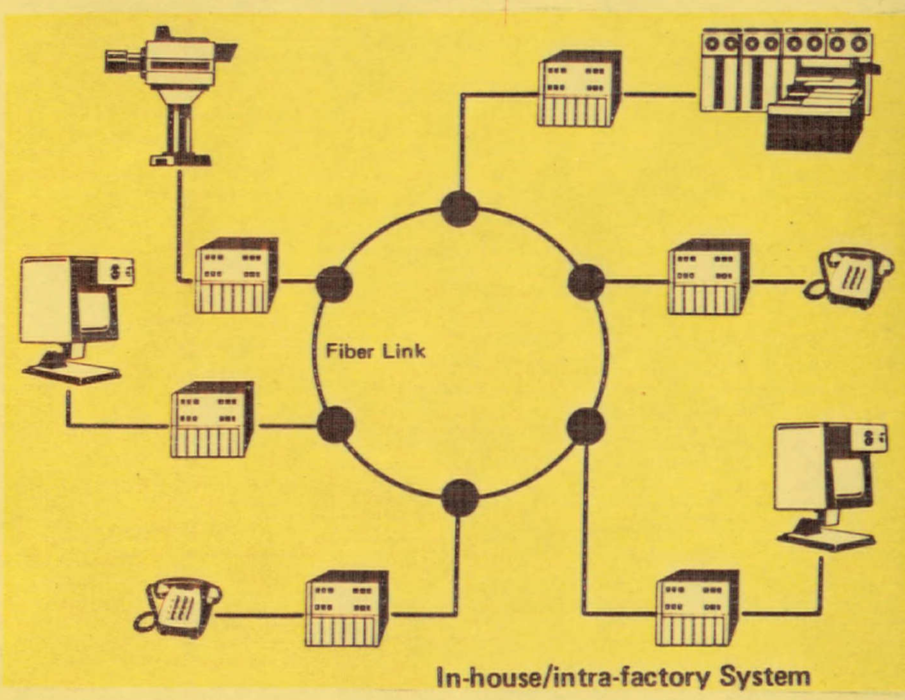
REPORT: FIBER OPTIC DEVELOPMENT NEEDS OF LOCAL AREA NETWORKS

- TASK 1, BACKGROUND RESEARCH



DSS CONTRACT NO. OST82-00134

FOR: DEPARTMENT OF COMMUNICATIONS

FROM: ANDREW T. SCHINDLER & ASSOCIATES INC.

January 27th, 1983.

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January 27, 1983.

Department of Supply and Services
Department of Communications

ATTENTION: - Mr. S. E. Cooper, Science Procurement Manager, D.S.S.
Dr. D. C. Johnson, Scientific Authority, D.O.C.

SUBJECT: Contract No. OST82-00134

ENTITLED: Fiber Optic Development Needs of Local Area Networks (LANs)

We are pleased to submit three copies of the "Task 1" report which provides the criteria used for the selection of the transmission medium for Local Area Networks, covering large building systems, CATV networks, telephone systems and special service systems

During the background research of this study and the preparation of this report, it became evident that Task 1 and Task 2 as defined in our work statement of November 9, 1982 could not be presented in two distinct and separate packages as earlier envisaged. The basic reason for this departure from the original plan is that in order to convey a well balanced, meaningful and comprehensive picture of the overall subject of this study, it is essential to interlink certain portions of Task 2 with the objections of Task 1. Hence, the ATS report on Task 2 will provide further updating on any additional information available on Task 2 and will include analysis of cost details.

However, in order not to change any contractual obligations, we are invoicing only for Task 1, at the present time.

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We take this opportunity to thank Dr. D. C. Johnson, the Scientific Authority on this project, for the valuable guidance provided to ATS during the conduct of this portion of the study.

Yours truly,

ANDREW T. SCHINDLER & ASSOCIATES INC.

A. T. Schindler,
President.

ATS/ds
Encls.

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1.0 INTRODUCTION AND SUMMARY

This report deals with the Background Research conducted by Andrew T. Schindler & Associates Inc. in the field of Fiber Optic Development Needs of Local Area Networks (LANs) as per Task 1 of the DSS Contract Serial No. OST82-00134.

The report briefly describes the evolution of Local Area Networks over the last couple of decades, enumerating several major systems that are now available as a result of this evolution, from a number of suppliers, for a variety of applications. This is followed by a listing of the broad and general characteristics of LANs and predicted market forecast for these networks which is estimated at an explosive U.S. $3.2 Billion by the year 1990.

A technical comparison of the various existing networks is made under the broad headings of transmission medium employed, interface units used and network connectors and stations available. Basic system topologies are discussed. This is followed by a more detailed review and comparison of some 15 different systems showing a wide variety and many possibilities of applications of these networks.

It becomes clear at this stage that the future LANs generally need the capability of transmitting video, data and voice requiring a broadband transmission medium. The criteria used for the selection of transmission media for Local Area Networks are determined. Characteristics of fiber optics as applicable to LAN systems are then discussed in depth and also their most effective configurations, including the active nodes, optical switches and passive couplers. This is followed by a discussion of fiber LAN systems using the bus, star and ring configurations.

2.0 LOCAL AREA NETWORK EVOLUTION

Local Area Networks (LANs) are evolving in a demand-driven environment. In the late 60's the Networks were based on twisted pair media in conjunction with Private Automatic Branch exchanges (PABX) within buildings. As the use of computers and terminals began to increase, there was a separation in networking of telephony and data, Accoustic couplers were developed to tie terminals to computers. Dedicated and leased pairs especially conditioned for data were the main transmission media. The computer users realized that the bandwidth limitations of the twisted pair was restricting the effective utilization of computer power. The initial result was the development of the data modem industry based on obtaining the maximum amount of data transfer through this limited bandwidth media.

In the 70's, with the introduction of mini-computers an increased demand for data networks resulted in the introduction of hybrid voice and data computer branch exchanges. These branch exchanges were able to drive the twisted pair cable capabilities further to provide improved service within the office buildings.

A major advance in baseband coaxial cable occured with the development of Ethernet by the Xerox Corporation. This system allowed the connection of up to 256 independent stations through an interface to a transceiver, which in turn connected to the coaxial cable. The stations can attach to the cable at any point and the system length without repeaters is limited to 1 km.

In the late 70's, the introduction of micro-computers coupled with greatly increased volume of installed minis and main frame computers together with word processors, etc., led to a quantum jump for short distance data communications resulting in massive development activity in the U.S. industry. By 1981, the list of major systems offered grew at a breakneck pace.

Fiber optics, in spite of their very attractive characteristics, have only very recently been considered for LAN's. Until recently, most LANs were based on coaxial technology.

3.0 GENERAL CHARACTERISTICS OF LANs

The general characteristics of local area networks are the following:

a) Privately owned (single owner);

b) Areas of application - campuses
- intra-building communications
- industrial plants
- hospitals, etc.;

c) Primarily initial justification to install LAN is data communications, however some voice and video (security) is being considered;

d) High intra community interest;

e) Non-switched service

f) Shared communications resource;

g) High bandwidth;

h) High reliability (no active components on mainline system);

k) Low cost terminal interface;

i) Broadcast communications.

4.0 MARKET FORECAST FOR LANs

In a report (Ref. 2) published by International Resources, the market for LANs will rise in the mid 80's and reach "explosive proportions". The report predicts a U.S. $3.2 Billion market in local networking by 1990. (See Fig. 1)

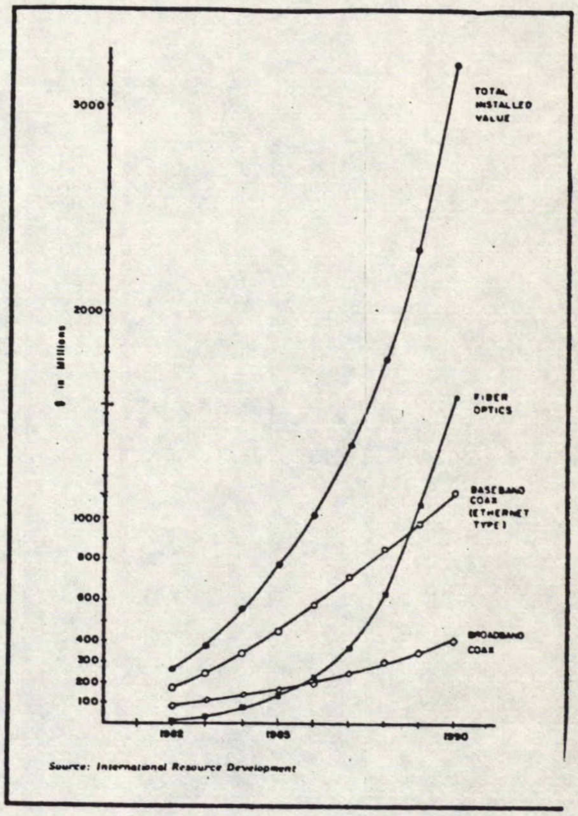
The study attributes this growth to the declining cost of mini-computers and the need to link information-processing equipment.

The predicted market segmentation by transmission media is the following:

1. Fiber Optics .... $1.6 Billion
2. Baseband Coax .... $1.1 Billion
3. Broadband Coax .... $0.5 Billion

While the growth of the market thus far has been impressive, the exact timing of the explosive growth forecast may be in question, but it is widely accepted that this growth will occur and that the ultimate size of the market will be so large that it is worth waiting for. The various participants in the market place, including fiber, cable, and equipment manufacturers in the U.S., continue to invest heavily in the technology and new participants appear on a regular basis.

With the move towards microprocessor-based distributed processing, the emphasis will be on linking distributed hardware to enhance decision making and significantly increase productivity. There are currently over 100 vendors for LANs for various applications.



Value of the installed base of local nodes by medium, 1982-1990

Figure 1.

