220 MHz of spectrum in the 2 GHz band for emerging telecommunications technologies and appears to be focusing specifically on up to 100 MHz within the 1850 to 1990 MHz band for PCS. Allocation within the 1710 to 2290 MHz band agrees with international allocation and is the band being considered in Europe.

One difference is that the U.S. does not propose to clear the incumbents from the bands and in fact the new technologies such as PCS would be required to protect existing users from interference. The Chairman of the FCC has stated that the FCC intends to authorize PCS by the end of 1992 and to date, 140 companies have filed applications for experimental authorizations of PCS (98 were granted). Bell Atlantic and Omnipoint Data are testing CDMA technology in the 902 MHz to 928 MHz, 2.4 GHz to 2.48 GHz and 5.725 GHz to 5.85 GHz bands. Ameritech plans a 100 cell, 1000 telephone test in Chicago using 1850 MHz to 1990 MHz using both CDMA and TDMA. Millicom

Incorporated's subsidiary PCN America Incorporated is working with Northern Telecom to demonstrate that CDMA radio can coexist with terrestrial microwave users in the same band with trials in Houston and Orlando.

Japan has announced plans to allocate a total of 100 MHz in the 1.9 GHz band for PCS. Hong Kong is proceeding with allocation in the 1850 to 1990 MHz band which Singapore is also considering doing.

Some security systems, particularly in residential applications, have started to implement RF links to the sensors distributed around the building. This is done to reduce the cost, time and damage incurred when retrofitting the remote devices. None of the other Building or Tenant services have implemented wireless communications.

There is some Canadian effort being applied to improving accessibility of office equipment to disabled staff and part of that effort is being directed towards wireless communications. Two of the Canadian organizations developing such devices are the Canadian Aging and Rehabilitation Product Development Corporation (ARCOR) and the Neil Squire Foundation.

2.3 The Building Communication Problems

There are essentially two basic problems to be addressed;

- a) The lack of knowledge about the characteristics of communications traffic generated by devices in a modern office building, and
- b) The difficulty in moving building and tenant service devices that require communications.

2.3.1 The Level of Traffic Problem

The telecommunications industry and to a lesser extent the computer industry, have a reasonable set of knowledge of the traffic levels generated by their present systems as they are typically integrated into one network each in most buildings. The significant difference between the two is the seemingly unlimited growth in computer network traffic.

Since the distributed networks of personal computers only began to be installed in the late 1980's and new applications such as multimedia are just beginning to be introduced, there are few studies of the traffic generated by typical workstations nor forecasts that consider new applications, although overall network traffic has been looked at. This makes it difficult to design new network technologies, particularly when communications requirements with completely different characteristics (such as voice or video) are to share the network. The total traffic is not simply the sum of the traffic requirements of the separate networks, although this is the method adopted by the telecommunications companies installing the single common wiring networks. The total proposed traffic over a combined network is actually the sum of all of the devices

that may be expected to communicate simultaneously, with their various characteristics, and therefore the widely varying requirements of workstations must be known.

The building service industry has no such comprehensive knowledge since integration of these systems has not been accomplished yet. This has not happened due primarily to the fragmented nature of the building industry, however pressure from building owners has forced manufacturers to participate in the process to create a common standard for this purpose. This is seen in the work done by the ASHRAE standards committee (with over 80 different organizations participating) and by the creation by Public Works Canada (Canada's largest operator of office buildings) of their CAB protocol and the availability of control technologies such as Echelon's LONworks. There are, however no studies available to determine the level of traffic and other requirements these new systems will face and therefore the feasibility of combining the networks has not yet been established. Very soon companies will be attempting to implement these standards and they will require this traffic information early in their development process.

2.3.2 The Difficulty in Moving Devices that Communicate

As described previously, the inflexibility of connecting building and tenant service devices by wire to a communications network or networks presents many problems for building owners and occupants. Very few office buildings function as originally designed, which is usually due to the fact that they are rarely used in the manner originally anticipated during construction and are almost always modified in an ad hoc manner after the fact to suit the needs of the tenants. These renovations involve the relocation of building service devices such as thermostats, light switches, and fire and

security sensors, and of tenant service equipment such as telephones, facsimile machines and computer workstations.

Building owners incur significant costs moving service equipment such as light switches or security cameras. This is compounded by the average annual "churn rate" (the rate of office moves in an organization) of over 30% [3] resulting in high costs and delays when attempting to move computer workstations, telephones or facsimile machines. Some estimates place the average number of moves of a single data terminal at between 1.5 and 3 times per year [27]. Large information users such as banks, insurance companies and large retail organizations have significantly greater problems. All of these problems can be attributed to the physical wired link between the devices and the organization's network.

Given that offices have an increasing communications load and that the hard wired media do not address all applications, consideration should be given to wireless media, either Radio Frequency (RF) and/or Infra-red (IR).

Just as Peter Goldmark correctly predicted the "wired-city" concept, Schilling, Milstein et al [28] have stated;

"Using spread spectrum, we predict a wireless city and wireless offices, with portable phones communicating directly to the Wireless Private Branch Exchange (PBX), wireless local area networks and wireless Integrated Services Digital Network (ISDN)."

Thomas Freeburg echoed this direction when he stated,

"What is needed is a high-performance, easy-to-deploy, user-transparent, reliable, wireless in-building communications network technology" [29].

He goes on to point out that such a communication system

"...could be implemented to eliminate the last 100 ft. of wiring to office desks and equipment, the wiring responsible for the vast majority of the costs and frustrations".

2.3.3 Reasons for Considering Wireless Communications

The basic reasons for using wireless communications in buildings are;

- a) for better building operation
 - easier relocation of devices and sensors would result in safer buildings and better adherence to building codes,
 - more flexible relocation of devices,
 - significant savings during renovations,
 - permit new applications that are now impossible due to wiring problems,
- b) for easier and cheaper installation of telecommunications devices such as telephones and facsimile machines.
- c) occupant benefits;
 - machines and controls can be moved easily and are therefore more conveniently and efficiently located.
 - less clutter of wires about the desk.
- d) broader access to telephone system;

- extension of and compatibility with cellular technology used by people on the move when away from their homes, offices, in cars, etc.

The use of wireless communications to connect these room devices to the building's networks would simplify their re-location thus reducing the cost and time involved. In addition, wireless remote controls would make new features such as selective dimming of lights possible. Portable computers may also represent a significant growth area for wireless communications over the next few years.

Another opportunity for the use of wireless communications may develop from society's concerns that living and working environments accommodate the elderly and disabled population. To implement the principle of universal access to these environments, different interfaces must be provided and the use of wireless communications could make a dramatic improvement in their flexibility and acceptance. Bringing a wireless control interface to the user would allow wheel chair users access to building controls for lighting, elevators and environmental systems and tenant services such as computer terminals. Also those requiring special paraplegic devices could have an interface customized to their needs which could be carried with them and would operate in any building.

The remote equipment can be low power, even battery operated. This has a number of advantages over wired systems including continued operation during power failures and being somewhat more difficult to circumvent for security systems. Since each sensor can have an identifier, it can serve as a locator for the source of the signal and thereby providing the location of fires, intruders or merely a window left open.

Chapter 3 Communications Traffic Generated by Specific Devices

When studying present systems, there is a fundamental problem of how to separate the user's requirements for communications from the rate of traffic provided by the particular hardware or permitted over the networks presently implemented. The definition of traffic is more a function of the size of the data and the user's specification of how fast it needs to be transmitted rather than the capability of present networks to carry this traffic. If the present state of the art in networks is not sufficient for a particular application, this will artificially limit the communications. Therefore it is more meaningful to examine the traffic that the source devices could generate than to study the traffic carried on any particular network.

Computer communications arise for three reasons;

- i) to share large or expensive equipment
- ii) to share common information
- iii) to pass information to remote users or systems

The original timesharing computers of the 1970's and 1980's shared centralized CPU's, memory, storage (disks and tapes) as well as peripherals (printers, plotters etc.) and the communications requirements were primarily low speed asynchronous lines connecting user terminals to the mainframe. The increase in processing power and the accompanying reduction in size and cost has made it feasible for each user to have the equivalent system on his desk in the form of a workstation. These workstations often still require communications, however the emphasis and characteristics have changed. Although some equipment such as laser printers is often shared over a network, much

of the communications relates to sharing of information stored on common software or data servers or to passing messages to remote users via electronic mail (e-mail). This communications tends to be larger messages, such as file transfers, which are transmitted at much higher speeds.

There are many parameters that affect the level of traffic on a network. These include the capabilities of the user device and its requirements for external communication which involves the proficiency of the user, the type and sophistication of the software, the speed and capabilities of the device's hardware and the compression, multiplexing and packetization techniques of the network itself.

Virtually all devices are driven by human interaction and therefore traffic generation is defined initially by the working patterns of the employees in the businesses. Characteristically the daily traffic level is bimodal with late morning and early afternoon peaks.

Other factors that affect a particular installation may relate more to the business than to the technology. There may be a requirement for one central information database accessed by a large number of users such as the Canadian Institute for Scientific Technical Information's (CISTI) large bibliographical database located in Ottawa which is accessed throughout the National Research Council and across Canada. Sometimes security of the data is the reason for central data storage such as with insurance companies or banking systems. Large central data bases also occur in manufacturing based upon computer aided design (CAD) and computer aided manufacturing (CAM). Hospital X-Ray systems are being developed that require

large data files as well. These large central data bases which often contain large data elements place heavy, bursty demands on their supporting networks.

Central systems that support a large number of data terminals such as banking and airline reservation systems place a different type of load, characterized by shorter, more frequent messages with peaks relating directly to customer loads.

Indirect cost and business decisions often alter the network demand due to factors other than the capabilities of the technology. Hard disks initially cost more than \$1000 per megabyte of storage which caused many buyers to opt for less expensive diskless workstations that shared one common hard disk by accessing it over the network. With the drop in price to under \$50 per megabyte, diskless workstations are used much less frequently which reduced the network traffic dramatically. Similarly, high memory costs prompted the use of memory swapping techniques to extend the physical workstation memory by creating logical memory segments that could be swapped to disk. When the disk is a network rather than local device, this causes very heavy network loads. Memory prices have since dropped even more dramatically than disk prices and swapping to network disks is used less often.

Another example involves the National Research Council of Canada that made the corporate decision to discontinue central timeshared research computing, opting instead for distributed computing. The network is changing from primarily terminal-to-host asynchronous communications to shared printer, file servers with local personal computers and multiple hosts. The traffic characteristics therefore will

change from frequent short asynchronous character messages to longer, less frequent file transfers.

Data traffic is very different from telephone traffic because of the variations in arrival rates, message lengths, transmission speeds, equipment characteristics and applications. As a generalization, the traffic is very bursty with a low utilization factor. The annual growth of data communications is 25-30% compared to 4-9% for voice [30].

3.1 Terminal / Host Asynchronous Computer Traffic

O'Neill [31] studied the arrival characteristics of 28 terminals connected to their timesharing system. Table 5 shows the results of this study.

Variable	Mean	Std. Deviation	Distribution
Arrival Time of Day	2:28 pm	3.5 hrs	Empirical bimodal
Interarrival Time	9.09 min.	7.51 min.	Gamma
Connect Time	13.25 min.	13.08 min.	Exponential
Inactive CPU time .	0.038 sec.	.0419 sec.	Exponential
Active CPU time	0.039 sec.	.0459 sec.	Exponential

Table 5 Characteristics of Interactive Terminal Facility Traffic

The distribution of the time of day of the arrivals was typically bimodal (mid-morning and mid-afternoon peaks) while the time between successive arrivals (interarrival time) was Gamma distributed where the density function was

$$f(x) = [1/(\lambda^\alpha \Gamma \alpha)] [e^{-x/(\lambda)}]^{(\alpha-1)}$$

where α and λ are positive factors and λ is a scale factor.

Uppal [32] found that, for a terminal connected to a timesharing system, on average, only one sixth of the physically connected terminals had at least 20 read requests in 7.5 minutes (his definition of active).

This type of traffic consists of a user terminal (TTY, CRT, Workstation running a terminal emulator, banking machines, online data collection machines etc.) connected to a host mini, mainframe or a file server running an application. The traffic is a dialogue with each cycle consisting of a user input message and a host response message. For the purposes of this study, the dialogue can be treated as one message. The arrival time for the dialogue is the total dialogue cycle time T_c which is:

$$T_c = T_u + T_i + T_{cr} + T_o$$

where T_c = total dialogue cycle time (holding time)

T_u = user think and typing time

T_i = input transmission time

T_{cr} = host computer think time

T_o = output transmission time

Total traffic N_t for the dialogue is

$$N_t = N_i + N_o$$

where N_i = number of input characters / message

N_o = number of output characters / message

There are four different terminal equipment / application combinations that generate traffic of this type:

<u>System</u>	<u>Description</u>
A	Time-sharing system - non commercial users (technical or scientific) TTY's and CRT's.
B	Time-sharing system - commercial users, TTY's and CRT's.
C	Real-time transaction processing - banking machines.
D	Online data collection (screen form data entry).

This type of traffic is very bursty in nature. It is generally assumed that data traffic follows the Poisson distribution and message lengths are assumed to be exponentially distributed [33]. Pawlita [34] cautioned that coefficients of variance (defined as the ratio of the standard deviation of X to the mean of X) greater than 1 for service time distributions (i.e. if N_i and N_o are used to determine service time) might be a serious problem because the waiting times are longer than for pure exponential distributions. In these cases, exponential distributions as conservative estimates cannot be used. Values of coefficients of variation > 1 for T_c might also influence arrival processes for small user groups.

As seen below, the coefficients of variation are > 1 for message lengths Nt for systems A and B and for all Tc 's. This indicates that individual arrival times cannot be Poisson distributed and Coffman [35] observed hyperexponential interarrival times in a time-sharing system. He suggests the distribution is a linear combination of two ordinary exponential distributions:

$$f(x) = a\lambda_1 e^{-\lambda_1 x} + (1-a)\lambda_2 e^{-\lambda_2 x}$$

where $a = 0.615$, $\lambda_1 = 0.030$ and $\lambda_2 = 0.148$

x = interarrival time in seconds

which is conservative from the viewpoint of system design by predicting higher load than actually encountered in his studies.

Uppal however suggests that while single user traffic is non-Poisson in nature, combined traffic of several users is. Therefore hyperexponential arrival times and service times are used if 3 or fewer terminals are active, otherwise Poisson arrival times and exponential message distributions are used.

Table 6 shows Pawlita's average or mean values for the systems and the distributions for buffered traffic. The associated distributions have been modified to take into consideration Coffman's and Uppal's findings. Table 7 shows the same values for unbuffered traffic for systems A and B only. The burstiness of the traffic is expressed by the low utilization factors (u). These have been uniformly related to 1200 bits/s

and the mean message length (N_t) is the sum of the means of the input (N_i) and output (N_o) characters.

	Message Length				Arrival Times				Utilization
	N_t	var.	distr.	distr.	T_c	var.	distr.	distr.	factors
System	(char.)	(C_{nt})	(< 4)	(> 3)	(sec.)	(C_{tc})	(< 4)	(> 3)	(u)
A	160.3	3.9	HE	E	25.6	2.1	HE	P	0.052
B	272.2	1.9	HE	E	32.5	2.0	HE	P	0.070
C	104.3	0.7	E	E	60.8	1.7	HE	P	0.011
D	946.5	0.4	E	E	34.8	1.4	HE	P	0.160

Table 6: Mean traffic generated by buffered devices

where C_x = coefficient of variation = ratio of the standard deviation of X to the mean of X

C_{nt} = coefficient of variation of N_t

C_{tc} = coefficient of variation of T_c

E = exponential distribution

HE = Hyperexponential distribution

P = Poisson distribution

u = utilization factor (mean msg. length / inter-arrival time) / channel capacity

	Message Length			Cycle Times		
	Nt	distr.	distr.	Tc	distr.	distr.
System	(char.)	< 4	> 3	(sec.)	< 4	>3
A	116.0	HE	E	16.1	HE	P
B	101.7	HE	E	19.7	HE	P

Table 7: Mean traffic generated by unbuffered devices

In general CRT's average greater message lengths than TTY's and network and host speed affects the interarrival times inversely. The fact that the mean number of output characters (N_o) of System B was nearly twice that of System A illustrates that commercial applications are generally more text-intensive than technical/scientific applications. Similarly, the mean number of input characters N_i was 34% higher for System B.

Systems which require the host to echo the character rather than using a local echo place a higher demand on the network as the echo should occur within 200 ms. Response time, which depends on host and network latency, are expected to be less than 3 seconds on average.

In 1983, Marshall [36] studied a system composed of higher speed (9.6 kbits/s) terminals and diskless workstations. The maximum packet length was 16 bytes. The terminal traffic demonstrated the typical two humped profile over the day with a dip in activity at lunch. The number of packets sent from the host computers was roughly double that sent by the terminals. Table 8 shows the mean values obtained.

	Terminal	Workstation	File Transfers
Holding Time	150 min	150 min	50 sec
Active Segment	30 min	45 min	-
Active/Holding Ratio	0.4	0.6	-
Terminal Packets/Active Second	0.8	1.1	12
Host Packets/Active Second	1.7	1.9	45

Table 8: Mean Values of Networked Terminals and Workstations Traffic

The character-burst parameters were determined to be as shown in table 9.

