FINAL REPORT

The Application of Fiber Optic Technology To The Access Network Evolution

PREPARED FOR: Department of Communications
300 Slater Street
Ottawa, Ontario
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DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

INFORMATION TECHNOLOGY AND SYSTEMS RESEARCH AND DEVELOPMENT

FINAL REPORT

THE APPLICATION OF FIBER OPTIC TECHNOLOGY TO THE ACCESS NETWORK EVOLUTION

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SUMMARY

The objective of this study is primarily to examine the feasibility of developing fiber optic access systems to provide existing and new telecommunications services. The study is limited to the analysis of the urban access network since it is anticipated, that the introduction of new services in urban centres will be much more rapid than in the non-urban/rural areas. Also, the economies of scale for the introduction of new technology can be realized in the urban areas due to the larger population growth. Urban areas are defined as towns and cities with a population of 20,000 or more. This covers almost 70% of the Canadian population.

The study provides a forecast for the period 1983 to 1992 in three segments:

i) Short term 1983 - 1985
ii) Meduium term 1986 - 1989
iii) Long term 1990 - 1992

For the purpose of forecasting service demand and determining access system requirements three groups of subscribers are considered:

i) Residential
ii) Small Business
iii) Large Business

Historically, narrow-band (voice and data) and wide-band (cable-TV) services evolved on separate carriage networks and were provided by usually different business entities. With the emergence of fiber optics, it becomes now technically possible to provide all services in an integrated way on a single carriage network. Therefore, for comparison purposes two access system evolution scenarios are considered:

i) Separate carriage systems for:

a) Voice, data and other than cable-TV and pay-TV wide-band services

b) Cable-TV and pay-TV services

Included in the data services could be ordering and usage measurement data for pay-TV services

ii) One integrated service carriage system for: voice, data and wide-band services including cable-TV and pay-TV.

The study shows, that the service requirements for residential and small business subscribers for voice and data services can be met by similar access systems at the same cost, and can therefore, be considered to be a single case from a network provisioning point of view. Large business subscribers service demands however require a different approach both in technology as well as in time and are therefore considered separately.

An extensive analysis of existing and new services evolution (Appendix F) for all three subscriber categories reveals, that in the near term telemetry and data services will gradually emerge for residential and small business subscribers and that this demand will accelerate in the medium and long term. Cable-TV and pay-TV will still be the predominant video services in the near and medium term. Services such as on-demand video and High Definition Television (HDTV) are expected to emerge only in the long term.

For large businesses there is a short term need for integrated voice and data systems. Access system to be developed in the short term will have the flexibility to also meet the diverse service requirements in the medium and long term.

Residential and Small Business Subscribers

From the service requirements, the cost of various technologies including twisted copper pairs, coaxial cable, fibre optics, digital switching and transmission, following access system evolution is expected:

i) Short term

Telemetry and data service can be cost effectively provided through "applique" systems over the existing copper pair plant. Cable-TV and pay-TV services will be provided over a separate coaxial cable network.

ii) Medium term

With the anticipated accelerated pace of digital switching modernization of the telecommunication network, a centrally switched star network topology with remote multiplexers will evolve to provide voice and data services. Remote multiplexers will be connected to the switching office via fibre optic feeders. Subscribers will still be connected to the remote multiplexers by copper pair plant. Cable-TV and pay-tV will continue to be provided via a coaxial cable network.

iii) Long term

With the demand for other than cable-TV and pay-TV video services, integration of voice, data and video will start to become attractive particularly with a longer term future view. However, for the time frame considered it will still be less costly from a capital expenditure point of view to provide video services over coaxial cable facilities. For any two way video services two separate coaxial cable facilities, one for upstream the other for downstream signals, at a total cost of $240 per subscriber may be considered. Regular cable-TV and pay-TV services would remain an a third separate coaxial cable system. Voice and data services would be provided with a system similar to the one considered for the medium term.

A summary of system cost for different time frames and subscriber distances from the switching centre (S.C.) are summarized in Table 1.

TABLE 1: SYSTEM COST PER SUBSCRIBER (1983$)

TECHNOLOGY ALTERNATIVES	DISTANCE FROM THE S.C. (km)			
	1.35	2.75	3.75	5.35
SHORT TERM (1983-1985)				
Paired Copper				
Telephony	$410	510	570	800
Telephony + Alarm	$740	840	900	1130
Telephony + Alarm + Low Speed Data	$940	1040	1100	1330
Coaxial Cable Tree Network Configuration Average cost per subscriber for CATV	$120			
MEDIUM TERM (1986-1988)				
Fiber Remote electronics, Fiber feeder and Digital copper distribution Integrated voice and data service	$480	580	610	620
LONG TERM (1989-1992)				
Fiber in the feeder and distribution Integrated services				
Option - A Voice, Data and non-CATV video	$1150	1350	1350	1370
Option - B Voice, Data CATV and non-CATV video	$1990	2190	2210	2240

Large Business Subscribers

Large business subscribers needs for integrated voice and data communications can most economically be provided through fibre optic digital trunks with flexible bandwidths (both transparent and multiple access systems) to connect subscriber premises located peripherals to the public and private networks. Costs obviously will vary depending on the required transmission bit rate and bandwidth. DS-1 rate (1,544 Mb/s) fibre optic transmission system cost estimates are summarized in Table 2.

TABLE 2: COST PER DS-1 LINE (1983$)

	DISTANCE FROM THE S.C. (km)				
	1	2	3	6	10
DS-1	$2800	3300	3900	5600	7900

In this study the fiber and associated hardware costs were projected based upon today's manufacturing volumes and processes. They are BNR estimates and do not imply the commitment of any particular manufacturer. It has also been assumed, that new services demand or other factors will not result in increased production volumes or drive research to achieve new processes which would result in lower cost products.

It should also be noted that the cost comparison presented in this study is only based on capital costs, and does not take into account ongoing operating costs such as maintenance. Since the optical fiber system design does not require field repeaters in the outside plant and can offer built-in maintenance and diagnostic features, it is expected that the operating cost will be less than for the cooper-based approach. If such costs are taken into account through a Present Worth of Annual Charges (PWAC) study, the comparison could be more favourable for fiber than indicated by Table 1, where only capital costs have been considered.

In summary, with the assumptions made in this study, for the time frame 1983 - 1992 following subscriber access network evolution and use of fiber optics technology in this plant can be expected:

i) For economic reasons, a fully integrated subscriber access network based on fiber optic technology to carry all voice, data and video services will not emerge.

ii) Optical fiber feeders will be used to connect digital switching centres to remote subscriber multiplex units. Residential and small business subscribers will remain to be connected to such multiplexers by copper pairs for voice and data services.

iii) Video services can most economically be carried by separate coaxial cable networks.

iv) Digital fiber optic trunks will be used to connect large business subscribers peripheral equipment to the private and public communications networks.

The main obstacles for a larger use of fibre optics in the subscriber access network and in particular the integration of video services with voice and data are:

i) High cost of fiber distribution cables

ii) High cost of video switches

A major commitment to introduce a fully integrated fiber optic subscriber plant on a large scale would be required to accelerate research for new processes and technologies that can achieve the desired cost reduction.

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ABBREVIATIONS

ADPCM	Adaptive Differential Pulse Code Modulation
AP	Adaptive Prediction
APD	Avalanche Photo Diode
CCITT	Consultative Committee for International Telephone and Telegraph
CO	Central Office
CVSD	Continuous Variable Slope Modulation
DAV	Data Above Voice
DBS	Direct Broadcast Satellite
EFT	Electronics Funds Transfer
GI	Graded Index
HDLC	High Level Data Link Control
HDTV	High Definition Television
ISDN	Integrated Services Digital Network
ISO	International Standards Organisation
LAN	Local Area Network
LAP	Link Access Protocol
LBRV	Low Bit Rate Voice
MCVD	Modified Chemical Vapor Deposition
NIC	Near Instantaneous Companding
ODV	On-Demand Video
OSI	Open System Interconnect
PCM	Pulse Code Modulation
SC	Switching Center
TCM	Time Compression Multiplexing
VAD	Vapor Axial Deposition

VCR	Video Casette Recorder
VMS	Voice Messaging Service
WDD	Wavelength Division Duplexing
WDM	Wavelength Division Multiplexing

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1.0 INTRODUCTION

A systems study was performed for the Department of Communications to examine the application of fiber optic technology in the access network to provide existing and new telecommunications services. Many new services other than basic telephony are contemplated, and capability to cost-effectively handle these services is a current driving force for network evolution. There is a basic need to understand the nature of the new services and their requirements and to assess the technology trends to develop appropriate network architectures, cost-effective system designs and standards. The study analyzed the technology alternatives, service integration prospects, system design options and market demand. It identified probable evolution scenarios. BNR projections of costs to implement the systems were developed. The results are summarized in this report, and will be beneficial to the DOC in formulating policies and fostering an environment which will help expedite the introduction of new telecommunications services and systems throughout Canada.

1.1 OBJECTIVES

The objectives of this study are to:

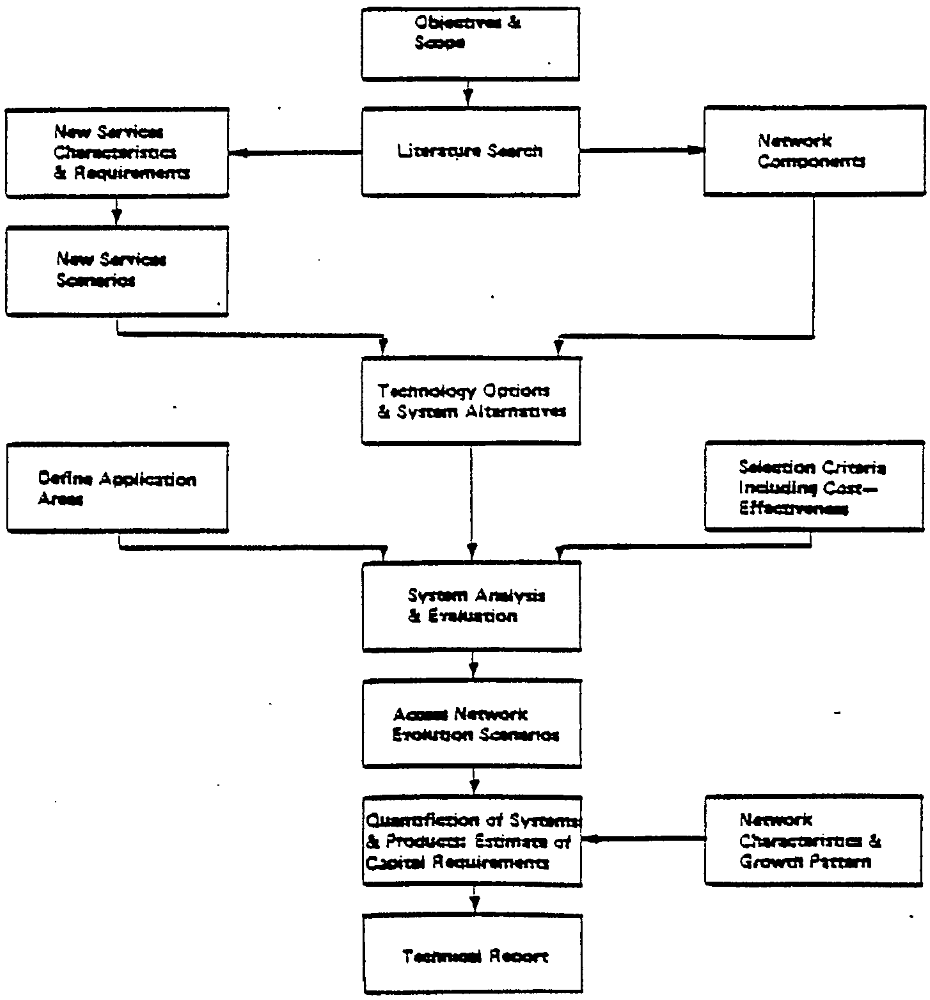
- Characterize existing and future telecommunications services.
- Consider two distinct levels of service integration
  - (a) Partial integration excluding CATV and Pay-TV, but including any new video services,
  - (b) Total services integration, including CATV and Pay-TV delivery
- Develop fiber based integrated services access system alternatives.
- Postulate evolution strategy and rationale.
- Project an average fiber optic access network cost per customer.
- Estimate the required capital at the aggregate macro-economic level to implement fiber optic access systems in Canadian urban centers.
- Identify key areas which require further technological development.

1.2 STUDY APPROACH AND SCOPE

The access network is part of the total telecommunications network, and consists of three major components: switch interface, feeder and distribution network (outside plant), and the customer interface. The definition does not include the switched network, interexchange trunking and customer terminals. The commonality of the definition has been maintained throughout the study, and in the comparison of access system alternatives.

The study approach is illustrated in Figure 1.1 in the form of a flow diagram.

FIGURE 1.1: FRAMEWORK FOR ACCESS NETWORK EVOLUTION STUDY



Future communication services were characterized in terms of penetration, usage, bandwidth, terminal and network resource requirements based on the analysis of residential and small/medium and large business market trends. A comprehensive report (TR 82-0060 "Future Communication Services: Analysis of Requirements") was issued to the DOC in November, 1982. The results of the characterization and a 10-year services scenario are presented in Section 3.

The impact of the services on access network design was assessed. Network technology alternatives to provide existing and new services are discussed in Section 4. Specific evolution alternatives are discussed in Section 5, based on the best technology match with the specified services. Cost projections for the various system alternatives are included in Section 6, including Canada-wide access cost projections over the period 1983-1992. Discussion on the results of the study, with recommendations for future research, are presented in Section 7.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Residential:

Short Term (1983 - 1985):

The existing paired copper network will continue to provide voice and voiceband data services. As the identified demand for telemetry type services is low, an applique system such as data above voice over paired copper facilities would be cost-effective. CATV and Pay-TV services will be provided by a parallel coaxial cable network.

Medium Term (1986 - 1989):

As data service penetration increases and as digital switching penetrates the network in greater volume, integrated voice and data digital access systems are likely to be introduced. Such systems offer the flexibility of moving towards the internationally accepted Integrated Services Digital Network (ISDN) concept. A switched star topology is recommended. Fiber optics will be an attractive technology for the digital feeder link to interconnect the distributed switching units with the switching centers. Paired copper will be adequate for distribution purposes. The coaxial cable network will continue to carry video services.

Long Term (1990 - 1992):

As new video services (e.g. on-demand video and HDTV) become popular, an integrated services centrally switched star system based on fiber optic technology appears to be the logical step in the access network evolution. The major components influencing the total system cost are the video switch and fiber distribution links. There is a large amount of copper in the field today, and further cost reductions are required for fiber optic systems if they are to compete with existing technology systems, particularly in areas already served by paired copper and coaxial cable systems. Following are additional observations on the long term system service/technology issues:

- Further exploratory research is required to develop low cost components for an integrated services fiber optic access system. Such a system offers the flexibility to add additional services , and the overall maintainability, availability and performance of fiber based systems are superior to the existing systems.

- Video switch research is in an evolutionary stage. Current research activities show the feasibility of building small size switches. Active research in this area should be pursued to develop more cost effective, high performance large size arrays to satisfy various service provisioning requirements.

- The cost breakdown of the integrated fiber system indicates that the fiber distribution cost is a major component of the total system cost. Work toward fiber cable cost reduction should continue.

- The fundamental bottleneck to providing high quality video, such as HDTV, is the bandwidth requirement and terminal cost for HDTV delivery. Digital techniques may be appropriate for bandwidth reduction, but are too expensive with todays video signal processing costs. Therefore, video codec research should continue, as the digital video format provides enhanced picture quality and is well suited to transmission over fiber.

- The service penetrations for future communications services are projected on the basis of existing consumer trends. In order for these demands to materialize, operating companies may have to be prepared to invest on new technology with a relatively long payback period to provide low cost services. This is characteristic of the 'chicken-and-egg' problem that occurs when the attractiveness of a service to the consumer is largely a function of the cost of the service. While this study has not included terminal costs for the associated services, there is no doubt that these will play a large role in determining service demand.

Business:

Short Term (1983 - 1985):

Increased communications services requiring high speed data transmission systems are foreseen. Large and medium size business demands may accelerate the introduction of integrated voice/data digital access systems. There will be an increasing deployment of fiber for interconnecting business premises located peripherals and exchanges to the public switched network and for private network applications. The communications requirements in the short term will probably not exceed the DS-1 rate (1.544 Mb/s) .

Medium and Long Term (1986 - 1992):

DS-1 rate access will be available to the customers premises in the medium to long terms. Three basic wideband access channel structures are proposed: transparent (sub DS-1 to DS-1), multiplex (nx64 kb/s) and composite multiplex access (a combination of transparent and multiplex). These varied, flexible "pipe" sizes will be able to meet the diverse service demands projected in the medium and long terms. Fiber is clearly suited to this application.

For higher bandwidth requirements (nxDS-1), a number of DS-1 rate fiber links could be assembled initially. If increased demand for this bandwidth materializes, suitable upgrades could be made to the proposed fiber based system for widespread use.

There is a lack of information regarding the locations and numbers of businesses in Canada. In an era of rapidly changing access technology offerings (e.g. microwave radio, fiber optics), there is a definite need to characterize the business network environment in terms of location and number of businesses by size and service demand.

3.0 NEW SERVICES SCENARIOS

A prime objective of the study was to characterize existing and new telecommunications services. This began with a description of the services and the associated network requirements, with the ultimate goal of producing market penetration forecasts for each service for the residential, and small, medium and large business market segments on a Canada wide basis.

In order to achieve this goal, an extensive literature search was conducted in conjunction with discussions with various experts internal and external to BNR. A long list of potential services was generated (Table 3.1). From this list, certain key services which were perceived to have the greatest market potential were selected and examined in detail (Table 3.2).

TABLE 3.1: LIST OF POTENTIAL SERVICES

TELEPHONY	MESSAGING	TELEMETRY	INFORMATION	TELECONFERENCING
	Facsimile	Security/Alarm	Home banking	Audio
	Voice Messaging Service	Energy Management	Database Downloading	Audio-Visual
	Electronic Mail	Auto Meter Reading	Teletex	Computer
			Videotex	Video
			Home Shopping	
			Credit Card Checking	
			Data Communication	
			Charge Display	
			Opinion Polling	
			Teledirectory	
			Diary Service	
			Telecalculations	
			Document Preparation	

ENTERTAINMENT	VIDEO
CATV	Video Archival Retrieval
Pay TV	Video Publishing
On Demand Audio/Video	Video Education Systems
Remote Games	Video Information Retrieval
MATV (Movienet)	Video Surveillance

NOTE: Video services may apply both conventional NTSC and extended definition and/or high definition television (HDTV) imaging.

TABLE 3.2: LIST OF KEY SERVICES

	TIME FRAME:		
	Short Term (1983-85)	Medium Term (1986-88)	Long Term (1989-92)
Residential	• Telephony • Basic CATV • Pay TV • Security / Alarms	• Voice Messaging • Telebanking • Energy Management	• On Demand Video • HDTV • Videotext
Small & Medium Business	• Telephony • Security / Alarms	• Voice Messaging • Energy Management	• On Demand Video • HDTV
Large Business	• Telephony • Voice Messaging • Database Downloading	• Videoconferencing • HDTV	• On Demand Video

3.1 RESIDENTIAL MARKET

The rapidly decreasing cost of microprocessor technology has introduced a potential cost-effective opportunity for residential customers to enjoy enhanced capabilities for communication, and for automated control in the home. This trend, coupled with the increasing consumer costs such as energy and transportation, is seen to be stimulating market demand for new products/services in the home.

In the residential market, the three primary service categories are: communications/information, security/control, video and entertainment. The specific services for application to the residential sector in each category will be highlighted in Section 3.3. These key services are included in Table 3.2.

In addition, the following factors are also driving developments in the residential market:

- increasing importance of leisure and time away from stressful activities,
- growing consumer demand for stay-at-home activities and entertainment,
- increasing awareness and dependence on mass media,
- changing lifestyles including more working women and single-parent households,
- growth in the number of households,
- increasing importance of improved child and adult education.

Each of these factors is affecting lifestyles in a manner which will continue to accelerate the demand for special information/communications, entertainment and convenience services in the home.

3.2 BUSINESS MARKET

In the analysis of the business market, small and larger businesses are treated separately, as their needs differ considerably. For the financial needs of small businesses, service costs must be low, or productivity/revenue increases associated with new services for this user community must be evident. Large businesses are not quite as financially constrained, and are more geared toward the streamlining of office operations and information communications in order to maximize productivity.

For purposes of this analysis, large business will be defined as businesses with sales exceeding one hundred million, medium business with sales ranging from one to one hundred million and small business as those having sales less than one million [Reference, TR 82-0060 "Future Communications Services: Analysis of Requirements", Table C-4 pg. 87]. Unfortunately the statistical data does not permit a clearer definition of small business.

Numerous magazines and reports have emphasized the need for integrated office automation systems, which comprise:

- basic telecommunications
- word processing
- electronic mail
- intelligent copiers
- teleconferencing
- storage, retrieval and filing
- database downloading
- data processing
- file searching

Table 3.2 shows the key services selected for small and large businesses.

3.3 SERVICE PENETRATIONS AND DEFINITIONS

In this section services are defined in terms of application areas and network requirements. Tables 3.3 to 3.5 summarize the penetrations of the various services over time. Service block diagrams and detailed penetration information are included in Appendix A. The short, medium and long terms represent 1983-1985, 1986-1988 and 1989-1992 respectively.

TABLE 3.3: RESIDENTIAL SERVICE PENETRATIONS (%)

SERVICE CATEGORY	KEY SERVICE	1985	1988	1992
TELEPHONY	TELEPHONY	100	100	100
MESSAGING	VOICE MESSAGING	5	20	40
TELEMETRY	SECURITY/ALARMS	1	3	7
	ENERGY MANAGEMENT	0	2	5
INFORMATION	HOME BANKING	0	3	7
ENTERTAINMENT	CATV (% OF HOUSEHOLDS)	67	77	88
	PAY-TV (% OF CATV SUBS)	10	29	51
VIDEO	ON-DEMAND VIDEO	0	0	4
	HIGH DEFINITION TV FOR BROADCAST AND ON-DEMAND VIDEO	0	0	1

TABLE 3.4: SMALL/MEDIUM BUSINESS SERVICE PENETRATIONS (%)

SERVICE CATEGORY	KEY SERVICE	1985	1988	1992
TELEPHONY	TELEPHONY	100	100	100
MESSAGING	VOICE MESSAGING	2	10	50
TELEMETRY	SECURITY/ALARMS	3	41	65
	ENERGY MANAGEMENT	2	10	50
INFORMATION	DATABASE DOWNLOADING	0	0.001	0.05
TELECONFERENCE	AUDIO	13	40	73
	AUDIO VISUAL	0	1	20
VIDEO	ON-DEMAND VIDEO	0	0	4
	HIGH RESOLUTION IMAGE PROCESSING	0	0	10

TABLE 3.5: LARGE BUSINESS SERVICE PENETRATIONS (%)

SERVICE CATEGORY	KEY SERVICE	1985	1988	1992
TELEPHONY	TELEPHONY	100	100	100
MESSAGING	VOICE MESSAGING	14	30	58
INFORMATION	DATABASE DOWNLOADING	25	50	63
TELECONFERENCE	AUDIO	99	99	99
	AUDIO VISUAL	40	75	90
	COMPUTER	10	30	50
	VIDEO	20	50	60
VIDEO	ON-DEMAND VIDEO	0	7	30
	HIGH RESOLUTION IMAGE PROCESSING	0	9	36

• TELEPHONY

The telephone is the most widely used device for home and business voice and information communications. The penetration of telephone service is currently at 98% of Canadian households, and both business and residential telephones have grown at 5% per year in the past. The projected growth of business telephones is 4% per year, while the residential forecast remains at 5%. The telephone has the potential to evolve into a true communications port whose functions might include:

- a message center,
- a personal tracking device (call forward),
- an information access point,
- a bill paying terminal,
- a conference port.

Basic analog voice communications services require approximately 4 kHz of bandwidth. With the anticipated widespread introduction of integrated digital voice/data communications in the near future, various alternatives to 64 kb/s PCM voice encoding are being investigated. CCITT Study Group XVIII has a mandate to converge on low bit rate voice (LBRV) coding standards within the coming years [1]. Adaptive differential PCM (ADPCM) with adaptive quantization and adaptive prediction (ADPCM/AP) offers robust algorithms at 32 kb/s, and is currently a favoured alternative.

• VOICE MESSAGING SERVICE (VMS)

VMS is an asynchronous form of store-and-forward voice communication between two or more parties. A user leaves a message in the system requesting that it be forwarded to another person. Added features of this service could include call-answering, call forwarding and time-specific message forwarding.

The ability to leave a message for any person at any time would obviously have applications and demand in all market segments. Communications cost reductions, convenience and efficiency all contribute to the attractiveness of this service to the consumer.

Basically, the 4 kHz analog voice bandwidth is sufficiant to deliver the message. Various editing and filing features could be provided using < 100 b/s of upstream signalling.

• SECURITY/ALARM SERVICES

A security/alarm service would alert the appropriate authorities in the case of a fire, intrusion or other alarm conditions.

In the residential market a number of factors are contributing to the marketability of this service. These include:

- increasing crime rates
- increasing number of families leaving the residence for long periods of time.

However, the acceptance of this service as being reliable and of value to the consumer is still uncertain. The relative value of the service must also be weighed against the required investment in terminal equipment at the subscribers premises (e.g. smoke sensors).

For the business market, this service is only applicable to the small businesses, as larger establishments tend to have "in-house" security services, due to insurance requirements.

The upstream bandwidth required to transmit the necessary status information to the appropriate status monitoring vendor or authorities would be around 300 b/s.

- ENERGY MANAGEMENT

This service involves the remote control and monitoring of energy consumption. Various levels of service can be implemented, such as remote control of energy consuming devices and off-site meter reading by utility companies. This would also allow for time-of-day pricing.

Currently, numerous trial experiments with this service concept are underway. This will generate valuable information concerning consumer acceptance, equipment and communications with subscriber located equipment. The driving force for this technology is the incentive to decrease energy consumption and costs, which involves the joint interest and participation of the government, utilities and consumers.

This service would be geared toward residential and small business customers. (Many medium and large businesses already maintain their own environmental control systems).