5.0 COMPARISON OF EXISTING LANS

One of the characteristics of LANs is that they vary greatly depending upon the communications services offered, application and the suppliers preferred direction for network development. This has led to a situation in which dissimilar products are competing in a breakneck fashion, with the potential user being confused as to which system will best satisfy his needs. It is difficult to make detailed comparisons as detailed information is not available due to the proprietory situation that exists in this quickly developing market sector. Although there has been a lot of papers published on the subject, these papers often lack technical substance. In order to make meaningful comparisons, it is necessary to understand the various technologies available on the market, so that at least to some extent their limiting differences may be recognized.

5.1 System Model

All LANs, regardless of network topology, access method or services provided consist of four fundamental components.

a) Transmission Medium -

Typically this is coaxial cable, telephone wire or fiber optic cable.

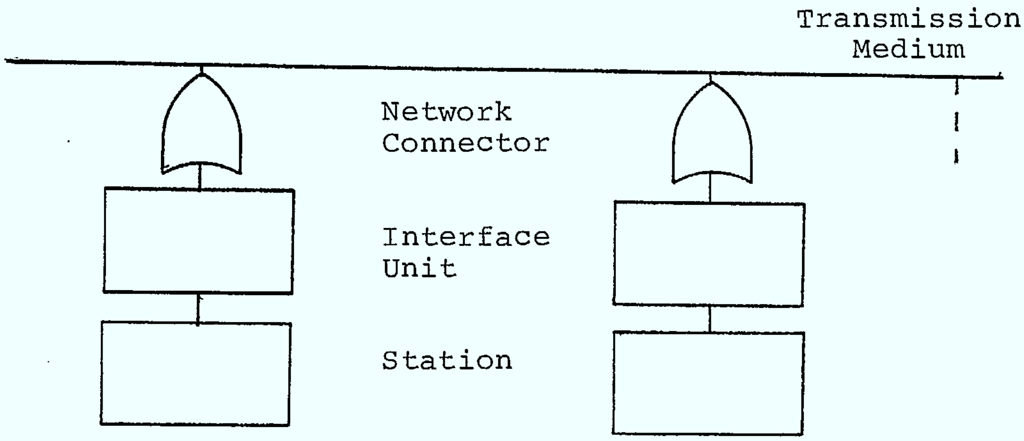
b) Interface Unit - Performs the signal transmission and protocol conversion functions. It also contains intelligence to determine the correct media access time, and to identify and collect messages destined for its attached stations.

c) Network Connector - Provides the hardware link from the interface unit onto the transmission medium.

d) Station - The terminal by which the user may interact with the system. This may be a micro, mini or main frame computer, network storage, work processor, video terminal or a telephone set.

A simplistic diagram illustrating the interrelationship of these basic units, is shown in Figure 2.

FIGURE 2. TYPICAL LAN CONFIGURATION



In addition, some suppliers provide a gateway interface to connect to other LANs or telephone networks. In some systems a centralized network controller is used.

5.2 Baseband vs. Broadband

The amount of data or other services able to be carried varies greatly depending on the type of transmission method, either baseband or broadband, which is used. Baseband systems operate over coaxial cable at speeds of up to 50 Mb/s. This is accomplished with Time Division Multiplexing (TDM) to share the information space amongst many users, although only one user is able to transmit at a time. All other users will be aware of the message being transmitted, but only the addressed destinations will receive the message. Contention problems are kept low because of the high speed of transmission.

Broadband technology provides much higher bandwidth, in the order of 250 MHz utilizing CATV type Frequency Division Multiplexing (FDM) technology. This is normally used in conjunction with TDM. This approach has the potential of provisioning video and audio services on the LAN. However, systems in this category are expensive and cost reduction of the associated RF components is unlikely, in the near future.

5.3 Basic System Topologies

The physical layout of the transmission medium, (the network topology) used for the majority of systems are:

- databus
- star
- ring

These are discussed in the following sections.

5.3.1 Databus Systems

This is the most common network topology used in LAN systems. It consists of a coaxial cable covering the service area terminated at each end with the cable characteristic impedence. Stations are connected along the length of the cable and communications between stations is established by transmission of signals in both directions of the media.

In this network topology, all stations have equal right to the transmit. To prevent collision or simultaneous transmission of signal from stations, CSMA/CD (Carrier Sense Multiple Access - Collision Detection) is employed. This contention scheme named Collision Detection determines when the media is not in use and then transmits the data. This method is 80% to 90% efficient during peak loads. If more than one station transmits simultaneously then a collision occurs which is detected by all stations and then back-off occurs which will delay re-transmission from stations on the basis of random amount of time before stations will try to transmit again. Configuration of the databus system is shown in Figure 3.

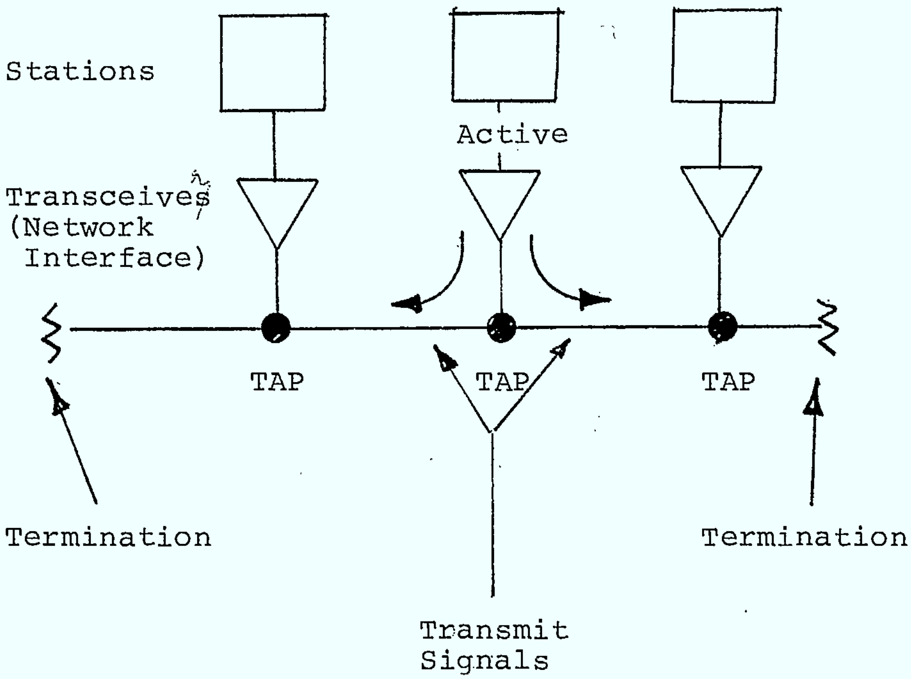


Figure 3. Databus System

5.3.2 Star System

In the star system all stations have a dedicated path to a central node. The node becomes a centralized controller and makes connections between attached stations as shown in Figure 4. This type of configuration is the same as

PBX telephone traditional network. The speed of each connection is usually limited to 64 kb/s. The main disadvantage of this system is that reliability of the system is totally dependant on the node. Also, the peak data through-put is lower than similar bus networks, although average data rates may be similar.