		Mean x (char.)	Var. of x C_x	Mean t (sec.)	Var. of t C_t	mean x/mean t (char. / sec.)	Σ mean x/mean t (char. / sec.)
Work Stn.	From term.	12	1.5	1	3.5	12	44
	From host	40	10	1.25	3	32	
TTY	From term.	1	0	1	4	1	18
	Host echo	1	0	1	4	1	
	Host resp.	128	2	8	3	16	

Table 9: Character-Burst Parameters

where x = # characters per message

t = interarrival time (seconds)

The maximum number of terminals actually connected was one-half the number available and on average only one-half of those were actively communicating.

The ratio of characters from host to terminal depends upon what the user is doing but averaged 15:1 to 20:1 for non-professional (technical) users to 3:1 for professional users (secretaries) using wordprocessing. On average the non-professional generates one character per active second while the professional generates two. In all sessions he found user interarrival times to be lognormal.

Brusil [37] studied the characteristics of user traffic generated by terminal/host office automation applications such as word processing, electronic mail (e-mail), presentation generation, scientific applications, program development, fiscal applications and management information systems. He believes that traditional analytical and simulation models are inadequate because they use overly simplistic assumptions about the traffic characteristics such as Poisson arrivals, stationarity, exponential message lengths and independence of traffic generators. The traffic generated depends on the nature of the device being used (TTY, buffered terminal, workstation, etc.), the size and processing load of the host computer and its operating system, the nature of the application, the language used, etc.

Brusil monitored the traffic from 60 devices over a four day period. He noted three peaks in the overall traffic rather than the usual double peak found elsewhere during mid-morning and mid-afternoon. He hypothesizes that the 8:00 a.m. peak may be due to large e-mail activity at the first of the day, particularly as Monday morning activity was low compared to the other days of the week. He noted that at no time were more than 50% of the terminals communicating. Also that 30% of the sessions lasted for one minute or less and over 50% were less than 30 minutes. Interarrival times within the sessions were less than 2 seconds. Although he had not tried to identify the

session length distribution he did feel that the data precluded an exponential distribution.

Interestingly he found that 60% of the time users were typing at instantaneous speeds in excess of 75 words per minute (1.25 five character words per second) and in fact 32% of the time instantaneous typing rates in excess of 170 words/minute occurred. Other studies indicate that 7% of the time instantaneous speeds of 300 words/minute and 1% of the time typists could attain 600 words/minute.

3.2 Workstations

The term workstation is used throughout this document to refer to a non-shared computer operated by one person. The term includes personal computers such as the IBM PC and the Apple Macintosh as well as the more powerful CAD and expert systems machines such as the Sun and Xerox workstations. They are the basic component of Office Automation systems, however as will be discussed, there is a broad range in their uses and capabilities.

Many organizations have installed a computer network to which most workstations are connected. Corporate E-mail systems are becoming common which by corollary means that virtually all staff must have access to a workstation. The net result is that it is not unusual, in the modern office, for there to be one workstation for each staff member. In addition, the workstations are being used in a wide and expanding number of applications ranging from light duty e-mail use to word processing, financial management, information management systems and to heavy and frequent file transfer requirements such as computer aided design (CAD) systems.

E-mail usage tends to be bursty in that most people read the bulk of their mail first thing in the morning and just after lunch. Otherwise a single message is sent or received randomly throughout the day. A receptionist who records telephone messages on the e-mail system will have significantly more frequent transmissions.

Except in the case of remote file or software access, wordprocessing will not result in communications. File transfer on the other hand may occur for a number of reasons including distribution of documents, saving important files on central servers or backup devices or the importation of data or information files from common storage.

Network printers are an inexpensive way of sharing the cost of laser printers. If a printer that uses Postscript is used, a significant overhead results from the addition of the postscript definition file to the beginning of any document. Graphic files, particularly bit mapped graphics, tend to be very large.

To fully define the traffic expected from a workstation therefore, one must first determine the operational purpose of the personal computer which will define the message frequency and then relate that use to the network access type to determine the message size that could be expected.

3.2.1 Workstation Message Frequency by Operational Purpose

The following are the most common operational purposes currently implemented. The accesses are estimates of typical values found in mixed usage in a research institute.

- a) casual user: Professionals and administrators whose primary function does not include the use of the workstation.
 - E-mail access = 1 access per hour
 - Print server access = 2 accesses per hour
 - File server access = 1 access per hour
 - If using a software server but having local disk space, 4 software accesses per hour
 - If using a diskless workstation, 4 software accesses per hour and 60 data server record accesses per hour
- b) office professional user: secretaries
 - E-mail access = 4 accesses per hour (up to 30 accesses per hour if used to forward telephone messages)
 - Print server access = 10 times per hour
 - File server access = 10 accesses per hour
 - If using a software server but having local disk space, 8 software accesses per hour
 - If using a diskless workstation, 8 software accesses per hour and 1000 data server record accesses per hour
- c) terminal emulation on host (see Terminal / Host Asynchronous Computer traffic)

- d) **computer professional user:** A developer of computer software or a CAD user.
- E-mail access = 2 accesses per hour
 - Print server access = 6 accesses per hour for normal files, and 4 accesses per hour for CAD and graphics files.
 - File server access = 10 data file plus 2 CAD file accesses per hour
 - Software server access would normally be at a rate of 4 files per hour.
 - This type of work should not be done from a diskless workstation.

3.2.2 Workstation Message Size by Network Access Type

Marshall's study [36], described earlier, included users doing software development, graphics, text editing, numerical computation and data storage. They were a mix of professional and non-professional users working on terminals and workstations.

The total daily character counts between a workstation (diskless) and host were dominated by downloads of programs and by bitmap transfers from screens to printers. Average rates were as high as 15 characters per active second from workstation to host and three times that from host to workstation (Table 9). He cautioned that this is strongly dependent on what the user is doing.

For file transfers, Marshall measured a mean packet length of 20,000 user characters per transfer with a return from the host of 5,000 characters. His system transfer rates, which were limited by the host computer's ability to send the packets, were up to 75,000 characters/second.

Suppan-Borowka [38] produced a complete user, resource, communications model for an IEEE 802.3 CSMA/CD LAN of RS-232 terminals. The theoretical study is significant as it models user behaviour as well as the behaviour of file servers. The results, using nearly 500,000 transactions, are statistically significant. The average user session time was 16.3 minutes. User input times were Poisson distributed with a peak of 3 seconds while user message length was exponentially distributed. Host delay was also Poisson distributed with a peak at 1.5 seconds and host message length show an exponential distribution.

The message size can be determined from the following network access types:

- a) Asynchronous terminal emulation
See Terminal / Host Asynchronous Computer Traffic.
- b) Electronic mail
- average message size is estimated to be 350 characters
- c) Print server
- for postscript printers, average message size is about 20,000 bytes
- d) File server: File access may be either to copy the entire file to or from the workstation or to access the server one record at a time.
 - File copying data traffic may be represented by an average file size of 20,000 bytes [39] or 160,000 bits.
 - Data traffic will be one record at a time with an average record size of 822 bytes [40] or 6576 bits.

e) Software server and diskless workstations

When using a software server, the workstation relies completely on the network server for all application software and data files. The software is loaded into the workstation when the application is started up and all data reads and writes to and from disk files travel over the network.

Gusella [40] studied the traffic on a 10 Mbit/s Ethernet LAN at the University of California at Berkeley and found the traffic to be substantially heavier than previously recorded, frequently exceeding 30% of the network bandwidth. The network connected about 100 workstations consisting of 41 diskless Suns, six Sun file servers, 23 Xerox Star workstations, 3 VAX's, several Micro VAX's and a few Symbolics and TI Explorer LISP machines. User activity included program development, text editing, program experimentation and operating-system research.

The study collected information over a three week period. The analysis of one 24 hour trace showed a total traffic of over 7,060 Mbytes including network headers. Mean utilization was 6.5% but it was very common in the afternoon to have relatively long utilization intervals above 30%. It was possible for just one Sun-3/50 workstation connected to a Sun-3/180 file server to reach 20% loading on the Ethernet LAN with peak transfer rates as high as 2.2 Mbits/s. The traffic distribution was found to be very uneven. The three most active diskless workstations and their file servers comprised about 41% of the total byte count.

The size of personal computer software that may be transferred from a software server to an IBM PC, for example, may average 1.15 Mbits on the assumption that the main

program and overlays necessary to run the program represent 25% of the actual program size. The average size for Word for Windows, WordPerfect, Excel, Foxpro and Corel Draw programs for example is 4.6 Mbits.

Table 10 shows the breakdown of the measured traffic. The remote disk access (ND) and file system (NFS) protocols have relatively large mean packet sizes and comprise 93.8% of the bytes transferred. Conventional character and file-transfer traffic, represented by Transmission Control Protocol (TCP) accounted for only 5.2% and consisted of relatively small packets.

Protocol	Packets		Data Bytes		Mean Packet (bytes)
	Number	%	Number	%	
nd	6,158,602	52.03	5,245,577,140	76.61	869.75
nfs	1,880,402	15.89	1,179,797,526	17.23	645.42
tcp	3,379,564	28.55	356,640,214	5.21	123.52
other	418,505	3.53	65,081,454	0.95	173.51
total	11,837,037	100.00	6,847,096,334	100.00	596.45

Table 10 Diskless Workstation Traffic

where:

- ND = Network Disk Protocol - a remote disk block access protocol used primarily for paging and swapping
- NFS = Network File System Protocol - which provides remote access to shared file systems
- TCP = Transmission Control Protocol - which provides character and file transfer communications

The remote disk access (ND) was primarily due to system activity such as paging, swapping and accounting. More than 50% of this traffic was due to paging which may have been due to the relatively small (2-4 Mbytes) size of the workstation's physical memory and to the tendency of virtual memory algorithms, designed when memory costs were high, to make maximum use of memory at the cost of generating some I/O traffic.

While the ND traffic was all within the local network, only 10% of the Transmission Control Protocol (TCP) was local, 89% was inter network but remained within the university campus with the rest being external. This traffic was essentially bimodal with peaks at 24 and 84 bytes and 90% of all packets were followed by the next packet within 18 ms. The number of active connections never went above 60 and averaged below 30 with no single machine transmitting more than 6% of the total TCP byte count. The TCP arrival traffic is exponentially distributed with 50% of the packets being followed by another within 11 ms, 10% within 2 ms and 90% within 52 ms.

The Network File System (NFS) protocol provides access to shared file systems over the network. Unlike ND traffic, NFS is user rather than system initiated and tends to be more bursty. Network utilization may stay around 10% of bandwidth for several seconds with occasional 1 second peaks at 15% which corresponds to 120 kbytes/s throughput. The packet lengths are bimodal, one distributed around 144 bytes and the other around 1500 bytes for an average of 822 bytes.

f) CAD systems

Computer Aided Design (CAD) systems are of several different implementations.

- Host based graphics terminals where all of the software and data are stored on a mini or a mainframe and the processing is done there as well with screen images exchanged with the terminal
- Standalone workstations where the workstation contains all of the software, data files and processing and display power required.
- File server connected workstations where data files and/or shared software resides on a file server but all of the processing and image display occurs within the workstation.

Chronologically the host based systems came first, followed by powerful standalone workstations and, with the gains in network performance and abilities, came the file server connected shared database systems.

In terms of communications requirements, the host based systems move complex screen images to the graphics terminals in response to fairly simple input. The standalone workstations have no communications except perhaps e-mail or printers and can be modeled as office professionals using these applications. The file server connected workstations can be modeled as office professionals using file servers. File server access will transfer larger files than normal or, if updating server file records, the message lengths will tend to be longer. CAD software tends to be much larger than the average office automation package so CAD software servers will transfer larger than average files.

Rao [41] studied an example of a host based distributed graphics system at the McDonnell Douglas Corporation consisting of 70 graphics terminals connected to 11 remote processors (PDD 11/70's) which in turn were linked to an IBM 370/3033 mainframe via 9.6 Kb - 56 Kb lines. Over 77% of the interactions were completed within one second and only 3.1% took longer than 10 seconds. Average response time was 2.11 seconds. The traffic over the remote to mainframe link (supporting 8 terminals) amounted to 43,798 bytes per second (2,183 from remote and 41,615 from host). Graphics and CAD files vary greatly in size but range from 20 Kbytes to several megabytes. He estimated the average size to be 150 Kbytes. CAD systems may represent less than 5% of the average organization's workstations.

Rao cautions that rapid changes in CAD/CAM technology will alter their configuration within six months. During the study several changes were made including changing the mainframe and the implementation of Large Model Access software which generates drawing sizes 20 times larger than CAD files.

3.3 Telecommunications

3.3.1 Telephone

Analog telephone signals are typically encoded using Pulse Code Modulation (PCM) at a rate of 64 kbits/s although lower rates of 32 kbits/s and 16 kbits/s are sometimes used however the quality is reduced. The typical T1 carrier multiplexes 24 channels of digitized voice into a 1.544 Mbits/s DS1 signal. Increased channel utilization may be achieved with silence suppression. The number of telephones in a system is typically 5-10 times the number that can be active simultaneously. The annual growth of voice services, as mentioned previously, is expected to be 4-9%.

A maximum delay of 100 - 200 ms can be tolerated between two stations and subjective tests have shown that generally customers tolerate delays in the range of 600 ms [42]. Assuming a LAN to public switched telephone network to LAN configuration between two telephones, the LAN delay should be no greater than 20 ms each (digital PBX delays are typically about 2 ms) [43].

Telephone traffic is generally considered to have a Poisson arrival process and the average holding time of a call is exponentially distributed with a mean time of 3 minutes offering 0.11 erlangs per unit.

A variation of the conventional telephone is a workstation equipped with a voice card, microphone and earphone which may be connected to a PBX or to a LAN. Options include compression and decompression of the two 64 kbit/s voice streams to/from 32 kbit/s or 24 kbit/s using the Adaptive Differential Pulse Code Modulation algorithm and silence suppression [44].

3.3.2 Facsimile

The first patent related to the facsimile process was filed in 1843 and the first CCITT standard, Group 1, was completed in 1968, however sales of the machines did not really pick up until the early 1980's. This was due to the release in 1980 of the Group 3 standard, the availability of long distance competition and a thirty fold decrease in cost between 1980 and 1992. Sales in the United States doubled annually between 1986 and 1988[45]. Facsimile machines have replaced much of the telex and telegraph traffic and some of the telephone traffic of a few years ago and have

generated additional traffic of their own. One 1987 Japanese study [46] of international telephone traffic showed that 48% of calls originating in Japan were facsimile transmissions and an annual growth rate of over 50%. It should be noted that this number may not be representative of other countries as the large use in Japan may be due to the difficulty in inputting the special character set on the standard keyboard. In general there may be one fax machine per floor or one per 25 people and the usage growth rate in North America may be 25-30%.

The arrival process for NTT's Facsimile Intelligent Communications System [47] was determined to be Poisson for single address calls and batch for multiple address calls. The service times for both were assumed to have exponential distributions. The offered load, α and peakedness, Z , of the batch arrival system, are defined as the mean and variance-to-mean ratio of the number of busy servers. The generating function for the distribution of the number of busy servers $P(Z)$ is given by;

$$P(Z) = \text{Exp} \left[-\lambda/u \int_z^1 [(1-A(u))/(1-u)] du \right]$$

where: $A(u)$ = the generating function of the batch-sized distribution

λ = the arrival rate

u = the service rate

The mean α , and the variance V of the number of busy servers is;

$$\alpha = \lambda m_b / u$$

$$V = \lambda (m_b + m_b^2 + V_b) / 2u$$

where: M_b = the mean of the batch-sized distribution

V_b = the variance of the batch-sized distribution

The Peakedness, Z , can be obtained as $Z = V / \alpha$

The communications standard used most often today is the CCITT's G3 which typically operates at 9600 bits/s although speeds up to 14.4 kbits/s are becoming common.

The Group 4 (G4) standard released in 1984, was designed for ISDN at 64 kbits/s, however it still has not reached any significant level of acceptance for three reasons;

- i) ISDN is still not implemented to any significant degree
- ii) G4 is more costly and is incompatible with G3
- iii) G3 improvements (updated 1984, 1988, 1992) offer features lacking in G4 such as file transfer and character modes and by 1993, G3 will include 64 kbits/s and ISDN capabilities.

Fax servers are now available that are able to send and receive up to sixteen documents each way simultaneously (with multiple lines), storing the documents on the server's hard disk. These servers are digital devices able to connect to digital PBX's and ISDN systems. The messages are stored in separate mail boxes which can be accessed by the appropriate users over the local network [48]. Textual faxes may evolve into multimedia documents and merge with multimedia e-mail in the near future.

An estimate of the size of a scanned file can be calculated as follows. Facsimile documents are typically scanned at a resolution of 465 dots/in. horizontally with a vertical resolution of between 98 (standard) and 391 (super fine) lines per inch. If the average page is 8 1/2" by 11" with an average of four pages per transmission, the scan is done at the standard resolution of 98 x 465 dots per inch, and allowing for a 10:1 compression ratio (for redundant information such as blanks), then the average page would be 426 Kbits (93.5 sq. in. x 45,570 dots/sq. in. / 10). The average document therefore would be 1.7 Mbits. The average transmission times at 9600 bits/s would be 44 seconds per page and 176 seconds per document. A four page document scanned in superfine mode could be as large as 72 Mbits. The transmission of grey scales instead of black and white would quadruple the message size and the change to colour would result in files 15 times the present size. To accommodate these features and the increased traffic, it is not unreasonable to expect that the standard facsimile transfer rate will increase to at least 64 Kbits/s over the next five years.