The network requirement for this type of service can be modelled after those of security/alarm services (300 b/s).

- HOME BANKING (Electronic Funds Transfer (EFT))

This residential service involves the application of communications technology to common financial transactions i.e. those typically handled by charge, cheque or cash. Thousands of Canadian consumers are already making extensive use of automatic debit and crediting facilities, including automatic teller machines (ATM).

Various display technologies can be foreseen for this service, ranging from simulated speach verification of a transaction to image display and hard-copy. For voice, 4 kHz will suffice, while for text and graphic information, 1.2 to 4.8 kb/s would be required. Higher resolution image transmission could require up to 64 kb/s. A secure access protocol would be necessary.

- DATABASE DOWNLOADING

This service involves the access to off-site computing facilities. This could be used to update or duplicate records between branches of a company or, for example, to access a remote vendor-owned database. This service has both residential and business applications. The sales of home computers can be used as a guide to the potential residential penetration of such a service.

The network requirements of such a service are the same as home banking.

- TELECONFERENCING

A teleconference is a remote interaction between three or more customers set up either automatically or by an operator.

There are four driving forces for teleconferencing:

1) increased cost of travel
2) decreasing cost of communications
3) growth of service sector, which is highly dependent on communications
4) drive for increasing worker productivity.

Table 3.6 lists the various conferencing alternatives and their network requirements.

There is current interest in digital wideband speech transmission for high quality applications such as teleconferencing. The use of techniques such as Continuous Variable Slope Delta Modulation (CVSD) and Near Instantaneous Companding (NIC) can be used to compress 4.5 - 7 kHz voice into 48,56 or 64 kb/s digital voice channels [1].

AT&T is planning to introduce audio and data bridging capability for up to 60 conference ports in order to provide audiographics teleconference services [2]. Data bridge access is planned for up to 56 kb/s with Switched Digital Capability, and up to 4.8 kb/s with a modem via the DDD network. These units will fit into the Network Services Complex, which will interface with the No. 4 ESS switch to

TABLE 3.6: TELECONFERENCING ALTERNATIVES

	CHARACTERISTICS	NETWORK REQUIREMENTS
AUDIO	Voice Only	4kHz/64kb/s, Audio Bridging
AUDIO VISUAL	Voice & Graphics	1.2 - 4.8 kb/s for graphics, data bridging (up to 64kb/s for higher resolution)
COMPUTER	Electronic Mail; Used (a) synchronously with conference	up to 64kb/s
VIDEO	Voice + Video display (face-to-face and full motion)	1.5 - 3Mb/s for digital 6 MHz for analogue

provide audiographics teleconference services that are transparent to the user.

In addition, the AT&T Picturephone Meeting Service (PMS) will be offered from a number of rental public rooms by the end of 1983 [3,4]. This service will use NEC switchable 3- or 6-Mb/s codecs, but plans are to retrofit or replace them with 1.5 Mb/s or even lower bit rate codecs in the future. The network associated with this two-way service will include a combination of T-1 terrestrial and satellite links. As an example, this service will cost business users $2380 (US) an hour between New York and Los Angeles for the use of conferencing facilities.

There are at least two major companies that manufacture full-motion DS-1 rate (1.544 Mb/s) codecs that cost about $150,000 (U.S.). NEC is manufacturing an interframe codec (NETEC X1), while Compression Labs Inc. (CLI) are selling a codec which employs an intraframe coding algorithm which is incompatible with NEC's. Clearly, there is an immediate need to reconcile the standards issue. (For an overview of coding techniques, see [5])

NEC is reported to be introducing a motion compensated interframe codec early in 1983 [3]. With this technique, picture quality obtained at 6.3 Mb/s can be achieved at 3 Mb/s. Research undertaken at BNR [6] shows that this is probably the most promising bandwidth reduction technique for video conferencing applications.

For applications where one-way video is required (e.g. training, seminars), CLI is producing send only and receive only codecs at about $75,000 U.S. each. In this way, a point-to-multipoint conference with one-way video and two-way audio can be achieved at a reasonable cost.

Small and medium sized businesses will most likely use audioconferencing only. For other types of conferencing needs, they would most likely rent facilities from a vendor, such as telcos.

Large businesses are expected to utilize all forms of conferencing, as they are best able to absorb the high terminal equipment costs and take advantage of the subsequent communications savings.

• CATV and PAY-TV

Today, approximately 65% of homes in Canadian urban centers subscribe to cable. Currently, 35-50 channels are offered to subscribers, and over 100 channels could be made available in the future.

Pay-TV services include flat-rate and pay-per-view formats. Flat-rate pay-TV requires a subscriber to pay a fixed amount regardless of the amount of TV watched. Technically, all that is required is the removal of a trap outside the home to allow the channel to be received.

Pay-per-view TV requires an addressable descrambler which can be activated individually (downstream) from the head-end. Subscribers are charged on the basis of the actual amount of programming requested. In this way, special programs and events can be charged at a higher rate than regular programming.

Pay-per-view systems (e.g. a BNR prototype) utilize a set-top unit with a key to initiate transmission [7]. This terminal retrieves an access code held in internal memory and uses it to decrypt the incoming Pay-TV signal periodically. The subscribers viewing time is retrieved for billing purposes. This information, stored in the set-top unit with each access, is collected via a no-test trunk. (This facility is used to test subscribers lines without ringing the telephone).

This form of "on-request" billing paves an avenue to introduce on-demand video services, where the subscriber can choose both the time and content of the transmission.

• ON DEMAND VIDEO

The video retrieval system allows the user access to programming from a "video library" upon request. The access time depends primarily upon the technology used to implement the library. For example, a collection of manual VCRs would incur larger delays than an automatically read high density optical storage disk. Immediate major uses include both entertainment, as well as educational programming for residential and business/industrial training applications.

For the residential sector, this opportunity for an unlimited array of programming is only an extension of the current trend in various home video disc/cassette technologies. The high start-up cost for a vendor to set-up a large library and establish adequate two-way communications capability are seen to be prohibitive to early introduction of these services.

Training and corporate communications seem to be the most important business uses of these services. This non-broadcast video service can be set up as an in-house operation, thus the business market is not as dependent on vendor interest in video libraries.

The network requirements for this service include 6MHz for video and < 100 b/s for signaling information.

• HIGH DEFINITION TV (HDTV)

HDTV is a new transmission technology that can provide for a greater level of image detail and picture clarity than standard (NTSC) television. No firm standards have been set yet, but a prototype 1125 line HDTV picture can resolve some five times as many picture elements (pixels) as standard 525 line television. Consequently, HDTV requires considerably more bandwidth than conventional TV (i.e., typically 20-30 MHz vs. 6 MHz). In the evolution towards HDTV, an intermediate form of enhanced television can be anticipated :

a) Analog FM transmission of standard composite video.

b) Analog FM transmission of seperate R, G and B components.

c) Digital component-coded video.

d) NTSC-compatible transmission, with signal post-processing after reception

Option a) could be easily implemented over existing coaxial cable installations. However, there would be a considerable decrease in the number of available channels. Options b) and c) require sufficiently large bandwidths that a higher bandwidth medium such as fiber optics would probably be necessary for their implementation. Option d) is already receiving some attention, as can be seen in International Telephone and Telegraph's (ITT) recent announcement that it will begin producing digital TV sets [8]. These sets incorporate a set of VLSI ICs for digital processing of all baseband signals in a TV receiver, and allow for a potential variety of sophisticated signal processing features which would not be feasible with analog techniques, such as improved picture quality through the use of echo cancellation and noise reduction circuitry. The possibility of full picture store could make, for example, freeze frame, zoom and clear large screen projection available at no extra cost. Work is underway at ITT to explore and develop such enhancements.

The cost of such a set will be competitive with medium to high quality sets currently on the market [9]. A number of major television manufacturers have already arranged to purchase ITT's VLSI components for use in their own products. The digital set will be able to receive all standard video formats (SECAM, NTSC and PAL), and will thus impact on the introduction of inter-continental broadcasting (e.g. direct satellite broadcasting). Finally, this advance will open the market to digital transmission techniques.

For analog transmission and reception of full 1125 line HDTV, the Half-Line-Offset (HLO)-PAL system has been developed, [10] in which the chrominance (C) and luminance (Y) components are frequency division multiplexed. This composite format is best suited to AM-VSB transmission in terms of bandwidth/picture quality trade-offs. The baseband bandwidth of this signal is 30 MHz. (Figure 3.1)

For FM or digital broadcasting, one of the most promising transmission alternatives for the full 1125 line HDTV signal is Time-Compressed Integration of Luminance and Line Sequential Chrominance components (TCI-LSC), which is being pursued by NHK. In this approach, both the luminance and chrominance components undergo signal processing for time-compression, and are then time division multiplexed in such a way that the total signal bandwidth does not exceed the total luminance bandwidth of 20 MHz (Figure 3.2). Essentially, the high frequency components of the Y signal, to which the eye is less sensitive, are traded for more colour information. This scheme is based on the assumption of the availability of digital pre- and post- processing equipment and analog transmission. Using DPCM of 4 bits/sample, a total bit rate of 250 Mb/s can be achieved for good picture quality. With the introduction of digital framestores and more bandwidth-efficient coding techniques, digital HDTV transmission could become realistic.

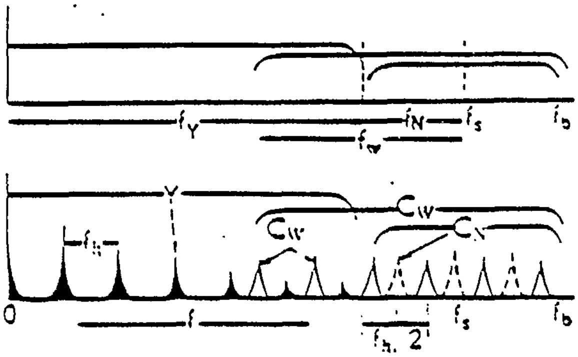
It is anticipated that HDTV will enter the market via several routes:

- major film studios
- videocassette and videodisc players
- closed-circuit programming to major theaters and CATV systems
- direct broadcast satellite (DBS) HDTV services.

The actual penetration of HDTV will depend partially on the cost of the HDTV set.

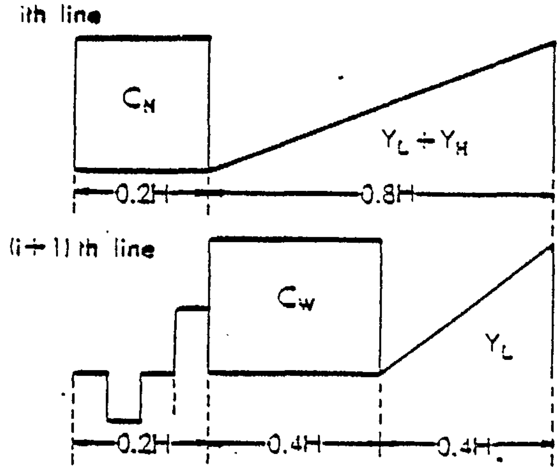
The uses of HDTV for business follow the pattern of on-demand video.

FIGURE 3.1: HLO-PAL FREQUENCY SPECTRUM



f_Y=19MHz, f_s=24.3MHz, f_b=30.0MHz
f_w=7.0MHz, f_N=5.5MHz.

FIGURE 3.2: TCI-LSC FREQUENCY SPECTRUM



Signal bandwidth

$Y_L + Y_H$	20MHz
Y_L	10MHz × 2 → 20MHz
C_W	10MHz × 2 → 20MHz
C_N	5MHz × 4 → 20MHz

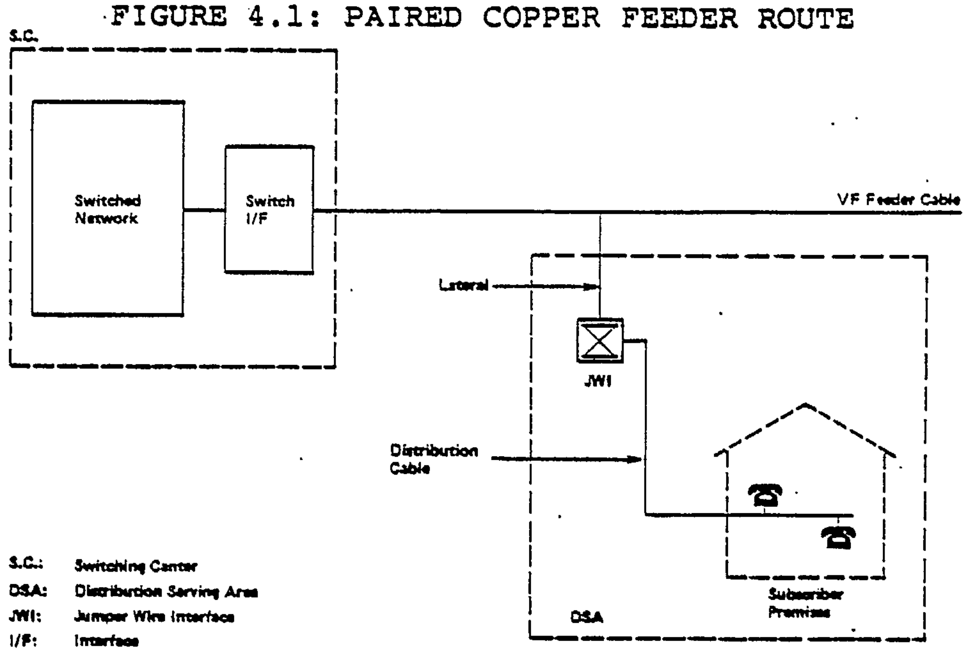
4.0 ACCESS NETWORK TECHNOLOGY ALTERNATIVES

Several of the service offerings that have been discussed are currently offered by either the telephone company or CATV operators. A number of the future service possibilities could be handled by the enhancement of existing access systems utilizing paired copper and coaxial cable facilities. The purpose of this section is to examine the existing and new access technologies, with particular reference to fiber optics, and evaluate their potential to carry new and integrated services. Sections 4.1,4.2 and 4.3 will assess paired copper, coaxial cable and fiber optic facilities as they apply to the carriage of existing, new and integrated services.

4.1 PAIRED COPPER

The telephone company has been using paired copper for plain ordinary telephone service (POTS) without significant changes to the medium for decades, save for cable design improvements. Copper comes in various gauges (19,22,24 and 26) in order to effectively and economically serve analog POTS to customers located at various distances from the switching center. Figure 4.1 illustrates a typical paired copper feeder route.

FIGURE 4.1: PAIRED COPPER FEEDER ROUTE



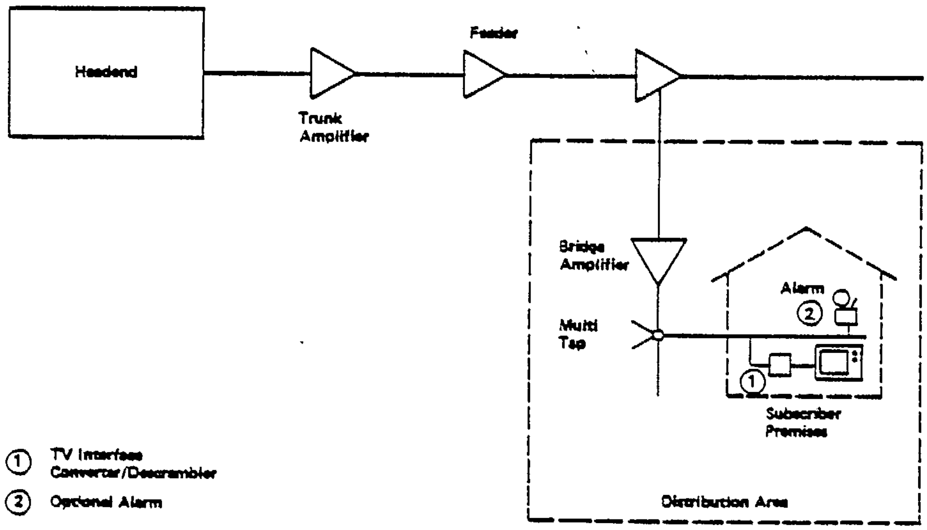
While there have been many changes in the switching and trunking technologies over the last decade, the loop plant has remained virtually untouched. Low bit rate services (up to 9.6 kb/s) can be accommodated on existing plant with only minor conditioning. The 0-200 Hz band below the voice band would constrain the data rate to less than 200 b/s, and is susceptible to noise generated by power lines and ringing tones. At least 1.2 kb/s can be multiplexed above the voice band. This system is limited to non-loaded loops, as the attenuation effect of inductive loading is prohibitive to above-band transmission. Bridge tap also limits the useful bandwidth of the loop, and studies on Bell Canada territory indicate that the above-band channel should be kept below 40 kHz [11].

At higher frequencies, crosstalk interference and impulse noise play a more important role in system limitations. Due to the nature of the loop plant in North America, the most promising alternative for transmission of up to 144 kb/s seems to be time compression multiplexing (TCM). The 144 kb/s signal can be distributed over 3 km of 26 gauge cable with a BER better than 10^{-7} [12]. This type of distribution would be used in conjunction with a pair gain system in order to shorten copper distribution loop lengths. Such a termination point would serve to multiplex digital subscriber lines onto a higher capacity digital feeder link to the switching center. This high capacity link will most likely be based on optical fiber. This distribution system configuration optimizes the use of existing plant for higher bandwidth communications. (Section 5 expands on this concept).

4.2 CATV COAXIAL CABLE SYSTEM

A CATV system is comprised of a head-end and a coaxial distribution network (Figure 4.2).

FIGURE 4.2: COAXIAL CABLE DISTRIBUTION NETWORK



The head-end contains the appropriate processing equipment to condition the incoming video signals for distribution over the coaxial cable network. Initially, these systems were provided only in locations where there was not satisfactory reception of direct broadcasts. Today, many urban centers are wired for CATV in order to increase the number of channels available. Approximately 85% of Canadian homes receive about 12-35 CATV-delivered channels. Modern CATV amplifiers can have a usable bandwidth of up to 400 MHz, permitting the transmission of as many as 54 (6 MHz) TV channels by frequency division multiplexing. Because of the increased cable attenuation at high frequencies (square root law), a 400 MHz system has approximately 20% more trunk amplifiers and as many as 50% more line extenders than a 300 MHz system [13]. Typical design parameters for a 400 MHz system are included in Table 4.1.

TABLE 4.1: CATV PARAMETERS

Cable Loss @ 400 MHz:	0.75" Trunk	3.6 dB/100m
	0.5" Distribution	5.0 dB/100m
	RG59 Drop	24.0 dB/100m
Amplifier Output:	Trunk	48 dBmV
	Bridge	41 dBmV
	Line Extender	46 dBmV
Required input at TV set :		3 dBmV

Recent innovations for CATV systems include the introduction of General Electric Company's COMBAND System [14]. In this system, excess vertical colour information, redundant vertical luminance information and unused portions of the NTSC time and/or frequency spectrum are combined to yield 2:1 bandwidth compression without significant picture degradation. This would offer an alternative to a complete system overhaul to increase channel capacity. Also of interest is the recent introduction of new, flexible cables with low attenuation (1.5 dB/100m at 400 MHz, 0.75" M/A-COMM QR series cable).

In order to upgrade existing plant to two-way operation, modifications must be made throughout the plant. These changes include the installation of: bi-directional repeaters to separate upstream and downstream traffic, failure-alarm circuitry and redundancy at each repeater, back-up powering, and the addressable converters at the subscribers premises. These additional features contribute to increased reliabilty of the network.

Times Fiber Communications Inc. [15] has developed a two-way in-building distribution system based on fiber optic technology. A coax feeder using a sub-split arrangement is used to interface between the CATV headend and a customer located 'mini-hub'. The mini-hub is, essentially, a microprocessor controlled cluster of converters and electro-optic equipment. Two fibers are provided to each subscriber for upstream and downstream transmission. Designed primarily for apartment buildings, the system is said to be the most economic service alternative for more than 24 co-located subscribers.

4.3 FIBER OPTICS

Optical fiber communications systems have undergone rapid advances since the early 1970's, when 20 dB/km glass fibers were first manufactured. By the mid-1970's, many field trials were underway. Experimental fibers being produced today are showing losses of less than 0.5 dB/km.

Fiber optic transmission technology is being economically employed in the trunk network in many countries, and a number of international telecommunications administrations are committed to research into subscriber loop applications. Appendix B includes a sampling of various activities involving this application scenario.

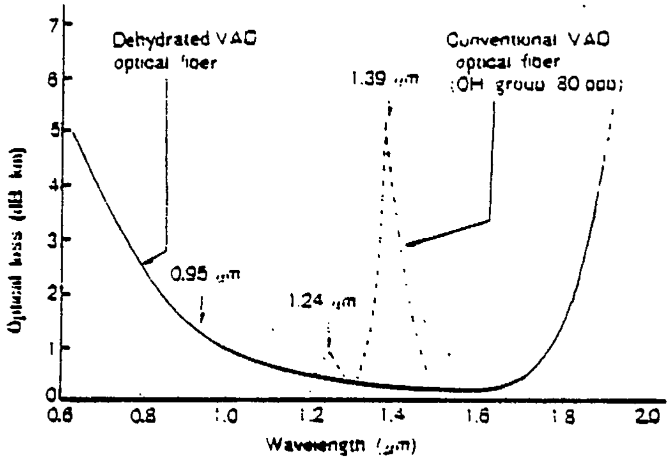
This section is dedicated to a concise discussion on the basic components of optical communications: fiber, sources, detectors, connectors and wavelength division multiplexers.

- FIBER

Optical fibers for general telecommunications purposes are manufactured of high purity glass. The fiber most often used for medium range (2-30 km) applications is graded index (GI) multimode fiber. The 50 um core/ 125 um cladding GI fiber typically displays an attenuation of < 1 dB/km at 1300 nm and 2.5 dB/km at 850 nm, with bandwidth capabilities up to 1 GHz-km.

There are various manufacturing techniques used to produce fibers, including modified chemical vapor deposition (MCVD) and vapor axial deposition (VAD), among others. NTT [16] has recently developed an enhanced VAD dehydration process, whereby very low loss optical fiber with low concentration of OH ions has been successfully manufactured (see Figure 4.3). The "sol-gel" method [17] of fiber production involves the use of relatively simple manufacturing techniques. While a number of technical problems remain to be solved, the low cost (projected at less than half that of VAD) of this method makes it an attractive potential alternative, although attenuation of fibers fabricated by this technique is currently around 6 dB/km at 850 nm.

FIGURE 4.3: ENHANCED VAD FIBER ATTENUATION



Cladding diameter	125 µm
Core diameter	50 µm
Refractive index difference	1.0 %

There are 3 major contributors to fiber cable attenuation:

- absorption, due to impurities in the glass
- scattering, due to material inhomogeneities and irregularities in the core-cladding interface
- radiation, due to sharp bends in the fiber.

Both modal and material dispersion can also limit the capacity of a transmission system. These factors relate to both the geometry and wavelength dependent properties of the fiber. The use of narrow spectral width sources helps to decrease material dispersion. Various alternative dopants to germanium are being investigated for use in silica based fibers in an additional effort to decrease material dispersion.

Initially, the short wavelength (850 nm) region was developed for lightwave communications due to the availability of sources and detectors in this region. The decreased attenuation at longer wavelengths has led to the development of components in the 1300 nm and , more recently, the 1550 nm region.

Single mode fibers do not suffer modal dispersion, and as a result can achieve high bandwidths over long distances (for example, 140 Mb/s over 102 km of single mode fiber at 1.52 um [18]).

Finally, fiber cabling design is an important parameter in cable performance. The two major problems to be addressed in the packaging of fibers are adequate protection against breakage and reduced attenuation due to microbending. The design developed at BNR is a slotted core loose packaging structure. The design is rugged, simple and reliable and can hold up to 72 fibers. The Seicor Optical Cable Co. [19] has investigated the reliability of fiber cables, and experience in BNR confirms that cable failure is very infrequent, and is largely due to uncontrollable circumstances (e.g. collapsing ducts).

- SOURCES

The two broad categories of semiconductor light sources used for optical communications are light emitting diodes (LED) and lasers. Some characteristics of typical devices are given below in Table 4.2 [Source:20]:

TABLE 4.2: SOURCE CHARACTERISTICS

PARAMETER	LED	LASER DIODE
Optical power rating	1mW	5-10mW
Useful optical power at end of connecting fibre	0.02-0.1mW	2mW
Corresponding current variation	100mA	20-30mA
Threshold current	-	20-150mA
Bandwidth	60-120nm	1-2nm
Modulation rate	50MHz	1000 MHz
Operating temperature range	0-40 C	0-50 C
Service life	~10^6h	10^5h
Ease of use	High	
Power consumption	Low	
Fibre type	multimode	monomode or multimode

[Source: 20, BNR]

Short wavelength LEDs are made of GaAs or GaAlAs alloy, while at long wavelengths, InGaAsP alloy is used. Both the surface- and edge-emitting LED structures are widely used. The edge-emitter has a smaller emitting area and a somewhat higher output power advantage.

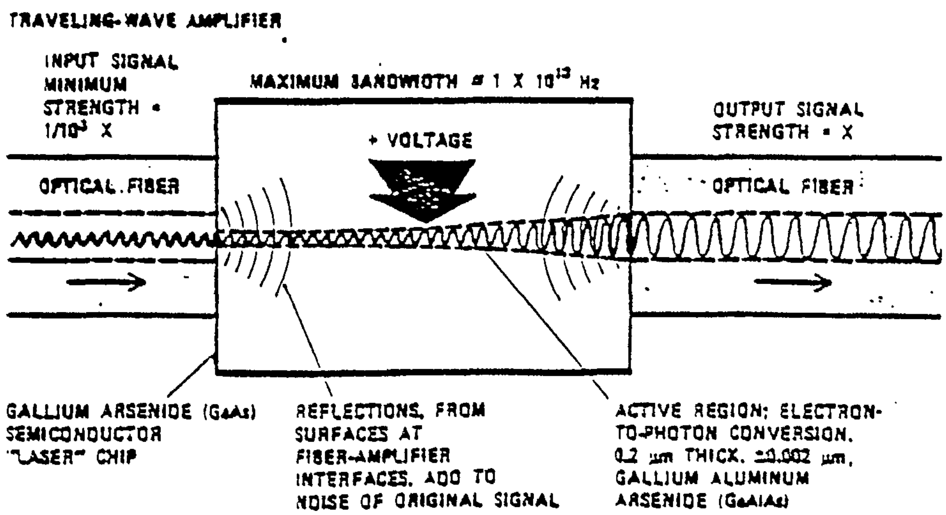
Lasers are favoured for use in higher bandwidth and/or longer distance spans, and are the subject of much current research and development to achieve [21]:

- increased source power output
- integration of electrical drive circuitry with optical components
- increased reliability of lasers.