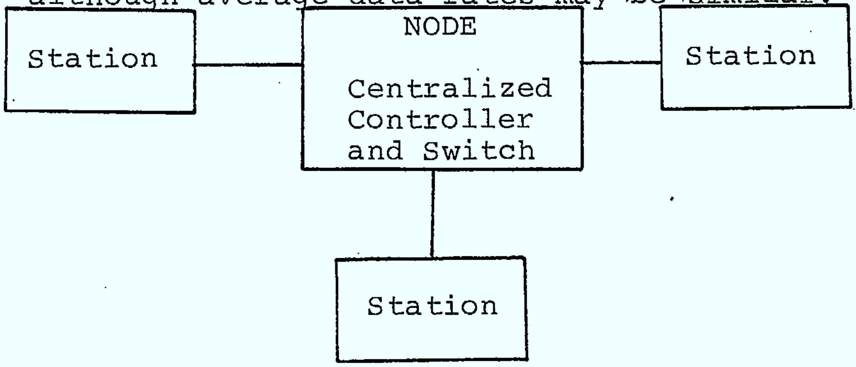


Figure 4. Star Systems

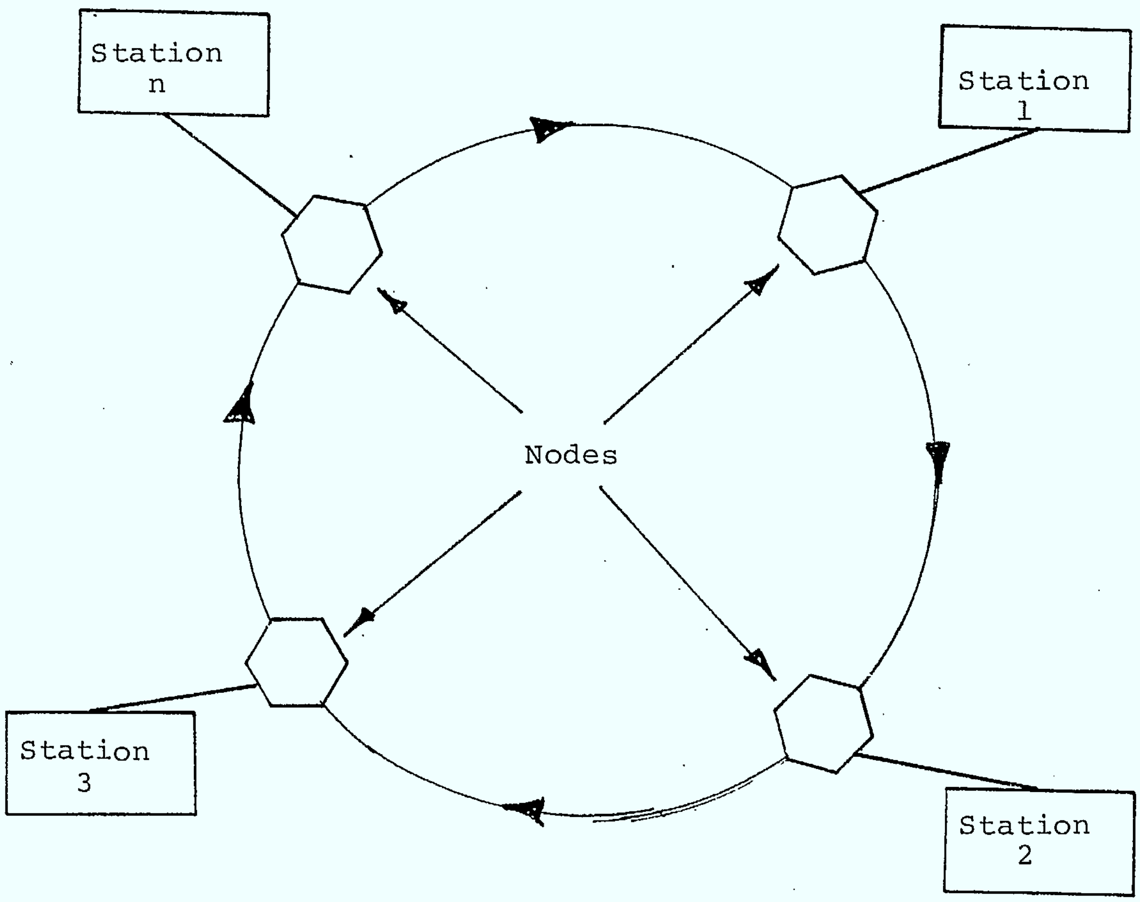
5.3.3 Ring Systems

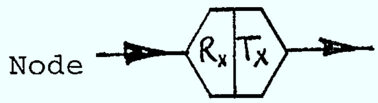
The data flow in a ring configuration is undirectional around the ring. The data is interfaced on to transmission media by stations with a receiver and a transmitter which are inserted in the ring. So the network consists of a number of nodes connected together in series. The data message passes through each node and it is the responsibility of the receivers to identify and drop the information which has been disignated to a given station. Once the transmitted information returns to the originating station, the information is removed from the ring.

The contention for access to the ring is usually handled by the token approach. At any given time only one station with the token is allowed to insert data onto the ring. Once the station with the token finishes transmitting, it passes the token onto another station.

The main weakness of the ring configuration is that failure of any node in the system causes total disablement of the ring.

Figure 5 Ring System





5.4 Review of Existing LANs

Background research on existing LANs has covered some sixty different systems; however, we have chosen 15 systems, on which sufficient information was available, for the purpose of making comparisons and also to show the diversity of characteristics. Table 2 lists the systems and gives a review of major characteristics of the selected LANs. In addition, the following summary comment is given on each of the systems identified in the Table.

Ethernet

This system has been standardized by IEEE and is probably the most known system in the industry. Ethernet is a truly distributed system. Although this system was initially conceived as a simple method of interconnection of various existing stations, it has quickly become a main motivator to Xerox, Intel and DEC to develop new stations filling new office requirements which were totally impractical before the existence of Ethernet.

Fibernet

The experimental Fibernet system was developed by Xerox-Siecor to test the optical technology attributes. The general conclusions of this experiment were the following:

- Fiber optics is a very suitable technology for high capacity data throughput;
- Lower installation costs;
- Network tapping was seem as a major obstacle limiting this system to 16 stations.

Z - Net

Z - Net is an attempt by Zilog Corporation, a subsidiary of EXXON, to cost reduce and make some refinements to the ETHERNET system. Its intent was to complement EXXON's activities in the office communications market.

ARC

Datapoint introduced this system in 1978. It is a baseband system with a CSMA topology.

HYPERCHANNEL

This system is intended primarily for host to host, high capacity data transfer. It is a baseband system best suited to interconnecting various types of computers.

COMPUTROL III

This system is based on a ring topology using twisted pair transmission medium. It was primarily designed to enhance the application of Computrol's data modems.

CLUSTER/ONE

This system is an inexpensive 26 wire ribbon cable for the interconnection of Apple micro computers. The bus speed is limited to 240 kb/s and it is limited to 150 meter distance coverage.

U-BITS

The Universal Bus Information Transfer System (U-BITS) is the largest capacity baseband LAN. This system is intended for high usage of closely located stations, e.g. an office floor. The system configuration is based on stations accessing a Network Management Unit (NMU). This unit does the packet assembly and disassembly, in addition to speed/protocol conversions. The NMU interfaces with a ribbon cable operating at a 160 Mb/s rate. For external connection a Global Interface Unit (GIU) is required. The GIUs are interconnected through a high speed point to point system. This system has the potential of provisioning video and voice services.

MITRE NET

There are two Mitre Net systems installed. One in the U.S. House of Representatives and the second at the Walter Reed Hospital. The system provides voice, video and data services.

also now on Parliament Hill Canada

LOCAL NET 40

This system is offered in two forms by Sytek Inc. of California. Local Net 40 which allocates five 2.5 Mb/s channels and Local Net 20 which allocates 120 channels operating at 128 kb/s. Both of these systems can operate simultaneously on a CATV system. For two way transmission dual cable installation is required. The 128 kb/s data is placed on a channel through an interface unit called T-Box in the upstream frequency band 40 - 60 MHz. This information is transmitted to the head-end T-verter unit for downstream transmission in the 192 - 262 MHz band. This provides access to all stations.

This system is a major contender for the provisioning of services via CATV network.

CAPAC

The Cable Packet Communications System (CAPAC) is a broadband CSMA/CD system designed by Digital Communications Corporation (DCC). The system design is based on a frequency agile RF modem (CAP) which accepts data at rates between 50 b/s to 38 kb/s. The CAPs interface this data onto a broadband bus in fixed 1 Mb/s channels. This system can provide both voice and and data services. The design is based on Mitre Net configuration.

WANG NET

This broadband system is capable of providing voice, video and data services. The system is based on broadband technology and the system design approach used by Wang Laboratories was to segment RF channel allocations for three main areas of usage. Thes are: 1) Wang office system; 2) Other suppliers data systems; 3) Voice and video services. The provisioning of these service sectors is accomplished by allocating 215-265 MHz for Service 1. The 42-72 MHz is used for services provided in 2, and 165-214 MHz for the third service sector. The Wang office systems operate at 12 Mb/s speed, the other or 2nd category of systems are provided with 9.6 kb/s to 64 kb/s with a switch option. It is reported that Wang Labs are developing a PBX for the third category of applications.

Video Data

The broadband system consists of two types of service delivery, multi-drop and point to point. In the multi-drop application, a centralized modem is used to perform a TDM function known as Autopoll. As well, modems at terminals or stations are required with intelligence to recognize addressing. The point to point transmission uses fixed frequency channels in full duplex mode with the aid of RF modems. In this mode no intelligence is required for addressing or any other reason. This system has been developed by Interactive Systems Corp, a subsidiary of 3M Corp. which has been involved in broadband communications for 10 years.

HUBNET

This system is a contention based, multiplex access network which uses high speed point to point optical links to interconnect HUBS and NACs. Signal regeneration takes place in the HUBS allowing for large scale network applications. The NACs are 16 bit micro-processor based unit with various interface options available. The HUB consists of a number of optical receivers and transmitters with common signalling processing functions. The prime system application is for data, however, it could in the future also provide voice communications.

Table 2. COMPARISON OF LAN CHARACTERISTICS

SYSTEM	SUPPLIER	TRANSMISSION MEDIUM	STATIONS MAX.	TRANSMISSION SPEED	GENERAL COMMENTS
Ethernet	DEC, Intel, Xerox	- Baseband - Coax 50Ω - 1 km. - bi-directional	5,560	10 Mb/Sec.	-Many installations: -CMSA/CD -Office automation -Databus configuration
Fibernet	Xerox Siecor	- Fiber - Uni-directional - Graded-index - 62.5 um core - 400 MHz/km - 0.5 km.	19	150 Mb/sec.	-Star configuration -Experimental -Transmission Star coupler -Low installation cost
Z-Net	Zilog	- Baseband - Coax 75Ω - 2 km.	250	800 kb/s	-Zilog subsidiary of Exxon -Office automation -Lower cost than Ethernet
Net/One	Ungermann - Boss	- Baseband - Coax 50Ω - 1 km.	35,000	4 Mb/s	-Office automation

SYSTEM	SUPPLIER	TRANSMISSION MEDIUM	STATIONS MAX.	TRANSMISSION SPEED	GENERAL COMMENTS
ARC Attached Resource Computer	Datapoint Corporation	- Coax - 7 km. - Passive or Active Hubs	250	2.5 Mb/s	-Databus -Good for voice with 1SX Switching System
Hyperchannel	Network Systems Group	- Baseband - Coax 75 - 700 Meters	65	40 Mb/s	-Mainly aimed at Main Frame computer applications
Computrol III	Computrol	- Twisted pair - 2 km. - FSK	64	9,600 b/s	-DEC/Intel Compatible
Cluster/One	Nestor Systems Inc.	- Twisted pair - 150 Meters	70	240 kb/s	-Aimed at linking together Apple Computers -Electronic Mail
U-bits	Amecom/ Litton	- Twisted pair - Coax 75 - 200 Meters	17,000	160 Mb/sec	-Video and Telephony may be added

SYSTEM	SUPPLIER	TRANSMISSION MEDIUM	STATIONS MAX.	TRANSMISSION SPEED	GENERAL COMMENTS
Mitrenet	Mitre Corp.	- Two Coax 75 - 8 km.	2,000	1 Mb/sec.	-Hardware developed by DCC -DCC interested in marketing Data, voice, video system (LAN)
Local Net 40	Sytek	- Coax 75 - 80 km. - Broadband System - FDM	1,000	12.5 Mb/sec.	-Works closely with General Instruments -Plans to develop system for CATV -Also have system Local Net 20 smaller capacity
CAPAC	Digital Communications Corporation (DCC)	- Coax 75 - 8 km.	2,000	1 Mb/sec.	-The same as Mitrenet
Wang Net	Wang Laboratories	- Two Coax 75 - 3 Broadband system - 2 km.	65,000	12 Mb/sec.	-Provision for future video and voice -Most Comprehensive system

SYSTEM	SUPPLIER	TRANSMISSION MEDIUM	STATIONS MAX.	TRANSMISSION SPEED	GENERAL COMMENTS
Video Data	Interactive Systems/3M	- Coax 75 - 9 km.	1,000 fixed plus 200 distributed	100 kb/s	-Two different methods of communications -Point to point -Multi-drop distribution
HUBNET	Canstar	- Fiber Optics - Star Configuration	65,536	50 Mb/sec.	-University of Toronto

5.5 DISCUSSION

Ethernet has presently become the leader among the baseband systems and is the only LAN presently standardized by IEEE 802 committee. The highest speed baseband system is U-BITS, offering 160 Mb/s. The ARC and Hyperchannel systems are also baseband systems which have gained significant acceptance by the users. It is quite likely that in the near future these companies will be developing special PBXs which will provide gateways for interconnection with the outside world as well as provisioning of telephone service within the office environment. The greatest strength of these baseband systems is the reliability of the transmission media (no active devices).