3.4 Video Services

Video Services include image communication, picturephone, television and video conferencing. The uncompressed North American Television Standards Committee (NTSC) (6 MHz analogue bandwidth) video images use about 90 Mbits/s of digital bandwidth [49]. Compression techniques are required to transmit this signal over a T-1 (1.544 Mbits/s) circuit. Prior to 1980, 60:1 compression was used to achieve 1.5 Mbits/s; after 1980, 100:1 compression lowered this to 768 kbits/s, 1985 advancements achieved 200:1 (384 kbits/s) and now 1000:1 compression enables transmission over 56 kbits/s circuits. Since compression algorithms have difficulty in compensating for motion, there is a stop motion effect to the picture at less than T-1

speeds. Therefore broadcast signals still use 1.544 Mbits/s. Video conferencing and security systems are able to use the lower speeds and seem to be split into high-end systems using more than 384 kbits/s and low-end systems at 384 kbits/s and below.

Desktop video conferencing has recently been introduced. Present technology limits this to freeze frame over standard voice grade dial-up circuits (64 kbits/s) and may be implemented as a separate device (AT&T's Video Phone 2500) or as an add on to a workstation (CLI's Model 2001 which connects to an Apple Macintosh). At present, LANs do not support desktop video well as they routinely interrupt data streams to send and receive data packets and the video picture freezes until the next packet arrives. In late 1991, IBM announced its intent to build multimedia support (voice, data, video and still images) into its Token-Ring Networks.

Table 11 shows the approximate size of image and data files before compression (compression factors of between 3 and 15 should be possible without loss of quality) [50]. The TV sizes represent one single image which may equate to about 92 Mbits (1.544 Mbits/s) of storage per minute for standard colour TV and 1320 Mbits per minute after compression of HDTV (22 Mbits/s) including audio.

Single Image or Data File	Data Volume in M bits
Colour television Image	4-6
High-definition colour TV image	16-24
A4 facsimile (black/white)	1-4
A4 facsimile (gray)	9-16
A4 facsimile (colour)	30-60
Newspaper page	200-600
High-definition computer graphics	20-100
Relatively large data file	several 100

Table 11: Before Compression Sizes of Image and Data Files

The demand for present and yet to be defined broadband applications is estimated in Table 12 [50].

Service Class	Comm. Struct. 1 or 2 way		Service	Required Transmission Rate on Subscriber line			Significance and use	
	narrow	broadb		≤ 2 Mb/s	≤ 34 Mb/s	≤ 140 Mb/s	Office	Home
Dialog	2	2	video telephone			X	high	high
	2	2	video conference			X	med.	-
	2	2	High-speed doc. traffic	X	X		med.	-
Retrieval	2	1	high-speed data comm.	X	X	X	med.	-
	2	1	broadband interact. video			X	low	med.
	2	1	document retrieval	X	X		med.	-
Access	1	1	cabletext	X	X	X	-	med.
Distrib.	1	1	TV			X	low	high
	1	1	HDTV			X	low	high

Table 12: Applications of Broadband Services in the Office and the Home

The significance and use is a general estimate of the level of use these applications might have at home and in the office in the future.

Although primarily aimed at consumer television, HDTV may first find uses in medicine, education, printing, corporate communications. Every major consumer electronics firm in the world from Matsushita to Philips and Zenith to Thompson is doing research and development into some form of HDTV. Total expenditures had reached \$2.5 billion by 1991.

Doubling the number of lines quadruples the required bandwidth, however the FCC has ruled that the systems must operate, without interference, inside the existing 6 MHz wide TV channels. Much of the work therefore centers around bandwidth reduction. Of the six systems under test at the Advanced Television Testing Center in Virginia, four use digital processing and transmission formats with transmission data rates (including four 20 KHz audio channels) of 19.43 - 24.39 Mbits/s [51]. The uncompressed HDTV video signal may have a rate of up to 1188 Mbits/s. Parallel evaluations are being conducted at the Advanced Television Evaluation Laboratories in Kanata, Ontario under the supervision of Canada's Department of Communications (DOC).

It is expected that the FCC will select a digital format when they announce their decision in mid 1993 and that Canada will likely choose the same standard [52]. After the standard is specified, U.S. broadcasters will have five years to set up HDTV channels alongside the conventional TV channels which will be phased out beginning in 2008. Japan already has one HDTV channel broadcasting eight hours per day

however both the Japanese and current European development systems are based on analog transmission.

One source estimated that HDTV will appear in the U.S. by the end of 1993 at the earliest but more likely by 1995 [53], however since standard selection has been delayed to mid 1993 followed by a five year implementation period, it is more likely that production programming will begin in 1996 with conversion of the majority of North American sets by 2008.

The CCITT's H.261 standard describes how video can be transmitted and decoded in increments of 64 kbits/s. This is considered a lowest common denominator standard but is supported by most codec manufacturers. Accompanying audio signals typically use a 64 kbits/s bandwidth although rates as low as 8 kbits/s are available at reduced quality.

Video on demand services are projected to be available for residential use within 2 years and by the year 2000 [54] at the latest. Provided from a central location (it is estimated that 100 locations could cover the United States), this service would allow a customer to select a movie and stop, continue, rewind and forward the selection on demand. This service will be available at a low incremental cost if there is a network with sufficient bandwidth to the customer and if database access technologies develop as projected. The service is based on an NTSC video encoding rate of 1.5 Mbits/s and an HDTV rate of 50 Mbits/s. Although video on demand services are primarily targeted at the home video market, they may also be applicable in the office environment for educational purposes. A second business purpose might be to

distribute coverage of conferences and meetings, particularly international ones where travel costs are high. Few companies are able to afford to send their staff to all of the conferences and meetings that they would like to but a service to tape and re-broadcast these proceedings on demand could be quite popular. Multimedia workstations and broadband networks in office buildings would support this type of service. Although there is still some doubt by parts of the industry, which still remembers the failure of video text a few years ago, that video on demand can be implemented profitably, there are prototype systems available now such as the one developed by Bell Northern Research and Bellcore. Microsoft, Intel and General Instruments are expected to announce the joint development of a combination personal computer and cable TV converter to help TV viewers tailor the 500 channels of programming that are expected to be commonly available soon. Besides this, the system may be interactive to provide two-way customized database and simplified pay-per-view access. IBM has developed a high-speed multimedia information transmission technology which is being field-tested in Toronto over Rogers Cablesystems Incorporated's fiber-optic cable network. The system will deliver movies on demand, video-telephone service and other interactive services to homes and businesses. Once video-on-demand systems become common in residential use, they may find applications in the business community which could radically increase the demand for communications..

3.5 Specialized Tenant Applications

There are a multitude of specialized applications that may be implemented by various businesses to address their information processing needs, each of which has a different, heavy communications requirement. Such systems include banking, imaging and multimedia systems.

Three of the many possible applications are described, primarily to show how great an effect different application software and hardware can have on the traffic generated. Applications that take into consideration the communications requirements during their design can significantly reduce the traffic while conversely it is possible for a poorly programmed application to saturate almost any network.

3.5.1 Banking Systems

There are two basic types of devices that are used in banking systems, teller terminals and touch tone pad (TTP) entry. Teller terminals may be characterized by professional terminal user statistics described earlier.

Dudick [55] studied short call inquiry-response systems including banking systems. This study, which was statistically significant, measuring 5,000-10,000 calls over two to three weeks, found the distribution forms to be stationary over time and that the distributions remained the same for different loads. Dudick's results are summarized in Table 13.

		Distribution
Holding Time (seconds)	28.	$\Sigma \Gamma$
No. of char. / user segment	18.	NR
No. of user segments / call	1.0	G
No. of computer segments / call	.92	B

Table 13: Touch Tone Pad Usage Characteristics

where: $\Sigma \Gamma$ = sum of two gamma distributions, representing the send and delay times

NR = non random process (fixed length char. string)

G = geometric distribution

B = binomial distribution

TTP's were more recently studied by Pawlita [34] as mentioned previously (System C under Terminal/Host Asynchronous Computer traffic). He characterized the message frequency as hyperexponential with a total cycle time of 60.8 seconds and the average message size as being 104.3 characters with an exponential distribution.

3.5.2 Radiology Systems in Hospitals

The Faculty of Engineering at the University of Ottawa is conducting research into the radiology communications problems associated with a proposed multimedia communication system for hospitals [56]. While this application is not expected to occur in office buildings, it presents a good example of the extreme loads that new applications can develop and illustrates techniques for reducing the communications demand.

The studies, part of the Multimedia System for Integrated Communications (MUSIC) project, support the capture and distribution of digitized X-Ray images and voice reports from the radiology department to the Physician. The system allows simultaneous access by the Radiologist and the Physician, at different locations, and allows them to engage in a consultation while viewing either the X-rays or the patient's files. Figure 3 illustrates the application. All implementations use high speed LANs with workstation based distributed processing structures as shown in Figure 4.

The system was used in a test trial at the Ottawa Civic Hospital. This prototype consisted of three clinical workstations and one database server, all connected to the hospital's SYTEK 6000 broadband data LAN which uses the CSMA/CD protocol. The test used a dedicated 2 Mbits/s channel.

The workstations were Compaq 386/20 minicomputers with 60 Mbyte disks and 13 Mbytes of RAM. For image storage, the entry workstation had a 760 Mbyte disk and each workstation had 450 Mbyte disks. A maximum image resolution of 2000 x 2400 pixels was possible with 10 bit pixel resolution.

The voice network used a dedicated mini PBX (Northern Telecom SL-1ST) to link each workstation. It digitized the standard 64 Kbit/s and compressed it using an 18 Kbit/s fixed rate sub-band compression algorithm. It was capable of storing up to 24 hours of digitized voice messages and was used largely by Radiologists to dictate reports which were later played back by the Physician.

Figure 3: Radiology Communication Service Problem *

Figure 4: Multimedia Radiology Communication Solution *

* Source: Karmouch (University of Ottawa)

The trial was conducted, over a seven week period in 1989, in the Emergency department, which meant that patient stays were 24 hours or less, there was a wide range of radiographic examinations and of skill levels (from interns to emergency physicians) and timeliness was a critical factor.

During the trial, a reduced resolution 8.2 Mbit image (1000 x 1024 8 bit pixels) was distributed to the workstations of the radiologist and physician, taking 90 seconds, (digitization took 80 seconds). This time was judged to be at the limit of acceptability normally and too large for seriously injured patients.

One problem with the application centered around the need to examine images sequentially on one screen rather than simultaneously as the radiologists and physicians had become accustomed to for comparison. The test, using a large memory space, did allow the viewer to switch between two images in less than 1.5 seconds but this was judged to be a disruptive process when trying to get an integrated diagnosis from several views. The magnification function, which brought a full-resolution image from the server to the workstation, was considered useful though not required for most diagnosis during the trial.

Technical details of the system are described by Mastronardi [57]. The Original Image File (OIF), stored at the Image Entry Workstation has a maximum size of approximately 48 Mbits resulting from the original 2000 x 2400 10 bit pixel scan. The Displayable Image File (DIF), which is a reduced resolution version of this by a factor of 2 (consistent with the display resolution), is stored at the workstation.

Other studies examined two different communications networks; one based on the IEEE 802.6 Distributed Queuing Dual Bus (DQDB) Metropolitan Area Network (MAN) and the other, based on a CSMA/CD LAN.

The DQDB MAN simulation [58] examined two browse techniques, one where the full resolution images were transferred on demand from the file server to the workstation and the second where a reduced image is sent and then improved upon based on the reduced-difference pyramid (RDP) data structure. In the latter case a reduced image is sent first and after an exponentially distributed time period, if the user has not requested another picture, the image is improved. This procedure is repeated until the full image is received.

The DQDB MAN used a fiber optic medium which was able to support up to 150 Mbits/s per bus and assumed a length of 25 kilometers to interconnect several hospitals. The simulation assumed a DQDB bit rate of 17.8 Mbits/s and had 8 file servers connected. With the RDP technique for browsing, the 1 Mbyte (1024 x 1024 8 bit pixel) original files are assumed to transmit 0.5 Mbytes on average.

The first browse scenario, showed display delay times of 15-40 seconds for full 41.9 Mbit (2048 x 2048 10 bit pixel) images which were considered too slow. The progressive resolution scenario however resulted in display times of less than the 1.5 seconds for the average 4.2 Mbit, RDP images. It is clear from this study that the user would like better performance than the system was able to provide and future

improvements, particularly in the file servers which were the bottlenecks, will result in higher bit rates.

Another University of Ottawa study examined the transfer of packetized radio graphic images over local area networks [59], including a FDDI-II LAN and a CSMA/CD LAN. In the former case, all images were stored on the file server(s) and downloaded to the workstation when the user requested it. The network was also divided into two parts for isochronous (voice) and for synchronous and asynchronous (image) communications. The initial file was a 1 Mbyte reduced resolution image and an enhanced magnification was available in 64 Kbyte sections extracted from the full 6 Mbyte image. They assumed that the user would request another image (either reduced or enhanced) after five seconds. Two cases were examined, one where 99% of the bandwidth was allocated to voice communications leaving only 1 Mbit/s for image transfers and the second allocated 90% to voice leaving a bandwidth of 10 Mbits/s for images. The delays were 60 seconds whether 1 or 2 file servers were used. With 8 workstations and a 10 Mbits/s transfer rate, the image delays at the workstation were more than 40 seconds if one file server was used and less than 20 seconds if two were used. Increasing the network speed to 100 Mbits/s would not decrease these delay times below those of the 10 Mbits/s system since the system's bottleneck was the file server network interface unit.

The CSMA/CD LAN simulated a PC-LAN of 2 Mbit/s and 10 Mbit/s with a different storage strategy. Instead of transferring the files on demand, all the patients' reduced resolution images were automatically downloaded from the file server to the workstations' local storage and a magnification of any part could be transferred (64

Kbytes) from the file server on demand. They assumed a patient load for an Emergency Department X-Ray room of between two and six and an average of four images per patient. On average, the physician might spend 5 seconds on any reduced image with an 80% probability that he would request a magnification from the file server.

The simulation showed that the image display delays without local storage (i.e. downloading the 1 Mbyte image on demand) for a network with 8 workstations and a 2 Mbit/s bandwidth were 70 seconds for one file server and 30 seconds for two. The 10 Mbit/s network under the same conditions resulted in image display delays of 45 seconds for one file server and 20 seconds for two. The display time for an image from local storage was a constant 6.4 seconds. Magnification delays were less than 3 seconds for no local storage and at either speed regardless of the number of servers, and slightly higher if they were contending with the download of full files to workstations with local storage.

3.5.3 Multimedia Systems

Multimedia is the recognition that communications between people goes beyond voice to include textual documents, pictures and video. There are a number of applications that will benefit from the introduction of multimedia capabilities such as:

- **Multimedia electronic mail:** This involves the addition of voice, image and video capabilities to the existing text systems. The existing X.400 and Office Document Architecture standards, which should greatly increase the universality of present text based systems, provide only limited support for temporal media types such as voice, animated image or video.

- **Real-time conferencing:** These permit multiple users to interact synchronously via their workstations, enabling long distance meetings without the cost, expense and effort of travel.
- **Cooperative design:** These include tools to permit collaborative writing of documents without physical proximity and meeting tools that provide "shared chalkboard" facilities for meeting participants.
- **Medical applications:** Hospital records include handwritten requests, typed forms, computer-based data, voice messages and reports and diagnostic information such as electrocardiograms and digitized X-rays (described previously).
- **Distance learning:** Interactive distance learning, such as London University's LiveNet, will provide an interactive multimedia learning environment from remote locations including the home.

Clark [60] examined the network requirements for multipoint multimedia conferencing carrying audio, still images (facsimile, slow-scan TV), computer data, and moving video. He determined that this form of conferencing has to provide the following facilities:

- Multiple call set-up
- Conference status transmission
- Real-time control of audio and video
- Dynamic allocation of network resources
- Multipoint data transfer
- Synchronization of shared workspaces
- Graceful degradation under fault conditions

He suggests the allocation of a permanent 128 kbit/s message channel throughout the conference and discounts the use of the ISDN D Channel due to the problem of indeterminate delays. The system must also allow for existing point-to-point equipment and protocols such as are used by fax machines.

Synchronization of events and system response become important issues. For example, the processing delays of audio and video vary considerably and must be corrected to ensure synchronization for the destination users. Pointing devices also need to be synchronized with the audio. System response for all sites is also an issue. For example, one application is a document editing session whereby a number of users simultaneously, in conference, edit the same document from different locations. Pointing, posting and insertion need to occur immediately on the displays at all locations.

The European ESPRIT program includes two projects studying the features and protocols needed for multipoint, multimedia communications. The Multipoint Interactive Audiovisual Communication (MIAC), the first project, developed the audiovisual infrastructure and applied it to teleconferencing. The second project, the Multipoint Interactive Audiovisual System (MIAS) constructed the system and demonstrated its capabilities.

The MIAS system has the following capabilities [60]:

- Chairman control of audio and visual facilities based on a structured message channel
- 7-kHz wideband speech to CCITT Recommendation G722
- Multipoint operation
- ISDN interface with call setup using 2 B + D channels
- Demonstration AVT designed as a single-user workstation with multimedia display
- Moving TV images based on CCITT Recommendation H261 video codecs at 1 x 64 kbits/s
- Group 4 facsimile available in addition to Group 3 facsimile
- File transfer between personal computers in a conference
- Interactive pointing and still image transmission
- Expanded protocol structure to support the above features.