Sources in the 850 and 1300 nm regions are now comercially available, with on-going development in the 1550 nm range.

Fiber optic system design traditionally incorporates the appropriate components to achieve a non-repeatered span between 'natural' termination points (e.g. Switching Center). So, for example, the use of higher bandwidth fiber and lasers might be called for in a design due to the high cost associated with installing a fiber optic repeater (detector/source) on a given route. In the October 1982 edition of Japan Telecommunication Review, a brief paragraph was included describing an "optical amplifier...which can amplify optical signal power by a factor of 300 to 1000 times". It has since been confirmed [22] that this device is a solid state laser which performs travelling wave amplification. Operating just below the lasing threshold, the device converts electrical energy to optical and injects about 20 dB (net gain) into the passing optical signal. This technology, (Figure 4.4) coupled with appropriate higher speed sources and detectors, may open up even more of the inherent fiber bandwidth potential, if means are found to reduce the high intrinsic noise of these devices.

FIGURE 4.4: OPTICAL AMPLIFIER



• DETECTORS

The optical detector must convert the received modulated optical signal back into electrical energy. In the short wavelength region, silicon PIN or avalanche (APD) photodiodes are used. The PIN detector is reliable and cheap, but the APD offers increased sensitivity. The relatively complex Si APD has been shown to have adequate reliability [23], although it has been recommended that procurement specifications are required to screen out potentially unreliable APDs.

In the long wavelength region, most receivers use PIN detectors in conjunction with FET front-end amplifiers. In this configuration, the receiver can be almost as sensitive (within 2-3 dB) as APDs at short wavelengths, whereas a good performance APD is difficult to fabricate for use at higher wavelengths. Studies at Bell Labs [24] have shown that a decrease of about 10 in primary dark current of the APD would yield significantly improved sensitivity over PINFET detectors. It is not clear, though, whether low dark current, reliable planar APD's can be fabricated using present technology.

There is some question as to whether the realizable economies of using APD photodetectors for long wavelength communications are valuable; nonetheless, research continues into the use of new structures and materials for such devices.

The major materials used in the long wavelength region include GaInAs (Bell Labs, ITT), HgCdTe (SAT) and Ge (Japan). While the Ge APD technology will be used extensively in Japan, the high dark current limits its operation to below 100 Mb/s at room temperature. Bell Labs, among other institutions, has been pushing GaInAs due to its ease of manufacture, reliability and potential detector/amplifier integration possibilities. Integrated GaAsIn PINFETs have already been fabricated, and show promising performance at a potentially low cost [25].

Table 4.3 shows a comparison of PIN and APD photodiodes. [Source:20]

TABLE 4.3: DETECTOR CHARACTERISTICS

PARAMETER	PIN	APD
Quantum efficiency	0.5 - 0.9	0.5 - 0.7
Sensitivity	0.5 - A/W	5 - 50 A/W
Multiplication factor		10 - 100
Bias voltage - Si - Ge - InGaAs - HgCdTe	 10 - 15V 10V 10V	 200V 10 - 15V 15 - 20V
Dark current - Si - Ge - HgCdTe	 0.2nA 1 nA	 5nA 0.1 - 1A
Response time	0.5ns	0.5ns
Operating temperature range	0-70 C	0 - 70 C
Thermal fluctuations	None	Significant
Predominant noise	Thermal	Thermal and comparable

[Source: 20, BNR]

- SPLICES & CONNECTORS

Fiber permanent splices must minimize through-losses, characteristically caused by misalignment, end separation and microbending. Figure 4.5 illustrates various fiber splicing techniques [Source:26].

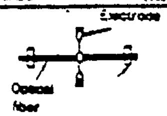
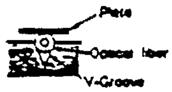
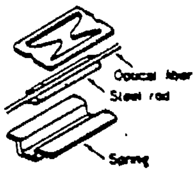
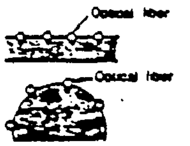
The arc fusion method has received much attention due to its overall excellent performance. Splice losses for this method average about 0.4 dB, but with increased training and expertise of personnel should approach 0.1-0.2 dB in the future.

Future research will include more durable and multiple fiber arc fusion techniques and improved single mode splicing techniques.

Connectors are passive devices used to connect fibers to other fibers, sources, detectors and various other devices (e.g. WDM) where ease of connection and reconnection are essential.

About 1 dB of loss is incurred at a connecting joint using fairly simple alignment techniques. The use of lenses offers somewhat lower losses, but imposes more stringent alignment requirements.

FIGURE 4.5: FIBER SPLICING TECHNIQUES

Method		Diagram	Process
Single Splicing Method	Arc-Fusion Method		Splicing fibers by arc-fusion
	V-Groove Method		Fixing fibers by plate and V-groove then fixed by an adhesive
	Spring Groove Method		Insert fibers between two steel rods and spring (ICC '80 Conference Record)
Multiple Splicing Method			Splice many fibers at the same time (6th European Conference on Optical Communication)

• WAVELENGTH DIVISION MULTIPLEXING (WDM)

WDM is a technique whereby the outputs of sources of different wavelength are multiplexed onto a single fiber The rationale for such a device is the cost savings associated with the decreased number of fibers.

The critical parameters of a coupling device include through-loss (typically about 5 dB for an optical combiner and splitter involving four wavelengths) and optical cross-talk introduced. If small wavelength separations are desired, lasers are best suited as sources due to their small spectral width. Where broad separations are tolerable (e.g. 850 and 1300 nm), the use of wavelength selective photodiodes increases channel isolation (e.g. Si is insensitive above 1100 nm, and InGaAs is insensitive below 950 nm. Ge, on the other hand, has a very broad spectral response and is thus not well suited to wavelength discrimination).

Another application of the WDM technique is bidirectional wavelength division duplexing (WDD), in which different wavelengths are used for separate directions of transmission over a single fiber. For example, dichroic filters achieve optimum performance at two wavelengths with an insertion loss of less than 1.5 dB [27].

Table 4.4 lists the advantages and disadvantages of available WDM couplers. [Source:28]

TABLE 4.4: WDM COUPLER COMPARISON

Coupler Type	Advantages	Disadvantages
Wavelength independent with selective filters or detectors	Simple Low cost	High loss Limited to few channels
Lensed dichroic	Simple Low cost Demonstrated thermal stability 10 channels demonstrated	Loss increases with number of channels High initial cost for filters
Prism	Loss not a function of number of channels Many channels possible	Nonlinear dispersion Large size and/or exotic prism materials required Tight source specifications Unknown stability
Grating	Loss not a function of number of channels Many channels possible Many good results published	Tight source specifications Unknown stability

5.0 ACCESS NETWORK EVOLUTION ALTERNATIVES

In the preceeding Section, the characteristics of the key access technologies were discussed. Coupling this information with the projected service requirements presented in Section 1 allows for an evaluation of access system alternatives suitable for the next ten years. In this Section, the residential/small business needs will be addressed, followed by medium/large businesses.

5.1 RESIDENTIAL NETWORK EVOLUTION

• NEAR AND MEDIUM TERM

In the residential market, the first broad segregation of services can be made by separating video from non-video services. This, of course, is reflected by the existing network structures of paired copper and coaxial cable. The structures of the existing and emerging CATV networks are not well suited to voice transmission, partly due to a lack of switching equipment and to the technological limitations on conventional CATV plant equipment. Therefore, the integration of voice and video carriage will only be considered for the long term, when access requirements for new services such as HDTV warrant the development of new systems.

The major bandwidth requirements (in addition to voice on paired copper and video on coax) up to 1989 are associated with very low bit rate upstream transmission (<300 b/s), and low bit rate downstream transmission (<1200 b/s). If database downloading becomes a popular service in the near term, there may be an additional need for 1200 b/s upstream as well. As discussed in previous sections, both coax and copper distribution technologies are suited for this increased capacity.

Coax:

In addition to new data-oriented services, there is a drive to increase TV channel capacity in order to satisfy customer demand for video services such as Pay-TV. For new builds on coaxial cable, the installation of a 400 MHz system is cheaper on a per-channel basis than for 300 MHz [29]. Pay-TV and Pay-per-view-TV will be the leading services that will spur operators to introduce some of the necessary modifications to allow for the full array of informational and interactive services. It is anticipated that this upgrade may cost about $100/km for existing systems without two-way capability, and as much as $900/km for older systems [29]. For new installations, the cost of stringing two cables together will probably be no more than 50% more than the cost of installing a single cable [30]. In general, the incentive to upgrade/build plant to include enhanced services will depend highly on the projected service revenues to CATV operators.

Paired Copper:

There is currently a well-defined and high momentum in the telecommunications industry towards the digitization of the network. The Integrated Services Digital Network (ISDN) concept is the focus of CCITT Study Group XVIII, with a goal of defining global digital network standards with which telcos can align their service offerings. This thrust is a natural offshoot of the introduction of digital switching techniques (e.g. Northern Telecom's DMS), and the inherent enhanced transmission performance and capability an all-digital network can offer.

The key concepts of the ISDN are listed below [31]:

1) The customer will be supplied with a communication capacity measured in maximum bit rate at a standardized interface.

2) Various defined communications "pipe" sizes will be available, transparent to the user. No fixed bandwidth is allotted to a user by the network; Rather, a variable bandwidth assignment is made with each customer access.

3) Signalling information will be multiplexed into this pipe.

4) Packet and circuit switching access will be available.

To address the residential market needs for digital services, a near term applique system is proposed. As described in Section 4.1, existing telephone pairs can be used for integrated voice/data transmission by superimposing the Data (< 1200 b/s full duplex) Above Voiceband (DAV). The data is FSK modulated, and carrier frequencies between 22 to 36 kHz are used (see Figure 5.1).

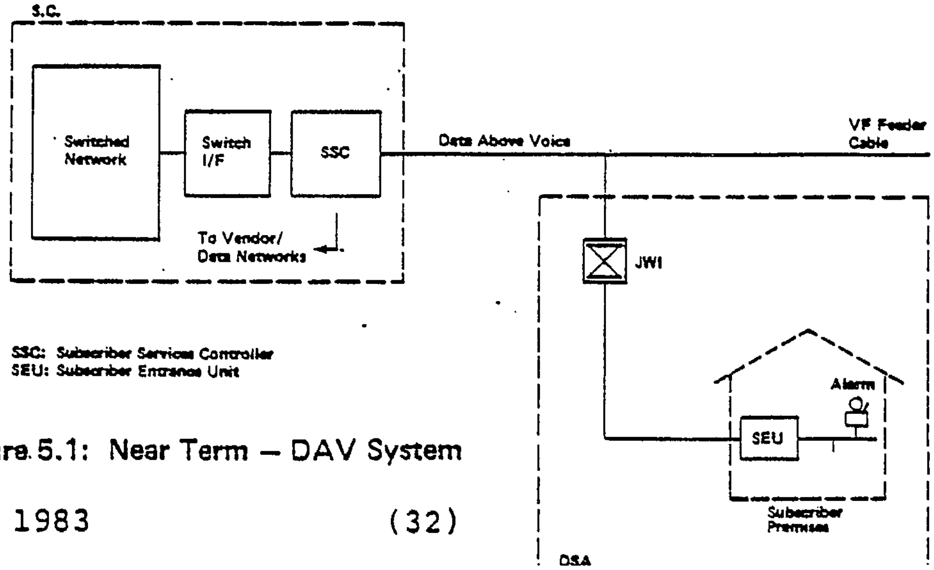


Figure 5.1: Near Term — DAV System

This scheme functions with any type of switcher, and involves only the conditioning of the existing loop and the addition of appropriate terminating equipment (e.g. modems, filters). Bell Canada [32] has already conducted a field trial of this 'hybrid' system. The experiment involved 5 alarm companies and 500 subscribers in Montreal and Toronto, with satisfactory results. This configuration can be easily upgraded as the demand for increased bit rates becomes a reality.

The ISDN channel structure, as currently defined, is 2B+D, where B is 64 kb/s and the D channel is 16 kb/s. The services associated with these channels are listed in Table 5.1 [33].

TABLE 5.1: ISDN SERVICES

B-Channel Services (64 Kbit/s)	D-Channel Services (16 Kbit/s)
Voice	Enhanced Telephony
High Speed Data (CS & PS)	Low Speed Data (PS)
High Quality Voice	Videotex
Voice & Data End-to-End	Teletex
Assembly of Subrate Channels	Telemetry
	- Emergency Services
Facsimile	- Energy Management
Slow-Scan Video	

CS: Circuit Switching

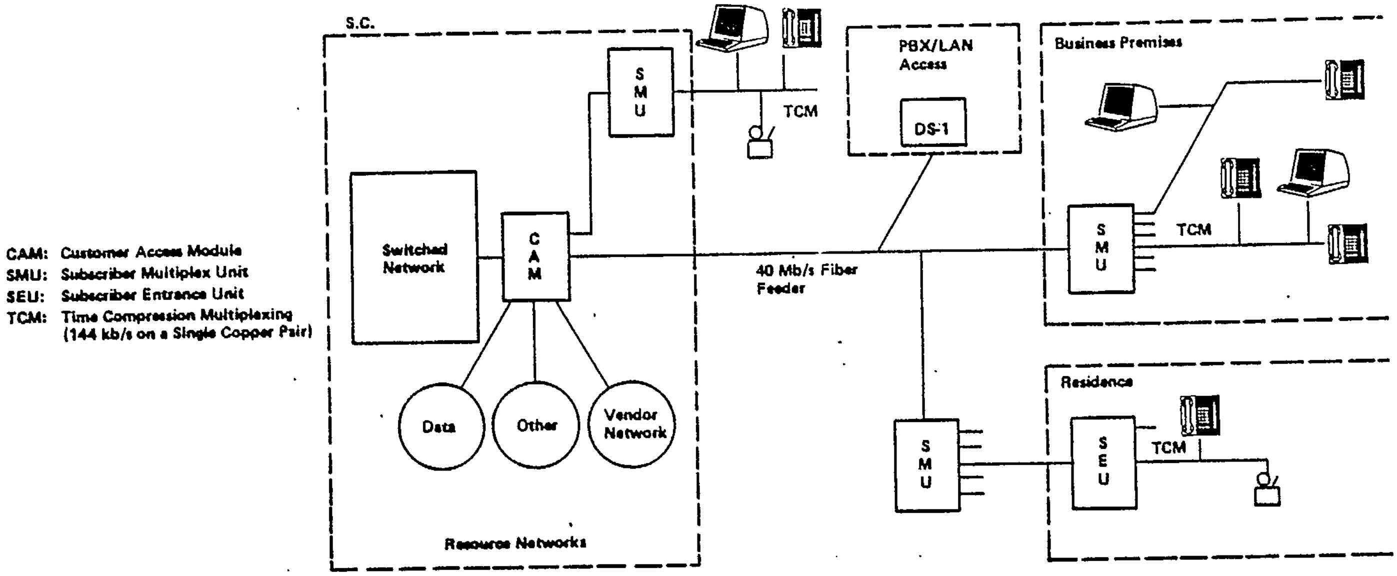
PS: Packet Switching

As an intermediate step towards total voice/data integration, a combined analog and digital format (A channel for voice, C channel of 8 or 16 kb/s for signalling and data) is proposed. Thus the DAV system can easily be seen to fit into this structure.

The medium term access system proposed here is aligned with the 2B+D channel structure. Figure 5.2 shows the configuration of such a system. For subscribers located at less than 3 km from the C.O., 144 kb/s can be delivered on paired copper. For distances greater than 3 km, subscribers are served by remote pair gain devices.

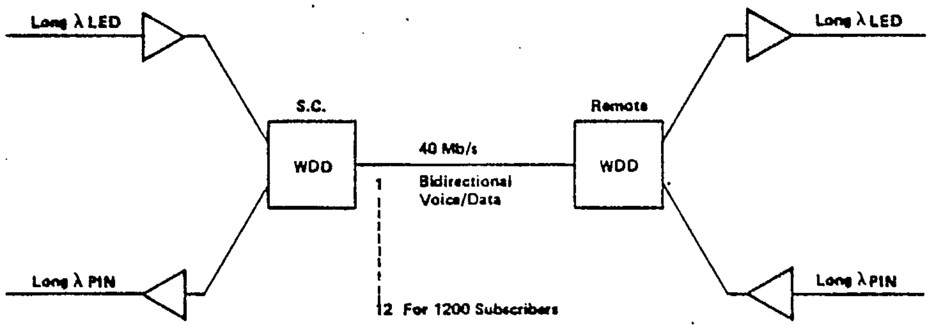
The subscriber multiplex units (SMU) serve to multiplex incoming subscriber lines onto a high capacity fiber feeder. Long wavelength LED sources, in conjunction with PIN detec-

FIGURE 5.2: MEDIUM TERM - SMU SYSTEM



tors and wavelength division duplexers are used to feed high quality graded index fiber (1.3 dB/km) over a maximum distance of 10 km (Figure 5.3). The use of remote switching units and existing pairs to provide increased channel capacity is viewed as a cost-effective strategy to offer new services [34].

FIGURE 5.3: VOICE/DATA FIBER FEEDER



One of the key elements in the design and success of the ISDN is the associated protocol. The definition being formed by the CCITT follows the Open System Interconnect (OSI) model of the International Standards Organization (ISO) and the CCITT. Some of the current trends are highlighted below [33]:

Level 1: PHYSICAL LAYER

- 4 wire user/network interface seems likely

- Issues to be resolved:
  - Power feeding from C.O. to subscribers premises through loops
  - Fault isolation and contention resolution in multi-terminal configurations

Level 2: DATA LINK LAYER

The link access protocol of the D-protocol (LAP-D) is used to establish and release multiple logical links over the D-channel, frame and sequence messages and detect/recover from errors.

- CCITT thrust to base LAP-D on level 2 of X.25 link access protocol balanced (LAP-B) and the high level data link control (HDLC). LAP-B is currently used in packet mode communications links.
- BNR [35] is supporting the initial introduction of a simple 'compatible subset' to LAP-D adequate for signalling and circuit switching, to be upwards compatible with full LAP-D. This would streamline the introduction of hybrid (A+C) systems.

Level 3: NETWORK LAYER

This layer builds upon layer 2, and performs the call set-up/clearing of integrated voice/data and the support of various enhanced telephony features (e.g. call forward). It should be compatible with level 3 of X.25.

- LONG TERM

Due to the anticipated increased demand for video services (e.g. on demand video, HDTV), service operators would be forced to install new plant to accommodate the increased transmission requirements. It is therefore appropriate, at this point, to investigate more fully the integration of video and non-video services. Specifically, two broad system alternatives are proposed:

a) CATV and Pay-TV on coax
   Voice/data and on-demand video/HDTV on fiber

b) All services on fiber.

There are numerous advantages to service integration, such as increased bandwidth/service flexibility and decreased maintenance and operating costs. These benefits can be easily and effectively derived from fiber optics. The medium term design option described earlier indicated the viability of introducing fiber in the feeder network. The concept of an integrated system using fiber optic technology is a logical evolutionary step if service demand materializes.

The topology chosen for the network is a switched star, based on the criteria presented in Table 5.2 [36]. The design chosen can be implemented using available technolgy. However, topologies such as the ring may well benefit from advances in fiber optic technology geared towards local area network applications (Appendix C).

TABLE 5.2: FIBER NETWORK TOPOLOGY

	TREE	RING	CUSTOMER-SWITCHED STAR	CENTRALLY-SWITCHED STAR
Service Evolution	-	0	-	+
Reliability	-	0	+	+
Maintainability	0	-	+	+
System Reach	-	0	-	+
Growth & Rearrangements	-	-	-	+
Fiber Cost	+	0	-	-
Electronic Costs	-	-	+	0
Technology Risks (1990)	-	-	-	+
TOTAL	-	-	0	+

\+ = Better
0 = Average
\- = Worse

The overall configuration for an integrated fiber system is illustrated in Figure 5.4. Following is a discussion of the component subsystems: feeder, switching and distribution.

• FEEDER

Three separate feeder systems can be envisaged: one for voice and data (as in the medium term), one for NTSC video (either CATV or on-demand) and a third for HDTV.

Using projected 1992 components, the NTSC video system would follow Figure 5.5. Two 6 MHz channels are frequency modulated and frequency division multiplexed. This then intensity modulates a long wavelength laser diode. Outputs from four such sources are then wavelength division multiplexed and are transmitted over a single graded index fiber. It is assumed that 48 TV channels and 48 on-demand channels would probably be sufficient to serve an area of 1200 subscribers, which would require twelve fibers carrying four channels each for a total of 96 channels.

FIGURE 5.4: LONG TERM - INTEGRATED FIBER SYSTEM

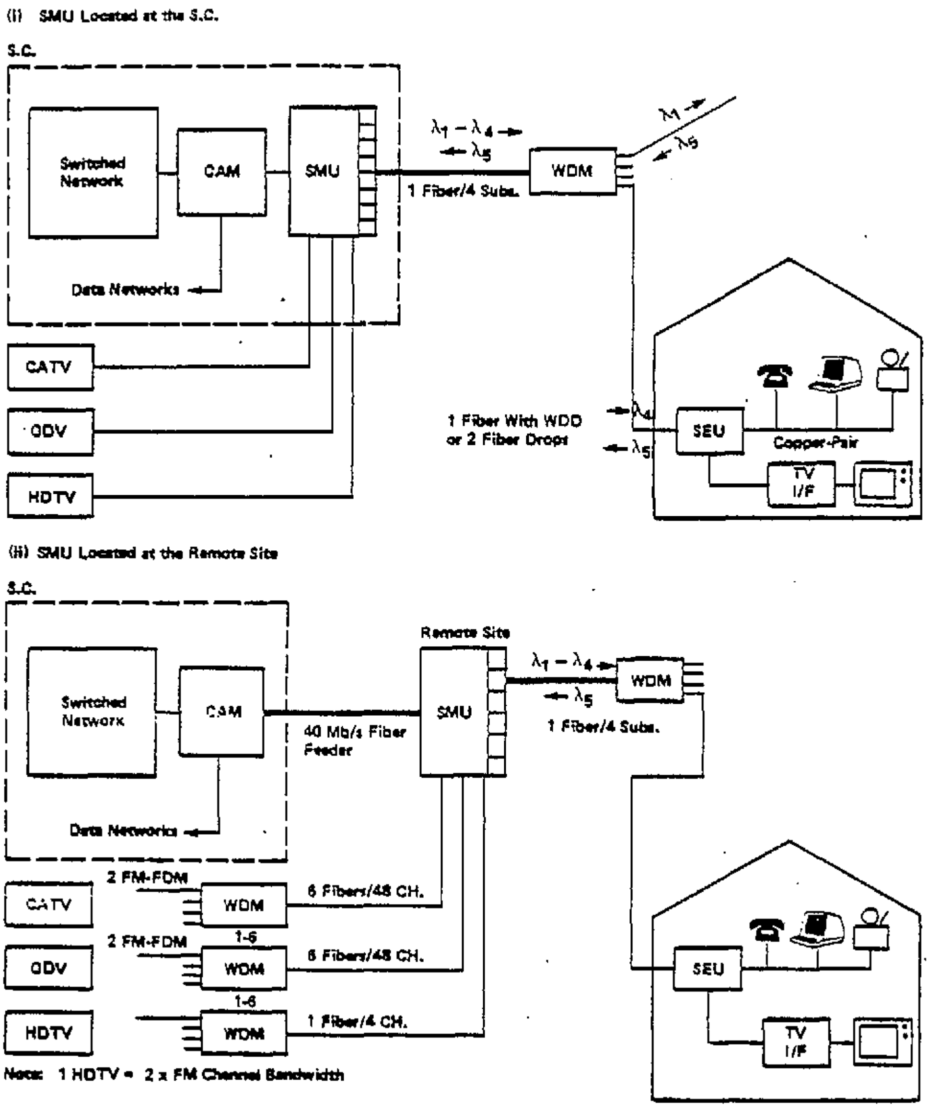
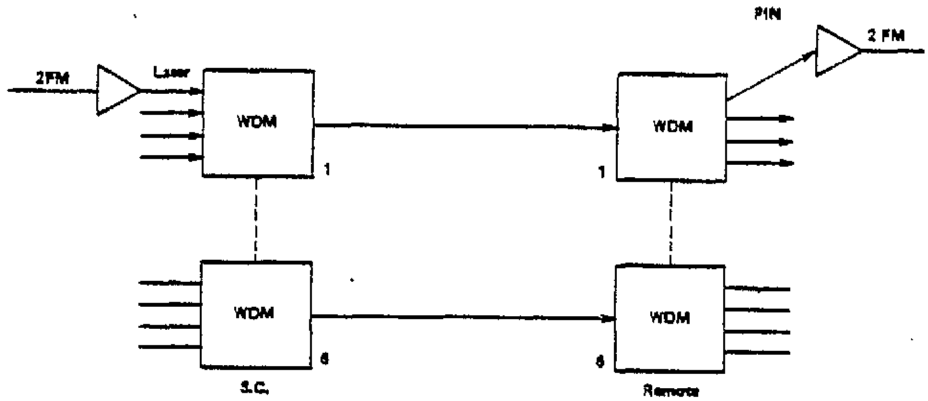


FIGURE 5.5: VIDEO FIBER FEEDER



There is no interference caused by intermodulation between the sidebands of the same video signal using FM modulation. Interference between sidebands of adjacent signals can occur. However, by careful choice of carrier frequencies, the products can be arranged to fall out-of-band. Where these products cannot be avoided, their effect is minimized due to the double FM process by which they were generated.

The major factors which affect the loop reach are: power coupled, fiber and connector losses and receiver noise and sensitivity. The first two control the signal power and the last refers to the effect of the noise power. The maximum loop reach is dependent on the minimum SNR design criteria. In the case of NTSC video, an unweighted SNR of 40 dB in the baseband channel bandwidth at the subscribers premises is required.