Systems in the broadband category are largely led by Mitre Corporation (U.S. Government) that has a total capability of transmitting video, data and voice services with the use of dual cables, one for upstream and the other for downstream communications. Other broadband systems are primarily designed for data transmission, however, most of these systems have the potential capability of subsequent introduction of video and voice. These broadband systems are more suitable for sharing of the LAN among a number of small user organizations located within the same office building. This can be accomplished by frequency allocation on a per user basis. Leading systems falling in this broadband category include LocalNet, CAPAC and WangNet.

It is quite possible that this burgeoning activity in local area networks will lead to the emergence of practical systems with integration of satellite, microwave and other long haul facilities forming a total network capabitily as shown in Figure 6.

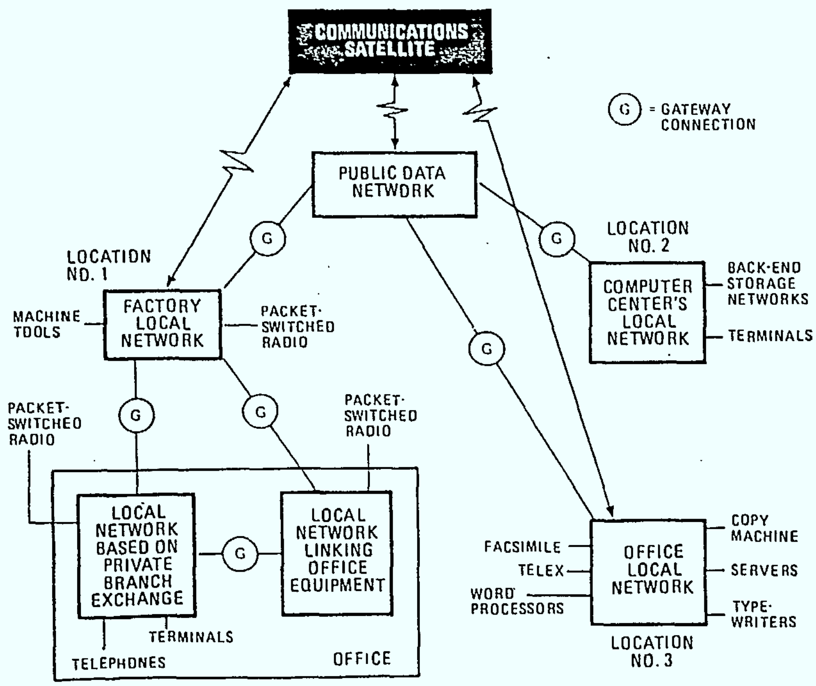


Figure 6. Future Hierarchial Network

6. FIBER OPTICS CHARACTERISTICS APPLICABLE TO LAN SYSTEM

The first local area networks evolved in environments in which the distances to be spanned by the network were within the range of inexpensive high speed data communications technologies. Today, the relationship has been turned around so that the distance range of local area networks is governed by the distance over which these inexpensive techniques can be used. The result is high speed data networks in which the cost of transmission and cost of control of transmission is very low compared to the costs associated with traditional data communications networks, providing some unique opportunities that conventional long haul networks do not afford.

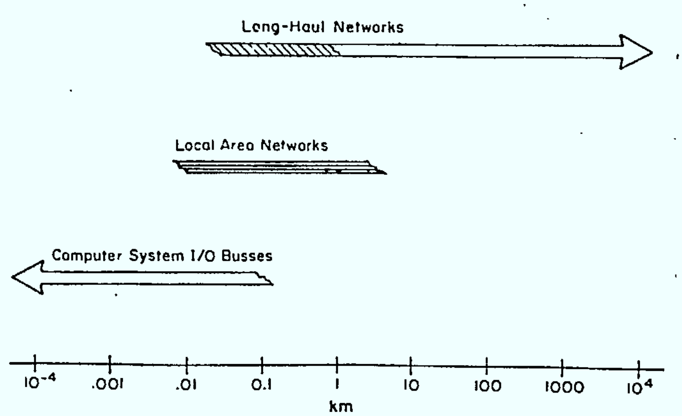


Figure 7. LAN Distance Range

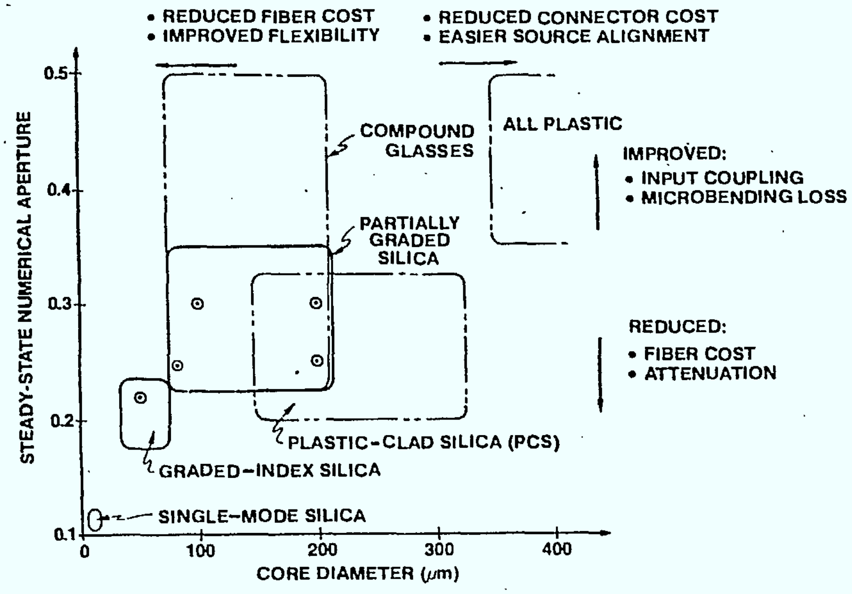
Since at first glance fiber optics offer low loss and high bandwidth, it appears to be an excellent media for LANS. In order to examine some of the fundamental characteristics of the fiber media as it applies to LANS, the following discussion is provided.

There are two parameters that are most important in specifying light coupling efficiency into a fiber. They are fibercore diameter and the numerical aperture (NA). Splices, couplers and connectors required in a fiber LAN have to be carefully considered to make accurate link loss budgeting realistic due to the large number of these devices required.

The light dispersion phenomenon caused by non-uniform propagation through the fiber, limits the transmission bandwidth. In addition, if the light signal is a mixture of serveral wavelengths such as emitted from LEDs, chromatic dispersion has to be considered as this phenomenon will also effect the transmission bandwidth of the link.

The selection of a large core size and large NA would be advantageous from coupling considerations. However, increasing NA decreases bandwidth.

From Figure 8 (Ref. 3), one can estimate the trade-offs involved in selecting core size, and NA for different types of fibers.



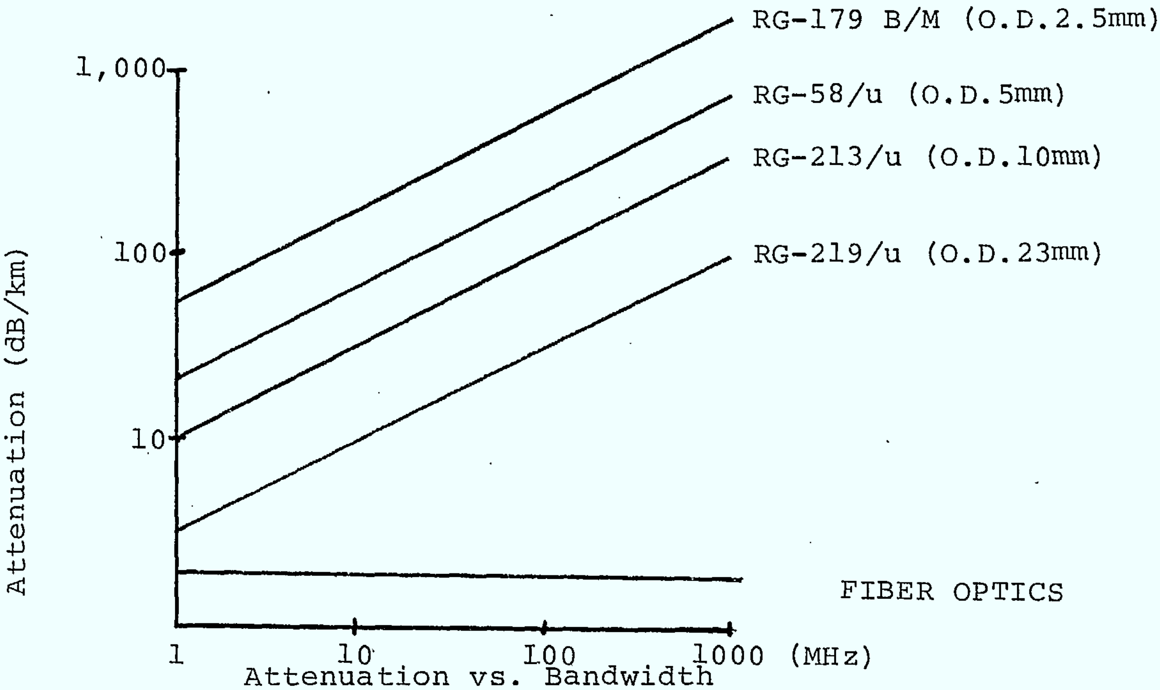
Numerical Aperture vs. Core Diameter

Figure 8

For short span systems, easy source alignment and improved coupling efficiency favour large NA fiber. On the other hand for long spans, fiber costs, attenuation and bandwidth are prime criteria and the graded index 50 um core, 0.2 NA fiber seems to be the best choice.