The system uses an ISDN basic access (2 B + D) to support single-person, personal computer workstations. The workstation displays moving video, conference management information and documents under a "windows" environment.

Interactive multimedia documents such as electronic magazines, books, reports, databases and TV shows are examples of the second type of applications.

The domain of a multimedia system, as described by Smith [61] is shown in Figure 5.

Figure 5: Multimedia System Model

where:

- Audio Server - Handles the storage, access and delivery of sound, voice and music
- Binary Server - Manages application software and data files
- Graphics Server - Provides still images and sketches and scanned image storage and delivery
- Text Server - Provides character - oriented file storage, access and delivery
- Video Server - Manages storage, access and delivery of full-motion video
- Library Bundles - are stored complete documents
- Matrix Maps - contain the links needed to present the information to the user

He notes that full motion video (with 100:1 compression) will require a throughput rate of about T1 speed (1.5 Mbits/s).

Loeb [62] cautions that the wide range of media and access patterns will generate new traffic patterns and performance considerations that are not addressed by current network protocols and application implementation strategies.

Users expect 0.2 second response to simple actions (e.g. keystroke echo) and system response to computations of 2 seconds. They give up waiting after about 20 seconds. Response times of 1 to 2 seconds are possible when transmitting text or grey scale images over 10 Mbits/s Ethernet, however, full colour without compression may take more than 4 seconds.

Table 14 shows Loeb's estimates of the composition of some of the present multimedia documents.

	Text	Graphics	Still Image	Motion Video	Audio	Slide Show
Movie	0	0	0	++	++	0
Newspaper	++	+	+	0	0	0
Magazine	++	+	++	0	0	0
Brochure	+	+	++	0	0	0
TV News	+	+	+	++	++	+

Table 14: Some existing multimedia documents.
(relative amount of each medium: 0,+,++)

A central concept of interactive multimedia documents is nonsequential viewing whereby a viewer can move between the segments by following links. Figure 6 illustrates this linking from the table of contents of a magazine to the articles.

Figure 6: An access graph of a magazine-class application showing the nodes available for reading from the table of contents [61]

Figure 7 illustrates the links as seen from pages in the magazine. The user can move from page to page, up to the table of contents or "read" the multimedia documents (text, video, audio) representing that page.

Figure 7: An access graph of a magazine-class application showing the nodes available for reading from the inside of an article and their various media compositions [61]

Loeb refers to each of the objects to be displayed (read, viewed or heard) as Presentation Objects (P-Objects). Table 15 shows the order of magnitude and viewing time of various P-Objects. The P-Object represents one image of the article or movie.

Document	P-Objects (single images)	P-Object Size (Mbits)	Number per document	Viewing time (minutes)
Magazine Article	Pages	1	5	2
	Side-bars	0.5	7-15	1
	Video clips	10-30	10	1-3
	Slide show	1	1-5	0.5-1
	Audio	0.1	1-5	0.1-0.5
Album Page	Slide show	1	5-8	0.5-1
TV News Article	News clips	10	1	1
Augmented Movie	Scene	20-30	30-60	2-3
	Annotations:			
	-video	20-30	5-10	2-3
	-text	1	5-10	2-3

Table 15: Order of magnitude of multimedia P-Objects

Table 16 shows the order of magnitude of the number of accessible segments and their size with and without video. Where Table 15 shows the size of individual P-Objects, Table 16 shows the size of the P-Objects that could be accessible at any point and therefore the Total Size Accessible represents the potential size of the communicated message. Documents containing video impose a very different set of demands on the delivery system.

Document	P-Objects	Number Accessible	Total Size Accessible (Mbits)	Total Size Accessible excluding Video (Mbits)
Magazine Article	Pages	10	20	10
	Side-bars	2	0.5	1
	Video clips	1	10-30	0
Album Pages	Slide show	5-8	5-8	5-8
TV News Article	News Clips	5-10	50-100	0
Augmented Movie	Scene	30-60	600-900	0
	Annotations:			
	- video	1	20-30	0
	- text	1	1-4	1-4

Table 16: Order of magnitude of accessible multimedia P-Objects

Document organization becomes very important given the large sizes of some of the P-Objects associated with any part of a document. A user is able to skip back and forth in a text document fairly easily but the same action in a multimedia document can have a devastating impact on network performance as image and audio transmission tries to keep up. Loeb therefore advocates the construction of a network "advise" facility to coordinate this access and to maintain links to multiple network addresses.

Davies [63] produced a particularly good study of multimedia computing technologies. He noted that, despite initial research successes, some of the more

advanced systems are already making demands on the technology that far exceed its capability. There are six different media types that may be used as follows:

- **Encoded text:** The ASCII or EBCDIC characters in common use today.
- **Vector graphics:** Images are stored using instructions on how to redraw them rather than storing the image itself. These are usually smaller than bit mapped graphics files.
- **Bit map graphics:** Representations of an image are stored in the form of dots. These tend to be large files.
- **Voice data:** Due to the limited frequency span of the human voice, the requirements for voice storage are significantly less than high quality audio.
- **High quality audio:** Digital audio of the quality associated with compact disks produces very large storage requirements.
- **Video:** Digitized video places an extreme load on storage and retrieval systems.

Table 17 shows the storage requirements for each of these media types along with the assumptions made in arriving at these figures.

Media	Assumptions	Uncompressed Storage/Speed	Compressed Storage
Encoded Text	<ul style="list-style-type: none"> - screen resolution 768x512 - char. size 8x8 pixels, 2 bytes/ char. - no. of char. per screen = 6144 	96 kbits (12 kbytes)	16 kbits
Vector Graphics	<ul style="list-style-type: none"> - screen size 768x512 pixels - 1 byte per line for attributes - 500 line average image 	22.4 kbits (2.8 kbytes)	22.4 kbits (unchanged)
Bit Map Images	<ul style="list-style-type: none"> - screen resolution 768x512 - char. size = 8x8 pixels - 256 colours per pixel 	3072 kbits (384 kbytes)	1200 kbits
Digitized Voice	<ul style="list-style-type: none"> - analogue bandwidth = 4 kHz, 8 bit sample size - sample rate of at least 8 kHz 	64 kbits/s (8 kbytes/s)	16-64 kbits/s
Digitized High Quality Audio	<ul style="list-style-type: none"> - analogue bandwidth of 22 kHz, 16 bit sample size - sample rate of at least 44 kHz 	704 kbits/s (88 kbytes/s)	704 kbits/s (unchanged)
Digitized Video	<ul style="list-style-type: none"> - phase alternate line (PAL) encoded with vision bandwidth = 5 MHz - frame rate of 25 frames / sec. - sample size of 24 bits - analogue bandwidth = 5 MHz - sample rate at least 10 MHz 	240 Mbits/s (30 Mbytes/s)	1.544 Mbits/s (NTSC) 22 Mbits/s (HDTV)

Table 17: Multimedia Storage Requirements

There is significant effort underway to find methods of compressing the various media particularly the digitized video. A video image is essentially defined by four parameters; the two spatial dimensions, a depth or colour parameter and the temporal resolution (number of frames per second) of the image. The Digital Video Interactive (DVI) system achieves a compression ratio in the order of 160:1 by saving only the changes that occur between frames. The actual compression on a single frame however is only 25:1 so the overall compression is dependent upon the speed at which the image is changing. This technique would store up to 72 minutes on a standard sized (600 Mbyte) optical disk. All compression techniques result in some loss of quality however and there may be some scientific or medical applications for which this would be unsuitable. For a packet, or cell, based telecom system such as ATM, video need not be transmitted at a constant bit rate.

The International Standards Organization's (ISO) Joint Photographic Experts Group (JPEG) has developed a compression standard for colour fax, graphics arts and desktop publishing. Their Moving Picture Experts Group (MPEG) has developed a standard, which is similar to H.261, for storing full-motion video. Both JPEG and MPEG were developed for use with Winchester disc drives, optical disks and CD roms [64].

Multimedia therefore requires high capacity storage and high transfer bandwidths. Magnetic media such as 600 Mbyte discs with 1 Mbyte/s transfer rates, which are presently available, are sufficient for text, vector and bit mapped graphics. Voice, audio and video however require new storage techniques such as optical disks, disk

arrays and solid state memory which are under development. Reliable, low cost, high transfer, write-many optical disks are not yet available. The disk-array technique proposes to stack disks such that a record is spread over several disks to reduce the seek time which is the limiting factor in most current magnetic disks. Solid state memory (or flash memory) are expected to provide up to 125 Mbytes of non-volatile memory supporting transfer rates up to 15 Mbytes/s. This would store up to 4.4 hours of voice, about 20 minutes of high quality audio or in excess of 10,500 pages of text. Table 18 shows the access and transfer rates for these technologies.

Type of disk	Transfer rate (kbytes/s)	Average access time (sec.)	Maximum access time (sec.)
CD-ROM	153	0.5-1	1-2
Winchester	625	0.05	0.1
Flash Memory	14800/120 *	135×10^{-9}	16×10^{-6}

Table 18: Disk Transfer Rates

* The first figure is the read and the second the write transfer rate

Significantly, measurements indicate that 15-20% of all newly-written bytes are deleted within 30 seconds and that 90% are deleted within a day.

Davies concludes that the present hardware, communications and software technology limitations pose severe technical problems to the implementation of multimedia systems however he notes that large resources are being made available to multimedia researchers to overcome these problems. Test systems are available today, however production systems may still be five years away depending on hardware and software

2 OF/DE 2

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

developments. Although there are no market studies available to project the level of acceptance of these systems, it would seem appropriate, based on the progress of the technology and its potential applications, to estimate a 30-40% penetration of multimedia in office workstations within 10 years.

3.6 Building Service Devices

Building services use essentially the same technology as tenant services (digital computers and communications). They typically have lower communications rates, shorter messages, are physically moved less often, and are greater in number. Although the messages are not time critical relatively speaking (up to 5 seconds), the transmission usually must be error free for safety and control reasons.

3.6.1 High Traffic Devices

Security cameras operate on the same principle as standard video services except that lower speeds and quality, freeze frame and black and white pictures are used most often.

3.6.2 Low Traffic Devices

a) HVAC: (thermostats and humidistats)

In an analogue system these devices transmit constantly but in a digital system they can be polled. Polling may be done every 30 seconds with a 6 byte control code and an 8 byte response.

b) Lighting: (switches, photocells, occupancy sensors and central controllers)

Switches and occupancy (motion) sensors send 8 byte messages when triggered. Photocells are polled devices which involve a 6 byte control code and an 8 byte response every 30 seconds. Central lighting controllers, in addition to responding to sensors and switches, initiate their own messages based upon a stored timetable. The 8 byte messages may go to some or all of the light fixtures or banks of fixtures. Motion sensors are typically installed at the rate of 1 per 2100 sq. ft. in open offices while individual offices have one each.

c) Security: (door access devices, motion sensors, door and window sensors)

Analogue, wired systems maintain a constant supervisory signal initiated by the controller to most security devices and sensors as a security measure. Digital wired systems may send 12 bytes every 10 seconds and wireless systems transmit every 10 minutes to 1 hour. All devices also initiate a transmission when activated.

d) People movers: (elevators (cab control, floor call buttons, door sensors, rooftop motors), escalators, automatic doors)

Given that the average person enters the office in the morning, leaves and returns at lunch and leaves at the end of the day, and that each trip requires activating two buttons, there will be eight 10 byte messages per person per day. The majority of entry and exit traffic does not occur at the same time as the peak traffic from tenant service devices, however the traffic that may occur during the morning and afternoon office automation traffic peaks may be estimated at 15% of the possible people mover traffic. Fire systems are

omitted as integration with a common wiring system is not permitted by code in Canada.

3.7 Summary of Device Traffic

This section summarizes the findings of the previous sections in this chapter and therefore summarizes all of the traffic expected from office building devices.

Table 19 summarizes the computer terminal traffic characteristics. The annual growth rate of these timesharing systems is actually expected to be flat with the movement towards distributed processing and local workstations which will perform a greater portion of the work.

Device	Message size			Dev. speed (kbits/s)	Cycle Times			Estimated annual growth %
	Avg. (kbits)	Distrib.			avg. time (sec.)	Distrib.		
		<4	>3			<4	>3	
Async. non-prof.	1.28	HE	E	2.4	25.6	HE	P	-5
Async. (professional)	2.18	HE	E	2.4	32.5	HE	P	-5
Async. (professional)	1.03	-	-	9.6	9	LN	LN	5
Touch Tone Pad	.834	E	E	-	60.8	HE	P	5-10

Table 19: Summary of Computer Terminal Traffic Characteristics

The average personal computer transfers at about 200 kbits/s, however the more powerful workstations such as the Sun and Xerox Star workstations achieve speeds of 2.2 Mbits/s. It is not unreasonable to project speeds of 500 kbits/s and 10 Mbits/s respectively within 5 years.

Table 20 summarizes the common workstation traffic characteristics, not including the new specialized tenant applications. These office automation systems are expected to continue to grow at a steady rate of 20-25% annually.

Estimations of the computer traffic, as shown previously, vary greatly as they are very dependent upon the design of the application and the manner in which it is used. Present trends are towards significantly more devices, used more frequently and transferring more data from central servers. For example, this 35,500 word thesis, stored in Word for Windows format was 280 Kbytes without the bit mapped images. With the bit mapped images, it grew to 1.16 Mbytes and, when formatted for a Postscript printer, it became 1.97 Mbytes (15.76 Mbits) which when sent over an idle 10 Mbit/s Ethernet network to a print server, took 42 seconds to transmit (for an effective rate of 375 Kbits/s using an IBM 386).

Continuous message traffic is summarized in table 21. Telephone traffic is experiencing steady, modest growth while facsimile traffic is increasing at a rate of 25 - 30% annually. Present document sizes average between 1.7 and 72 Mbits depending upon the scanning resolution. Future use of grey scale or colour scanning will multiply these sizes by four and by fifteen respectively. Therefore, there may be a requirement for higher speed facsimile transfer in the order of 64 Kbits/s or more.

Usage	Avg. msg. (kbits)	Avg. Inter- arrival time (min)	Estimated annual growth (%)
a) Casual Users			
- e-mail	2.8	60	20
- printing	160	30	20
- file xfer.	160	60	25
- access software server	1500	15	5
- diskless workstation record access	6.6	1	15
b) Office professional			
- e-mail	2.8	15	20
- printing	160	6	20
- file xfer.	160	6	25
- access software server	1500	7.5	2
- diskless workstation record access	6.6	3.6 sec	20
c) Term. Emulation see Async prof. @ 9.6 kbits/s	-	-	-
d) Computer professional			
- e-mail	2.8	30	20
- printing normal	160	10	20
- printing graphics	1500	15	20
- CAD/graph files	1200	30	15
- file transfer	160	6	20
- access software server	1500	15	5

Table 20: Summary of Workstation Traffic Characteristics

Device	Encoding rate (kbits/s)	Holding time		Arrival distribution	Estimated annual growth
		mean (sec)	distrib.		
Telephones	64	180	Exponential	Poisson	4-9%
Facsimile	9.6-14.4	176	Exponential	Poisson	25-30%
Broadcast TV	1,544	hours	-	-	10%
HDTV	22,000	hours	-	-	? (new)
Teleconf. video	64 - 1,544	2-4 hrs	-	-	5%
Freeze frame	64	hours	-	-	5%

Table 21: Summary of Continuous Message Device Traffic Characteristics

Broadcast television (NTSC standard) and Community Antenna television (CATV) are growing steadily in the home environment with limited penetration in offices although this may change with the development of interactive training systems. The technology will be used increasingly for video conferencing and for multimedia, particularly with the introduction of HDTV quality. It is impossible to predict the timing and speed at which HDTV will be implemented since the technology is still at the prototype stage, however, predictions are that production systems will start in 1996 with the majority of sets being replaced by 2008 when the present NTSC standard begins to be phased out. Desktop video and video telephones use either freeze frame or stop motion technology because of the limitations in the bandwidth of the computer LAN's and telecommunications networks. These applications will experience limited growth until such time as the universal communications systems are able to support full motion video at which time 10-20% annual growth may occur.

They will not justify the implementation of high speed, nation wide networks but if such networks do evolve, these systems will be adopted widely and will therefore add significantly to the communications requirements of office buildings.

Use of the facsimile machine has doubled and tripled over the past four or five years because it was a simple method of delivering documents from one place to another instantaneously. It is possible that the video equivalent may be developed in the near future that would allow real time transmission of multimedia documents. The "message" being sent may contain a person's voice track, video image showing the documents being described, still images and a text document. If fax machines evolve into these multimedia devices, they will have a significant impact on the requirements for communications in office buildings.

Table 17, shown previously, summarizes the estimated communications requirements of multimedia documents. Since these applications are still under development, these estimates are very preliminary.

Table 22 summarizes the traffic requirements found in the Radiology Systems at the University of Ottawa which is indicative of the requirements of the new imaging applications under development for hospital X-rays, military projects, engineering research and other disciplines where detailed, complex, high quality images are used. The objective is to store, transmit and display pictures electronically. A single X-Ray picture required 48 Mbits of storage and although a number of transmission and viewing techniques were investigated to permit their transmission over existing

networks, ideally they require network speeds over 100 Mbits/s for practical implementation.

Building service device traffic, summarized in table 23, is most significant by the number of devices and their locations throughout the building rather than by the message size of any one device.