A SNR of > 60 dB for the video feeder from the headend to the C.O. is achievable. Using current technology, a feeder (between the SC and the SMU) transmitting two NTSC FM channels per laser and WDM, will provide a maximum reach of 16 km (SNR > 45 dB).

The HDTV system considered here is actually enhanced television, with a baseband bandwidth of 12 MHz. Due to the higher bandwidth, there is only a single channel per source. WDM is used to obtain a total of 4 HDTV channels between the SC and the remote switching unit.

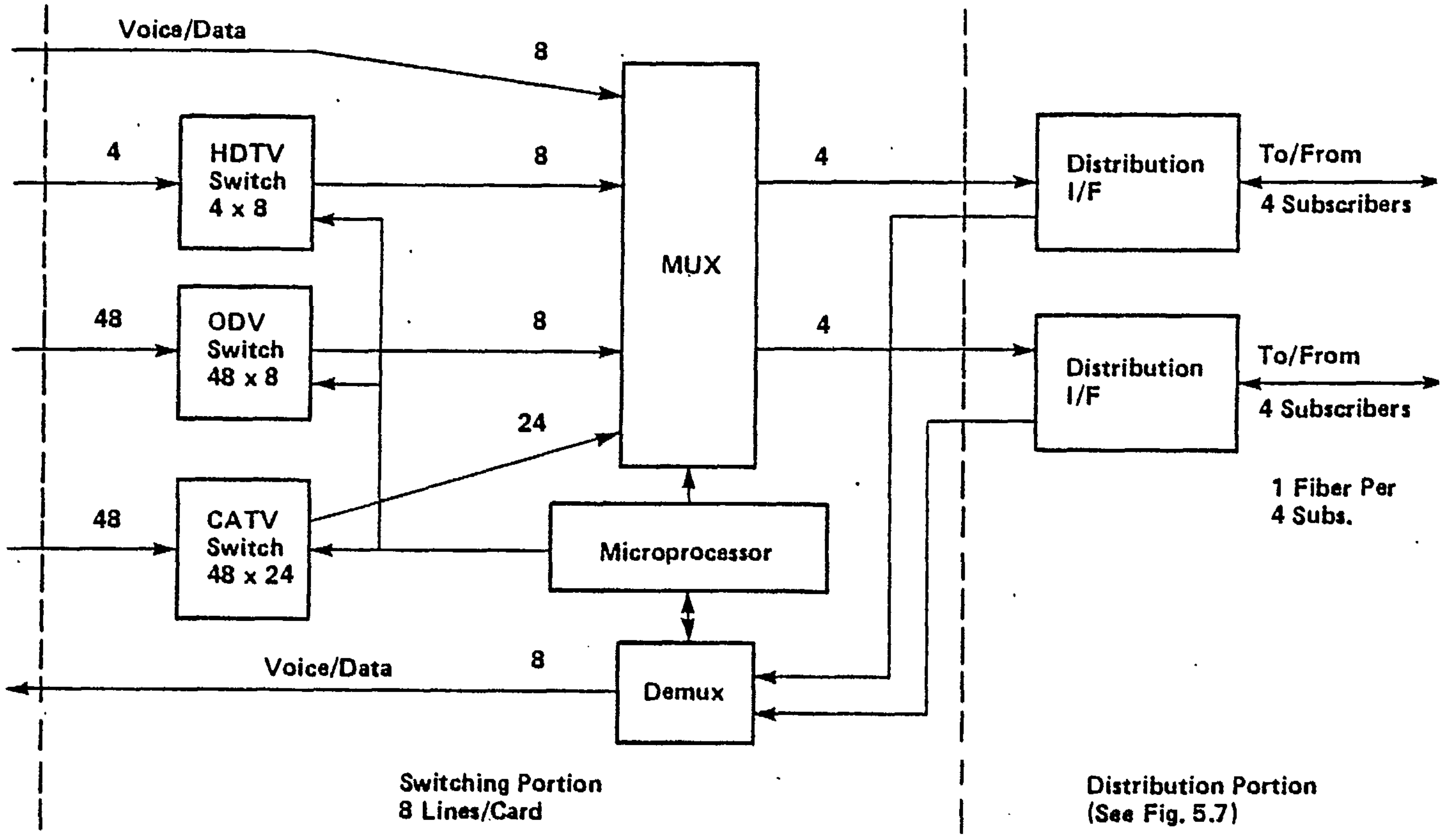
If HDTV with a 30 MHz bandwidth is required, a laser source should be used between the SMU and the subscriber. Today, a reach of 4 km (SNR>43 dB) can be achieved for two HDTV (30 MHz) channels. In the feeder, a laser with WDM could be used, permitting 1 channel of HDTV per laser for a 10 km feeder (at 43 dB SNR) at present, rising to 13 km in the future.

The alternative to analog video transmission, which remains unattractive due to the high codec cost required to achieve bandwidth compression. Codec costs for immediate and long term applications for both broadcast and conferencing applications are included in Appendix D.

- SWITCHING

The subscriber multiplex unit (SMU) is located either at the switching center or at a remote site to terminate the distribution lines carrying voice, data and video services.(See Figure 5.6).

FIGURE 5.6: SUBSCRIBER MULTIPLEX UNIT, INTEGRATED SERVICES



In the case of the remote application, the voice/data and video fiber feeders are used to link the C.O. to the remote. Voice and data services are routed to the conventional public switched network and data network facilities. Video services require a special switch arrangement. Two options are considered: (1) A central switch, shared by all subscribers in the serving area. This switch would distribute up to 3 NTSC channels or 1 HDTV channel and 1 NTSC channel to each subscriber. Any of the three NTSC channels could be on-demand. (2) Distributed switching which is integrated onto the voice/data line card of the SMU. Serving , for example, 8 subscribers, there would be (i) 1 switch for CATV distribution with 48 inputs and 3x8 outputs (3 TV channels per subscriber), (ii) a second switch for on-demand video distribution with 48 inputs and 8 outputs (1 channel per subscriber) and (iii) a switch for HDTV with 4 inputs and 8 outputs (1 channel per subscriber). A built-in microprocessor would handle the routing of control signals from subscribers to the switches.

The design of option (1) is somewhat more sophisticated than option (2), and is beyond the scope of this study. Therefore, a simple design approach based on option (2), as shown in Figure 5.6, has been adopted for system design and costing.

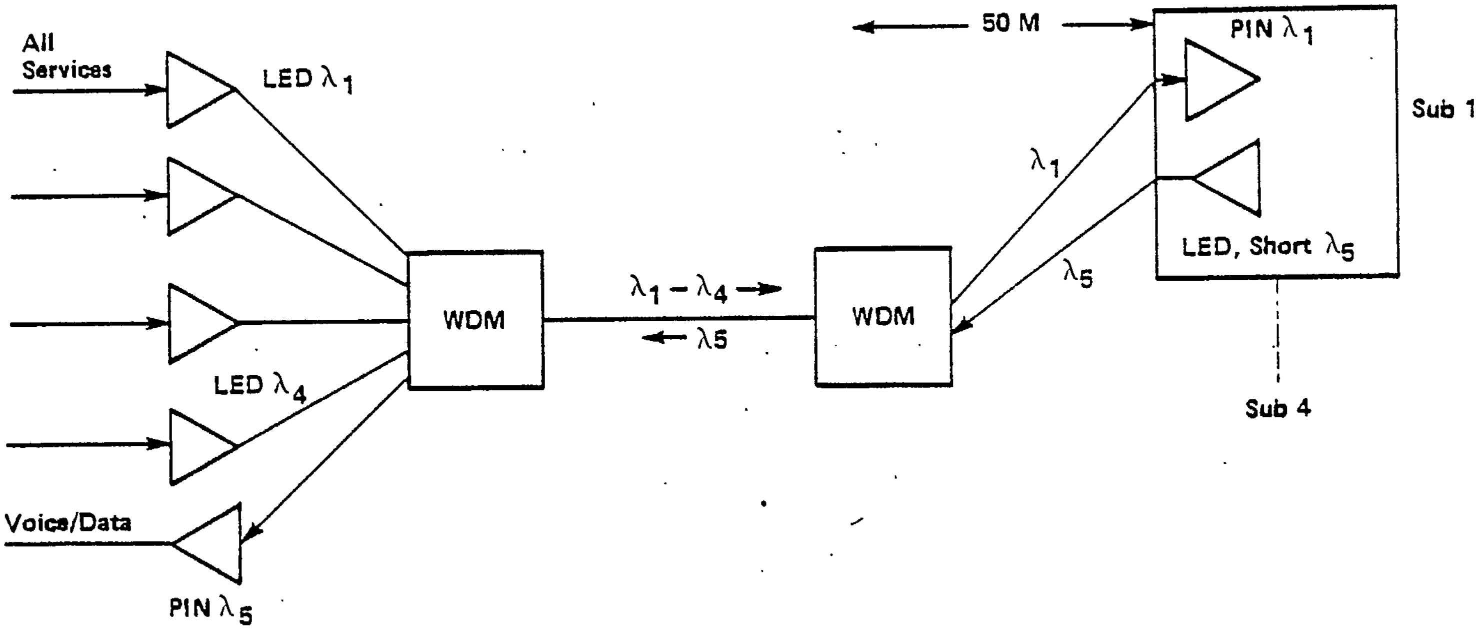
Information on video switch technologies is included in Appendix E. Switch costs for current and long term applications are also provided.

- DISTRIBUTION

The outputs from the switch, either at the C.O. or the remote, are then distributed via fiber to the subscribers. As illustrated in Figure 5.7, four subscribers are served by a single fiber using WDM. The downstream information of the four subscribers is multiplexed using four separate wavelengths, and is distributed via a single fiber to an outside plant distribution terminal, housing WDM components. The drop from the device is dual single fibers, terminating at the subsciber entrance unit on the premises. Long wavelength LED and PIN are used in the downstream direction. For the upstream transmission of voice and data, a short wavelength LED is used at a common fifth wavelength at each subscribers premises. Subscribers are 'polled' sequentially by the switch for information, thus requiring only a single transmission wavelength and rugged passive devices in the outside plant terminal. At the switch interface, a PIN detector is employed.

Using todays long wavelength LED technology, a maximum reach of 3 km between the SMU and the subscriber is achievable with a SNR of 41 dB for the distribution. The system provides three NTSC channels, FM encoded, frequency division multiplexed per LED with a topology as in Figure 5.7. A potential reach of 6 km with a similar system performance is expected with improved component performance over the next five years. Such systems could suport one channel of enhanced television (EDTV) plus one of NTSC.

FIGURE 5.7: FIBER DISTRIBUTION SYSTEM



At the subscribers premises, the network termination used in the medium term scenario is preserved and augmented by appropriate filtering and electro-optic equipment (as described) to form an integrated entrance unit. In-house distribution can still be over existing copper and coaxial cable.

5.2 BUSINESS NETWORK EVOLUTION

Data rates of more than 1.5 Mb/s are already being demanded of the telcos and cable companies by a number of large businesses. In the business market, there is a definite need for local concentration and networking of in-building lines, and the large and growing number of installed PBXs, key systems and local area networks (LAN) are meeting this need. The features that are evolving for such network 'hubs' include [34]:

- integrated digital switching for voice and data
- featured voice telephones, modular data terminal interfaces and integrated voice/data work stations
- attached value added service processors and peripherals

- DS-1 (1.544 Mb/s) trunk interfaces
- enhanced signalling and management features
- communications gateways for voice and data.

As an example of manufacturers interest, these principles are embodied in Northern Telecom's OPEN WORLD announcement. It is expected that initially, DS-1 rate systems will be used for PBX-PBX connections, evolving towards PBX to Class 5 switch demands.

In the business sector, the ISDN concept will have to include an additional higher bandwidth (nx64kb/s) availability to the 2B+D structure. The traffic offered to the pipe will certainly vary according to the individual user's overall needs. It is, perhaps, more important to consider the economies of sharing the pipe between a number of services, and the impact this has on the access network offering.

The combinations of service offerings throughout the Canadian business market and the degree to which any bandwidth 'pipe' will meet the variable traffic/transmission demands presented by these services are anyone's guess at this point. It is expected that the initial service offering will require the DS-1 rate (1.544 Mb/s).

There are three basic wideband-ISDN access types envisaged for the business environment - transparent, multiplex and composite multiplex. (See Table 5.3).

TABLE 5.3: WIDEBAND ACCESS CHARACTERISTICS

ISDN ACCESS TYPES	CHANNEL FEATURE	SERVICE EXAMPLES
TRANSPARENT	• End-to-end connection over full channel • Digit sequence integrity in full channel	• Video Conferencing • PABX Interconnection
MULTIPLEX	• Independant end-to-end connections over nx 64 kb/s (+) Channels • Digit sequence integrity in each B channel	• PABX • LAN
COMPOSITE MULTIPLEX ACCESS	Composite of transparent and multiplex wideband access	

The transparent access is intended for DS-1 and sub DS-1 bulk data rates (above the 144 kb/s provided by paired copper). The multiplex access is an assembly of B channels, suited for voice/data communications up to 64 kb/s per channel. The composite multiplex access is a combination of the transparent and multiplex access types. The aggregate bit rate for wideband ISDN access is 1.544 Mb/s, with the actual channel structure including signalling and framing information. Standardization activities pertaining to wideband access alternatives are on-going.

Three user communications profiles (hospital, bank, manufacturer) have been developed within BNR in order to portray the varying needs within market segments (Table 5.4).

The access technologies appropriate for the service demands outlined in Section 3 for the near to medium term would follow the example of the ISDN service vehicle presented in Section 5.1. Figure 5.8 details the evolutionary access scenarios in the business environment.

DS-1 access would most likely be provided initially by special assembly of a fiber optic system. Short wavelength LEDs and APD detectors are used in a WDD scheme that enables unrepeatered transmission over 10 km of 3 dB/km GI fiber.

There are a number of transmission system alternatives to fiber:

- MICROWAVE RADIO
  - Point-to-point or point to multi-point (TDM/TDMA shared access, cellular approach)
  - Requires frequency coordination, line of sight clearance
- SATELLITE
  - Expensive earth terminals for DS-1 access applications, more cost effective at nxDS-1 rate
  - Requires sharing of transponder space to reduce cost
- CATV COAX
  - High channel capacity with shared use
  - Lack of privacy, security and low reliability

Studies within BNR suggest that if coax is to be used for wideband business access, a preferred configuration would be to use a 'hub' concept, whereby a dual cable feeder system would interface with an intelligent hub. Subscribers would

TABLE 5.4: BUSINESS USERS COMMUNICATIONS PROFILE

A. HOSPITAL (500 EMPLOYEES)

APPLICATIONS	1985	bits/yr	1992	bits/yr
VOICE	150 lines	6.48×10^{12} 7.96%	150 lines	6.48×10^{12} 6.46%
TERMINALS	33 units	1.7107×10^{12} 2.103%	42 units	2.1772×10^{12} 2.17%
CPU-CPU	2 hrs/day	1.1523×10^{11} .141%	4 hrs/day	2.304×10^{11} .230%
FACSIMILE	3525 msg/yr	3.8775×10^{8} .0009%	1776 msg/yr	1.9536×10^{8} .0002%
COPIER	1.535 M/yr	7.8321×10^{10} .096%	1.7343 M/yr	8.8449×10^{10} .088%
IMAGE	393 k/yr	7.2626×10^{13} 89%	492 k/yr	9.092×10^{13} 90.59%
VIDEO TELECONFERENCE	5/mth	3.3254×10^{11} .409%	7/mth	4.6569×10^{11} .464%
TOTAL		8.134×10^{13}		1.0035×10^{14}

B. BANK (1000 EMPLOYEES)

APPLICATIONS	1985	bits/yr	1992	bits/yr
VOICE	200 lines	1.152×10^{13} 70.16%	200 lines	1.152×10^{13} 65.6%
TERMINALS	83 units	4.3027×10^{12} 26.2%	100 units	5.184×10^{12} 29.52%
CPU-CPU	4 hrs/day	2.30×10^{11} 1.403%	6 hrs/day	3.456×10^{12} 1.968%
FACSIMILE	5875 msg/yr	6.4625×10^{8} .003%	2960 msg/yr	3.256×10^{8} 0.0018%
COPIER	1.91966 M/yr	9.7902×10^{10} .60%	2.1679 M/yr	1.10565×10^{11} .629%
VIDEO TELECONFERENCE	4/mth	2.66112×10^{11} 1.62%	6/mth	3.99168×10^{11} 2.27%
TOTAL		1.64177×10^{13}		1.7559×10^{13}

C. MANUFACTURING (2000 EMPLOYEES)

APPLICATIONS	1985	bits/yr	1992	bits/yr
VOICE	200 lines	1.152×10^{13} 46.52%	200 lines	1.152×10^{13} 35.27%
TERMINALS	57 units	2.4624×10^{11} 0.93%	66 units	2.8512×10^{11} 0.872%
CPU-CPU	4 hrs/day	2.3×10^{11} 0.93%	66 hrs/day	3.456×10^{11} 1.06%
FACSIMILE	2937 msg/yr	3.2312×10^{8} .0013%	1450 msg/yr	1.595×10^{8} .0005%
COPIER	1.15179 M/yr	5.8742×10^{10} .2372%	1.3007 M/yr	6.6339×10^{10} 0.203%
CAD/CAM	36 units	1.2442×10^{13} 50.24%	58 units	2.0045×10^{11} 61.37%
VIDEO TELECONFERENCE	4/mth	2.662×10^{11} 1.75%	6/mth	3.9916×10^{11} 1.222%
TOTAL		2.4763×10^{13}		3.26614×10^{13}

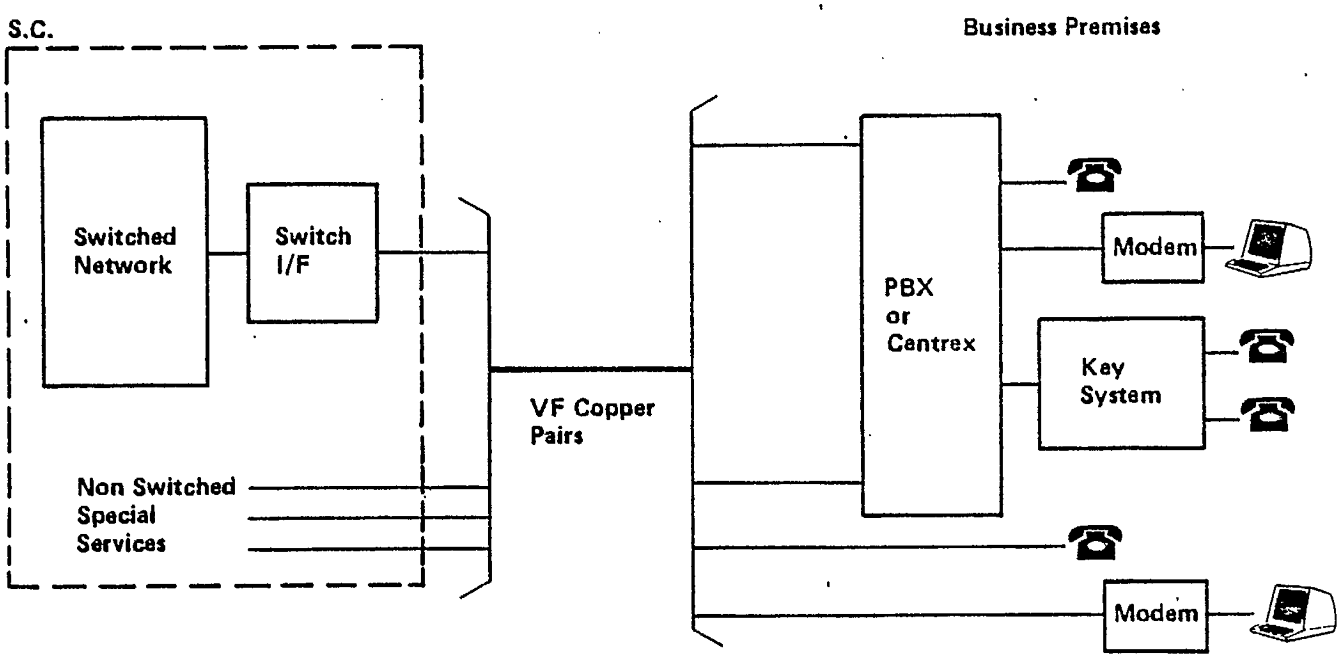
send and receive baseband signals via dedicated drops. The multiplexing and modulation of the various analog and digital signals could be performed within the hub. The sharing of processing facilities would bring cost savings to subscribers.

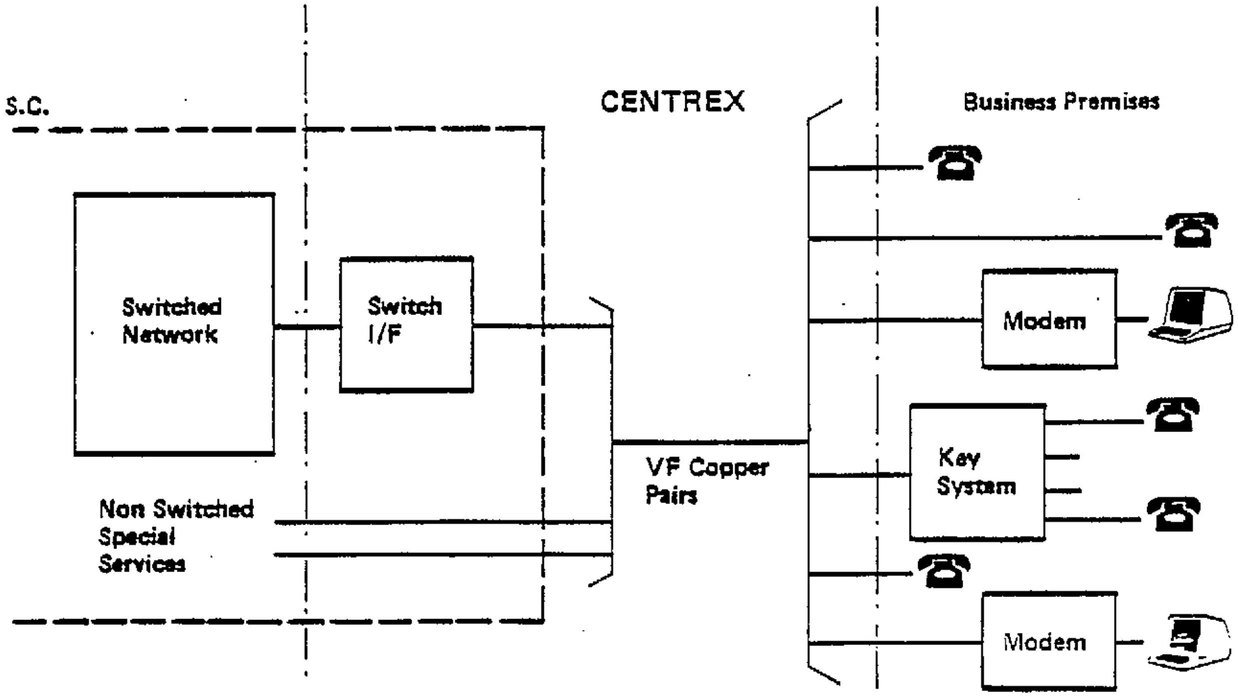
Video service requirements can be handled either by coax for analog (e.g. Bell Canada's local broadband network (LBN), serving Montreal, Ottawa and Toronto) or on DS-1 rate facilities for digital video. It is expected that the major business use of video will be the digital video conference service.

In-building distribution on the business customers premises will likely be copper and/or coax in the near/medium term. The long term view is an access arrangement that is optimized for the total communication needs of the user. A discussion on 'Fiber Optic Applications to Local Area Networks has been included in Appendix C.

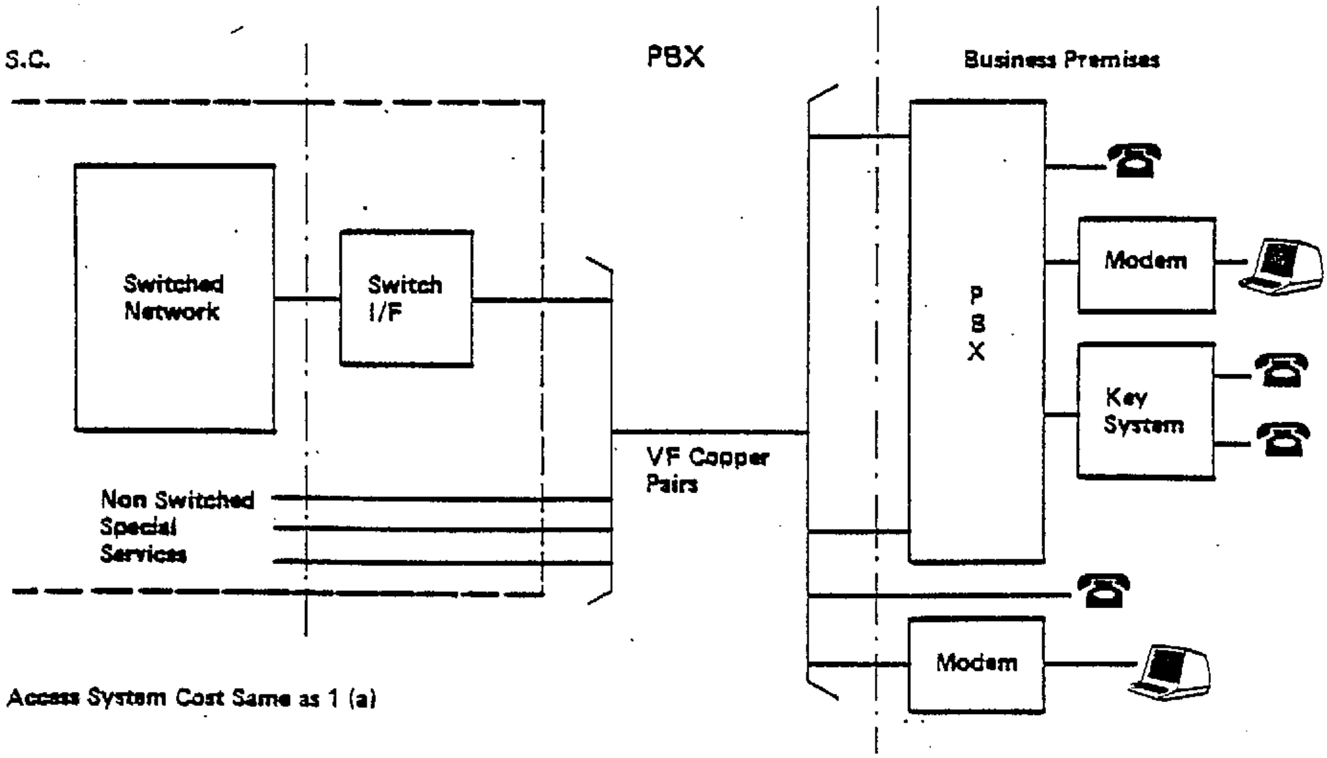
FIGURE 5.8: BUSINESS EVOLUTION SCENARIOS

SHORT TERM





Access System Cost Same as 1 (a)



Access System Cost Same as 1 (a)

6.0 ACCESS NETWORK APPLICATION ANALYSIS

The service projections presented in Section 3 are tailored to the Canadian communications market environment. In Section 6.1, the model chosen to represent Canadian urban subscriber distribution is discussed. Growth projections over the period of 1983-1992 are presented, based on population statistics and historic growth rates. Relevent system cost parameters are included in Section 6.2. Access system costs are projected on a macro-level in Section 6.3, and conclusions concerning the evolving applications of fiber optics to the access network are summarized in Section 7.