7. FIBER SYSTEM

From the point of view of reliability and cost, short span system designers are presently relying on LEDs; PIN and an 0.8 um fiber. For longer span systems the 50 um core graded index fiber has a bandwidth distance product of 600 to 1000 MHz range and an attenuation of 2 to 4 dB per km. at 830 um. For applications of 3 km. or less the fiber attenuation charateristic is independent of modulation frequency. Figure 9 shows a comparison of coax vs. fiber attenuation characteristics.



Attenuation vs. Bandwidth

For Coax and Fiber

Figure 9

A comparison of fiber and coaxial cable system by Personick (Ref. 11) addresses the fundamental limits of the two media and the evaluation is made on the basis of SNR (Signal to Noise Ratio).

The SNR in a metallic system is limited by thermal noise, whereas in a fiber system the performance is limited by quantum noise. It is found that a 3V peak into a 100 ohm line impedance has about 57 dB more signal to noise ratio that a LED coupling 25 uW peak. The metallic advantage is lost quickly as the signal bandwidth and reach are increased. Hence, the bandwidth-distance product is the parameter which determines the technical suitability of the system. In addition, there are other parameters that can be assessed for any specific application. These are shown in the following table.

Table 3.

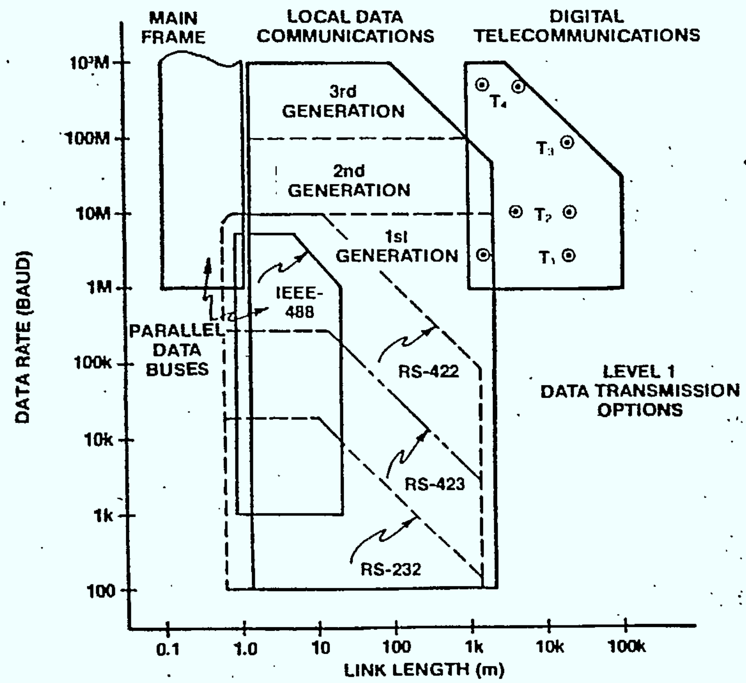
Media Characteristic Merits

Fiber	Coax
1. Bandwidth-distance	1. Simple to connect
2. Safety (Non-conductive)	2. Easy to tap
3. No Cross talk	3. Availability of technology
4. Small size	
5. Transmission security	
6. Light weight	

In addition, the safety aspect of fiber cable is worth emphasising, reduced fire hazard, no need for lightning protection and installation advantages of the fiber medium. Fire regulations for toxic type coaxial cables require them to be placed in metallic conduit if they are placed in an air plenum.

At this time it is not clear which regulations will apply to fiber optics cable. It is well known that lightning can cause severe damage to electronic equipment connected to conductive media. In the case of LANS, usually the equipment attached is very expensive, host computers, etc. The additional safety characteristics of the fiber media may be very attractive to the users.

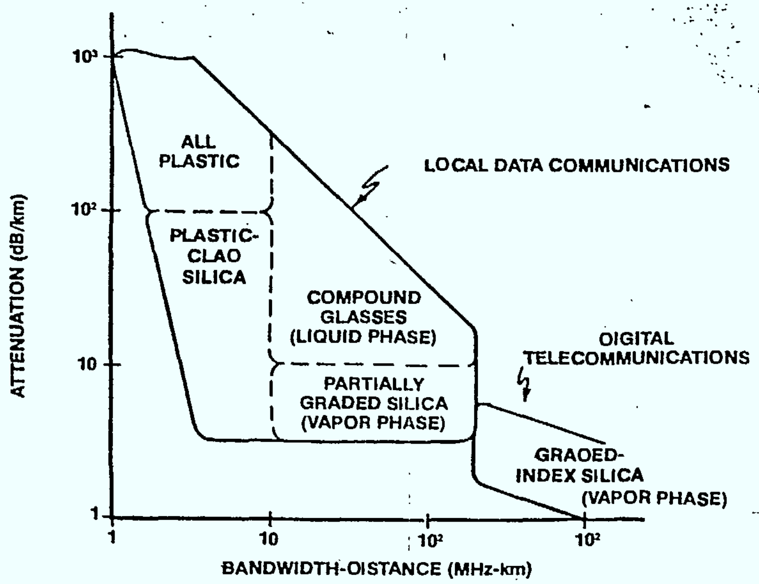
The upper boundary transmission requirements (data rate and link length) for local area networks are shown in Figure 10 (Ref. 3).



Data Rate vs. Link Length

Figure 10

Figure 11 shows the attenuation versus bandwidth-distance which meets the Figure 10 requirements.



Optical Transmission Requirements vs. Technology Choices for LANS (825 nm)

Figure 11

Fiber optic links can be most effectively configured in the star or ring topology with active repeaters incorporaing power splitters or hybrid techniques. The distributed data bus technique chosen for coax system is difficult to consider with fiber optics. Bidirectional fiber taps do not exist. In order to add new couplers, it would be necessary to shut down the system to introduce couplers in the fiber link making this system impractical in most applications.

The fiber optic network node access to the medium can be realized in essentially three different ways:

1. Active Nodes;
2. Optical Switches;
3. Passive Couplers.

The active nodes receive an optical signal, convert it to electronic signals, regenerate, drops and inserts it, then retransmits the signal over the optical media.

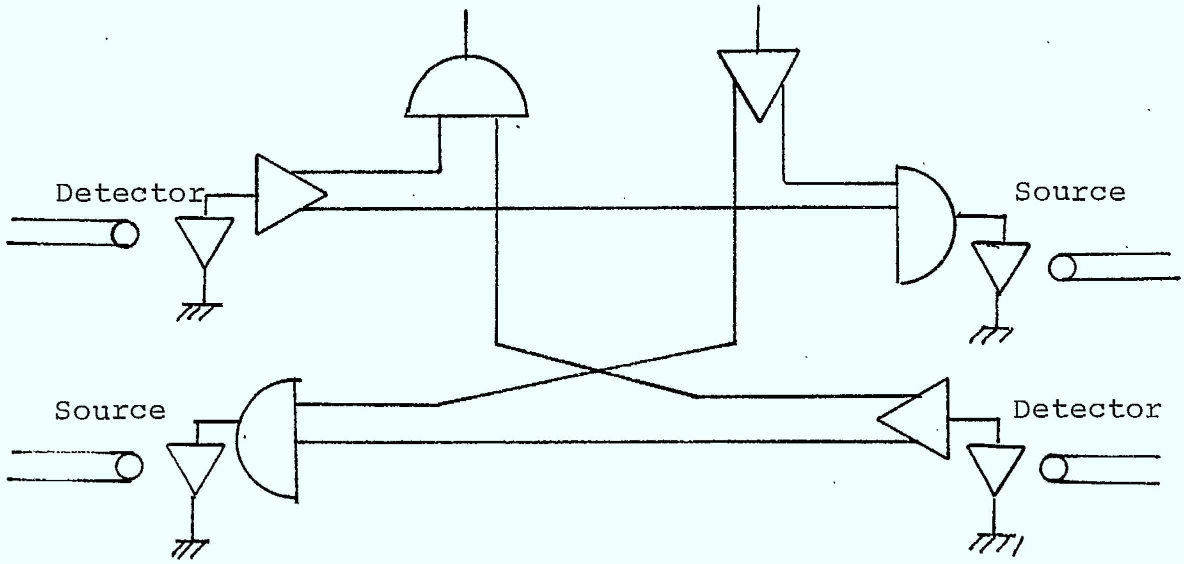
The optical switches provide the flexibility of sharing the full power on a time shared basis.

The passive couplers allow the light to be guided into or out of the fiber. The coupling ratio and insertion loss are important characteristics.

7.1 Active Nodes

In the ring and modified bus configurations, every node is active and can regenerate, drop or insert the information. In the active star configuration the central node or the HUB needs to be permanently active. The operation of the node is very complex as it must manage the interconnection of many links.

A dual fiber cable system in which each fiber carries information in opposite directions can be implemented with the active T node as shown in Figure 12.