These systems lag behind in their implementation of computer and communications technologies by 3-5 years and therefore their growth has been relatively flat, however this is expected to change. Besides implementing distributed computing and network communications, projects are underway now to dramatically improve the services provided by reducing the energy used by these systems while providing more services to the occupants which will expand the communications requirements. These may prompt an annual growth of 10-20% in this area over the next 5 years.

Network Type	Network Speed (Mbits/s)	Number of Servers	Full Image (Mbits)	Reduced Image (Mbits)	Image Display (sec.)
CSMA/CD broadband LAN	2	1	48	-	-
			-	8.2	90
DQDB IEEE 802.6 MAN	17.8	8	41.9	-	15-40
			-	8.4	-
			-	4.2*	1.5
FDDI - II LAN	-	-	41.9	8.4	-
	1	1	-	8.4	60
	1	2	-	8.4	60
	10	1	-	8.4	40
	10	2	-	8.4	20
	100	1-2	-	8.4	20
	1-100			0.5**	1-4
CSMA/CD LAN			41.9	-	-
a) No local storage	2	1	-	8.4	70
	2	2	-	8.4	30
	10	1	-	8.4	45
	10	2	-	8.4	20
b) Pre-loaded local storage	2-10	1-2	-	8.4	6.4
c) Magnification image	2-10	1-2	-	0.064	2-4

Table 22: Summary of Radiology System Traffic Characteristics

* average file size using reduced-differences pyramid technique

** magnification image

Service	Device	Number	Average msg. length (bits)	Inter-arrival times (sec)
HVAC	- thermostats	1/office or 1/3000 sq. ft.	112	30
	- humidistats	1/8000 sq. ft.	112	30
	- mixing boxes	1/office or 1/3000 sq. ft.	112	30
	- central unit	1/floor - 1/building	112	30
Lighting	- switches	1/office or 1/1200 sq. ft.	112	30
	- photocells	1/office or 1/1200 sq. ft.	112	30
	- occ. sensors	1/office or 1/2100 sq. ft.	112	30
	- central controllers	1/building	112	30
Access	- door access	varies	96	on activation
Control	- elevator access	varies	96	on activation
Security	- motion sensors	in critical areas	96	10 & activation
	- door sensors	ground floor & critical	96	10 & activation
	- door switches	ground floor & critical	96	10 & activation
	- video	ground floor & critical	see table 21	continuous
Elevators	call buttons	2 per elevator per floor	80	on activation

Table 23: Summary of Building Service Device Traffic Characteristics

The heaviest continuous traffic will be HDTV (averaging 22 Mbits/s), broadcast TV (1.544 Mbits/s), and high quality audio (704 kbits/s), most likely due to the use of multimedia applications. The heaviest file transfer demands will come from facsimile machines (1.7 - 72 Mbit files) and specialty image applications such as radiology (48 Mbit files), software servers (4.6 Mbit files) and bit mapped graphics (1.2 Mbit files).

Chapter 4 Communications Traffic Generated Within An Office

The number of tenant and building service devices can both be related to a building's size and floor space as an initial approximation, and then to the specific applications expected if known. Public Works Canada guidelines allocate 13.9 sq. m. (150 sq. ft.) per person in either open or private office space which therefore defines the number of telephones and workstations (1 each per person) for a given building. This space does not include circulation areas which occupy 20% - 35% of floor space nor meeting rooms, supply rooms, etc. Note too that 3% - 5% of offices/desks may be unassigned at any given time. Office pools such as wordprocessing, telemarketing or document entry may have twice this density, averaging 75 sq. ft. per occupant.

The floor layout and building size has a direct relationship with the building service equipment. Private offices each contain a thermostat, light switch and fire sensor. Open areas have fewer such devices per unit area.

In order to calculate the typical and peak traffic generated in office buildings, first a case study of floor space utilization is presented to illustrate a typical installation today and then suggested worst traffic case models of smaller areas are presented and the peak traffic calculated for each. Finally the original case study is re-examined taking into consideration the projected growth over the next 10 years.

4.1 Case Study of a Present Day Office

Place Bell Canada in Ottawa, a typical open office concept building with about 33,700 sq. ft. of useful office space per floor, was examined as a case study of traffic levels in the average office in 1992. Figure 10 shows the layout of the tenth floor which has a mixture of applications from middle management administration to telecommunications engineers and computer professions.

There are 230 desks of which 7 are unassigned (3%) averaging 146.5 sq. ft. per desk. Each desk has a telephone and a workstation (Macintosh or PC). The workstations are connected to a 10 Mbits/s Ethernet LAN running ethertalk. Five percent of the workstations have modems and there are two rooms reserved as computer labs. There are eight shared printers around the floor and about 18 terminals connected to a mini over 2400 bits/s lines. There is also an X.25 PAD containing 25 modems, accessible from any workstation.

There are sixteen thermostats and humidistats around the floor and eight ceiling mounted centrally controlled clocks. The building uses a central controller for lights so there are no active light switches on the floor. The controller automatically shuts the lights off at 6:30 p.m. and occupants can turn them on again by entering a code, which identifies the particular bank of lights, into the telephone. Although all of the lights are presently programmed to come on in the morning, this will soon be changed such that the occupant must enter the code to do so (an energy saving technique). There are 560 fixtures in the office area per floor, divided into banks of 20 fixtures.

Figure 8: Place Bell Canada 10th Floor Plan

4.1.1 Estimation of Maximum Instantaneous Communications Traffic

The following is a very approximate estimate of the maximum instantaneous traffic that can be reasonably expected from all of the devices on the tenth floor of Place Bell Canada. The applications, the number of devices in use, and the message lengths are approximated using the information in chapter 3.

The following assumptions were made:

- The number of assigned desks is $230 - 7 = 223$.
Occupants are at their desks 75% of the time = 167 people.
- Of the 167 people able to use workstations,
 - 5% are "office professionals" = 8 people
 - 10% are "casual users" = 17 people
 - 85% are "computer professional" = 142 people
- The workstations are used primarily for e-mail and printer access; 5% may be accessing a file server for file transfer; none are diskless and no CAD work is being done.
- Terminal/Host Traffic:
 - 18 asynch. terminals @ 2400 bits/sec
 - 1/6 of the terminals are active = 3 terminals
 - all are used by computer professionals
 - average message length = 272.2 characters = 2.18 kbits
- Workstations:
 - Ethernet 10 Mbits/s LAN
 - est. max. speed per device = 200 Kbits/s over a busy LAN

- 167 people - 3 terminal users = 164 people
- at most 50% of the workstations are being used and 50% of those are communicating ($164 \times 0.5 \times 0.5 = 41$ workstations)
- 60% are using e-mail = 24 workstations
- 35% are using printers = 14 workstations
- 5% are transferring files = 3 workstations
- **Telephones:**
 - of 167 people in their office, 11% are actively using telephones = 18 calls.
- **Facsimile machines:** 7 fax machines x 9,600 bits/sec. (all active)
- **Building Services**
 - 16 thermostats and humidistats, @ 8 character messages.
 - 28 banks of lights - switched twice daily.
 - Security sensors: none on this floor.
 - Coded door locks are mechanical.
 - Security Cameras: none on this floor.
 - Elevators: 223 people x 2 messages x 10 bytes
 - assume all 223 people are at work and 15% are using the elevators = 33 people, however, there are only 8 elevator cars so at most only 8 buttons can be activated simultaneously on this floor.

The estimated maximum traffic shown in Table 24 is the instantaneous traffic.

Device	No. active/ Xmit. dev.	Discrete				Continuous		
		Peak Msg. size (kbits)	dev. speed (kbits/s)	Max. traff.: (kbits/s)	hold time (sec)	dev. speed (kbits/s)	Max. traffic (kbits/s)	hold time (sec)
Terminals	3/1	2.18	2.4	2.4	0.908	-	-	-
Workstations:								
- e-mail	24/6	2.8	200	1200	0.014	-	-	-
- printing	14/4	160	200	800	0.8	-	-	-
- files	3/1	160	200	200	0.8	-	-	-
Telephones	18	-	-	-	-	64	1152	180
Facsimile	7	-	-	-	-	9.6	67.2	176
HVAC sensors	16/4	0.112	2.4	9.6	0.047	-	-	-
Lighting banks	28/7	0.112	2.4	16.8	0.047	-	-	-
Elevator calls	8/4	0.08	2.4	9.6	0.033	-	-	-
Totals	129/27			2,238.4	-	-	1219.2	-

**Table 24: Estimated Maximum Instantaneous Traffic,
10th floor, Place Bell Canada**

Considering the hold time of the devices, a reasonable estimate of the maximum average traffic might be to consider that at the very most, only 25% of the discrete traffic devices send their messages simultaneously. The column indicating "No active/Xmit devices therefore indicates the number of devices in use and an estimate of the maximum number that may reasonably be expected to be transmitting simultaneously. This would give an instantaneous discrete traffic level of 2,238.4 Kbits/s, continuous traffic of 1,219.2 Kbits/s and a total instantaneous average traffic level of 3457.6 Kbits/s which in this case equates to an average of 103 bits/s per square foot of floor space.

4.2 The Office of the Future

Given the developments in information processing hardware and software technologies, the growing user expectations for the delivery of more information faster, possible increases in facsimile traffic and the possible use of multimedia systems and HDTV, offices of the future may require orders of magnitude increases in access to information. For read only type of access, these large volumes of data may be stored locally on compact disks and other devices or they may reside on a central server linked to the various workstations over a network. The latter scenario places a much heavier load on the communications network but results in equipment cost savings and it is substantially easier and cheaper to keep the information current if it is stored in one location.

Where documents are created as well as accessed from a file server, the network may need to support the multi-user concept which allows joint authorship and remote editing and review.

The biggest change in workstation applications over the next ten years may be the increased use of multimedia documents. Where virtually all of today's databases are textual, new multimedia systems may account for 30 to 40% of the devices and about 70 to 80% of the data communications traffic, depending upon the applications and the ability of networks to support this level of traffic. Historically, new devices are expensive and customers try to share them over a network. This creates heavy demands on the network which precipitates developments in network technology to accommodate it. Eventually equipment costs come down and network capabilities increase until a balance is reached. In order to define the office of the future, assumptions must be made about the development of user applications, the cost and capabilities of equipment and the characteristics of future networks. It is unrealistic to assume that applications and equipment will evolve without a similar evolution in the ability of networks to support them.

This section examines theoretical worst case scenarios in which maximum use is assumed of high traffic devices while keeping within reasonable expectations. "Hot spots" will occur whenever a number of high traffic devices or a large number of medium traffic devices are located in close physical proximity. This may be a planned occurrence such as the creation of computer rooms, telemarketing rooms or publisher's editing offices or may occur in an ad hoc fashion such as when, during a break in a meeting, many of the attendees use their PCN telephones to check with their offices or their portable computers to read their e-mail. Chapter 3 identified the following applications as potentially generating high traffic;

- telephone use

- multimedia document editing
- professional computer use
- HDTV

Case studies are presented below that evaluate the traffic generated in a telemarketing room, a multimedia facility, a computer room facility as well as an individual office. In addition, the previously described case study of the tenth floor of Place Bell Canada is re-examined taking into consideration future growth and new applications. Any application that includes video or high quality audio, such as multimedia, conferencing and HDTV will have the greatest affect on the communications loads.

4.2.1 Telemarketing Model

Telemarketing is the process of placing a large number of telephone calls to the public to solicit business. Typically this is done by having a number of operators continuously making phone calls throughout the day, although automated computer controlled systems are also available.

For this model, the following assumptions have been made:

- open concept office of 50' x 36' (1800 sq. ft.) containing 24 cubicles (75 sq. ft. each).
- each cubicle contains a telephone set and a computer terminal
- average workstation transfer rate = 500 Kbits/s
- all telephones are in constant use with an average hold time of 2 minutes

- the terminals access a central list of telephone numbers, keeping track of those already called and automatically dialing the next number. They also record sales in the database simultaneously with the phone call.
- assuming all operators are recording a sale on the database, this might require a message of 6 lines averaging approximately 300 characters per message. In the worst case, perhaps half the messages are sent simultaneously

Based on the device traffic characteristics shown in chapter 3, the traffic generated by this model under these assumptions is as follows:

- Telephones: $24 \times 64 \text{ Kbits/s} = 1.536 \text{ Mbits/s}$
- Workstations:
 - $300 \text{ char} \times 8 \text{ bits} = 2.4 \text{ Kbit files}$
 - 6 transmitting at $500 \text{ kbits/s} = 3 \text{ Mbits/s}$

Maximum total traffic of this model = 4.536 Mbits/s

4.2.2 Multimedia Models

The difficulty in modeling multimedia systems in the office of the future is that such applications exist now only in the research labs. Therefore it is necessary to speculate about the techniques that will be used to implement such systems before estimating the level of traffic they will generate. These models therefore are very tentative as they are based upon large assumptions of how the systems will be designed.

One of the most significant changes in information handling is the idea that continuous message traffic can be stored in digital form in a file and then, not only can it be rebroadcast at a later date, it can also be moved over the network without viewing like copying a computer file. Transmission times equal to the viewing time will be unacceptably slow for copying such files. Multimedia documents are a good example of this problem, for example one chapter of a document may be composed of the following:

text: 20 pages x 16 Kbits/pg	=	320 Kbits
voice: 2 minutes x 64 Kbits/s	=	7,680 Kbits
audio: 4 minutes x 704 Kbits/s	=	168,960 Kbits
bit map images: 5 images x 1200 Kbits	=	6,000 Kbits
NTSC. video: 2 minutes x 1.544 Mbits/s	=	<u>185,200 Kbits</u>
total file size	=	<u>368,240 Kbits</u>

If HDTV were used instead of standard broadcast video, this file size would be 2,823 Mbits! A single user could saturate the new FDDI 100 Mbit/s network for half a minute with a workstation capable of transmitting at that speed and conversely, it would take 3.9 hours to transfer the file at the present workstation speed of 200 kbits/s.

Offices publishing multimedia documents would provide a good example of the total communications requirements. This application may have two separate processes, document creation where the components of the various media types are assembled into the original document, and document editing. By definition, the creation process

would use full resolution files and images and would likely (although not ideally) be done on standalone workstations. The editing process may not require the full quality of the document and therefore might operate over a network from a central server by using techniques such as reduced resolution images, compression of high-quality audio to voice bandwidths and compression of the video to freeze frame speeds. Case 1 illustrates the traffic generated by this scenario.

Another method would have the server display the document on the workstation in real time, giving the user the capability to pause and step forward or backward in the document. Transmission rates need only be calculated at the required display rate. For documents that do not require the full bandwidth continuously (i.e. if only 10% of the document was video or audio), buffering could be used to pre-load part of the next segment. Another factor may be the rate at which the user views the document. People read text at different rates and may cause pauses in the transmission (or perhaps the systems will require a user action to turn the pages). A further saving could be obtained if the workstation stored the document at the same time as displaying it so that any backward scans could be done locally. Case 2 illustrates the traffic generated by this scenario.

The following assumptions have therefore been made for both models:

- open concept office 50' x 36' (1800 sq. ft.) containing 12 work areas (150 sq. ft. each)
- each work area contains one multimedia workstation and a telephone
- 6 of the occupants are editing multimedia documents
- 4 of the occupants are actively using their telephones

- 2 are not using communications (editing offline or in meetings)

Based on the one chapter example shown previously and the device traffic characteristics shown in chapter 3, the traffic generated by these models under these assumptions is:

i) **Case 1: Multimedia files downloaded to the workstation as a file**

- images are sent at a reduced resolution of 384 x 256 (instead of 768 x 512) pixels resulting in 768 Kbit files
- high-quality audio is reduced to voice grade at 64 Kbits/s
- Video is compressed to the upper limits of freeze frame at 64 Kbits/s
- **Multimedia Workstations:**

text: 20 pages x 16 Kbits/pg	=	320 Kbits
voice: 2 minutes x 64 Kbits/s	=	7,680 Kbits
audio: 4 minutes x 64 Kbits/s	=	15,360 Kbits
bit map images: 5 images x 768 Kbits	=	3,840 Kbits
video: 2 minutes x 64 Kbits/s	=	<u>7,680</u> Kbits
total file size	=	<u>34,880</u> Kbits

If a reasonable transfer time is 5 seconds, the transfer rate required per workstation would be 6.98 Mbits/s. It is unlikely that more than half of the workstations would transfer simultaneously so the maximum transfer rate for 3 workstations is 20.94 Mbits/s

- **Telephone use:**
4 users x 64 Kbits/s = 256 Kbits/s

Therefore the maximum total traffic for this model = 21.2 Mbits/s

If the reduced resolution is not used for the images, audio and video and the full 368.2 Mbit file is transferred in the five seconds, then a transfer rate of 73.6 Mbits/s would be required for each workstation and the total model traffic would be 221 Mbits/s.

ii) **Case 2: Multimedia documents are displayed directly from the server.**

- assumes full resolution for all media
- assumes all six workstations are receiving simultaneously
- assumes file is stored locally while it is being displayed to eliminate re-transmission
- assumes acceptable display times are 2 seconds for text and 4 seconds for bit mapped images
- to error on the conservative side, no buffering or pause factor is used
- as a worst case scenario, it is assumed that the video and voice are continuous throughout the document with the text, audio and images appearing periodically and sequentially. Therefore the maximum traffic = Video + Voice + Maximum (text or image or audio)

Model Traffic:

Multimedia workstations

i) **Maximum (text/image/audio)**

text: 1 page x 16 Kbits/2 seconds	=	8 Kbits/s
bit map graphics: 1 image x 1200 Kbits/4 seconds	=	300 Kbits/s
high quality audio:	=	704 Kbits/s
- Maximum (text/image/audio)	=	704 Kbits/s

ii) **Voice and Video**

voice:	=	64 Kbits/s
video:	=	1,544 Kbits/s

iii) Total Multimedia:

Maximum (text/image/audio)	=	704 Kbits/s
Voice	=	64 Kbits/s
Video	=	<u>1,544 Kbits/s</u>
Maximum traffic per workstation	=	<u>2,312 Kbits/s</u>
Maximum total traffic for 6 workstations	=	13,872 Kbits/s

Telephone use:

4 users x 64 Kbits/s	=	256 Kbits/s
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Therefore the maximum total traffic for this model	=	14.128 Mbits/s
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If HDTV were used instead of broadcast TV, the traffic per station would be 22.768 Mbits/s and the total traffic for this model would be 136.6 Mbits/s assuming different signals for each of the six workstations.