6.1 URBAN APPLICATION MODELS

- RESIDENTIAL

The key parameters that must be addressed in choosing application models are (a) the number of customers (households) at (b) a given location demanding (c) a specific service.

a) Based on the latest available Statistics Canada information (1981), there are 66 census areas (CA) with populations ranging from 20,000 to 99,000. Similarly, there are 24 census metropolitan areas (CMA) with population greater than 100,000.

In order to simplify the calculations involved in macro-level costing, urban centers have been grouped together where appropriate, and an average figure assumed for existing number of households. Table 6.1 shows a breakdown of population centers into 18 'clusters'. Based on historic growth patterns determined by previous Canadian statistics, projected linear growth estimates were made.

The scope of this study is limited to urban Canada. Listed below is the overall current coverage of the population centers of more than 20,000.

NO. OF HOUSEHOLDS IN CMA'S (POP 100K)	= 4,849,085
NO. OF HOUSEHOLDS IN CA'S (POP 20K - 99K)	= 1,029,680
TOTAL NO. OF URBAN HOUSEHOLDS STUDIED	= 5,878,765
TOTAL NO. OF HOUSEHOLDS (ALL OF CANADA)	= 8,281,530
PERCENTAGE OF TOTAL HOUSEHOLDS IN CMA'S	= 58.5 %
PERCENTAGE OF TOTAL HOUSEHOLDS IN CA'S	= 12.4 %
PERCENTAGE OF TOTAL HOUSEHOLDS STUDIED	= 70.9 %

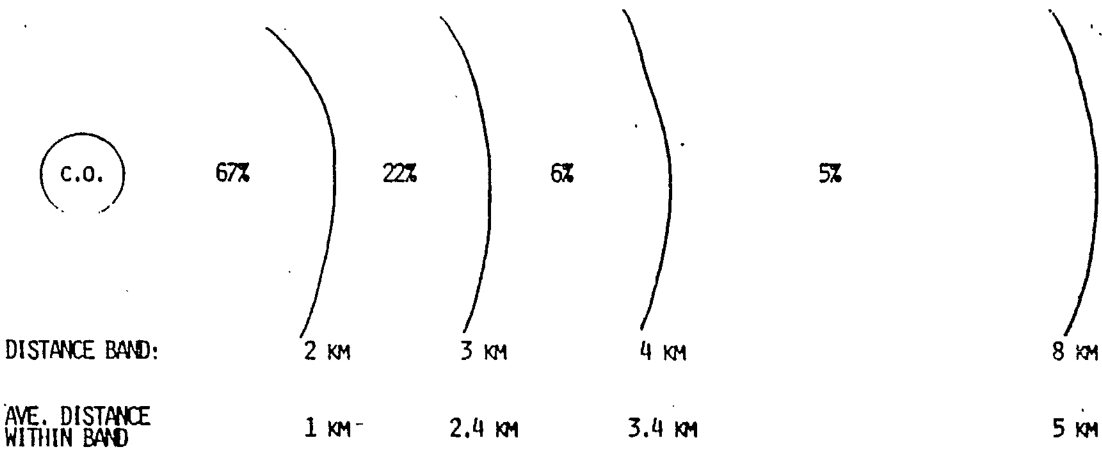
TABLE 6.1: CANADIAN URBAN STATISTICS

POPULATION PER CENSUS AREA	CLUSTER	NUMBER OF HOUSEHOLDS ('000)	NUMBER OF CENSUS AREAS
SMALLER THAN 100,000	1	7 - 10	17
	2	10 - 15	22
	3	15 - 20	10
	4	20 - 25	7
	5	25 - 30	4
	6	30 - 40	6
GREATER THAN 100,000 (METRO CENSUS AREA)	7	37 - 43	5
	8	48 - 51	2
	9	57 - 59	2
	10	86	1
	11	94 - 99	3
	12	106	2
	13	190 - 195	2
	14	211 - 232	3
	15	256	1
	16	477	1
	17	1027	1
	18	1040	1

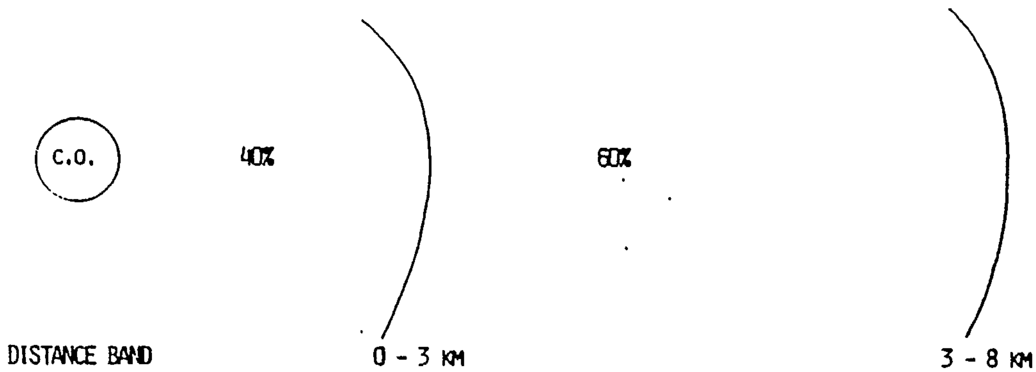
b) The distribution of subscribers along the feeder route portion of the access network must be determined in order to accurately project network costs. Studies done in BNR indicate that for urban routes, the distribution of subscribers with respect to distance from the switching center follows Figure 6.1 (a). The distribution of growth follows Figure 6.1 (b).

FIGURE 6.1 : DISTRIBUTION OF SUBSCRIBERS
Urban Residential and Small Business Routes

DISTRIBUTION OF EXISTING SUBSCRIBERS:



DISTRIBUTION OF GROWTH:



For the actual distribution portion of the network, an aggregate distribution entity model (Figure 6.2) was chosen in order to estimate distribution and drop costs for the system alternatives. For the coax tree distribution system, a detailed distribution design was performed. For star-configured networks, an average distribution length was assumed, based on the dimensions of the model entity.

c) Table 6.2 (a) summarizes the number of households by distance to switching center. A summary of residential telephone lines, existing and growth, is presented in (b). Part (c) is a list of services growth assumption.

FIGURE 6.2: DISTRIBUTION ENTITY MODEL

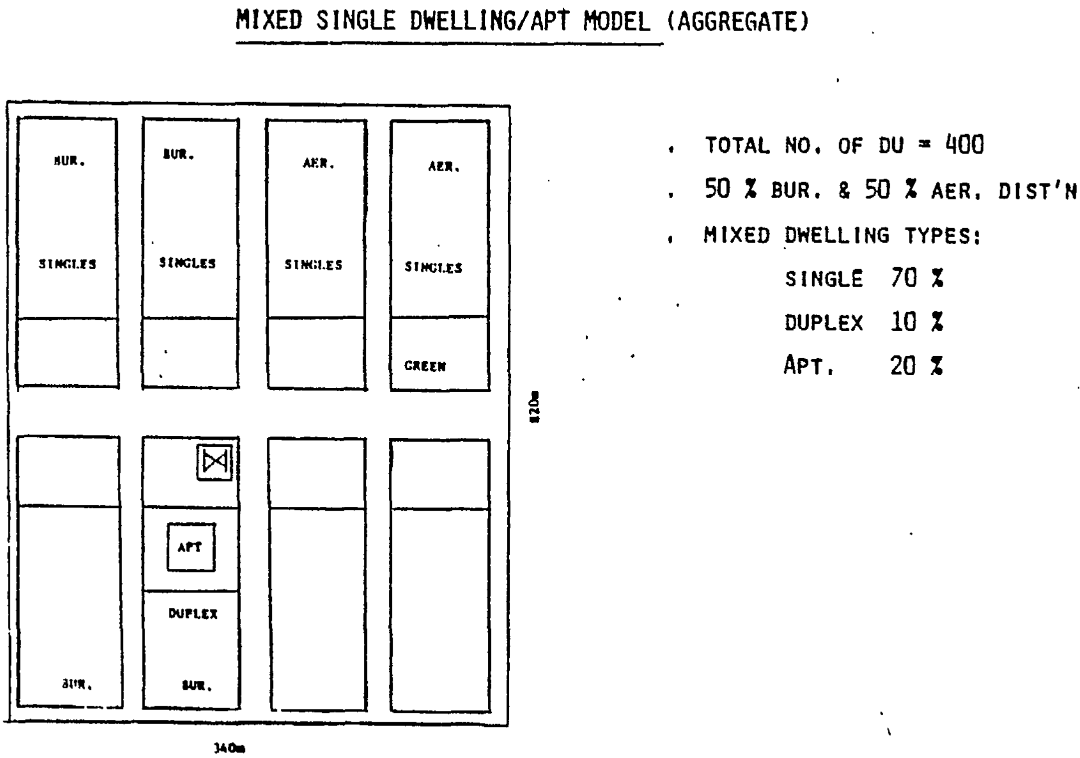


TABLE 6.2: APPLICATION MODEL PARAMETERS - RESIDENTIAL

a) NUMBER OF HOUSEHOLDS (MILLONS)

PERIOD (YEARS)	DISTANCE FROM THE S.C. (Km)				TOTAL
	1.35	2.75	3.75	5.35	
EXISTING 1982	3.991	1.310	0.357	0.298	5.956
GROWTH 1983-1985	0.074	0.039	0.081	0.049	0.243
EXISTING 1985	4.065	1.349	0.438	0.347	6.199
GROWTH 1986-1988	0.064	0.034	0.070	0.042	0.210
EXISTING 1988	4.129	1.383	0.508	0.389	6.409
GROWTH 1989-1992	0.086	0.045	0.094	0.056	0.281
EXISTING 1992	4.215	1.428	0.602	0.445	6.690

b) TELEPHONE GROWTH MODEL (MILLION LINES)

PERIOD (YEARS)	DISTANCE FROM THE S.C. (Km)				TOTAL
	1.35	2.75	3.75	5.35	
EXISTING 1982	5.388	1.769	0.482	0.402	8.041
GROWTH 1983-1985	0.100	0.052	0.109	0.066	0.327
GROWTH 1986-1988	0.086	0.046	0.095	0.057	0.284
GROWTH 1989-1992	0.116	0.061	0.127	0.075	0.379
EXISTING 1992	5.690	1.928	0.813	0.600	9.031

SERVICE PENETRATION ASSUMPTIONS
(HH: household)

Short Term (1982-1985)

- 1% of HH - Data above voice on copper
- 65% of HH - CATV on coax by 1982
- 67% of HH - CATV on coax by 1985
- 9% of HH - Pay-TV by 1985

Medium Term (1986-1988)

- All new growth is served by SMU (IVD: Integrated voice and data), but only 6% of these have SEU, as only these customers require the use of the D-channel.
- 6% of existing lines (1985) are cutover to SMU with SEU (replacement), as they demand new services.
- 77% of HH - CATV on coax by 1988
- 19% of HH - Pay-TV
- 12% of HH - Pay-per-view TV

Long Term (1989-1992)

- 50% of the growth is in new development areas.
- All new development areas are served by the integrated fiber SMU. The rest of the growth is served by the IVD-SMU.
- Of the 50% growth lines on the IVD-SMU, only 10% have SEU.
- 10% of existing lines (1988) are cutover to replaced by SMU (with SEU), as they demand new video services.
- 88% of all HH - CATV by 1992
- 100% of HH in new development areas take CATV of the remaining growth, 77% are served by CATV on coax.
- 30% of CATV subs take Pay-TV, 20% Pay-per-view TV
- 80% of HH in new development areas have ODV
- 10% of HH in new development areas have HDTV

• BUSINESS

The business sector is split into two segments: small and large. Several attempts have been made to characterize business services. Except for the fact that most of the head offices and high-rise business premises are located in the metro-core areas, there is no identifiable pattern on the size of the business (which may correspond to the number of telecommunications facilities required in the premises) and its location (the distance from the switching center). Therefore, a general model based on some available information on the existing network provides a distribution of large business lines versus distance, as shown in Figure 6.3. Small business characteristics follow the residential service pattern. Macro-level business access system costs are based on these models.

FIGURE 6.3: DISTRIBUTION OF BUSINESSES

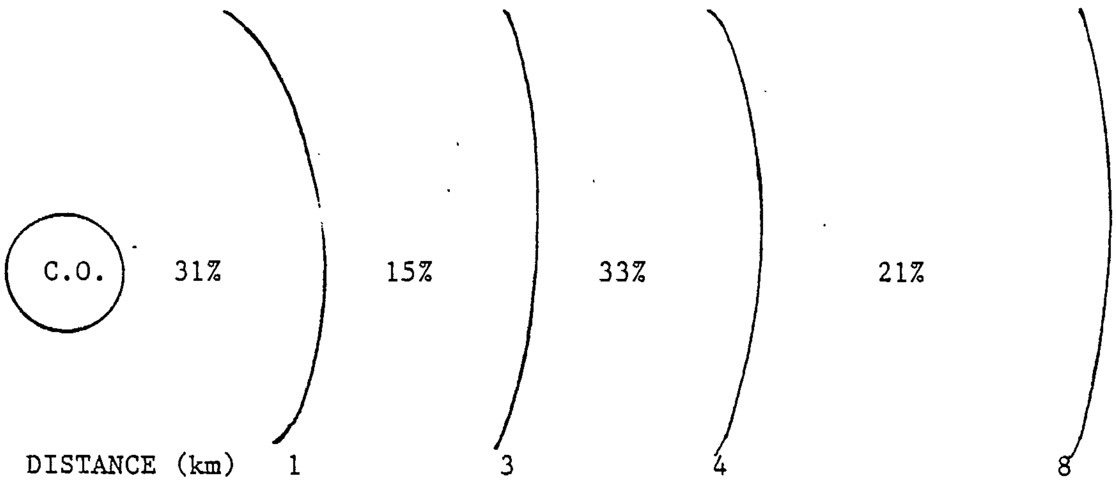


Table 6.3 (a) and (b) shows the service growth by distance band for the business customers.

TABLE 6.3: APPLICATION MODEL PARAMETERS - BUSINESS

a) SMALL BUSINESS GROWTH MODEL (THOUSAND LINES)

PERIOD (YEARS)	DISTANCE FROM THE S.C. (Km)				TOTAL
	1.35	2.75	3.75	5.35	
EXISTING 1982	350	115	31	26	522
GROWTH 1983-1985	12	6	13	8	39
GROWTH 1986-1988	12	6	13	8	39
GROWTH 1989-1992	17	9	18	11	55
TELEMETRY SERVICES					
SHORT TERM (DAV)	8	4	9	5	26
MEDIUM TERM (SMU)	46	24	51	30	151
LONG TERM (SMU)	142	75	156	93	466

8% of the existing plant may be replaced in 10 years.

b) LARGE BUSINESS GROWTH MODEL (THOUSAND LINES)

PERIOD (YEARS)	DISTANCE FROM THE S.C. (Km)				TOTAL
	1.35	2.75	3.75	5.35	
EXISTING 1982	537	163	163	96	959
GROWTH 1983-1985	43	13	13	8	77
GROWTH 1986-1988	43	13	13	8	77
GROWTH 1989-1992	57	17	17	10	101

c) SERVICE ASSUMPTIONS:

- Short Term : All copper facilities
- Medium Term : 20% of growth on DS-1
  Balance on IVD-SMU
- Long Term : 40% of growth on DS-1
  Balance on IVD-SMU
- 12% of the existing plant may be replaced over 10 years.

6.2 SYSTEM COSTS: MICRO LEVEL

Included in this section are the relevent system cost components for each design option. The format of presentation includes a system diagram, followed by a table itemizing the <u>costs per subscriber in 1983 dollars.</u> For the medium and long term designs, costs are projected to the appropriate time frame, with BNR assessment of technology trends and assumed component demands of ≥ 10,000.

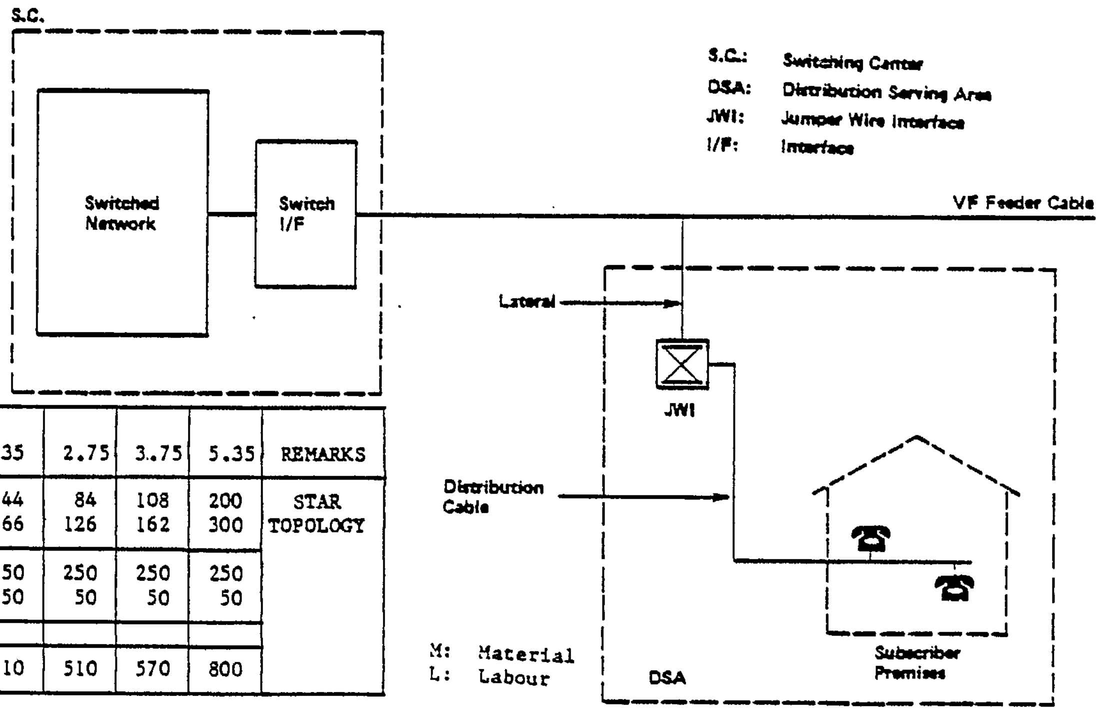
All costs presented herein are BNR estimates, and are not associated with the price commitment of any particular manufacturer unless specifically noted.

It should be noted that the cost of structure (e.g. conduit) has not been included here. As structure is common to all access technologies it has been excluded from the costing exercise. While it may be argued that, for example, fiber occupies less duct space than copper or coax, the benefits of decreased duct utilization may only appear in the time period beyond this study.

The experience within BNR has shown that actual construction costs can vary widely between geographical areas. This phenomenon exists even at the level of urban vs. suburban construction in the same area. The costs estimated here reflect an average situation.

I. PAIRED COPPER TECHNOLOGY

a) Telephone Service

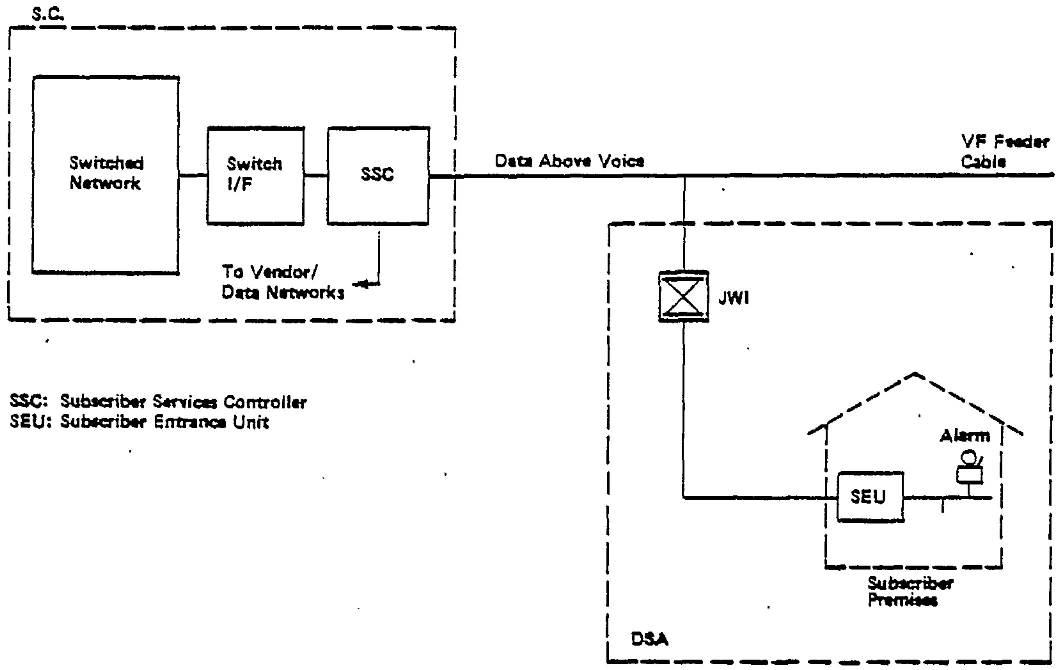


<u>COST PER SUBSCRIBER</u>

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35	REMARKS
COPPER CABLE (FEEDER + DISTRIBUTION)	M L	$ 44 66	84 126	108 162	200 300	STAR TOPOLOGY
SWITCH INTERFACE	M L	$250 50	250 50	250 50	250 50	
TOTAL VF SYSTEM COST		$410	510	570	800	