Active Bidirectional

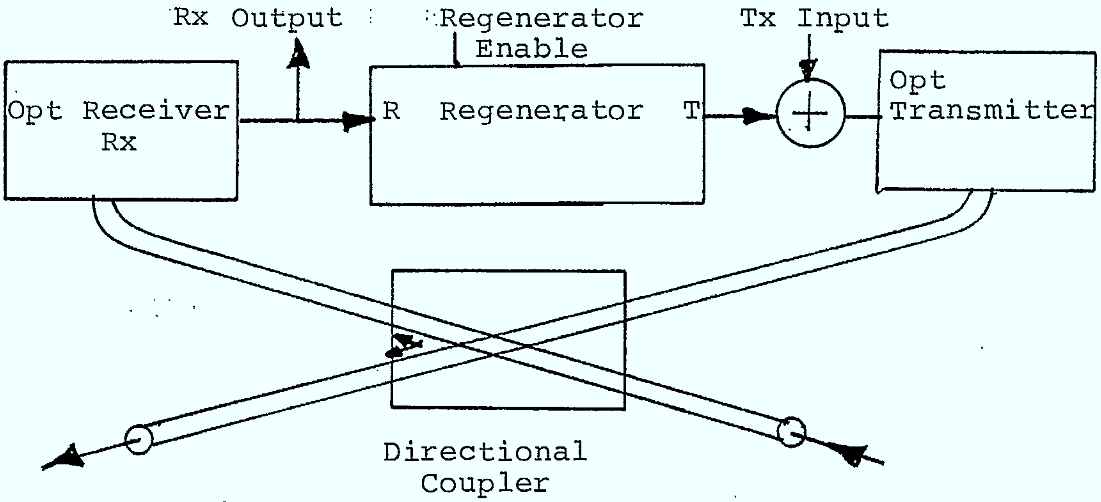
Figure 12

This approach requires fiber per direction and two receivers and transmitters per node. The configuration that can be accomplished with this coupler are inexpensive. However, future insertion of new nodes would cause a service interruption and the use of active components in a ring or bus configuration would decrease the reliability of this system. However, in dual fiber ring applications, one of the two rings could carry data during an active component failure or insertion of additional Ts.

Although dual fiber rings offer some advantage, full bidirectionality is rarely a requirement since the data reaches all the stations with a single ring.

A different approach to an active node has been prepared in Ref. 12. It consists of an active repeater with a passive directional coupler as shown in Figure 13. This type of fail safe node has been reported to operate at 16 Mb/s in a digital ring configuration. The number of stations is independent of the coupler insertion loss and the network still works with the loss of power in one or more locations. The system uses

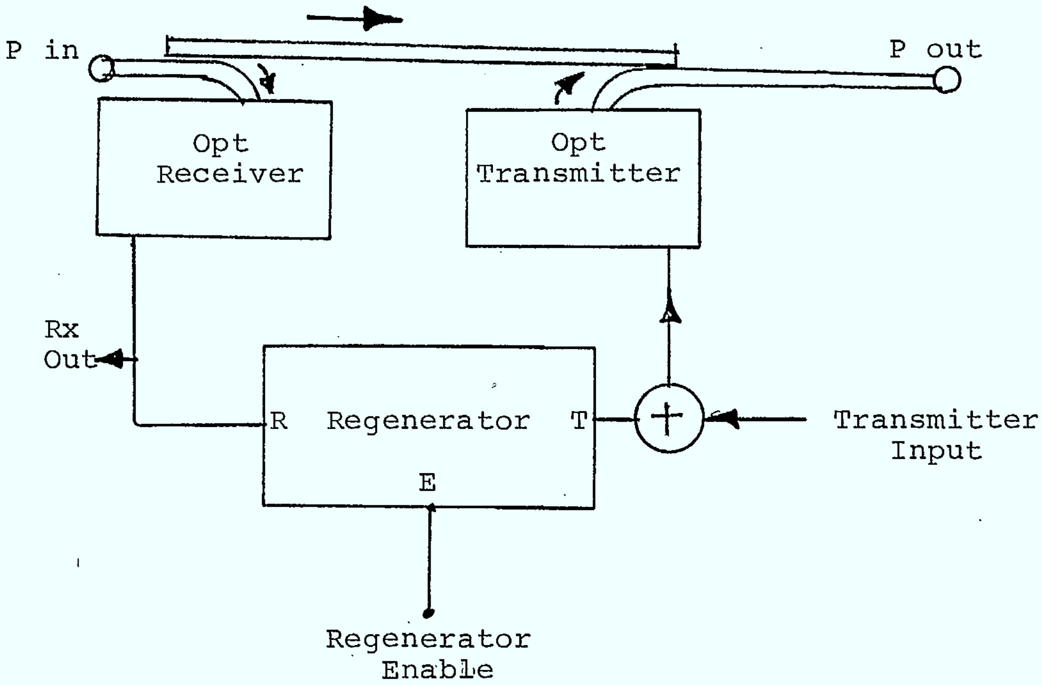
LEDs and APDs at 0.8 um. The configuration is shown in Figure 13.



Fail Safe Active Mode

Figure 13

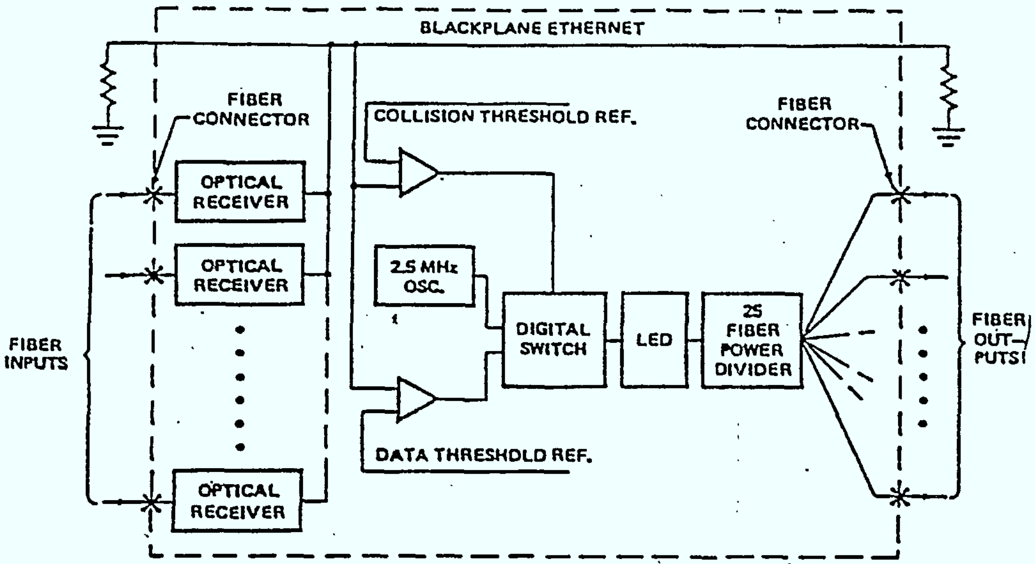
This approach utilizes one or two couplers. In the Figure 13 configuration shown, the receiver must be off when the transmitter is on in order to avoid saturation. This can be avoided if the transmission format utilizer 50% duty cycle. Otherwise, a two coupler mode is required as shown in Figure 14.



Two Coupler Fail Safe Mode

Figure 14

The active star-configured LAN is best illustrated by Fibernet II Ref. 13 with an active star HUB. The hub is an active repeater connecting up to 25 transceivers as shown in Figure 15. The signals coming from stations are all transmitted over separate fibers and connected to individual receivers in the active star. Signals transmitted from the active HUB to the stations via a 25 fiber fused biconical tapered power divided. The HUB transmitter is LED based and each fiber port accepts between 50 and 60 u watts.



The Active Star of Fibernet II

Figure 15

7.2 Optical Switches

The main application of currently available optical switches is presently seen as a by-pass relay in the case of active-node failure. However, in the future, if both the insertion loss and switch time characteristics are improved, optically switched tree networks could be designed.

There are two major types of optical switches, integrated optics switches and bulk optic switches. The integrated optics switches have the following characteristics; they are fast and their power consumption is low, Ref. 14. The bulk optic switches are basically mechanical and there are two different types currently available, namely, the external deflection switch and the fiber alignment switch.

In the external deflection switch, the fibers are kept fixed but the beam eminating from an input fiber is directed to an output fiber by means of a moveable part. The insertion loss of this type of switch is 1 to 2 dB and the optical isolation is about 50 to 65 dB.

The following table compares the isolation and insertion loss of currently available external deflection switches.

Supplier	Insertion Loss	Isolation
Bell Labs	3	40
NEC	0.75	55
NTT	4	65

Table 4. External Deflection Switched Characteristics

The fiber alignment switches work on the basis that the fiber is moved between positions of alignment with other fibers. The switch actuation is provided by mechanical, magnetic-mechanical or electro means. The insertion loss of these switches is about 0.5 dB and isolation 50 to 60 dB.

Table 5 shows a comparison of performance of some of these switches.

Supplier	Insertion Loss dBo	Isolation dBo
Siemens	1.5	50
NEC	1	55
OXFORD	0.1 to 2.5	N/A
Bell Labs	0.25	60

Table 5. Fiber Alignment Switches

The utilization of optical switches in LANS would greatly improve reliability of these systems. The insertion loss and the node separation should be such that a number of nodes can be by-passed without system degradation.

7.3 Passive Couplers

The passive couplers are used in LANS as star couplers and branching networks. There are basically two design approaches for these devices. The first being the use of optical components such as prisms, lenses and beam splitters, which are permanently assembled. The second makes use of fiber only, where a number of fibers are twisted together and fused.

The star couplers are made with identical fibers in order to realize equal coupling coefficients while preserving a low access loss.

The fabrication of a transmissive star in which the number of input and output fibers is different has been reported in Ref. 24. The application of this type of coupler could be in a fiber LAN where several remote terminals need to access a central host computer in a master/slave operation. Figure 16 examines various types of transmission couplers. Performance of some commercially available couplers is given in the Table 6.