As was mentioned previously, new applications and installations are created under a number of restrictions including the cost and capability of the equipment. If networks cannot cope with this traffic, perhaps multimedia workstations will start out as stand alone systems, as did the early CAD systems. The next stage might be the connection of multimedia workstations to a file server over a separate, high speed network. For example a 100 Mbit/s LAN would be theoretically capable of supporting up to 14 downloading 7 Mbit/s workstations. There also needs to be development work done on file server technologies to enable the transfer of such high data rates.

Eventually compression and file handling techniques will reduce this file size and network speed will increase. If an additional 100:1 compression is achieved (difficult since the HDTV is already compressed) and 500 Mbits/s networks become cost effective then it may be practical to re-connect the multimedia workstations to the common building LAN.

An interim solution might be to limit file server access of multimedia documents to read-only real time applications which would reduce the network demand. File editing and update might be done offline on a device directly connected to the workstation (e.g. read-write optical disk). Alternately, multimedia files might be downloaded during off hours as a batch process. Another solution that might be particularly suitable for editing of multimedia documents might be the use of reduced resolution image techniques similar to those developed at the University of Ottawa for the transfer of X-rays.

4.2.3 Computer Room Model

Although separate computer room facilities occur less frequently today since the reduction in cost of workstations has lead to provision of one in each office, it may still occur for business or security reasons or in the initial implementation of costly multimedia facilities.

The following assumptions have been made for this model:

- large open concept room 50' x 36' (1800 sq. ft) containing 24 workstations (75 sq. ft. each)
- of the 24 workstations, 6 are not being used (25%)

- all users are computer professionals
- Workstation transfer rate is 300 Kbits/s
- CAD station transfer rate is 500 Kbits/s
- Multimedia workstation transfer rate is 7.0 Mbits/s
- of the 18 workstations in use, 14 are actively using communications (77% utilization) as follows:
 - 3 are transferring e-mail
 - 3 are printing
 - 2 are downloading text files
 - 3 are downloading CAD files
 - 3 are downloading multimedia documents
- Multimedia traffic is as described in the multimedia case 1 model

Based on the device traffic characteristics shown in chapter 3, the traffic generated by this model under these assumptions is shown in table 25 to be 24.84 Mbits/s. Without the multimedia application, the traffic drops to 3.9 Mbits/s.

use	Number of users	Message size (kbits)	Transmission rate (kbits/s)	Total traffic (kbits/s)	Transmission time (sec.)
e-mail	3	2.8	300	900	0.028
printing	3	160	300	900	1.6
text files	2	160	300	600	1.6
CAD files	3	1200	500	1500	5.0
Multimedia	3	34,880	6.98 Mb/s	20.94 Mb/s	5.0
Total traffic				24.84 Mb/s	

Table 25: Computer Room Model Traffic

4.2.4 Individual Office Model

The physical floor space is defined at 150 sq. ft. (13.9 sq. m.) which is the size of the average single occupant office.

The following assumptions have been made for this model:

- a single occupant office
- 1 telephone
- 1 multimedia workstation, viewing directly from a file server
- 1 HDTV

Based on the device traffic shown in chapter 3, the traffic generated by this model is:

- telephone 64 Kbits/s
 - multimedia workstation 2,312 Kbits/s
 - HDTV 22,000 Kbits/s
- Maximum total traffic of this model is 24,376 Kbits/s

Without multimedia and video and assuming the workstation is transmitting CAD files at up to 500 kbits/s, the total traffic for the office drops to 564 Kbits/s.

4.2.5 Combined Office Model

Without a building network modeling and a simulation program (BNSP), it is difficult to accurately determine the combined traffic in the office of the future, however, a rough estimate may be made using the case study of Place Bell Canada with adjustments for future changes based on the preceding models.

To account for the growth expected and the possible introduction of multimedia and HDTV over the next ten years, the following modifications have been made to the 1992 model to obtain conservative (i.e. worst case) estimates of the traffic;

- there is one multimedia room matching the criteria of the downloading multimedia model
- 11 of the offices are equipped with HDTV of which 5 are in use, each on different signals
- 20% of the workstations are direct view multimedia of which half are in use
- there is one computer room matching the computer room model but not using multimedia
- there was a four fold increase in the number of fax machines with speeds of 64 kbits/s
- the workstation speeds have been increased from 200 kbits/s to 500 kbits/s

- the speeds of the terminal and building service devices have been increased from 2.4 kbits/s to 19.2 bits/s.

Table 26 shows the maximum instantaneous traffic for the office floor of the future.

Device	No. active/Xmit devices	Discrete		Continuous	
		dev. speed (kbits/s)	Max. traffic (Mbits/s)	dev. speed (kbits/s)	Max. traffic (Mbits/s)
Terminals	3/1	19.2	.0192	-	-
Workstations:					
- multimedia room	6/3	6,980	21.2		
- other multimedia	8/4	2,312	9.248		
- e-mail	14/3	500	1.5	-	-
- printing	7/3	500	1.5	-	-
- files	3/1	500	.5	-	-
HDTV	11/5	22,000	110		
Telephones	18	-	-	64	1.152
Facsimile	21	-	-	64	2.496
Building Services	100/25	19.2	.48		
Totals	129/27		144.45	-	3.648

**Table 26: Future Maximum Instantaneous Traffic,
10th Floor Place Bell Canada**

The total traffic for this case study is therefore projected to rise from 3,457.6 Mbits/s to 148.1 Mbits/s in tens years if the assumptions about growth, multimedia and HDTV are correct. The traffic per square foot of floor space would rise from 103 bits/s to 4.4 kbits/s. If broadcast TV were used instead of HDTV, the total traffic would be 42.15 Mbits/s of which 30.4 Mbits/s is due to the multimedia applications.

4.2.6 Model Summaries

Table 27 summarizes the four models of possible future traffic in offices. These models show the estimated maximum traffic that might be expected from limited areas containing concentrations of the highest traffic devices to be no more than 25 Mbits/s. Traffic in other areas of any floor of an office building will be lower than these "hot spots". However comparison of the present and future case studies for the complete floor model showed a 4,183% increase in the expected maximum instantaneous traffic. Since HDTV and multimedia are still in the development phase and their level of adoption in office buildings is still unknown, the level of traffic predicted by the models that include these applications is speculative and not likely to occur before 1997.

Although not modeled, it is also conceivable in the extreme case that a concentration of HDTV devices might exist. This would require multiples of the 22 Mbit/s traffic, assuming different signal sources. This might occur in hospital X-Ray facilities or in media related facilities such as newsrooms but are not likely to be common in office buildings. For this reason, this type of model is not considered to be a reasonable requirement for average office building networks in the next ten years.

Model	Floor Area (sq. ft.)	Devices	Highest traffic device (kbits/s)	Total Model traffic (Mbits/s)	Avg. traffic per sq. ft. (kbits/s/sq.ft.)
Case study of 1992 Office	33,700	no multimedia no HDTV	200	3.4576	.103
Telemarketing	1800	24 telephones 24 workstations	500	4.54	2.52
Multimedia					
a) downloading	1800	12 workstations	6,980	21.1	11.7
b) direct viewing	1800	12 workstations using HDTV	2,312 22,768	14.128 136.6	7.84 75.9
Computer room	1800	18 workstations (14 active)	6,980 (720 without MM)	24.84 (3.9 without MM)	13.8
Individual office	150	1 telephone 1 multimedia 1 HDTV	22,000 (240 without MM and HDTV)	24.376 (0.564 without MM & HDTV)	13.54
Case study of 2002 Office	33,700	multimedia HDTV	22,000	148.1	4.4

Table 27: Summary of Future Traffic Models

where MM = multimedia

Chapter 5 Opportunities for the Use of Wireless Communications

The most significant driving force towards wireless communications is the introduction of second generation cordless telephones (CT-2 Plus) and Personal Communications Networks (PCN's). As mentioned, this market is expected to service 5 million users at a cost of \$3 billion by 1997, expanding to \$12 billion by the year 2000 which will have a significant impact on in-building communications. In addition, increased use of wireless LANs and possible wireless connections for portable computers are additional factors.

Most systems today use wire based media, which greatly restrict mobility and increases retrofit costs. With the exponential increase in the requirements for communications due to the rapid development of electronic information systems, a 30% average rate for office moves, and the heavy competition in the space rental market, building owners and operators are experiencing serious retrofit cost and modification problems in adapting their existing systems. Wiring costs which average \$300 - \$1000 per drop, re-occur each time a retrofit or office move occurs.

This chapter therefore examines some of the criteria for using wireless communications and some of the current studies and projects including the proposed PCN networks.

5.1 Criteria for Using Wireless Communications

Devices presently in use and those anticipated in the near future need to be evaluated for wireless communications based on the following criteria;

- The device is or should be movable for technical or operational reasons,
- There is a cost benefit over the lifetime of the building,
- There is a convenience benefit to the occupant,
- The building owner or occupant may want it for some other reason.

There are two ways in which CT-2Plus and PCN systems may be used in office buildings. They are primarily being designed as access points to the public telephone network which will represent the largest initial use. A second use is to provide wireless drops to any of the other tenant and building service devices for voice, video and data communications within the building. This would permit equipment such as portable computers to use their wireless modem to connect, perhaps automatically, to the building's network for e-mail and printer access while still being able to dial into outside networks. In addition the electronic business organizers could be enhanced by having a common workspace between the executive and his secretary so they both could be editing the same schedule and be in constant contact regardless of travel location or time zone. Wireless connections would similarly permit workstations and facsimile machines to be moved freely to suit the purposes of the organization. Portable computers might represent 10-20% of an organization's workstations in the future. Their traffic may tend to be less intensive (e-mail, printing, file transfer), requiring speeds of up to 64 Kbits/s although adoption of video conferencing or multimedia applications, as modeled in chapter 4, might require up to 7 Mbits/s.

Personal Communications Systems (CT-2 Plus and PCN), as mentioned in chapter 2, are expected to be in common use within 10 years for telephone traffic, however market studies are not yet able to predict the degree to which they will replace wired telephones. The prediction of 450 million subscribers worldwide by 2010 is estimated to represent about 20% of the office building telephones. During the same time, wireless LAN's and wireless connections to LAN's, also described previously, will evolve to represent about 20% of the device connections. Building Services, particularly in the security industry, are also moving towards wireless connection of devices to simplify installation and renovation.

Battery life may be a factor for many devices such as building sensors (thermostats, motion detectors, etc.) that don't require connection to the power line, although it is now possible to construct a TDMA/CDMA spread-spectrum 915 MHz transmitter for \$5.50 and an associated receiver for \$18.00 [65]. A 2.4 GHz transmitter providing 10 mW of output power requires 75 mA of power at 8 V and a 915 MHz, 1 W transmitter will require 420-470 mA. Transmitters used intermittently for sensors (every 10 minutes or so) will operate on one \$2.00 lithium battery for up to 10 years.

Receivers are harder on batteries as they typically remain on all of the time. Present receivers draw about 100 mA which should be reduced to 30 mA with further development. Implementation of polling schemes that cycle the receiver may yield 1000:1 reductions in receiver current resulting in battery life in excess of 1 year.

5.2 Integrated Communications Using PCN

As explained earlier, wireless communications, for the last few feet connecting devices to the building, would alleviate a number of wiring problems within office buildings and are beginning to be implemented in various services. To date, these systems are incompatible, however, the movement towards Personal Communications Networks (PCN's) will require that all buildings have a wireless network installed to support them which presents an ideal opportunity to offer an integrated standardized wireless network to support all devices within the building

Sanderford [65] noted that PCN will not only provide information, voice, data and pictures to people but they will move about with them. He supports the idea of using the systems for the many different communications requirements in our buildings. He also goes on to suggest that PCN's might open the door to emerging applications such as automatic meter reading, improved fire detection and security systems, access control, process control, long-range data collection and distribution, etc.

Personal communications networks (PCN's) consist of an RF link from the device to the antenna which then can be modulated onto the PBX or data LAN for transmission around the building and to the outside world as shown in Figure 9. Typically one antenna will be installed in each 150 sq. ft. individual office and several in larger, open offices. A cell may be defined as the maximum area that can be covered without reusing any of the frequency spectrum, regardless of the number of antennas used. The cell size is dependent upon the frequency used, its bandwidth, and its propagation characteristics through walls and floors. In the 18 GHz band, the same frequencies can be reused beyond 120 ft (without walls) [29]. In a cell, the originating device

would direct the gateway to connect either to the PBX for an external line to the public switched telephone network (PSTN) or to the building's LAN as appropriate. The PCN gateway would have to be able to handle the total traffic from its cell. As discussed later, the PBX wiring and LAN cabling may be replaced with a single in-building network in which case the gateway will choose the appropriate channel or frequency on the network.

Assuming the average cell size to be 1800 sq. ft. (50' X 36'), the case studies described in chapter 4 may be used to determine the maximum traffic that might be expected from the most heavily used cells. Without multimedia or video, it can be seen from table 27 that the highest total traffic for a cell would be from the computer room model at 3.9 Mbits/s. If multimedia is used (video compressed to 64 Kbits/s) the highest traffic occurs in the computer room model which shows a maximum traffic of 24.8 Mbits/s. The worst case model is the direct viewing multimedia model using HDTV with a transfer requirement of 136.6 Mbits/s. The traffic over any individual wireless drop not using HDTV would be no more than 7 Mbits/s.

The IEEE (802.11) and several manufacturers, have been developing narrowband wireless LAN's with speeds up to 15 Mbits/s [66]. This would therefore be adequate for installations not using multimedia or HDTV. Since multimedia workstations, using no more than broadcast quality video, require between 64 Kbits/s - 6.98 Mbits/s, a limited number of these could be supported by a cell operating at 15 Mbits/s. HDTV applications, averaging speeds of 22 Mbits/s could not be connected through these PCN cells. To support the worst case multimedia and HDTV models, rates similar to Sonet's OC-1 (51.84 Mbits/s) or OC-3 (155.52 Mbits/s) may be required.

However, considering that HDTV will only begin to be commercially available in 1996, that multimedia workstations can use transfer rates as low as 64 Kbits/s for video and that the level of use predicted by the worst case scenarios will not occur in the next five years, the 15 Mbit/s PCN systems should be adequate for all office requirements at least until 1997. This allows time for PCN technology to develop speeds that could support the worst case models.

Figure 9: Possible PCN Office Building Cell Configuration

The small size of PCN cells is a distinct advantage in reducing the bandwidth required to service a building as frequencies can be reused. The backbone network connecting all of the cells together would naturally have to be designed to accommodate the total traffic for a floor and for a building.

Chapter 6 Integrated Networks

The case study models presented in chapter 4 give some idea of the communications required in small installations of broadband multimedia networks and of one floor in the office of the future. To properly evaluate the requirements of a single office building network that could support all of these devices, a full building network modeling and simulation program (BNSP) would have to be written and cases studied. This is beyond the scope of this thesis however some of the present integration projects are reviewed in this chapter and a possible structure for an integrated building network with preliminary estimates of its requirements is presented. Typically integration efforts start either from the telecommunications perspective with expansion to include the computer data networks or from the building services perspective where the primary objective is to integrate the service communications systems themselves before considering LANs and telecommunications.

Although it is possible to specify a single medium in-building network designed to carry the maximum traffic in the building, this would be excessive since many parts of the network would be over designed. In-building networks are most efficiently designed as hybrid systems utilizing high speed, perhaps fiber optic, components for sections that carry traffic from a large number of devices such as the building backbone or that support high bandwidth devices such as HDTV or computer graphic workstations. Low speed devices such as sensors may utilize twisted pair and many future devices may use wireless infrared or RF (CT-2 Plus or PCN) drops to link to the backbone. The in-building network therefore could be one logical network

utilizing several different media as appropriate. As Buchholtz [15] points out, although structured distribution systems lessen the expense and inconvenience of wiring, ultimately wired and wireless networks will coexist to address particular user needs.

A second consideration is the possible isolation of traffic within the area defined by its source and destination. IBM studies show that 50% of the distribution of office automation information is within the department and 75% within 600 ft. [3]. The traffic can be restricted to these areas through the use of bridges which therefore reduce the traffic load on that portion of the network outside the area. This type of customization is very organization dependent and is usually performed after the network is installed to address high traffic areas identified by the network traffic monitors. In order to predict this behaviour during the initial design, the BNSP would have to be used to identify these opportunities. The program would also be useful during retrofits or during organizational moves to predict the impact on the network.