M: Material
L: Labour

b) Telephone, Telemetry and Low Bit Rate Data Service

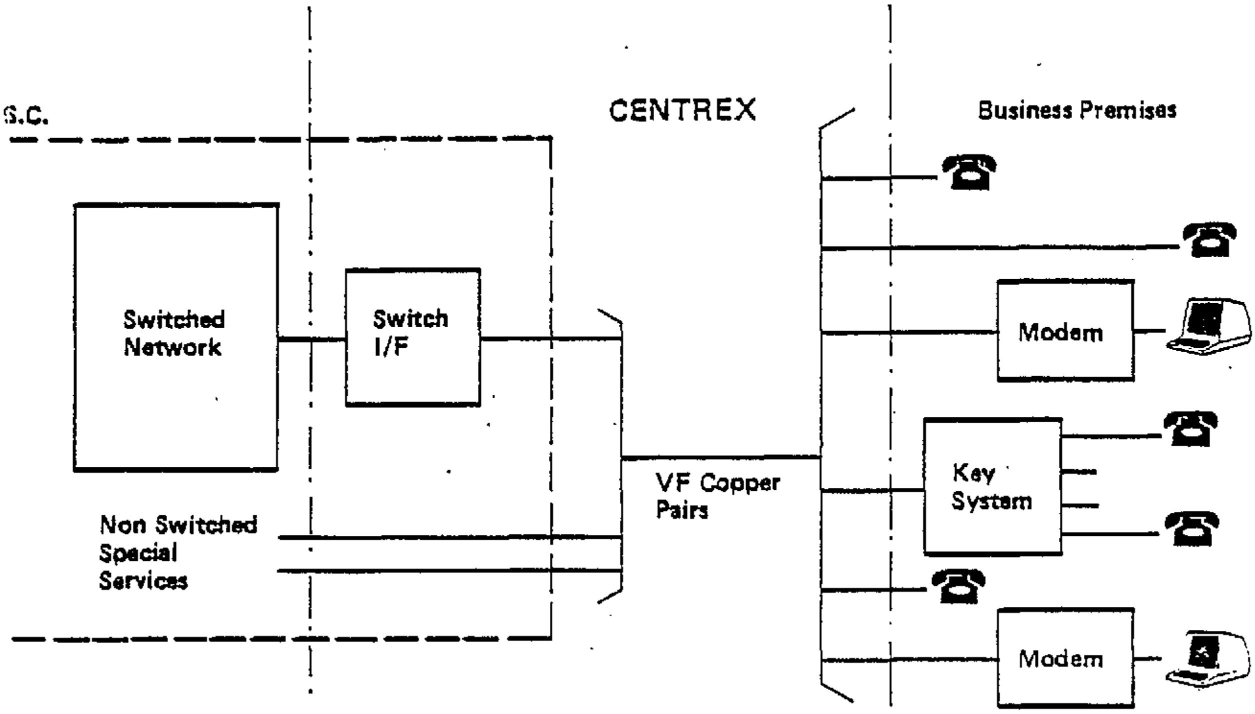


SSC: Subscriber Services Controller
SEU: Subscriber Entrance Unit

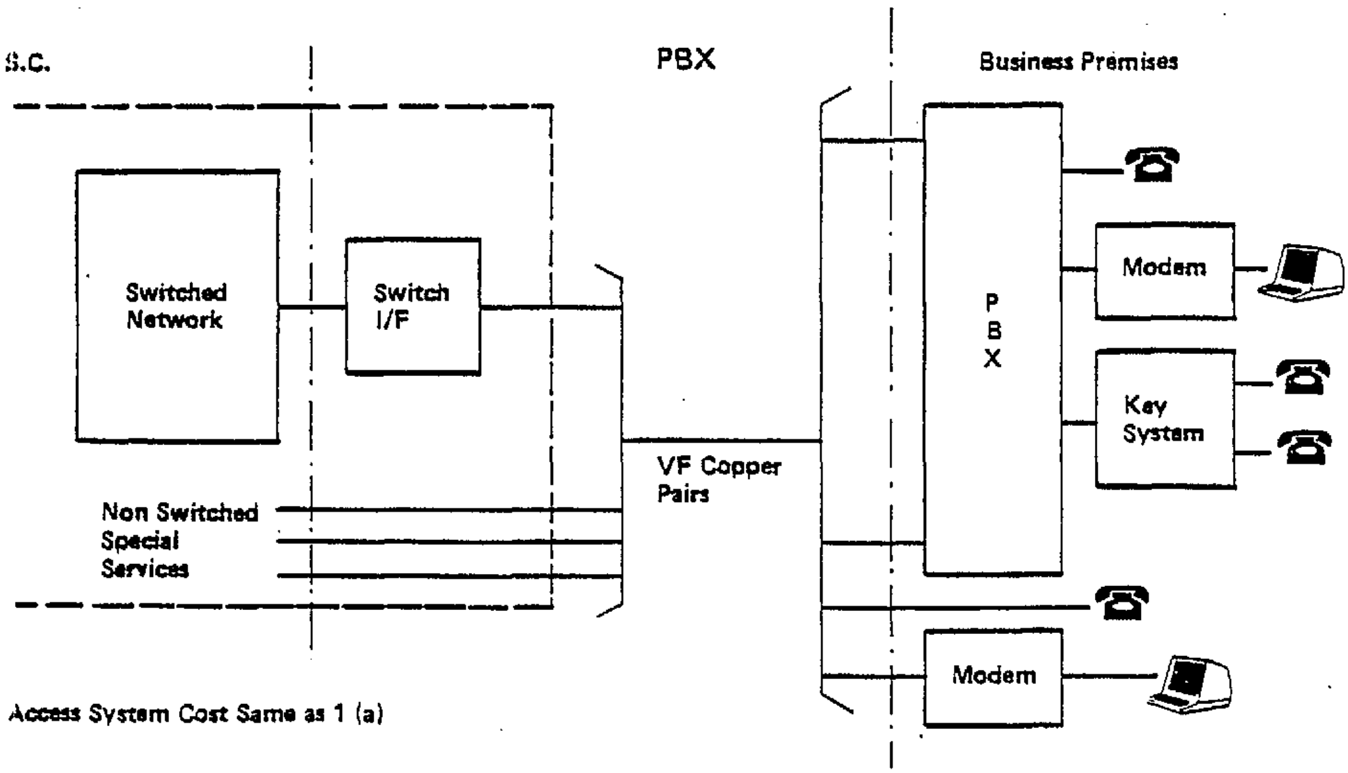
COST PER SUBSCRIBER

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35	REMARKS
VF SYSTEM COST						
MATERIAL		$294	334	358	450	
LABOUR		116	176	212	350	
ADDITIONAL COST FOR						
ALARM ONLY	M	$277	277	277	277	
	L	53	53	53	53	
ALARM + LBR DATA	M	$445	445	445	445	
	L	85	85	85	85	

c) Business Telephone and Data Service



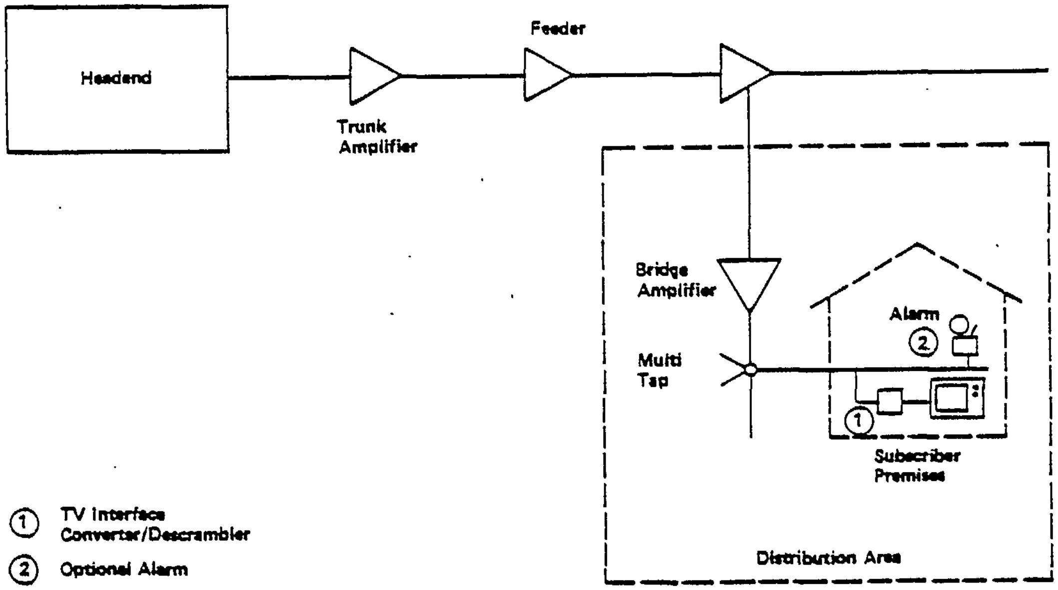
Access System Cost Same as 1 (a)



Access System Cost Same as 1 (a)

II. COAXIAL CABLE TECHNOLOGY

CATV Service



50 TV CHANNELS 1 WAY 400 MHZ SYSTEM
TREE CONFIGURATION
SYSTEM COST IS SHARED BY ALL SUBSCRIBERS

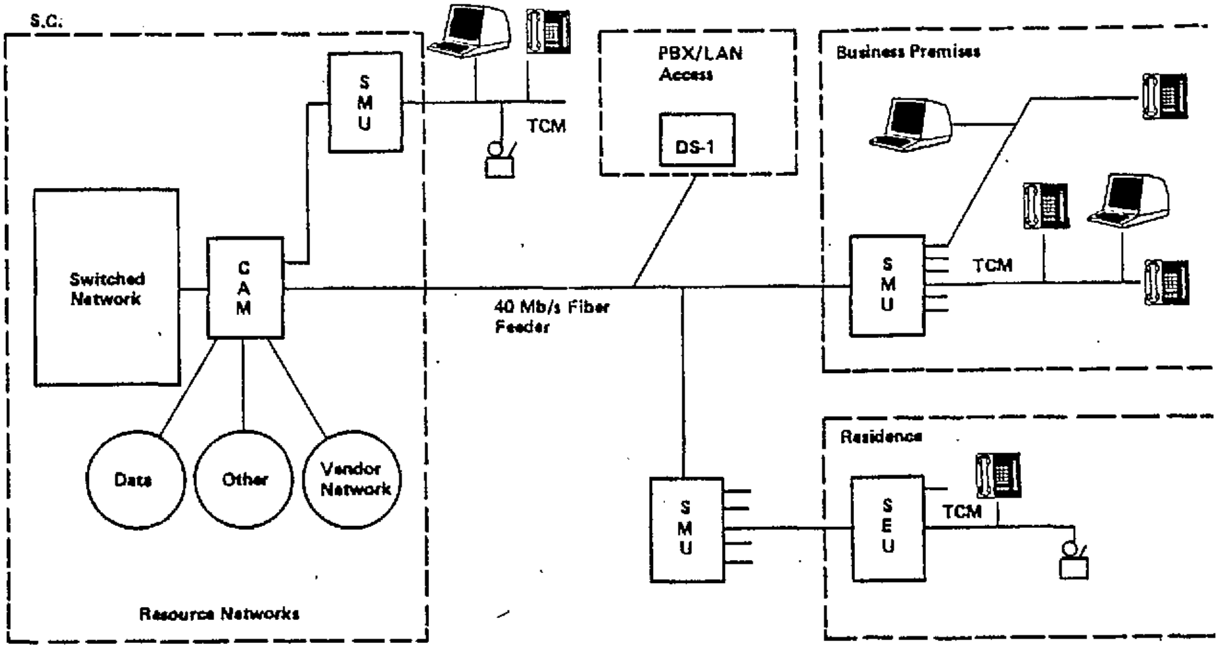
	(85% PENETRATION)	(60% PENETRATION)
FEEDER	$ 10	$ 15
DISTRIBUTION	110	160
AVERAGE COST PER SUBSCRIBER	$ 120	$ 175

ADDITIONAL COST FOR

PAY-TV DESCRAMBLER (FLAT RATE)	$ 25
PAY-PER-VIEW (METERING)	$ 120

III. FIBER OPTIC TECHNOLOGY

a) Residential and Business Market



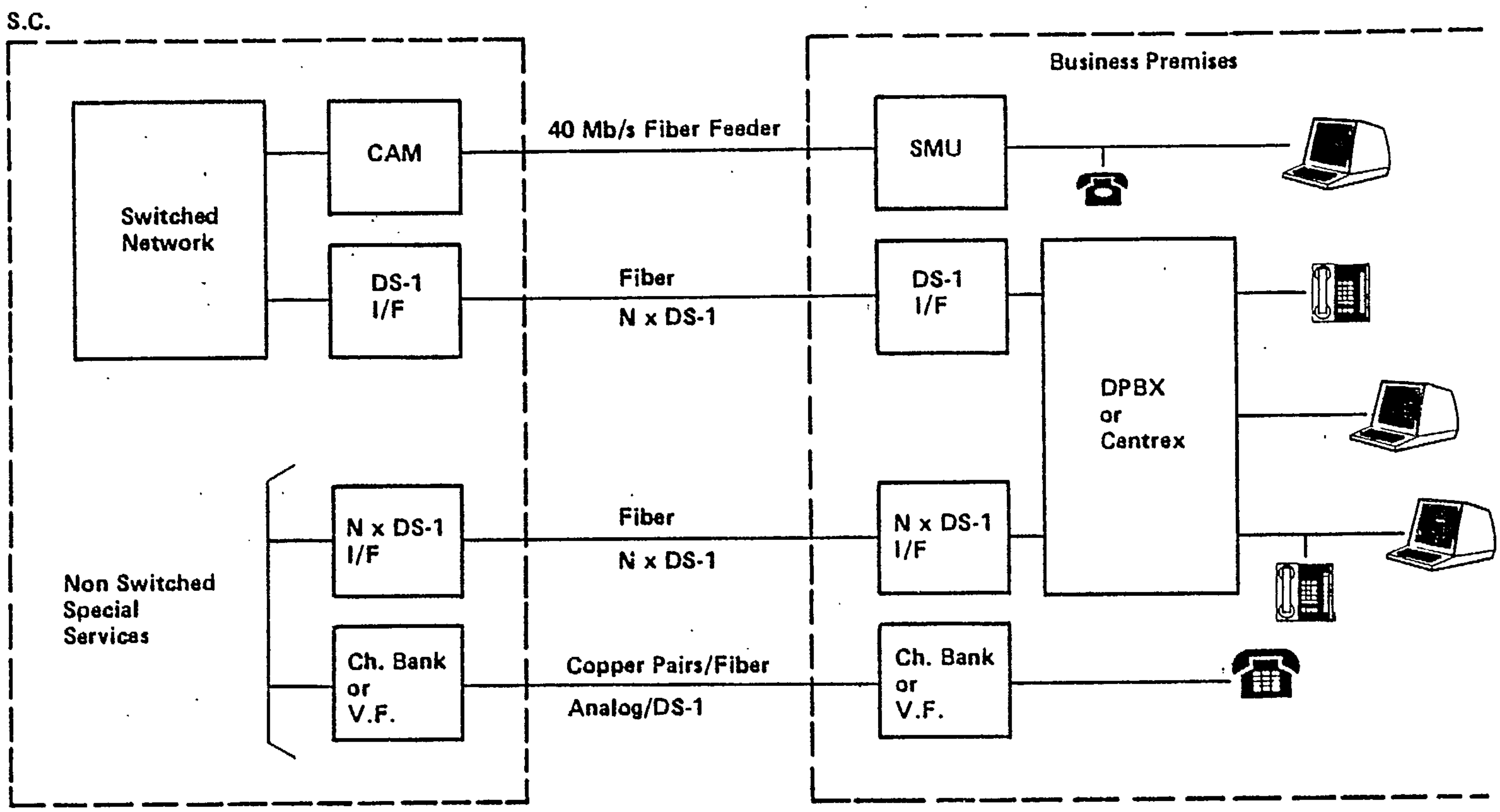
CAM: Customer Access Module
SMU: Subscriber Multiplex Unit
SEU: Subscriber Entrance Unit
TCM: Time Compression Multiplexing (144 kb/s on a Single Copper Pair)

COST PER SUBSCRIBER

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35	REMARKS
SMU & SEU	M	310	310	326	326	
	L	60	60	204	204	
FIBER FEEDER	M	—	—	22	30	FOR SMU
	L	—	—	8	10	LOCATED IN THE FIELD
COPPER CABLE (FEEDER AND/OR DISTRIBUTION)	M	44	84	20	20	(≥3 km FROM
	L	66	126	30	30	SC)
TOTAL SYSTEM COST		480	580	610	620	

(1986 PROJECTED COST IN 1983$)

b) Large Business Sector



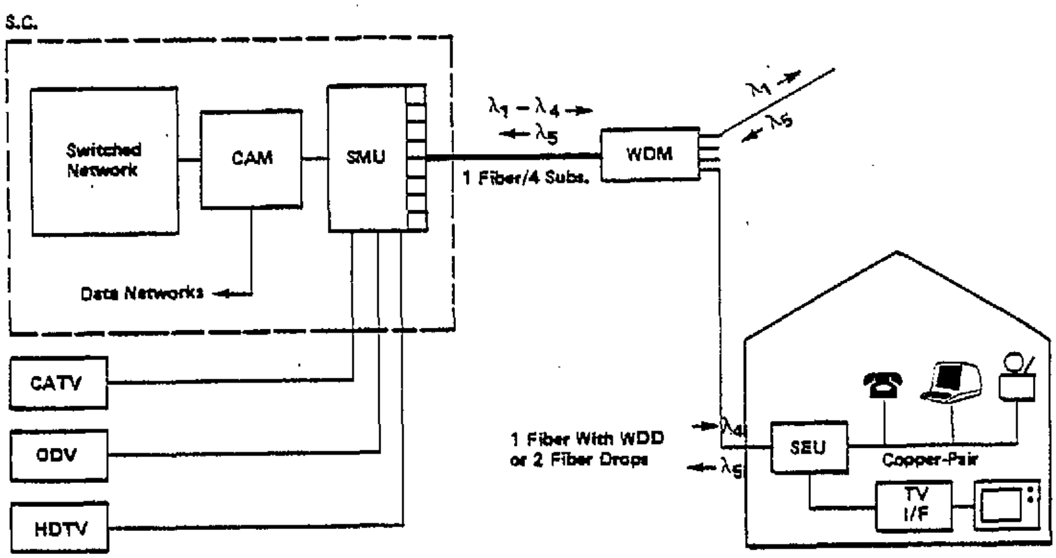
AVERAGE FIBER SYSTEM COST
COST PER DS-1 LINE

DISTANCE FROM THE S.C. (KM)	MATERIAL	LABOUR	TOTAL
1	$ 2360	$ 400	$ 2760
2	2820	510	3330
3	3280	620	3900
6	4660	950	5610
10	6500	1390	7890

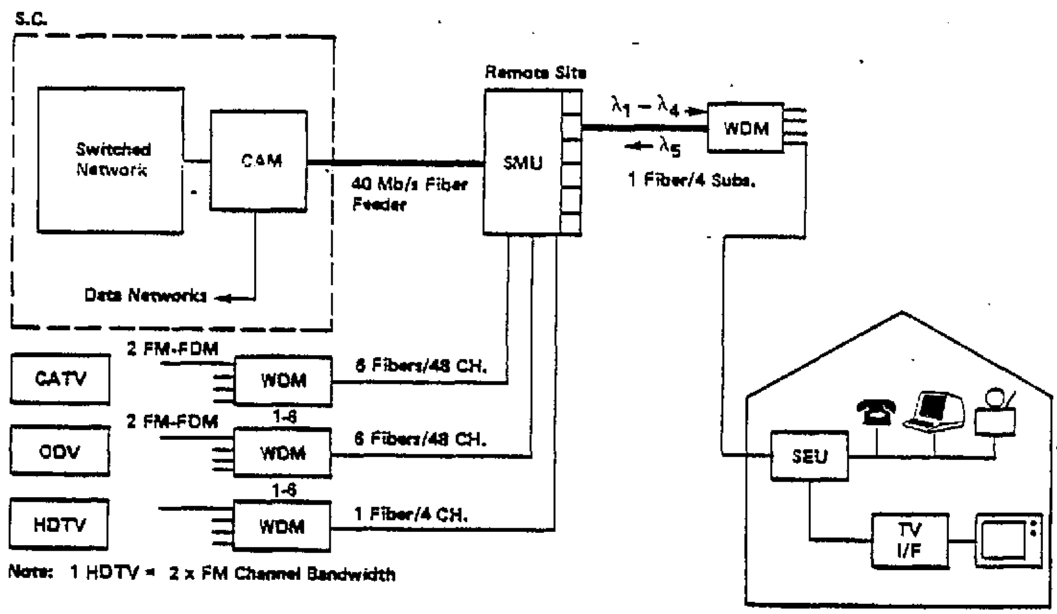
NOTE: For n DS-1 lines, n x the above cost.

c) Voice, Data and Video Integration

(i) SMU Located at the Switching Center



(ii) SMU Located at the Remote Site



SYSTEM COST FOR INTEGRATED SERVICES
OPTION A: Integration of voice, data and non-CATV services

COST PER SUBSCRIBER

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35	REMARKS
FEEDER						
VOICE/DATA	M	—	—	10	14	
	L	—	—	10	16	
ON-DEMAND VIDEO	M	—	—	14	17	
	L			6	13	
HDTV	M	—	—	7	7	INCREMENTAL COST FOR FIBER MATERIAL
	L			3	3	
DISTRIBUTION	M	230	300	210	210	
	L	190	320	160	160	
VOICE/DATA SWITCH, VIDEO SWITCH, SMU & SEU	M	620	620	650	650	SMU IS LOCATED IN THE FIELD BEYOND 3.0 KM FROM THE S.C.
	L	110	110	280	280	
TOTAL SYSTEM		$1150	1350	1350	1370	

(COST IN 1983$ BASED ON THE PROJECTED COST FOR VOLUME PRODUCTION IN 1990)

The above costs for ODV and HDTV are based on 100% penetration in a serving area. With a penetration level of 80% ODV and 10% HDTV in a serving area, the feeder costs are as follows:

		3.75 km	5.35 km
ODV	M	18	20
	L	12	15
HDTV	M	25	30
	L	5	5

SYSTEM COST FOR INTEGRATED SERVICES
OPTION B: Integration of voice, data, non-CATV and CATV video

COST PER SUBSCRIBER

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35	REMARKS
FEEDER						
VOICE/DATA	M	—	—	10	14	
	L			10	16	
ON-DEMAND VIDEO	M	—	—	14	17	
	L			6	13	
HDTV	M	—	—	7	7	INCREMENTAL COST FOR FIBER MATERIAL
	L			3	3	
CATV	M	—	—	14	17	
	L			6	13	
DISTRIBUTION	M	230	300	210	210	-
	L	190	320	160	160	
VOICE/DATA SWITCH, VIDEO SWITCH, SMU & SEU	M	1320	1320	1350	1350	SMU IS LOCATED IN THE FIELD BEYOND 3.0 KM FROM THE S.C.
	L	250	250	420	420	
TOTAL SYSTEM		$1990	2190	2210	2240	

(COST IN 1983$ BASED ON THE PROJECTED COST FOR VOLUME PRODUCTION IN 1990)

6.3 SYSTEM COSTS: MACRO LEVEL

The growth in the short, medium and long terms is estimated. The services penetration are based on the assumptions listed in Section 6.1. Although there is no predetermined procedure to replace some portion of the network it is not unusual for operating telecommunications companies to undertake modernization programs either to upgrade the service provisioning capabilities or to reduce the maintenance and repair costs. A small percentage of the existing plant to be replaced is factored into the growth. The system costs included in Section 6.2 are applied to the urban residential growth model described in Section 6.1. Tables 6.4 to 6.6 contain macro-level cost estimates of the facilities required to provide for the growth and replacement in the 10 year time frame for the residential market. Material and labour costs components are identified, and appropriate quantities of network components are included.

TABLE 6.4: MACRO LEVEL COST PROJECTIONS, 1983-85

SYSTEM	$M MATERIAL	$M LABOUR	COMPONENTS QUANTITY
PAIRED COPPER (VOICE)	110	165	330 K SUBS 1040 Mm
DATA ABOVE VOICE	60	10	62 K SUBS
CATV COAX	40	30	580 K SUBS
PAY-TV	10	5	560 K SUBS

M : MILLIONS K: THOUSANDS
SUBS: SUBSCRIBERS

TABLE 6.5: MACRO LEVEL COST PROJECTIONS, 1986-89

SYSTEM	$M MATERIAL	$M LABOUR	COMPONENTS QUANTITY
INTEGRATED VOICE AND DATA - SMU	150	60	3050 UNITS
SEU	35	10	390K SUBS
FIBER FEEDER	7	3	7 FIBER Mm 13K Tx/Rx
PAIRED COPPER	13	18	290 Mm
CATV COAX	90	75	1360K SUBS
PAY-TV (FLAT RATE)	15	5	660K SUBS
PAY-TV (PER VIEW)	25	5	770K SUBS

M : MILLIONS K: THOUSANDS
SUBS: SUBSCRIBERS Mm: MEGAMETERS

REFER TO TABLE 6.2 FOR GROWTH ASSUMPTIONS AND PAGE 51 FOR SERVICE PENETRATION ASSUMPTIONS

Two system alternatives (medium term IVD-SMU and long term Fiber SMU) are jointly deployed to provide for the residential growth in the long term. The macro level costs are summarized separately in Tables 6.6 (a) and (b).

TABLE 6.6: MACRO LEVEL COST PROJECTIONS, 1990-92

INTEGRATED SERVICES SYSTEM
MACRO LEVEL COST PROJECTIONS

SYSTEM		TOTAL COST $M MATERIAL	TOTAL COST $M LABOUR	COMPONENTS QUANTITY
OPTION-A:				
FIBER CABLE:	FEEDER	2.5	2	11 FIBER Mm
	DISTRIBUTION	6	12	23 FIBER Mm
E/O EQUIPMENT:	FEEDER	4.5	1	6 K Tx/Rx
	DISTRIBUTION	23	7	35 K Tx/Rx
SWITCHING		90	40	141 K SUBS
	TOTAL:	126	62	
OPTION-B:				
FIBER CABLE:	FEEDER	3	3	15 FIBER Mm
	DISTRIBUTION	6	13	23 FIBER Mm
E/O EQUIPMENT:	FEEDER	6	1	7 K Tx/Rx
	DISTRIBUTION	23	7	35 K Tx/Rx
SWITCHING		190	60	141 K SUBS
	TOTAL:	228	84	

M : MILLIONS
SUBS: SUBSCRIBERS
K : THOUSANDS
Mm: MEGAMETERS

INTEGRATED VOICE AND DATA SYSTEM

SYSTEM	TOTAL COST $M MATERIAL	TOTAL COST $M LABOUR	COMPONENTS QUANTITY
SMU	186	57	3100 UNITS
SEU	58	11	655 K UNITS
FIBER	8	4	5 Mm
PAIRED COPPER	16	22	330 Mm
COAX - OPTION A	62	52	953 K SUBS
OPTION B	53	45	812 K SUBS
PAY-TV	11	2	548 K SUBS
PAY-TV (PER VIEW)	17	4	549 K SUBS

Table 6.7 shows tha macro level cost projections for the large business sector, while Table 6.8 addresses the small business service demand. Due to the level of uncertainty associated with the business user model, only the telephony and telemetry services are cost estimated on an aggregate basis. Services such as video would most likely be offered on a per business basis, and the information available only allows for an analysis on a per line basis.

TABLE 6.7: MACRO LEVEL COST PROJECTIONS, LARGE BUSINESS ($M)

COMPONENTS		SHORT	MEDIUM	LONG
PAIRED COPPER	M L	$ 75 110	3 5	—
MEGAMETERS		2480		
SWITCH I/F	M L	260 50	—	—
UNITS				
SMU	M L	—	21 7	21 7
UNITS			470	470
DS-1 I/F	M L	—	1830 280	4890 750
Tx/Rx UNITS			1920	5144
FIBER	M L	—	923 222	2420 580
MEGAMETERS			3	6

TABLE 6.8: MACRO LEVEL COST PROJECTIONS, SMALL BUSINESS

COMPONENTS		SHORT	MEDIUM	LONG
PAIRED COPPER	M	34	4	14
	L	52	6	21
MEGAMETERS		1172	157	484
SWITCH I/F	M	141	—	—
	L	28		
THOUSAND UNITS		562		
DATA ABOVE VOICE	M	24	—	—
	L	5		
THOUSAND UNITS		26		
SMU	M		35	107
	L		18	56
(250 LINES) UNITS			789	3990
FIBER	M		3	7
	L		1	3
MEGAMETERS			3	10

7.0 ACCESS NETWORK EVOLUTION: ANALYSIS

A summary of system costs is provided in Table 7.1. Discussion of the results of the micro-level cost exercise for the residential market is included in Section 7.1. The business market results are discussed in Section 7.2.

TABLE 7.1: SUMMARY OF SYSTEM COSTS

SYSTEM COST PER SUBSCRIBER (1983$)

TECHNOLOGY ALTERNATIVES	DISTANCE FROM THE S.C. (km)			
	1.35	2.75	3.75	5.35
SHORT TERM (1983-1985)				
Paired Copper				
Telephony	$410	510	570	800
Telephony + Alarm	$740	840	900	1130
Telephony + Alarm + Low Speed Data	$940	1040	1100	1330
Coaxial Cable Tree Network Configuration Average cost per subscriber for CATV	$120			
MEDIUM TERM (1986-1988)				
Fiber				
Remote electronics, Fiber feeder and Digital copper distribution Integrated voice and data service	$480	580	610	620
LONG TERM (1989-1992)				
Fiber in the feeder and distribution Integrated services				
Option - A Voice, Data and non-CATV video	$1150	1350	1350	1370
Option - B Voice, Data CATV and non-CATV video	$1990	2190	2210	2240

7.1 RESIDENTIAL ANALYSIS

In the short term, the telemetry service can be provided by both paired copper and coaxial cable systems. The cost of providing this service by either technology seems comparable, which is apparent from the similar rates being charged by both telephone and cable companies.