NO. OF PORTS AND TYPE	LOSS PER PART (dB)	OUTPUT UNIFORMITY (dB)
Reflective Star:		
4	7	1
8	9	1
16	13	1.5
Transmissive Stars:		
4 x 4	7	1
8 x 8	10	1

Table 6. Comparison of Couplers

8. EVALUATION OF VARIOUS FIBER LAN SYSTEMS

8.1 Introduction

As indicated before, the fiber advantage resides primarily in the high bandwidth-distance product. Furthermore, because it is a dielectric medium, EMI immunity is an important advantage for high speed transmission up to 1 Gb/s (Ref. 25). These speeds could be realized with LEDs (Ref. 26), although most of the applications envisaged are more modest, with rates of about 20 to 250 Mbits/sec. over distances of up to 2 km.

The fiber network topologies are strongly dependent on cable access techniques discussed in section 7. Recent progress in these techniques has caused a reassessment of some of the fiber optic network configurations that were rejected a priori. Due to changing requirements for LANS, different physical environments, and design trade-offs, a variety of fiber LAN implementations with different topologies and network architectures have surfaced. This work is reported in the following sections.

One of the fundamental requirements in a LAN system is the ability to connect stations to the network. The foregoing discussion on active modes, optical switches and passive couplers show clearly that there is a tremendous variety of optical devices that can be used for this purpose in fiber local area networks.

8.2 Performance of Fiber LAN Systems

In this section, a sample of different types of fiber LAN system illustrating the bus, star ring configurations are discussed.

8.2.1 Bus Systems

Two types of bus systems have been implemented, the Parallel Bus and Bidirectional Multidrop Bus. The performance characteristics are given in the following section.

Parallel Bus

A parallel bus point to point system was reported by Siemens in 1981. The distance was about 130 meters. The information rate was 10 Mb/s. The fiber cable used was a 20 step index type, with a NA of 0.3 and 190 um core.

The working wavelength was 900 nm. and the attenuation was 30 dB/km. The sensitivity of the monolithic photodiode (Fairchild) receiver was 0.35 A/W. The interface cable assembly consists of quad module housing which includes four LEDs or four photodiode receivers with plastic moulded precision aligned blocks guiding fibers through the holes.

Bell Laboratories have reported (Ref. 29) that they have designed a LED array connector for data links. It consists of six GaAs LEDs with a fiber-ribbon connector. The LEDs are driven with 80 mA, coupled average optical power is 5 uW. The fiber used is 55 um core diameter with a 0.22 NA. The connector insertion loss is 0.4 dB, and the cross-modulation between LEDs is less than -50 dB.

Bidirectional Bus

The Swedish Telephone Administration reported (Ref. 30) a dual bidirectional passive multidrop link utilizing two fibers. This bus network was intended to connect a Host computer to 12 stations. The cable length was 200 meters using 200 um silica core diameter, with an attenuation of 40 dB/km. The system works at a 20 Mb/s speed at a BER of 10^{-9}. The receiver sensitivity was -37dBm with a dynamic range of 30 dB to compensate for distance variation from the host computer. The central processor sensitivity was -31 dBm with the dynamic range of 20 dB.

8.2.2 Star System

The example of a passive star system is Fibernet I described in section 7. The error rates accomplished in this system were better than 10^{-11} with data rates of up to 150 Mb/s. The fiber cable 62.5 um core was supplied by Siecor with Corning fiber. A 19 channel star coupler was used in the system, it was the biconical fused taper design. The coupling efficiency was -2.6 dB.

In addition a further experiment with a 100 port star was reported. The transmission results on this system of 0.5 km. length were excellent, BER could not be measured, better than 2" x 10" data bits.

The Fibernet II is an example of an active star system. This system is intended to serve as an extension of existing coaxial Ethernet installations. The transceivers were reported to be able to support up to 8 stations per fiber, when used with Ethernet multiplexer, for a total of 200 stations on a 25 fiber active star. A fused tapered fiber power divider was used with the 25 fibers.

8.2.3 Ring Systems

The ring systems have been used by Japanese companies, such as Fujitsu, Mitsubishi and Hitachi.

The Mitsubishi system reported in Ref. 31 is intended for a large scale, multi host network based on a two fiber ring operating at 100 Mb/s. The system uses one passive tap per node, in addition a switch is provided for the ring for the purpose of alternate routing in the event of node failure.

The Hitachi system, Ref.   was designed for an industrial application. The system operates at 10 Mb/s for an interstation distance of 2 km. A by-pass switch is provided at each node to protect the system in the event of node failure. The switch insertion loss was 1.7 dB and switching time was 30 msec. The ring consisted of 32 stations, covering a distance of 10 km. The data throughput was 900 Kb/s. The LEDs coupled -13 dBm into the fiber and the receiver sensitivity was -33 dBm.

The Fujitsu system designed for highway traffic management is presently the largest "LAN" installed. It consists of 370 km. of fiber which included 280 km. of 0.21 NA and 50 um graded index fiber and 90 km. of 0.27 NA, 85 um core diameter step-index fiber for in-building applications. The system configuration consists of a ring for highway application with node separation of 3.5 km. and star topology is used for in-building application. LEDs at 830 nm wavelengths were used.

The receiver used both APDs and PINs. The highway system operates at 33.3 Mb/s. In addition 10 video channels were provided for highway surveillance.

The experience gained from this system indicated that installation, including placement and splicing, was substantially less compared to a coaxial system.

The most comprehensive LAN from the viewpoint of services is the Carthage system, which we believe is ahead of its time. The following is a comprehensive discription of the system as presented at the ISSLS '82 conference.

AN INTEGRATED SERVICE LOCAL NETWORK FOR DISTRIBUTED ACCESS OF HETEROGENEOUS TERMINALS MADE FOR FIRM MANAGEMENT THE PROJECT CARTHAGE

Roger RENOULIN : Head of Department Integrated Service Local Network for Firms (REM *)
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This contribution claims to show that the CARTHAGE Network, far from being a new "in abstracts" technique of communication, is in fact geared toward satisfying the different needs of office communication. The main technical features which guided us are all well-know already, from digital time multiplexing for voice to circuit and packet switching for data, as well as broadcasting. The use of these proven techniques does not prohibit an evolution toward high speed (including broadband) user-friendly interfaces and modularity, since the network has a hybrid communication technique (circuit/packet) and topology (ring/star). CARTHAGE is a synthesis of well-know techniques, using existing standards (X50, X21, X25...); and its implementation allows the use of gate arrays circuits which are being defined, or even custom VLSI. It will thus allow a graceful migration from the existing networks and communication techniques to the future Integrated Services Data Network (ISDN).

CARTHAGE : Distributed Access Switching unit for Heterogeneous Terminals (is a patented network by CCETT).

In French : REM*: Réseaux d'Entreprises Multiservices.

INTRODUCTION

Although recent conferences on Local Networks have familiarized specialists with the different techniques used in Local Networks (I.E. CSMA/CD, TOKEN PASSING, EMPTY SLOT, TIME SLOTTED), as well as the "Local networks vs PABX debate, few contributions have been made on the concept of Integrated Service Local Network (ISLN) showing the possibilities for marrying these two complementary approaches. The resulting Network can be used both as a ring structured LAN and as a Star topology for Integrated Service PABX (cf CBX concept).

The project CARTHAGE, developed at the CCETT in RENNES, France, includes all the technical features needed for such a global approach which also includes compatibility with data broadcasting techniques used on the Television Broadcast Network.

DEFINITION AND GOAL OF THE PROJECT CARTHAGE

The project CARTHAGE in its basic version uses a fiber optic ring topology and accomodates the data transmission and switching at one and the same time in the packet mode and synchronous circuit mode as 64 Kbit/s PCM voice transmission and switching.

The basic version at 8 Mbit/s for each ring has been designed to serve a 500 person center with about 100 Erlangs voice traffic and 2 Mbit/s data traffic. The network is dynamically shared between voice and the resources unemployed for one can be employed for the other. However, to extend network throughput, two rings will be located inside the CCETT's research center, interconnected via classic TDM PABX for voice and a gateway for data.

Finally, since the CCETT Research Center is involved in video broadcasting and distribution, it was decided to add a small video switching unit to the CARTHAGE Local Network in order to study the signaling needed to command such a unit.

In addition, this network conveys unconverted DIDON ANTIOPE format packets making it possible to connect cheap terminals for which LSI circuits in communications are already available. This broadcast communication mode can also be used as a pseudo interactive mode with a feedback channel using an asynchronous circuit.

A diagram of CARTHAGE is shown in figure 1.

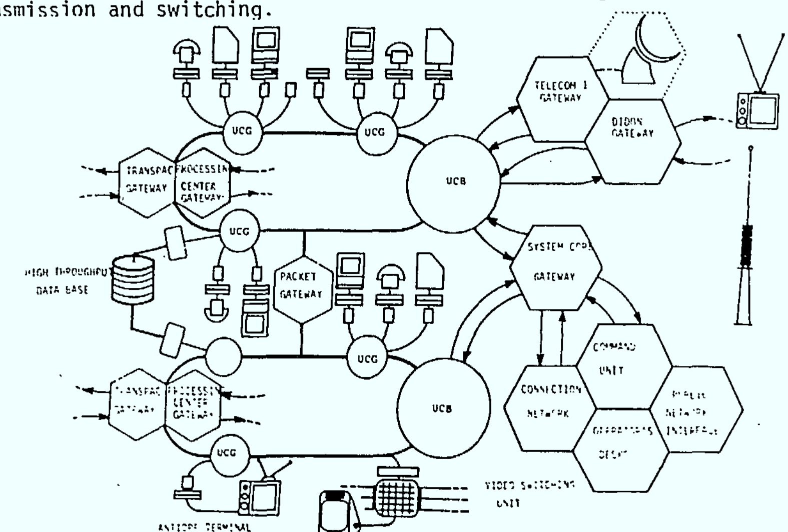


Fig 1

CARTHAGE AND PUBLIC NETWORKS; GATEWAY PROBLEMS TAKEN INTO ACCOUNT AT A BASIC LEVEL

Unlike networks such as Ethernet, gateway problems in CARTHAGE have been taken into account at a low level so that the gateway functions do not increase in proportion of the complextity of the procedures involved on the network. So the French context of Communication Administration has been studied and CARTHAGE supports in itself the means to communicate very easily towards outsides.