Armbruster [50] suggests that the future broadband ISDN subscriber line requirements for the office can be satisfied by the following bi-directional channels.

- two 64-kbit/s channels with additional 16-kbit/s signaling capability,
- channels for high-speed document traffic or data communication (e.g. 2 Mbit/s) and
- one 140-Mbit/s broadband channel, e.g. for video telephony.

In contrast, he recommended the following for home applications:

- three unidirectional television channels of - for example - about 140 Mbit/s each (providing a choice of programs from a wide range),
- a bi-directional video telephony channel (140 Mbit/s),
- channels for stereo radio reception,
- two 64-kbit/s dialog channels for telephony and data communication, and
- a 16-kbit/s channel for signaling, program selection, etc.

One optical fiber operating at 600 Mbits/s in the direction of the subscriber and 150 Mbits/s in the direction of the exchange would carry this traffic. He suggests the in-house (and office) cabling will be a universal B-ISDN bus based on copper, coax or optical fiber and that universal sockets will be used to permit multi-vendor equipment to connect anywhere in the building.

6.1 Integrated Telecommunications and Computer Networks

Each type of transport protocol used by a computer network has different characteristics. CSMA/CD networks such as Ethernet are very sensitive to the number of active messages and peaks that last several seconds may overload them. Where a single user may be able to use 80 - 90% of the available 10 Mbit bandwidth from a powerful workstation, the network will saturate at 30 - 35% load if many devices are attempting to broadcast, due to the collision detection strategy. Transport protocols also may increase network load by as much as a factor of 2 due to the overhead of acknowledgement traffic. FDDI-II utilization may achieve 80% of the raw network bandwidth [12] and, as mentioned earlier, Sonet's overhead is about 4.5%.

The results of a study [67] done of the ability of 4 LANs to carry voice traffic without silence suppression are shown in Table 28. Table 29 shows the voice capacity of the 10 Mbit/s LANs, with voice suppression for various levels of data load.

	Max. Delay	Ethernet	Token Bus	Expressnet	TDMA ideal
10 Mb/s (1 km)	2 ms	30	51	67	96
	20 ms	100	129	138	147
	200 ms	125	153	154	155
100 Mb/s (5 km)	2 ms	-	165	650	961
	20 ms	125	848	1378	1470
	200 ms	1100	1441	1541	1552

Table 28: Number of Possible Voice Stations, No Data Transfer

where:

- Voice = 64 Kbits/s
- without silence suppression

It was noted that Ethernet capacity at lower delays barely increased at 100 Mbit/s over the 10 Mbit/s network due to the fact that the small packet lengths were not as viable at the higher speed. Table 30 shows the number of possible voice stations, with a 20% data load, that can be carried over a 100 Mbit/s LAN with various maximum delays with silence suppression.

	Data Load Offered		
	0%	20%	50%
Ethernet	257	103	0
Token Bus (TRT = 20 ms)	232	207	197
Token Bus (TRT = 25 ms)	232	187	153
Expressnet	291	265	158

Table 29: Number of Possible Voice Stations with Data Traffic

where:

- 10 Mbits/s LANS
- maximum delay = 20 ms
- with silence suppression
- TRT = Token rotation time

	Max. Delay		
	2 ms	20 ms	200 ms
Without silence suppression			
Token Bus (TRT = 20 ms)	0	757	1429
Expressnet	408	1159	1525
With silence suppression			
Token Bus (TRT = 20 ms)	15	1132	2936
Expressnet	880	2694	3396

Table 30: Number of Possible Voice Stations for Various Delays

- where:
- fixed data load = 20 %
 - 100 Mbits/s LANs

These show that Ethernet exhibits good performance at high delays and low loads and might be good as an intercom system but its poor performance at low delays suggests limitations for use on the telephone network. Token Bus was more suited to integrated voice/data applications though limited at low delays. Expressnet, a round-robin scheduling scheme, performed well for voice/data, carrying 270 voice stations over a 10 Mbit/s network and 2694 voice stations over a 100 Mbit/s network (both at 20 ms delay and 20% data). It should be noted that the 20% data component does not reflect the future loads predicted earlier for workstations considering that 2694 voice stations would imply the same number of workstations may also exist.

To effectively integrate voice, data, video and the other signals, the different characteristics of the traffic must be recognized. Voice, audio and video are very sensitive to absolute delay, tolerating less than 200 ms for voice and even less for video. Digital data, on the other hand, is generally less sensitive as users will tolerate delays of 2 - 20 seconds depending upon the application. For error rates, however, the inverse is true. Voice signals in fact tolerate relatively high error rates while data transport must be virtually error free.

Data traffic is also substantially more bursty than voice or video, both in the size and number of messages. These different characteristics imply that an integrated network would have to either provide the highest common denominator for all communications (guaranteed low delays and low error rates) or it would have to provide different services for each of the three different communications types. The former would result in an over designed network however the latter scenario, a separate but integrated network, could provide the simplified network while still meeting the

requirements of each communication type. With the ability to have multiple signals, modulated at different frequencies, propagated over the same medium such as with asynchronous transfer mode B-ISDN, the full range of devices could be accommodated on one network. Frequencies could be assigned to low-speed and high-speed CSMA/CD systems, to token-passing and to point-to-point TDMA systems allowing the access methods to be tailored to the user's bandwidth requirements. The same network could also support analogue and digital communications including video, interactive video, voice and audio. Broadband, as the basis for CATV networks is a proven technology. Sytek Incorporated has installed 300 networks with over 25,000 connections for mixed modes [68].

In Europe, the RACE program is preparing for the introduction of Integrated Broadband Communications (IBC) with the target of community-wide services by 1995. Project R1044 defined the minimum service set for this system as [69];

- POTS
- Distributed TV
- N-ISD Services
- fully deployed set or subsets of B-ISDN Services
- IN services
- Operation, administration, maintenance and provisioning (OAM & P Services)
- merging of the previous

The project advocates the use of Synchronous Digital Hierarchy (SDH) and ATM to support these services.

6.2 Integrated Building Service Networks

An integrated building services network called SEIS (System for Intelligent Buildings), based on ISDN, was proposed [70]. It would provide the following services:

- **Access Control:** controls building access, logs entry and locates people in the building.
- **Building Information:** Provides information about the building, its occupants, keeps meeting room reservations.
- **Diagnostic and Maintenance:** Tests the other services, initiates preventative maintenance, logs damaged equipment and monitors and manages alarms.
- **Emergency Service:** Detects emergencies such as fires, toxic gases and floods as well as guiding people during an evacuation.
- **Energy Management Service:** Monitors instantaneous energy demand, forecasts total consumption, supervises peak-load situations and sheds loads.
- **HVAC Service:** Maintains a comfortable safe working environment in coordination with the Emergency and Energy Management Services.
- **Lifts Service:** Controls and manages the lifts, gathers statistical information and tunes the lift behaviour.
- **Lighting Service:** Controls lighting, manages time switching programs, monitors brightness, and interfaces with the Energy Management and Emergency Services.

- **Receptionist Service:** Provides the functions usually performed by a receptionist such as recording entry, providing information on building occupants, guiding visitors, locating occupants and taking messages.
- **Security and Surveillance Service:** Controls surveillance cameras, monitors intrusion detectors and supervises security patrols.
- **Teleaction Service:** Interfaces SEIS with the outside world, controls system access.
- **Time and Attendance Service:** Records the time in and out for each worker and maintains attendance records.

The system may also integrate with computer networks such as Ethernet.

6.3 The Completely Integrated Building Network

An Integrated Building Network (IBN), identified as Level V integration in chapter 1, would have to support all of the voice, data and video requirements detailed previously. A typical IBN can be divided into three parts; the backbone, the floor branches and the device drops as illustrated in figure 10. The device drops need only be capable of carrying the traffic for the specific device. If a star topology is used for the floor branches, any single branch need only carry the traffic of the highest traffic device that could be installed which would be an HDTV system at 22 Mbits. If a ring is used in the branch, the total traffic for the floor (or section of the floor if more than one ring is used) must be accommodated. The gateway would have the capacity to process all of the traffic from its network of branches however more than one gateway could be installed per floor. The backbone riser would need to be designed to carry the traffic from all gateways. It should be noted that, as explained previously, not all

of the traffic may reach the backbone nor travel its full length since bridges can be used to isolate high traffic areas.

Figure 10: Integrated Building Network Components

The future office case study in chapter 4 estimated the maximum total traffic on one floor of an office building to be about 148 Mbits/s. This would be the sum of the traffic through all of the floor's gateways. If 50% of that remains on the floor, as suggested by the IBM study, then about 74 Mbits/s would be passed to the backbone. The gateway would have to be able to process the traffic in the worst case cell, which

was calculated earlier to be no more than 25 Mbits/s, so 3 gateways would be needed for this floor.

Given that there are 23 office floors in the case study building then the theoretical maximum traffic on the backbone would be about 1,700 Mbits/s. If this figure is reduced by 25% on the assumption that some of the traffic can be localized between floors then the backbone traffic would be about 1,300 Mbits/s.

Chapter 2 outlined several network developments that could be used to provide the IBN identified as Level V integration in chapter 1 although most are being designed primarily for high capacity trunks outside of buildings or for high data rate computer applications. Of these, two appear to offer the greatest potential of being used as the Integrated Building Network. The Sonet system using synchronous transfer mode (STM) is available today at speeds up to 2.488 Gbits/s with lower speeds of 51.84, 155.52 and 622.08 Mbits/s available as building blocks. The asynchronous transfer mode (ATM) B-ISDN standard agreed to by the CCITT, although not yet available, will also support a wide range of speeds up to 135.168 Mbits/s. NTT expects to be providing 622 Mbit/s B-ISDN Service by 1996 and to have switching and transmission equipment available with capacities to 10 Gbits/s at that time.

Networks are necessarily designed to carry less than the absolute peak traffic possible from all connected devices and the estimates for the office of the future and the projections of those onto the building backbone all contain assumptions that less than the maximum possible traffic will occur the majority of the time. The peak demand on the network may exceed the design specifications from time to time and the

network must be designed to degrade properly. Delays for time dependent communications such as voice or video must be limited while fax machine and printer traffic for example are less sensitive to delays. It may also be necessary to completely block access to a device wishing to join the network under these infrequent peak load conditions, however the network should never deny access to critical devices such as safety or environmental controls and should try to avoid denying access to telephones.

There is a marketing and implementation question about who will manufacture the integrated network and who should implement it. Although it may be logical for the building owner to install this universal network and supply communications services to all tenants, they may be reluctant to add this cost to the price of the building without a proven return on their investment. They might, however, be willing to contract all of the communications out to communications companies who could bear the up front costs in return for long term management contracts.

Chapter 7 Conclusions

This thesis has examined the present characteristics of communications in office buildings. Historic and present levels of usage of various communications devices as well as current technological developments and future uses were projected over the next decade. Five characteristics were considered:

- 1. the level of traffic**
- 2. the use of broadband communications**
- 3. the use of wireless communications**
- 4. the use of PCN's**
- 5. the potential for in-building network integration.**

The first characteristic, the level of traffic generated by specific devices in office buildings, was summarized in section 3.7. This type of traffic is typically bimodal with a morning and afternoon peak. Based on current trends, groups of terminals can be modeled at speeds of 9.6 Kbits/s using Poisson arrival times with exponential message lengths of 1-2 Kbits on average. The level of traffic depends on the experience of the user in that professional typists generally have 34% higher character input rates than casual users and 60% of the time the professionals achieved speeds in excess of 75 words per minute with short instantaneous peaks up to 600 words per minute. The trend towards distributed computing has stopped the growth of central processing time sharing systems.

Personal computer workstations are presently able to transmit at around 200 Kbits/s however the more powerful workstations can achieve transfer rates up to 2.2 Mbits/s. These rates may increase to 500 kbits/s and 10 Mbits/s respectively within five years. Distributed processing has resulted in the growth in the number of workstations in the office such that there is typically one workstation per employee. The traffic generated by a workstation is dependent not only on the experience of the user but the characteristics of the hardware and the software applications being used. Table 20 summarized the traffic that could be expected from workstations based on the various types of users and applications presently installed. Message traffic typically consists of the transfer of a complete file although central database servers are often accessed one record at a time. File sizes vary greatly from 2.8 Kbits for electronic mail to 1.15 Mbits for application software files and up to several megabytes for CAD graphics and printer files (this thesis sent a postscript printer file of more than 16 Mbits to the network laser printer). Significantly heavier network traffic can be expected from systems that use software servers, diskless workstations or file servers for applications such as CAD.

Personal computer networks are often set up with the software programs located on a network software server rather than on each PC. In this case each time a program is started (estimated at between 4-10 times per workstation, per hour), an average of 1.15 Mbits is transferred to the PC with the result that 100 workstations could theoretically saturate (30% loading) a 10 Mbits/s Ethernet LAN. Software servers therefore represent a heavy consistent loading on their networks.

Although the average CAD file may be only 1.2 Mbits, they grow rapidly with the complexity of the application and files ten times that size are not uncommon. In addition, the average CAD printer file is ten times the size of text printer files. On the other hand CAD workstations may represent less than 5% of the average office workstation inventory and the average access rate may be only 4 files per hour per workstation. Computer Aided Design therefore can normally be treated as average network loading with less frequent but larger files, however it is quite possible in an organization specializing in CAD work for it to present very significant bursty, loads on the network. On average, overall workstation traffic is expected to experience an annual growth of 20-25%.

Telephone traffic is experiencing annual growth rates of 4-9% and will continue to require transfer rates of 64 Kbits/s for the foreseeable future. The average installation contains 5-10 times the number of devices than can be active simultaneously. The maximum station-to-station delay tolerable is 100-200 ms which also means that the in-building network must not add more than a 20 ms delay to calls outside the building. Telephone traffic may be modeled as a Poisson arrival process with exponentially distributed holding times averaging 3 minutes.

Facsimile traffic growth is 25-30% annually with new systems capable of receiving multiple calls simultaneously and of connecting as a fax server to the local area networks. The average document consists of 4 pages which takes about 176 seconds to transmit at the present 9.6 kbits/s G3 standard. Some machines are now capable of communicating at 14.4 kbits/s and if the transmission quality increases over the next 5 years to include grey scales and colour, the message size will increase 4-15 times

which might require a speed increase to 64 kbits/s or higher to maintain acceptable transmission times.

The traffic generated by building service devices is relatively small compared to tenant service systems with messages averaging 100 bits and inter-arrival times in the order of 30 seconds. The fact that there are, on average 3.5 times as many building service devices and that they are spread throughout the building, needs to be considered when planning the number of connections in the physical network. Since the average message is only 100 bits, and the inter-arrival times are in the order of 30 seconds with a lower requirement for response time, the traffic generated by Building Services is significantly lower than Tenant Services. The case study of traffic on one floor of an office building identified only 36 kbits/s of Building Service traffic out of a total traffic of 1,219 kbits/s (although there were no security cameras on that floor). Indications are that these systems will begin to use common networks in the next five years and the nature of their traffic is such that integration with the tenant service networks is possible without changing the speed requirements of those networks. Projects to improve building service systems may result in an annual growth of 10-20% over the next five years.

From the foregoing, it is concluded that the level of traffic characteristic will reach a state of Level III which corresponds to data device speeds from 500 Kbits/s-10 Mbits/s with a 25% growth in the overall traffic and continuous traffic device growth of 4-9% using speeds of 64 kbits/s. This growth will double the present workstation traffic every 3 years and double the continuous message traffic every 7.2 years. In terms of the average traffic generated per square foot of office space, the chapter 4

case studies projected this to rise some 4,183% from 103 bits/s per sq. ft. to 4.4 kbits/s per sq. ft.

The second characteristic under consideration is the possible use of broadband (video and audio) communications. Applications include pure video uses such as TV broadcasts, picturephones, video conferencing, imaging and closed circuit TV as well as integrated applications such as multimedia. There is presently very little utilization of broadband communications in office buildings (except for security video) however indications are that this could change dramatically. The projections concerning multimedia and HDTV technological developments have been fairly well documented however there is little information about the final applications of the technology nor about their possible penetration in offices. Consequently estimates of the level of future use are very tentative.

Standard broadcast signals operate at 1.544 Mbits/s while specialized lower quality, freeze frame rates are available as low as 64 Kbits/s. These lower rates are used in the new desktop video conferencing systems and security systems to enable communications over standard voice grade telephone lines. Full broadcast quality pictures however will require the 1.544 Mbits/s at least and HDTV technology requires an average of 22 Mbits/s. The compression techniques used to reduce the raw HDTV signal from about 1200 Mbits/s result in speeds that vary with the contents of the signal by transmitting only the changes from one image to the next. This may be significant when considering network protocols such as ATM which need not be transmitted at a constant bit rate.

The storage requirements for desktop, broadcast and HDTV video signals are 480 Kbytes, 11.5 Mbytes and 165 Mbytes per minute respectively. Present storage devices with 600 Mbyte capacity and 1 Mbyte/s transfer rates are insufficient for production of video applications however new technologies such as high capacity read-write optical disks, disk arrays and solid state memory are under development to address this problem. It is expected that these new technologies are five years away from release as production systems.

Over \$2.5 billion was spent on HDTV development up to 1991 and virtually all consumer electronics firms are continuing their development efforts. As a result, production HDTV will likely become available in North America by 1996 and the majority of TV sets may be replaced by the year 2008 when the present broadcast systems begin to be phased out. Of the six systems under test at the U.S. Advanced Television Testing Centre in Virginia and at the Advanced Television Evaluation Laboratory in Kanata, four use digital processing formats with transmission rates of 19.43-24.39 Mbits/s. These low rates are necessary to meet the FCC directive that the HDTV signals must fit into the existing 6 KHz wide TV channels.