The penetration of new services in the near future is low, making an applique system such as DAV attractive to an operating company. As service demand increases and the switched digital capability of the telephone network progresses, the use of integrated voice and data digital access systems will become more attractive.

The SMU proposed for the medium term access alternative is a suitable vehicle for such applications. This integrated system is the most economical to provide voice and one additional data service (e.g. alarms).

Studies conducted within BNR suggest that fiber feeder systems are economical compared to copper based wideband systems (e.g. T-1) in digital remote applications. Fiber based systems are cost competitive on a first cost basis, and when maintenance costs are considered, fiber optic systems show clear economic advantages over repeatered copper feeder systems. A rapid introduction of fiber in the feeder network is foreseen. The distribution network will remain as paired copper, which is still capable of providing basic ISDN (144 kb/s) access. This network structure will co-exist with CATV networks, which will continue to provide video services.

The costing exercises included in Sections 6.2 and 6.3 assumed 100% service penetration in order to derive costs on a per subscriber basis. These costs were sensitized using the following scenarios:

1) 100% penetration in a serving area,
2) 85% penetration in a serving area,
3) 50% penetration in a serving area.

Table 7.2 shows the variations in system costs for different levels of video service penetration in a serving area.

TABLE 7.2: INTEGRATED SERVICES SYSTEM COST SENSITIVITY

(Per subscriber cost in 1983$, system introduced in the long term)

AVERAGE DISTANCE FROM THE S.C. (Km)		1.35	2.75	3.75	5.35
OPTION A					
SCENARIO	1	$ 1150	1350	1348	1360
	2	1200	1410	1440	1450
	3	1230	1440	1450	1470
OPTION B					
SCENARIO	1	$ 1990	2190	2206	2220
	2	2040	2250	2300	2320
	3	2070	2280	2320	2320

OPTION A: Integration of voice, data and non-CATV video
OPTION B: Integration of voice, data, non-CATV and CATV video

In general, the cost of an integrated fiber distribution system seems somewhat higher than providing equivalent service using a combination of paired copper and coaxial cable facilities. For example:

Voice, data and non-CATV video:

		2.4 km	5.0 km
(Dual Coax Cable System)	Coax + SMU	$ 820	$ 860
	Fiber	$1350	$1360

Voice, data, non-CATV and CATV video:

(Three Coax Cable System)	Coax + SMU	$ 940	$ 980
	Fiber	$2190	$2220

With due consideration to maintenance costs over time, the upkeep of a copper distribution network and two parallel coax networks weigh favour to the notion of an integrated fiber system including the carriage of about 50 switched video channels, with a single channel distributed to each subscriber.

The following general observations can be made on the integrated fiber system design:

- The inclusion of video switching onto the voice/data line card is expensive, as can be seen in the cost differential between the scenarios including and excluding CATV service. The development of a suitable video switch should be explored, including detailed traffic analysis in order to optimize switch layout.

- The sensitivity analysis indicates that the additional feeder cost (e.g. to accommodate an increased number of video channels) does not significantly influence the total system cost.

- The fiber distribution cost is predominant in the overall facilities cost. Bringing fiber to every home still does not appear to be economical.

- The FM video EDTV format included in the integrated service offering could be provided over existing coaxial cable plant with satisfactory transmission quality. For higher bandwidth transmission formats, the attenuation and group delay distortion limitations of the existing coaxial plant becomes prohibitive to quality HDTV transmission. Fiber optics is a suitable technology for this application, and a stand-alone HDTV fiber distribution system could easily evolve if the service demand materializes. Such a system would probably adopt a hub-type configuration.

- If the cost of video codecs decreases, and NTSC/HDTV video can be digitally distributed, fiber will definitely be suited for this application.

7.2 BUSINESS ANALYSIS

The diversity of service demand in the business market points toward a digital 'pipeline' to the customers premises. Fiber optic transmission systems are capable of high and flexible bandwidth transmission, and show good potential for introduction as this pipeline. The penetration of fiber feeders in conjunction with SMUs will initiate the penetration of fiber into the access network, and will form the backbone of the emerging fiber access network. The system costs for a varying number of DS-1 rate fiber links are included in Section 6.2.

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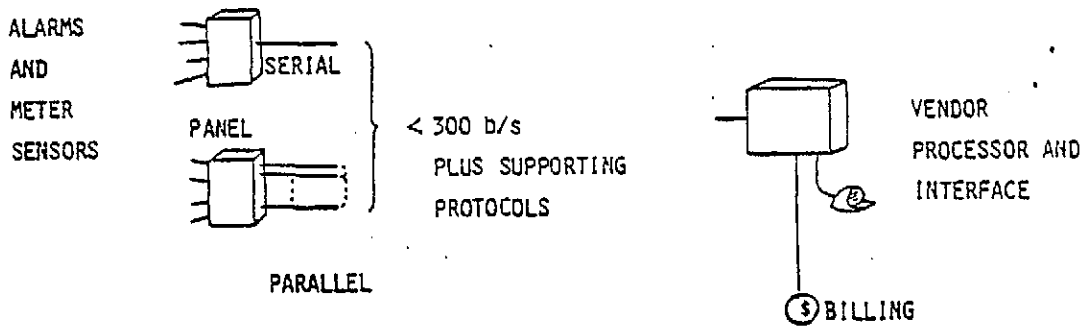
APPENDIX A: SERVICE BLOCK DIAGRAMS AND PENETRATIONS

SECURITY/ALARM AND ENERGY MANAGEMENT: TERMINAL/NETWORK REQUIREMENTS



Security/Alarm Services

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE (millions)	PENETRATION	NUMBER USING SERVICE	# ALARMS/YEAR	SERVICE BUSY PERIOD	ALARM MESSAGES/ YEAR	BANDWIDTH
1983	Residential	8.1	1% (.5)	81,450 (40,500)	3		0.3 0.15	300 bps
	Small Business			10,820 (1,803)	4 messages/ day/business	8-9 am 4-5 pm	10.8 (1.8)	
1988	Residential	9.2	3% (1%)	227,014 (92,000)	3		0.7 0.3	
	Small Business			146,857 (26,129)	4 messages/ day	8-9 am 4-5 pm	146.8 (26.1)	
1992	Residential	10.0	7% 2%	700,525 (200,000)	3		2.1 0.6	
	Small Business			235,162 (92,730)	4 messages/	8-9 am 4-5 pm	235.2 (92.7)	

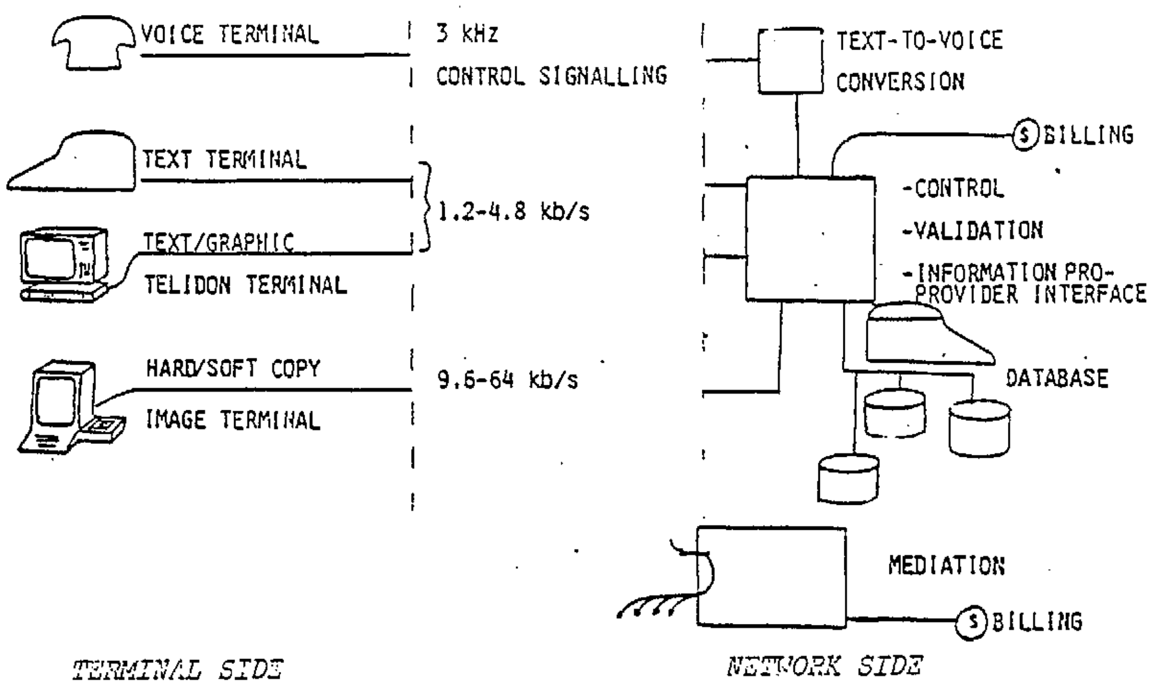
ALARM MESSAGES PER YEAR : Business: 4 mess/day/bus X 250 work days X #bus.
Residence: No. of alarms/year X no. using service

Energy Management*

* Assumes polling 4 times a day

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE (millions)	PENETRATION	NUMBER USING SERVICE (thousands)	NUMBER OF MESSAGES/YEAR (millions)	BANDWIDTH
1983	Small Business	1.0	2% (0%)	20.8 (-)	30.0 (0)	300 bps
1988	Residential	9.2	2% (.5%)	184.7 (46.2)	270 (67)	
	Small Business	1.0	10% (.5%)	104.2 (5.2)	150 (7.5)	
1992	Residential	10.0	5% (1.5%)	500.4 (150.1)	720 (216)	
	Small Business	1.0	50% (1%)	521.0 (10.4)	750 (15)	

TELEBANKING AND DATABASE DOWNLOADING: TERMINAL/NETWORK REQUIREMENTS



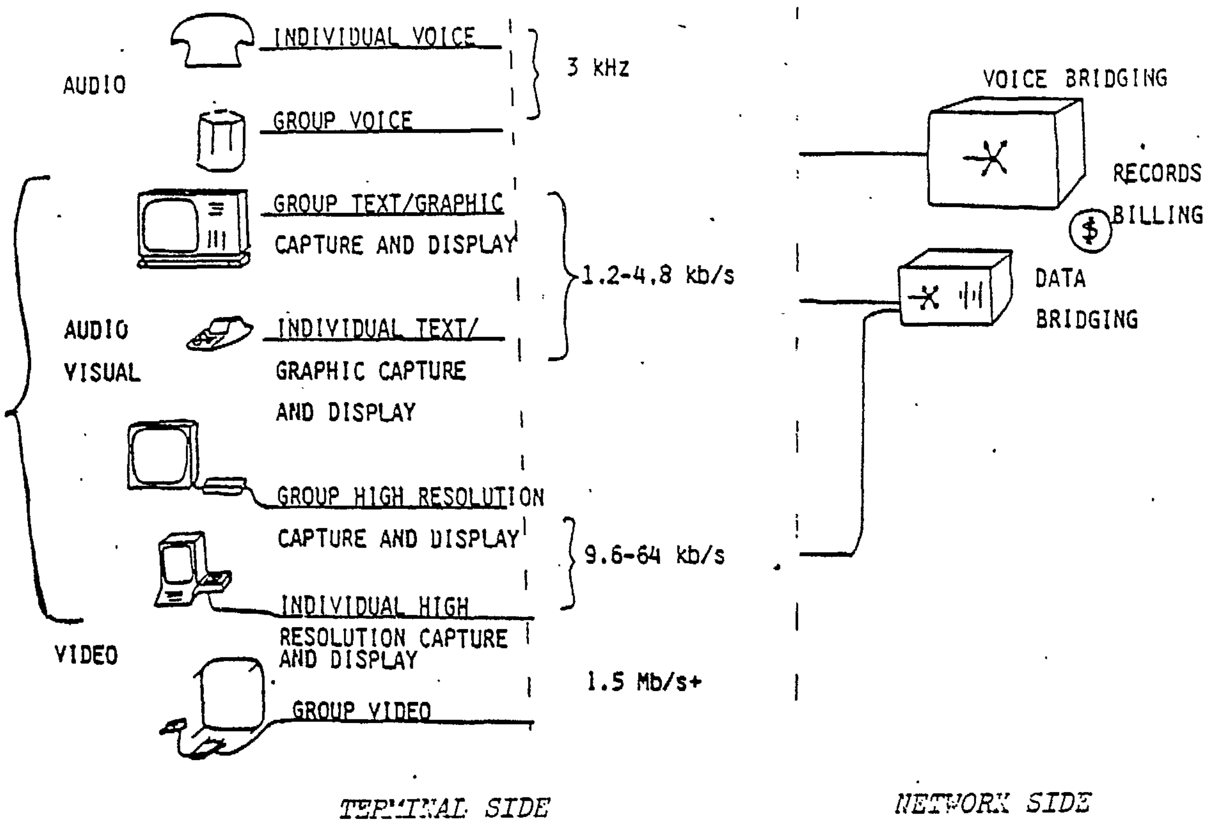
Home Banking

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1988	Residential	9 million	3% (2%)	270,000 180,000	3/month	5-9 pm Thurs.-Fri.	15-30 seconds	4.8 (2.4)	3 kHz (voice)
1992	Residential	10 million	7% (4%)	700,000 (400,000)	6.3/month	5-9 pm Thurs.-Fri.	15-30 seconds	21.8 (10.9)	1.2-4.8 kbps (terminal) 9.6-64 kbps (hard/soft copy)

Database Downloading

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1983	Large Business			Business Location 4,756 (1,806)	2 hours/ week	~ night		17.2 (6.5)	3 kHz (voice) 1.2-4.8 kbps (terminal) 9.6-64 kbps (hard/soft copy)
1988	Small Business	1 million		1,000 (500)	50/busi-ness/year		1 hour	1.8 (0.9)	
	Large Business			9,162 Business Location (5,058)	2 hours/ week			32 (18.2)	
1992	Small Business	1 million	.05 (.01)	5,000 1,000	50/busi-ness/year		1 hour	9 (1.8)	
	Large Business			11,658 Business Location	2 hours/ week/ business location			42 (27)	

TELECONFERENCING: TERMINAL/NETWORK REQUIREMENTS



Teleconferencing: Audio

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1983	Small Business			36,880 23,070	2/business/year	9-12 am 1-3 am	¼ hour	2.0 (1.2)	1.2 - 9.6 kbps
	Large Business	464	99% (90%)	460 418	5 conferences/business location/year	9-12 am 1-3 am	¼ hour	7.5 (6.8)	4 kHz
1988	Small Business			109,540 (54,540)	3/business/year	9-12 am 1-3 am	¼ hour	8.9 (4.4)	
	Large Business	464	99% 90%	460 418	50/business location/year	9-12 am 1-3 am	¼ hour	24.8 (23.8)	
1992	Small Business			202,900 (156,620)	5/business/year	9-12 am 1-3 am	¼ hour	27.3 (13.4)	
	Large Business	464	80% (75%)	371 (325)	75/business location/year	9-12 am 1-3 am	¼ hour	29.7 (27.1)	

Teleconferencing: Audio Visual

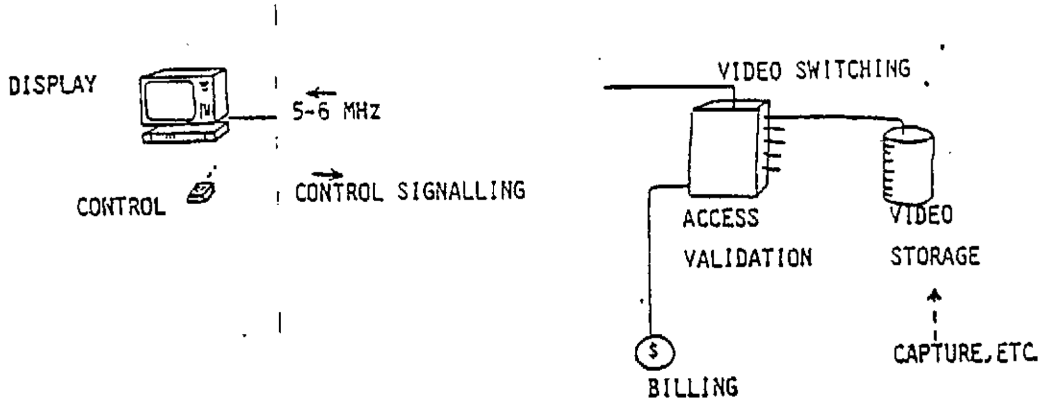
YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1983	Large Business	464	40%		60 conferences/ business/ year	9-12 am 1-3 am	1 hour	0.4 (0.3)	1.2-4.8 kbps High resolution 9.6-64 kbps
1988	Small Business			200 (100)	2 conferences/ year	9-12 am 1-3 am	1 hour	0.01 (0.007)	
	Large Business	464	75% (55%)		20 conferences/ location/ year	9-12 am 1-3 am	1 hour	10 (7.3)	
1992	Small Business			1,000 (600)	5 conferences/ year	9-12 am 1-3 am	1 hour	7.2 (3.6)	
	Large Business	464	90% (70%)		40 conferences/ location/ year	9-12 am 1-3 am	1 hour	24 (18.7)	

Videoconferencing

YEAR	CUSTOMER TYPE	NUMBER USING SERVICE	NUMBER OF CONFERENCES	SERVICE BUSY PERIOD	HOLDING TIME	COST/YEAR (millions)	BANDWIDTH
1983	Large Business		1,700 (200)	9-12 am 1-3 pm	1½ hours	0.09 (0.01)	1.5 mbps
1988			16,000 (3,000)	9-12 am 1-3 pm		0.8 (0.2)	
1992			24,250 (8,500)	9-12 am 1-3 pm		1.3 (0.5)	

Computer Conferencing

YEAR	CUSTOMER TYPE	NUMBER OF CONFERENCES	CALL FREQUENCY	BUSY HOUR TRAFFIC	HOLDING TIME	CCS/ YEAR (thousands)	BANDWIDTH
1983	Large Business	496 (50)	20 conferences/ year	9-12 am 1-3 am	½ hour	8.9 (0.9)	3 kHz (voice channel)
1988	Large Business	14,130 (983)				254 (17.7)	
1992	Large Business	254,340 (17,694)				423.9 (16.6)	



Basic CATV

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1984	Residential	7 million	85%	5,950,000	6-10 pm	6 hours/ day	463,881.6	5-6 MHz
1988	Residential	8 million	91%	7,300,000	6-10 pm	6.5 hrs/ day	621,784.8	
1992	Residential	10 million	95%	9,500,000	6-10 pm	6.8 hrs/ day	802,922.4	

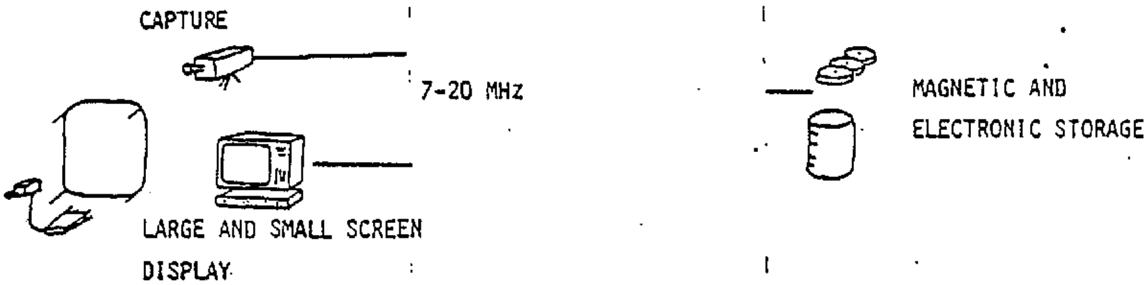
Pay TV

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE (millions)	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1983	Residential	5.9 million	10%	.6	1/week	6-10 pm	1.8 hrs	2,021.8	5-6 MHz
1988	Residential	7.3 million	29%	2.1	1/week	6-10 pm	1.8 hrs	7,076.2	
1992	Residential	8.8 million	51%	4.5	2/week	6-10 pm	1.6 hrs	26,956.8	

On Demand Video

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1988	Large Business			20 (-)	10/location 1 year	9-12 am 1-3 pm	2 hours	0.4 (-)	5.6 kHz
1992	Residential	10 million	4% 2.7	270,000	8/year	6-10 pm	1.5 hrs	116	
	Small Business			19,500 (-)	1/business	9-12 am 1-3 pm	2 hours	1.7 (0.6)	
	Large Business			91 (42)	100/location/year	9-12 am 1-3 pm	2 hours	19.7 (9.1)	

HIGH DEFINITION TV: TERMINAL/NETWORK REQUIREMENTS



High Definition TV

YEAR	CUSTOMER TYPE	POTENTIAL MARKET SIZE	PENETRATION	NUMBER USING SERVICE	CALL FREQUENCY	SERVICE BUSY PERIOD	HOLDING TIME	CCS/YEAR (millions)	BANDWIDTH
1988	Large Business			23 (10)	100/business/year	Business hours	1 hour	7 (3)	20 MHz
1992	Residential	10 million	1% (.5%)	100,000 50,000			1 hour/day/residential user	36 18	
	Small Business			2,500 (250)	50/business/year	Business hours	1 hour	4.5 (2.3)	
	Large Business			94 (45)	100/business/year	Business hours	1 hour	27.1 (12.8)	

APPENDIX B: FIELD TRIALS

A) ELIE : Manitoba Telephone System, Northern Telecom, Bell-Northern Research, Canadian Telcommunications Carriers Association, Department of Communications

- rural project, initiated in 1981
- services included: telephone, CATV, FM radio and Telidon
- remote switched star network configuration

Some of the results include:

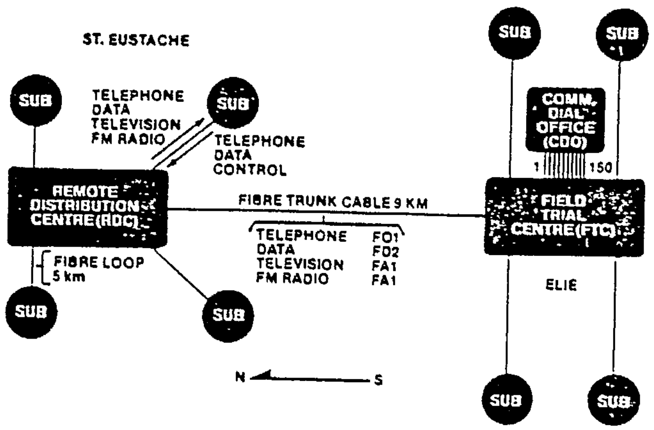
- No breaks in service caused by failure
- No reliability difference between short wavelength laser and LED
- Single party telephone service was the most popular service
- MTS project manager predicts that integrated fiber system will only become cost effective in 5-10 years

• FIBER PARAMETERS

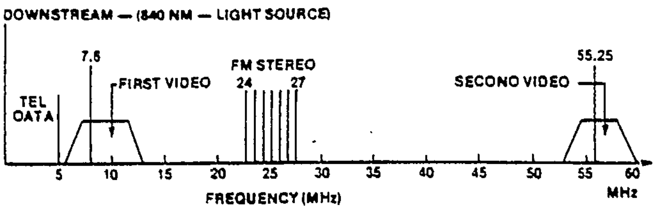
TYPE	GRADED INDEX
PROCESS	I.V.P.
NA	0.17
ATTENUATION	<4 db/km (840 and 930 nm)
3 dB — OPT. BDW.	600 MHz
CORE — DIAM.	50 µm
CLADDING — DIAM.	120 µm
COATING — DIAM.	320 µm

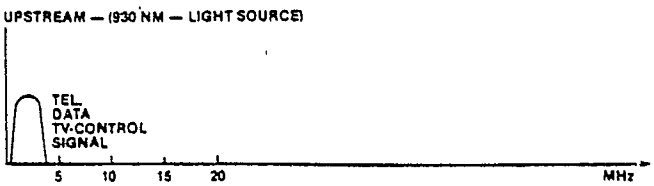
• CABLE INSTALLATION DETAILS

TRUNK LENGTH	9 km
TOTAL LOOP LENGTH	75 km
CABLE PLACEMENT	70% BURIED 30% AERIAL



ELIE : SPECTRUM ALLOCATION



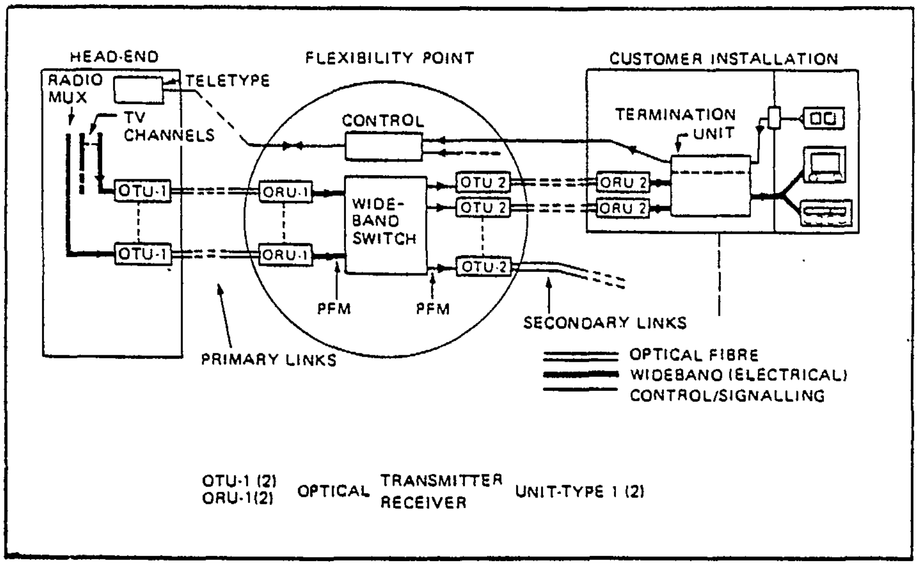


B) MILTON KEYNES 'FIBREVISION' (British Telecom)