Video usage in office buildings is presently limited to security systems, some video conferencing and a small number of video telephones. Most of these applications have freeze frame, stop motion or low picture quality characteristics due primarily to the lack of low cost, high speed broadband communications. The availability of a better quality product with the introduction of higher speed broadband networks for other purposes may result in a growth rate of 10-20% annually for these applications.

Although broadcast TV is primarily a residential service, new applications that may result in greater use of video in the office include multimedia, video on demand and special imaging systems. Of these, multimedia has the potential for the greatest impact due to its wide range of applications including electronic mail, real-time conferencing, cooperative design and multimedia documents of all types including training courses. Its ultimate benefit is the use of several media including text, voice, audio, images and video, to convey the information. A workstation may be used to display text in one window with a voice narrative describing the information as it relates to a still image or a video clip in another window.

Prototype multimedia hardware systems exist today although the technology issues described previously that are associated with the storage, communication and display of the large data files required by audio, imaging and video systems similarly limit the present systems. Other multimedia specific problems being addressed include synchronization of the various different signals into one cohesive view since they are all stored and transmitted separately and the operational problems associated with allowing the viewer to move about a document. Chapter 3 described in detail the structure of multimedia documents and some of the problems associated with their use. Chapter 4 modeled the effects of their use in the office of the future by considering two cases, the downloading model where a multimedia file is transferred to the workstation before viewing and the direct view model where the document remains on a central file server and is sent to the workstation's screen on demand. The models are based on a theoretical single chapter of document model consisting of 20 text pages, 2 minutes of voice, 4 minutes of audio, 5 bit mapped images and 2 minutes of broadcast video for a combined file size of 368.2 Mbits. If HDTV were used the

file size would be 2.8 Gbits. The downloading model required a transfer rate of 6.98 Mbits/s to transfer the file in 5 seconds. It was estimated that this would be the longest that an average user might be willing to wait in a production environment. The model also estimated that a 12 workstation cluster, given reasonable levels of usage, would require a combined transfer rate of 21.2 Mbits/s.

The direct view model calculated that the maximum traffic to the multimedia workstation would be the sum of the video, voice and the highest of the text, image and audio rates on the assumption that the video and voice would be continuous throughout the session. It was calculated that each workstation would require a transfer rate of 2.3 Mbits/s and the same 12 workstation cluster, again under reasonable usage conditions, would require a rate of 14.1 Mbits/s. Production multimedia systems may begin to appear in office buildings in five years and could represent 30-40% of the office workstations within 10 years.

Video on demand applications would allow a user to remotely select a program and start, stop, forward or rewind the program on demand. For the residential customer, the system would provide the equivalent of access to a video tape rental store without leaving home. There may be applications for this service in the business environment for training purposes and the re-broadcast from an internal or external library of seminars and presentations. Although there is some uncertainty on the part of manufacturers, who recall the failure of video text, about the profitability of video on demand, it is projected to be available commercially by the year 2000 and therefore may pose a broadband load on office buildings in the future.

The process of digitizing complex images to permit their storage, transmission and viewing on digital computer systems is becoming increasingly desirable, however again the technology limits the ability of production systems to store and transmit these images to the satisfaction of the users. A single X-Ray produced a 48 Mbit file which cannot be transmitted at full resolution over the standard 10 Mbit/s shared networks unless the network is dedicated to a very limited number of workstations. The high quality of HDTV systems may make their use in imaging systems particularly attractive, if the quality of the scanned images can also be improved. This would dramatically increase the size of the files and the requirement for transmission speed however it is not expected to occur in production systems within the 10 year period of this study.

The second characteristic, the use of broadband communications, therefore is expected to achieve a state of 30-40% multimedia usage, some use of high quality images and limited use of HDTV. Video conferencing and video on demand will also play a role.

The third and fourth characteristics, the use of wireless communications and the use of Personal Communications Networks (PCN's) were examined in Chapter 5. Cordless telephones (CT-2Plus) and PCN's represent the most significant driving forces towards the use of wireless communications in office buildings. In addition, their infrastructure and technologies present opportunities for using wireless connections for many of the other devices in buildings, not only for connection to the external telephone network but for in-building voice, video and data communications as well.

CT-2 Plus wireless telephones will be licensed for sale by the end of 1992 with predictions of 5 million users by 1997, while PCN technologies and standards are still at the research stage. The United Kingdom, Europe, Japan, the U.S. and Canada either have already or are now considering setting aside frequencies between 1.7 and 2 GHz for this service and a number of companies are researching the technologies in this band. Other research, including work being done at Carleton University as part of a CITR project, is examining the possible use of millimeter wavelengths in the 20-60 GHz band.

PCN's consist of an RF link from the device to the antenna which could connect directly to external telephone lines, to the building's PBX or of the building's LAN. The bandwidth, frequency used and propagation characteristics of the signal determine the size of any one cell. A single floor of an office building may therefore consist of a number of cells and each cell may service more than one office using a series of antenna.

Present PCN systems operate at speeds up to 15 Mbits/s which would be sufficient for telephone only use as demonstrated by the telemarketing model which predicted traffic of 1.536 Mbits/s from 24 telephones used continuously. It would also carry the 3.9 Mbits/s traffic of the computer room model if multimedia is not used. A very limited number of multimedia workstations which may require 2.3-7 Mbits/s each could be accommodated but the full multimedia models which require between 14.1 and 21.1 Mbits/s could not be completely served from one PCN cell. The foregoing assumes that the video component of the multimedia signal is either stop motion at 64

Kbits/s or broadcast quality at 1.544 Mbits/s. With an average transfer rate of 22 Mbits/s, the HDTV signal could not be carried over the present PCN systems.

Wireless communications systems are now available for computer networks, operating at speeds between 230 Kbits/s and 15 Mbits/s either in the 902-928 MHz band or at 18 GHz. The per workstation capital cost of a wireless connection is presently higher than the cost of wired system connections, however the portability factor avoids the \$300-1000 rewiring cost which can be significant given the average office move churn rate of 30%. At present, only specialized applications use wireless connections however the proliferation of battery operated portable computers presents an ideal market for manufacturers to take advantage of and may eventually represent as much as 20% of the workstations in an office.

Personal Communications Networks (PCNs) are expected to be in common use within 10 years with estimates of 450 million subscribers by the year 2010 which may represent 20% of the office building telephones.

CT-2 Plus and PCN modules may be used in portable computers, notebook computers and facsimile machines, particularly with the development by Apple Computers of a data PCS. Since personal communications networks will require the common installation of antenna systems in all buildings, this will make its use for other in-building devices particularly attractive.

It can be concluded from the above that wireless systems (characteristic 3) will be implemented for about 20% of the devices in office buildings within the next 10

years. Its growth at that time, with PCN systems in their infancy is expected to be high. For the fourth characteristic, PCN systems, it is concluded therefore that they will be implemented and that they could be used for both voice and data transfer.

The first four characteristics define the level and characteristics of the traffic expected in office buildings while the fifth investigated the potential for supporting all of their communications on one integrated in-building network. It was estimated that such an integration would simplify the installation and reduce the initial and ongoing costs by as much as 35%.

Although a proper evaluation would require a full building network modeling and simulation program (BNSP), the overall requirements of an integrated building network (IBN) were estimated based on the model calculations in chapters 4 and 6. The physical layer of any IBN will likely be a hybrid system utilizing high speed media such as fiber optic cable for heavy traffic areas such as the building backbone or broadband devices such as HDTV, and twisted pair for lower speed devices such as building service devices. In addition, wireless communications may be used for many of the device drops. Another consideration is that studies show that 50% of the distribution of office automation traffic is within the department and 75% within 600 feet. An efficient IBN should therefore isolate traffic as much as possible through the use of bridges although the potential for this is very dependent on the location of the tenant service devices. Isolation however requires either that a BNSP be used during the network design for each building or that customization be performed based on the network traffic monitors once the system is in use.

Not all of a network's raw bandwidth is available for use since the transport protocols themselves require between 4.5% (Sonet) and 20% (FDDI-II). The capacity of networks using CSMA/CD protocols such as Ethernet also degrades with the number of active messages due to their collision detection schemes. A single user may have access to 80-90% of the available 10 Mbit/s Ethernet bandwidth however the network may saturate at 30-35% capacity when a large number of devices attempt to broadcast simultaneously.

Integration studies, simulations and tests have shown the feasibility of voice/data integration of telephone and computer terminal traffic on network LAN's with a capacity of 2694 telephones at 20 ms delays and a 20% data component over a 100 Mbit/s Expressnet LAN. These studies illustrate that the two types of communications can co-exist however they do not reflect the higher levels of data traffic predicted by the models in chapter 4 and again a full study using a BNSP would be required to properly estimate the requirements for integrated voice, data and video communications.

Any network used to integrate this diverse range of devices and applications must take into consideration the different traffic characteristics such as the low delays required by voice (< 200 ms), video and high quality audio, the low error rates required by data and safety systems, the continuous nature of telephone, facsimile, voice and audio and the burstiness of data.

Another characteristic to be considered is the wide range of device speeds from as low as 1.2 Kbits/s for terminals and sensors up to an average of 22 Mbits/s for HDTV.

Also that some devices such as HDTV do not broadcast continuously at the same rate since the compression algorithms are based on the signal contents. The asynchronous transfer mode (ATM) B-ISDN standard could address the variable bit rate requirements of such devices.

A typical IBN is composed of three parts, the backbone, the floor branches and the device drops and the capacity requirements are different for each. Device drops need only carry the traffic for the specific device however the branch, in a star topology, must be designed to carry the highest traffic device. As mentioned previously, it is possible to isolate traffic to certain areas of a floor or building so the backbone may not be required to carry all of the traffic from the devices on all floors.

Figure 11 illustrates a fully integrated in-building network (IBN) and some of the services it could support. Chapter 3 and 4 identified the device speeds to be no more than 22.768 Mbits/s for HDTV multimedia workstations and no more than 7 Mbits/s without HDTV. It was also estimated that branch speeds of 25 Mbits/s would be sufficient if HDTV were not used and that the combined traffic for one floor of the 33,700 sq. ft. case study office floor could be about 148 Mbits/s. If half of any floor's traffic can be isolated on that floor and 25% of the inter-floor traffic can be isolated within a few floors, the backbone of this 23 story office building would need to carry about 1,300 Mbits/s.

Figure 11: Integrated In-building Network

Although this thesis has not examined network developments in detail, there are two that appear to offer the greatest potential for use as the IBN. The Sonet system using synchronous transfer mode is available today with speeds up to 2.488 Gbits/s. The B-ISDN ATM standard set by the CCITT, although not available today, will support a wide range of speeds at variable rates, up to 135 Mbits/s.

It can be concluded therefore that the potential for in-building network integration, the fifth characteristic, exists and could achieve the state of full integration within 10 years.

7.1 Recommendations for Future Work

As mentioned previously, a building network modeling and simulation program (BNSP) would provide a more comprehensive and accurate method for evaluating the communications requirements of a specific office. This would require the development of a demand model consisting of technology models for each communication generating device, and models for the various different types of users. Supply models also would need to be developed to represent the ability of the various networks to meet the communications demand. The resulting BNSP would be very useful in determining the best network for a particular demand model or organization and would therefore be instructive to network manufacturers as well as installation managers.

This thesis looked at the electronic communications requirements of office buildings at present and in the future. While the BNSP would be useful in describing the

present conditions or the requirements under any other technological steady state conditions, projection of these requirements into the future requires that the development and acceptance of the technologies be similarly projected into the future. It is possible to construct a short range model of the evolving communication requirements of specific, accepted technologies based upon the known developments in research and an evaluation of societies' perceived needs (as was done empirically in this thesis). Forecasting beyond 5-10 years at most however is very much more difficult since the success of a technology is as dependent on the economic, social and cultural realities of the society as on scientific and technological factors. The latter determine if a development is possible, the former determine if it can be commercialized and whether the product will be accepted by the society. As Basalla [71] said, "Any society, at any time, commands more potential for technological innovation than it can ever hope to exploit" and ultimately the selection is made by the society based on its prevailing values and perceived needs.

It is therefore recommended that a BNSP be developed to accurately study the communications requirements of today's buildings and that a short range model representing the evolution of each technology be incorporated. A long range model incorporating the evolution of technologies would be of academic interest to evaluate major directions for society and technology, however it may not be possible to apply these results with any accuracy to specific technologies or needs. As Johnston [72] said, "...there is no inevitability in technical change: neither its pace nor its direction is predetermined...and the success of an innovation is never certain".

Appendix A Building and Tenant Service Systems

A.1 Building Services

This section presents a description of the common installations of each building service.

A.1.1 Heating Ventilating and Air-conditioning

While office buildings may have used dual-duct, induction, or fan-coil systems in the past, more recently variable air-volume (VAV) systems (with reheat) and deluxe self-contained perimeter unit systems have become more common [73]. Generally there is one thermostat per room which controls a damper and reheat coil in the ceiling plenum. In terms of the air handling equipment, each floor may be divided into two zones, an exterior and an interior one. Each zone therefore may be made up of several rooms. The HVAC System may also control special area exhaust ventilators and provide washroom ventilation.

- **Components and their communications requirements:**
 - **Thermostat (sensor and control):** good application for wireless might use multiple sensors in large rooms with segmented HVAC systems.
 - **Humidity and other air quality sensors including dangerous gas sensors (CO, Radon)** have simple low traffic but high reliability communications needs.
 - **Fans, Chillers and other fixed plant equipment installed outside the tenant access areas** will likely not benefit from wireless communications as they do not change location often, are not accessible by users and are often located in areas of high Electro Magnetic Interference (EMI).

A.1.2 Security (Access and detection)

There are two categories of security systems, access systems to control entry and detection systems to detect access violations. Electronic access systems utilize a central controller with remote readers which may be a numeric pad, a magnetic card or a proximity card. These systems are unmanned.

Detection systems also consist of a manned central controller and monitor with remote motion, door and window sensors. A video camera system may also be implemented on the ground floor and in high security areas. The video systems are usually stop motion black and white displays to reduce the communications load. A full motion, colour system that could be provided at a competitive cost would be accepted very quickly and would greatly increase the communications requirements.

A.1.3 Lighting

Central lighting controllers are commonly used to switch off all lights in the building on a schedule. Occupancy sensors are beginning to be used to turn lights on and off automatically in individual offices and storage areas. Light level sensors are also being used to compensate for the amount of daylight that enters a room and may switch off lights near the windows.

A.1.4 Fire Safety

Fire systems are omitted as integration with a common wiring system is not permitted by code in Canada.

A.1.5 People Movers

People movers include elevators, escalators, moving walkways and automatic doors. Escalators and moving walkways may require remote communications so they can be turned on and off remotely based upon a schedule. Automatic doors may be connected to the security system as well as their local motion sensors.

Elevators require the highest level of remote communications with 2 call buttons per car per floor and a full panel of call buttons in each car. There is usually a display of the car's position at the ground floor and possibly at the security station. Each car also carries an emergency telephone. Most of the communications is carried over cables that travel down the shaft from the elevator controller at the top. Sophisticated controllers use sensors and predictive algorithms to optimize the traffic flows.

There is a possible opportunity to utilize wireless personnel sensors developed for security to determine the presence or size of a group waiting for elevators, exactly as traffic lights use sensors imbedded in the road to determine when to change the signal and how long to keep it green. Elevator response strategies do attempt to optimize traffic flows but are presently based upon the number and frequency of calls on the button plus time of day scheduling.

A.1.6 Water Control System

The potable water control system maintains water pressure in tall buildings using booster pumps and circulates the hot water continuously throughout the building to provide instant hot water in any washroom. It also controls separate boilers for the potable hot water and monitors areas for water leaks.

A.1.7 Energy Management System

Energy management systems may be separate control systems that link to the HVAC, lighting, power, people mover and water systems or they may be strategies built into each service. There is increasing activity in the building service industry to achieve greater energy and operational efficiencies in the supply of each service.

A.2 Tenant Services

There are opportunities for wireless communications for virtually all tenant service devices as the ability to locate and re-locate them to the satisfaction of the tenants would be a very useful feature. Even though most still require electrical power which has less flexibility than wireless systems, 110 volt power is much more widely distributed than the average communications network. In addition there is a trend in many tenant services towards battery operated devices (portable computers).

A.2.1 Voice Communications

- telephones, teleconferencing
- voice messaging
- multiple PBX's
- intercoms

The progressive increase in size of typical PBX's is shown in table 30.

Annual Req	1987	1988	1989	1990	1991
Ports	200	660	1305	1805	1955
Trunks	10	20	25	30	30

Table 31: PBX System size [74]

This illustrates the increased use of private building telephone networks over individual circuit switched lines to the local telecommunications supplier's office.

A.2.2 Data Communications

Digital communication is required to support the following devices:

- facsimile machines
- personal computers, CAD systems, minicomputers
- central computers
- data collection equipment
- computer networks - multiple LANS (up to 10 M bps) and access to WANS
- video conferencing
- handicap communications and control
 - User interface makes it possible to operate building controls from a wheel chair.

A.2.3 Video Communications

These broadband devices include:

- multimedia workstations video conference TV's
- videotape distribution
- cable TV distribution

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