- 1982 implementation
- switched (star) TV program provision under microprocessor control to 18 customers (upgradeable to include other services)
- CATV signals distributed by pulse frequency modulation of short wavelength ELED
- switching system uses ECL buffers and reed relay cross-points, although noise leakage was a problem

Some of the needs identified in this trial for future implementation of fiber optic distribution systems include:

- overall cost reductions in medium-high quality components (e.g. high bandwidth LEDs, low loss double-window fiber)
- improved, less labor intensive techniques for connecting and splicing fibers
- wider range of optical couplers to facilitate WDM and tapping of the optical signal



The basic Fibrevision trial network

C) BIGFON (Deutsche Bundespost)

- in service by late 1983, operational till 1986
- mixed analog and digital and all-digital transmission experiments
- services: n * ISDN, 4 PAL TV, 4 FM stereo and videophone

Observations on the goals of this experiment:

- cost reductions are required for fiber optic cables in the
  subscriber loop
- widespread introduction of digital transmission techniques will require the development of VLSI
- this sort of gamble on technology will help create the demand that will drive the costs of components down

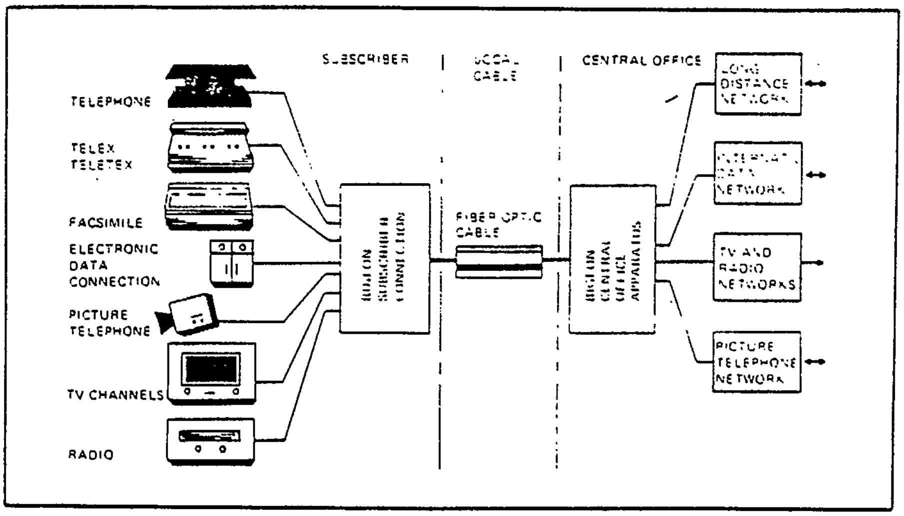


Diagram of services on BIGFON prototype networks

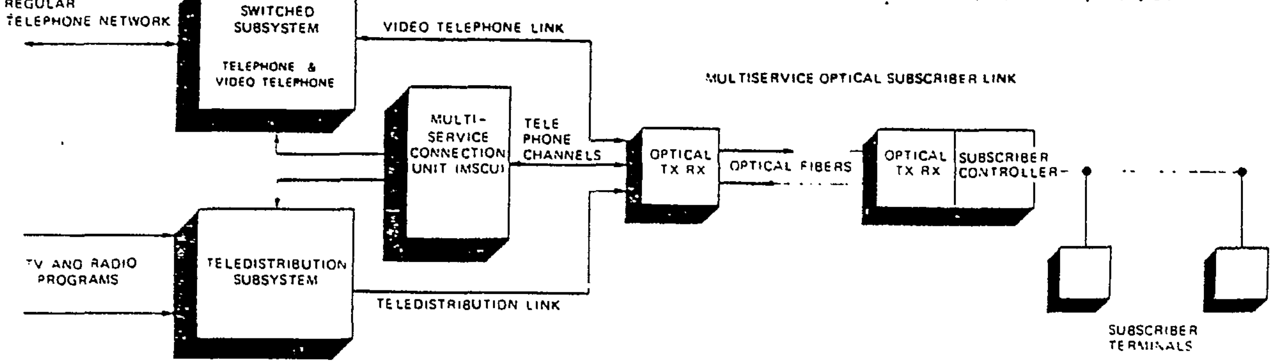
D) BIARRITZ (Direction Generale de Telecommunications, Societe Anonyme de Telecommunications, Lignes Telephoniques et Telegraphiques)

- under installation (1983)
- services: 2 SECAM TV, digital voice, 1 FM radio, videophone
- short wavelength components used - FM radio feeder and upstream subscribers transmission use LED, all others use lasers, all but subscribers premises (PIN) use APD
- TV, videophone are FM modulated while FM radio is transmitted at 128 kb/s

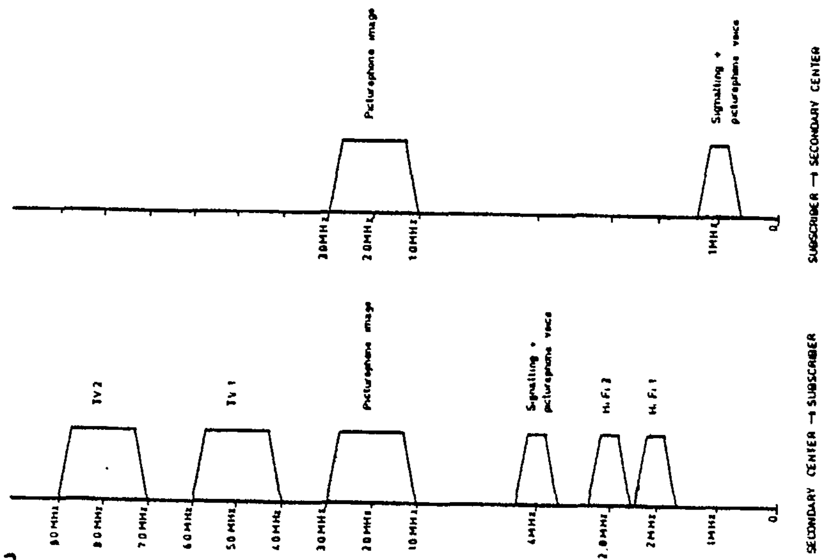
Future developments anticipted in the subscriber loop include:

- improved video switching (less crosstalk)
- minimization of fiber costs points toward increased use of WDM and optical components for network

BIARRITZ: NETWORK CONFIGURATION



BIARRITZ: SPECTRUM ALLOCATION



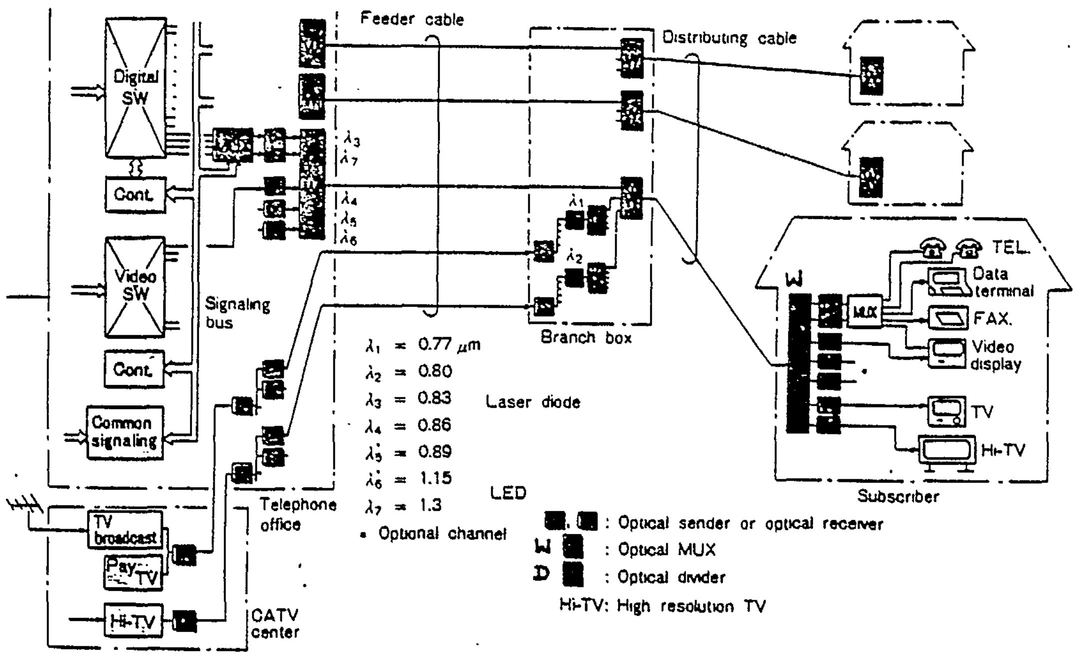
E) JAPAN (NTT)

- residential and business subscriber loop field trial in Yokosuka in 1980-1981
- experiments conducted on LED and laser FM-IM, PCM-IM and PFM-IM video transmission
- Mitaka field trial to be conducted for subscriber loop system in order to isolate technical problems and determine service trends
- after 1985, integrated fiber subscriber loop systems will be introduced on a nationwide scale

Main Parameters of Field Trial Systems

Items \ Systems	Business-use subscriber systems		Home-use subscriber systems		CATV distribution systems		1.5Mb/s digital system
Transmission signal	6.3Mb/s digital	4MHz NTSC-TV	1.5Mb/s digital	4MHz NTSC TV	HD-TV	VHF TV	1.5Mb/s digital
Transmission distance	7 km		5 km		—		12 km
Optical fiber cable	Graded index multimode fiber*1						
Modulation scheme	CMI	analog baseband	CMI	analog baseband		VHF band	CMI
Optical source	GaAlAs-LD		GaAlAs-LD / InGaAsP-LED	GaAlAs-LD / InGaAsP-LED	GaAlAs-LD		GaAlAs-LD
Wavelength *2	down 0.80μm / up 0.83μm	down 0.86μm / up 0.89μm	down 0.89μm / up 1.15μm	down 0.86μm / up 1.3μm	0.86μm	0.80μm	down 0.83μm / up 0.89μm
Optical detector	Si-APD	Si-PIN-PD	Si-APD / Ge-APD	Si-APD / Ge-APD	Si-APD		Si-APD
Multi/demultiplexer	grating type		grating + interference filter type		interference filter type		interference filter type

*1 transmission loss [illegible] 4 dB/km bandwidth [illegible] 150 MHz·km
*2 down: end office to subscriber, up: subscriber to end office



One future image for optical fiber subscriber loop system

REFERENCES: Field Trials

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(4) P. Gravey, "The Wired City of Biarritz: A First Step to an Optical Multiservice Network", Proc. ICC '82.

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"Experiences with the Elie Fiber Optic Field Trial"
"The Fibrevision Trial at Milton Keynes"
"The Bigfon Project of the Deutsche Bundespost"
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(6) M. Shinji, M. Koyama, K. Asatani, "Present and Future of Fiber Optic Subscriber Loop Network in Japan", Proc. ICC '82.

(7) T. Soejima "Research and Development on Optical Fiber Cable Transmission", Japan Telecommunications Review, October 1982.

APPENDIX C: FIBER OPTICS IN LOCAL AREA NETWORKS

A local area network is a communications medium used to interconnect computers, terminals and other peripheral equipment, typically located within a few kilometers of each other. The drive for the development of such networks is a reflection on the decreasing cost of sophisticated terminal hardware and the consequent drive to interconnect these workstations in an economic way.

Some of the key criteria of LANs follow:

- 100% availability
- growth capability without interruption or reconfiguration
- low cost

While relatively simple protocols can be used to cost effectively implement LANs, it must be kept in mind that in the future, LANs will interconnect to various other public and private data networks. The IEEE 802 committee is working towards a standard protocol, aligned with the ISO Open Systems Interconnect layered architecture.

Table C1 [1] lists the network topology alternatives and features of LANs. To date, the most popular methods used to share the LAN medium have been contention/collision detection (CSMA/CD) and token passing. PBX manufacturers are also beginning to offer integrated voice and data switching, and Northern Telecom's OPEN WORLD announcement is a reflection on this evolution towards efficient, consolidated and flexible business communications offerings.

TABLE C1: LAN NETWORK TOPOLOGY ALTERNATIVES

	Parameters			Features		
Network topology	Number of network links	Network protocol	Link data rate	Ease of expanding or tapping	Perceived network reliability	Ease of synchronization
Fully connected	$\frac{1}{2}(N)(N-1)$	Polling	Node rate	Difficult (many extra lines)	High	—
Star	N	Polling	Node rate	Moderate	High	Easy (nodes independent)
Ring or loop (active repeaters)	N	Multiplexing or contention	$> N \cdot$ (node rate)	Moderate (shut down network)	Low	Easy
Distributed data bus	1	Contention	> (node rate)	Easy (with coax)	High	Difficult

Currently, most LANs use coaxial cable. However, these networks offer some inherent drawbacks: intolerable variable delays (CSMA/CD), security problems, power distribution problems and noise interference. These networks encompass data rates from about 100 bd to 10 Mbd and link lengths from 1 - 2000 meters. It has been suggested [1,2] that for first generation local networks, coax-compatible fiber optic LANs will be developed and used primarily to extend link lengths and provide noise immune transmission where required. When higher speed (> 10 Mbd) communications requirements mature, fiber will play a more central role. One forecast [3] predicts that demand for fiber based LANs will exceed all other LAN technologies as early as 1986. The contrasting fiber optic equipment requirements different communications needs are included in Table C2 [1].

TABLE C2: CONTRASTING DATA COMMUNICATIONS REQUIREMENTS

Application summary			
Link length (km)	Long (> 1.5)		Low–moderate (< 2)
Data rate	Moderate–high		Low–high
Digital terminal hardware	Complex		Simple
Diversity of applications	Low		High
Disconnections and changes	Low		High
Design choices	First generation:	Second generation:	
Optical source	LD at λ_0 = 850 μm	LED at λ_0 = 1.3 μm	Light-emitting diode (LED)
Optical detector	Silicon APD	GaInAs p–i–n	Silicon p–n or p–i–n diode (PD)
Multimode fiber design			
Attenuation (dB/km)	Low (< 7)	Low (< 2)	Moderate–high (5–300)
Bandwidth–distance (MHz-km)	High (≥ 200)		Moderate (10–200)
Numerical aperture (NA)	Moderate (0.2)		Moderate–large (0.2–0.5)
Core diameter (μm)	Small (≤ 50)		Moderate–large (80–400)
Optical connector loss (dB)	Low (0.5–1.0)		Moderate (1–3)

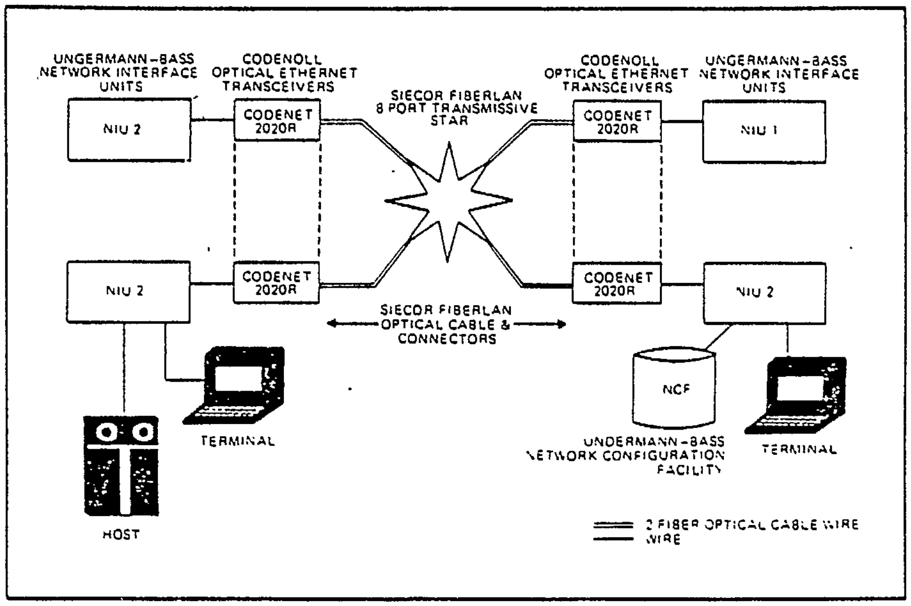
Some of the problems in implementing a multiply-tapped bus on fiber include:

- difficulty in launching adequate power
- receiver design constraints in implementing dynamic contention protocols
- difficulty in fabricating low loss optical splitters and couplers. Also, insertion of devices into the bus will take the bus out of operation.

The lack of reliability, serviceability, standardization of components and high cost of fiber technology due to the newness of the technology make it somewhat less competitive than coax for immediate application. Due to the ease of designing point-to-point fiber connections, a ring-based system is well suited to implementation in fiber. While the contention bus has received the most developmental attention in the U.S., the ring has undergone much research in Europe and Japan. BNR is currently involved in the design of an 80 Mb/s fiber ring LAN using short wavelength LEDs and PIN detectors. The maximum loop length in this system is 10 km, with a maximum of 256 nodes spaced at a maximum of 0.5 km apart. A token pass protocol is used.

Ungermann-Bass has recently introduced Net/One, a fiber optic local area network compatible with existing CSMA/CD networks (e.g. Ethernet) [4]. With a BER measure at $< 10^{-9}$, this system boasts double the Ethernet 500m link length. With the current system configuration (Figure C1) and a receiver sensitivity of -43 dBm, up to 32 ports could be configured at a node separation of 2.2 km.

FIGURE C1: NET/ONE FIBER OPTIC LAN



Configuration of Siecor, Codenoll, and Ungermann-Bass' Fiber Optic Net/One

Transmitter output power	–5 dBm, worst case
Receiver sensitivity for 10^{-12} BER	–32 dBm
Connector loss, 1 dB/connector	4 dB total
Transmissive star loss	10.5 dB, worst case
Fiber loss, 2 x 500 meters	6 dB
Margin*	6.5 dB
Total available system gain	26 dB

*Note: given a margin of 3 dB, a 16 port star could be used with the present equipment.

Other possibilities for networks utilizing fiber include a switched star fiber LAN utilizing TDM-PAM, based on a broad-band analogue optoelectronic PBX [5].It has been suggested [6] that TDM may be the simplest medium sharing scheme where there is sufficient bandwidth to implement it, as is the case with fiber. In the example network, voice and data up to 64 kb/s or 100 kHz could be switched, in addition to standard VHF-TV channels. A summary of existing (1982) fiber optic based LANs can be found in [7].

A thorough review of fiber optics applications to LANs was recently conducted within BNR. The major observations and conclusions include:

1) Fiber cable is the most expensive item in networks over about 500m, thus the cost of cable suitable for intra-building communications must come down to below $1/m. This cable must be easy to install and meet safety and mechanical specifications appropriate to inexpensive in-building distribution.

2) Receiver circuitry is liable to be a high cost component in several LAN applications. A streamlined design in a cheap and easy to connect package is necessary.

3) Active (regenerating) nodes are attractive due to the 'unlimited' number of nodes which can be accommodated.

In conclusion, point-to-point LAN systems are the easiest to implement with fiber optic technology. Low cost components are available today, and nodes for 20 and 80 Mb/s fiber optic systems can be obtained for about $70 and $125 respectively, based on off-the-shelf components. Several manufacturers have already committed to fiber optic LAN technologies, in an effort to provide what they view as the most viable long term strategy for local area networks.

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APPENDIX D: SYSTEM COST INFORMATION

Cost details for the access systems are included in this appendix. These costs are BNR estimates, and do not imply the price commitment of any particular manufacturer unless specifically noted.

ACCESS SYSTEM FACILITIES COST (1983 $)

COAXIAL CABLE (FEEDER AND DISTRIBUTION)

CABLE COST $ PER METER

SIZE	MATERIAL	LABOUR	TOTAL
.75"	2.50	3.75	6.25
0.5"	1.60	2.40	4.00
0.412	1.20	1.80	3.00
RG59	0.25	0.35	0.60

EQUIPMENT (400 MHz, 1-WAY) COST

	MATERIAL	LABOUR	TOTAL
TRUNK AMPLIFIER	2000	1000	3000
BRIDGING AMPLIFIER	2300	1200	3500
LINE EXTENDER	460	230	690
MULTITAP	30	30	60

ACCESS SYSTEM FACILITIES COST (1983 $)

PAIRED COPPER (FEEDER NETWORK) $/PAIR

DISTANCE BAND (KM)	0-2	2-3	3-4	4-8
AVERAGE DISTANCE WITHIN BAND (KM)	1	2.4	3.4	5
MATERIAL	30	70	100	180
LABOUR	40	100	140	270
TOTAL	70	170	240	450

NOTE: DISTANCES REFLECT GAUGE CONSIDERATIONS

DISTRIBUTION: AVERAGE DISTANCE 300 METERS OF 28 G AT $20.00

ACCESS SYSTEM FACILITIES COST (1983 $)

- BASED ON THE ESTIMATED COST OF PLACING 24 FIBER CABLE
- FIBER CABLE CONTAINS 2 COPPER PAIRS
- COST PER FIBER - KM (VOICE/DATA)

	MATERIAL	:	$ 460
LABOUR	CONDUIT	:	$ 110
	AERIAL	:	$ 75
	BURIED	:	$ 115

- FIBER CHARACTERISTICS

	830 NM	1300 NM
ATTENUATION (DB/KM)	2.5	0.9

ACCESS SYSTEM FACILITIES COST (1983 $)

DS-1 ACCESS USING FIBER FACILITIES

END-TO-END BUSINESS APPLICATIONS

APPROXIMATE REACH 12 KM

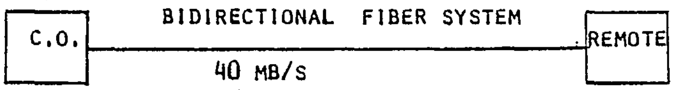
E/O EQUIPMENT COST PER DS-1 (BOTH ENDS)

	MATERIAL	LABOUR	TOTAL
E/O TX/RX	1200	200	1400
. SHORT λ LED			
. APD DETECTOR			
. WDD			
. CONNECTOR			
. ADDITIONAL ELECTRONICS	700	100	800
* EXCLUDING FIBER AND TERMINATIONS		TOTAL	$ 2200

ACCESS SYSTEM FACILITIES COST

1986 PROJECTED COST FOR VOLUME PRODUCTION (1983 $)

DIGITAL FEEDER LINK FOR MULTIPLEX REMOTES
APPROXIMATE REACH 10 KM



E/O EQUIPMENT (BOTH ENDS)

	MATERIAL	LABOUR	TOTAL
E/O TX/RX	1300	200	1500
LONG λ LED			
PIN DETECTOR			
WDD			
CONNECTOR			
ADDITIONAL ELECTRONICS	130	20	150
		TOTAL$	1650

* EXLUDING FIBER AND TERMINATIONS

VIDEO CODEC COSTS ($K)

APPLICATION	BIT RATE (Mb/s)	1983 (SMALL QTY)	1990 (VOLUME PRODUCTION)	COMMENTS
Broadcast & Program Production	90 45 20 - 30	10 40 - 50	2 - 3 10 - 12	. Simple technique to reduce from 112 Mb/s. . More sophisticated (e.g. adaptive DPCM)
CATV	90 45	8 - 10 20	2 - 3 5 - 6	. See above . Can use relatively simple coding (e.g. 1-dimensional DPCM)
Video Conferencing	1.5 750 kb/s 256 - 500 kb/s	200 ? ?	60 - 70	. Current coding techniques produce noticable picture quality degradation. Next generation (2 years) will improve. . More complex coding . Special applications only

General Comment: Progress in Custom VLSI development and product automation could substantially reduce costs projected (1990)

APPENDIX E: VIDEO SWITCHING TECHNOLOGIES

Various technologies have been reviewed for application to video switching, including reed relays, solid state devices, and optical switching. The system objectives are a signal bandwidth up to about 100 MHz with isolation ranging from 50 to 100 dB at 100 MHz.

Commercially available reed relay switches have bandwidths extending from DC to over 100 MHz with an isolation of about 110 dB at 100 MHz. Large arrays comprising 3200 crosspoints are currently offered at a cost of about $70 per crosspoint. High power consumption and large sizes are the disadvantages of this switch. Since reed relay technology is relatively mature, it is unlikely that the price will decrease with time or volume production.

Solid state devices such as FETs can be applied to both analog and digital switching. An isolation of 57 dB is attainable at 100 MHz if 3 FETs in a T-configuration are used at each crosspoint. The cost today for a JFET switch is $10,450 for a 15 input, 10 output switch with remote control, built-in power supply, etc. (i.e. $70 per cross-point in low volume).

Another attractive solid state technology is current mode logic (CML) or ECL. A 4x4 CML IC switch has been fabricated by NTT and Fujitsu. A digital 97.58 Mb/s (NRZ) color video signal has been switched using this device with no visible picture degradation. It appears that a high bandwidth switch using ECL is realizable, although at this time no design exists.

There are a number of optical switching techniques being explored. Many suffer from high insertion loss and crosstalk due mainly to problems in accurate alignment and power coupling. Among the more recent publications, the electro-optic switch [1] is quite promising. Basically, an electrical signal drives an LED, which is directed to 7 output PINs by a power splitter. The PIN detects the signal, then converts it back to an electrical signal which is amplified and distributed to the subscriber line. The basic configuration of the switch is a 1x7 matrix, which can be stacked to form larger arrays. The performance characteristics of this switch are suitable for video transmission, and in fact both analog and digital signals can be switched. The switch is currently priced at $150 per crosspoint, but for volume production in 1990 it is projected at $18 per crosspoint.

A promising 4x4 electro-optic switch has also been developed [2]. Intended specifically for multimode fiber applications, switching is done via controlled reflection from two layers of nematic crystal. The novel matrix architecture provides low levels of optical crosstalk (>53 dB), and the switch has a bandwidth estimated at 300 MHz. The insertion loss for this device is about 6 dB.

In general, further R&D work is necessary in order to implement a large size video switching array. Detailed examination of the alternatives is required, and factors such as power consumption, size etc. must be carefully evaluated in order to optimize the switch design.

REFERENCES

(1) E.H. Hara, R.I. MacDonald "A Broadband Optoelectronic Microwave Switch", IEEE Trans. on Microwave Theory and Techniques,MTT-28, June 1980.

(2) R.A. Soref, "4x4 electro-optical matrix switch for fiber optic networks", SPIE Vol. 326 Fiber Optics-Technology '82 1982.