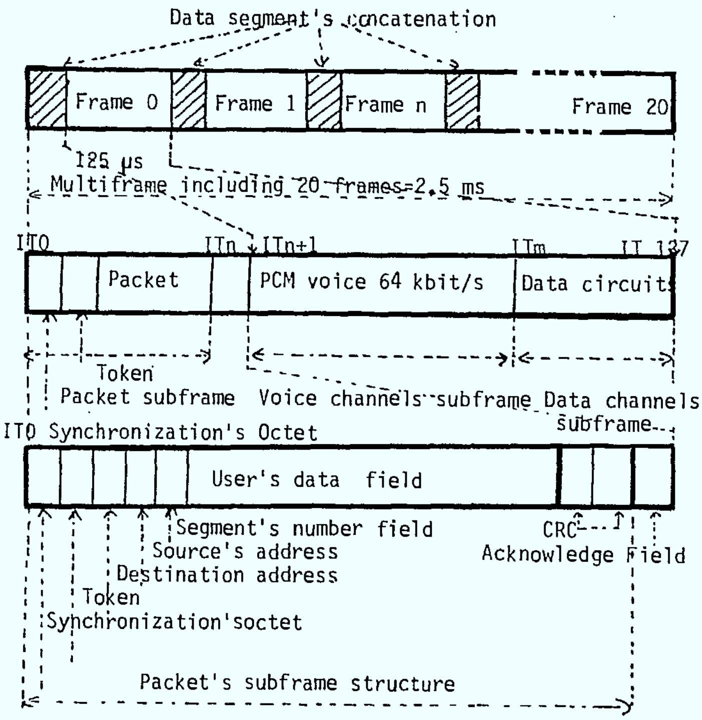
For telephone, it appeared logical to continue the 64 Kbits/s PCM channels up to the terminal via the ring with data circuits replacing the modems in the first stage, and then allowing, an easy access toward or via TRANSPAC and TELECOM 1.

For packet mode data, while the datagram is an easy means of communication on the ring, the use of TRANSPAC in the exchanges, the virtual circuits become necessary as a service.

With regard to procedures, the level 2 procedure is a subset of HDLC, which is less sophisticated than the level 2 of X25; yet it ensures the congestion control of the station, including the gateway itself. At level 3, flow control is performed between data origine and destination in order to offer services like PAD (X28, X29) at the station level. Lastly, the X21 and DIDON-ANTIOPE protocols are also proposed. Thus CARTHAGE offers a whole set of rules allowing a soft connection between Local and Public Networks.

SPECIFICATIONS AND TECHNICAL FEATURES

In accordance with the OSI (Open System Interconnection) reference model of the ISO (International Standards Organization) we shall now describe the specifications of the CARTHAGE Network from the physical layer (1) up to the Transport Layer (4) including the link layer (2) and the network layer (3).



CARTHAGE'S TDMA HYBRID PACKET/CIRCUIT FRAME

Physical layer

Because the network is designed to convey both, voice and data, the transmission support must be shared. Therefore, a Time Division Multiplex Frame has been defined. The 125 μs frame (corresponding to the PCM sample rate) is structured as a multiplex of 128 64 Kbits/s channels conveying an octet in 1 μs (125/128).

For mixing the packet mode and the circuit modes, the frame is divided into a packet subframe and a circuit subframe. As showing in 2 the circuit subframe is, itself, shared between voice channels and data channels for which a 2,5 ms multiframe of 20 frames is defined above the frame level in a X50 fashion.

Special aspects involved by the ring structure

Since the TDM frame is carried by the ring structure, the frame and the multiframe must be resynchronized in the loop controller to adjust the propagation delay around the ring which depends on the distance and number of stations. Indeed in the packet mode, since a station must recognize its own address, it needs 1 μs for that and eventually an other us to give a destination address if it wants to send a packet.

The loop controller thus resynchronizes the stream bit "modulo 125 μs" for the frame and modulo 2,5 ms for the multiframe by means fo FIFO memories. At the same time it ensures the reliability of the "token" used in the packet mode.

Althrough resynchronization may appear sophisticated, it must be emphasized that such a mechanism allows the use of the same time slot for a full duplex exchange so that throughput of such a synchronized ring is twice that of a bus structure for the same rate.

Other rules must be as compatible as possible with CCITT standardized access such as X121 and X25 and must ensure full interconnectivity with public data network such as the Packet Data Network TRANSPAC and the Data Circuit Network TRANSMIC and the forthcoming satellite TELECOM 1, making it possible to reach every terminal connected to the Network by a Direct Dialing In mechanism.

In our mind it is madatory for a Local Area Network to be open at a general Network Concept : it must implement a true Network Level (3) in its structure to ensure full interconnectivity required mainly for Office Automation services. Many approaches suggest using end to end subaddressing at the transport level (4) but today, the only addressing scheme supported by a standardization authority seems to be the X21 and X25 level 3 standardized by CCITT and allowing a Direct Dialing Input at the level 3.

Processing of a high speed link level

The link level 2, processed by a boolean processor built with field programmable logic sequencers is able to reaches 8 Mbits/s and higher rates without any problem. In fact, this device can run at processing times of about 300 ns making it possible to realize very high speed controllers with a link level as powerfull as that of the HDLC protocol. Indeed, immediate acknowledgement and flow control allows the use of an HDLC subset without the window mechanism on the ring. This link level processor will be implemented in a LSI circuit using a prediffused gate array.

This last feature (connection matrix) is commonly used in telephone technology; each cluster is equipped with two types of matrices (or memory) : a frame-connection matrix and a multi-frame-connection matrix. The frame-memory is used to transmit and receive the contentes of a time-slot, or a basic frame (64 Kbit/s). The multi-frame matrix memorizes the time-slots allocated within the multi-frame.

Transport layer

This layer ensures the independance of the network means with respect to upper layers; it chooses the kind of ressource, depending on the quality of service (throughput) error rate,...), for the connection mode and provides the network with the multiservice signaling channel. The primitives employed by the signaling channel are :

TYPE	FUNCTION	PARAMETERS
CALL REQUEST	To establish a call	. Addressee's address . Caller's address . Throughput . Circuit type - virtual - actual - TDM - Video - ... . My-reference
CALL RESPONSE	To accept a call	. Your-reference . My-reference
RESET REQUEST	To purge the circuit	. My-reference
RESET RESPONSE	To confirm the purge	. My-reference
LIBERATION REQUEST	To end a connection	. My-reference . Cause of liberation
LIBERATION RESPONSE	To confirm a liberat	. My-reference

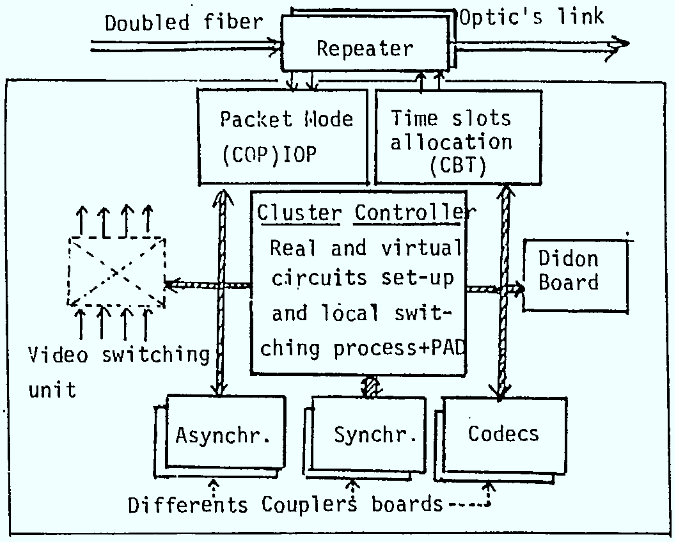
The reference concept replaces the logical link concept. In fact, in public data networks (like TRANSPAC), the network, itself, translates the logical link numbers between the two endpoints during the data transfer phase.

In local networks, the two endpoints speak to each other, and translation is unnecessary. The data exchange uses the references exchanged during the connection phase. This reference exchange is made via an intermediate process, which must know all the ressource requests on the network. This also avoids reference collisions (as do the logical link numbers in X25).

The set up of a video connection should be considered as a particular example of connection; a special cluster unit acts as a video switching unit and connects input lines to output lines (exactly as a PABX does with telephone lines). In the future, it will be possible, with a truly multiservice signaling channel, to set up an audio, video and data communication within the same call.

ARCHITECTURE OF THE DIFFERENT ELEMENTS

Cluster architecture



The different boards are detailed below :

CBT-BOARD : - synchronization handling on the fiber optics
- transmission and reception of data in accordance with the connection matrices
- interface with processor and telephone via CODEC-BOARD

CODEC-BOARD : - handling of 8 telephone sets

ASV8-BOARD : - handling of 8 asynchronous terminals (V24)

COP-BOARD : - access to the PACKET resource
- handling of levels 1 and 2 of the PACKET protocol

MX25-BOARD : - processor board which allows two X25 links.

The different software module are :

ACTUAL CIRCUIT PROCESS : - handles the connection between clusters and etermediate process in charge of actual circuit set-up

VIRTUAL CIRCUIT PROCESS : - same, with virtual circuit

DATA CIRCUIT : - handles multiframe connection matrix and exchanges on actual circuits

SPEECH CIRCUITS : - handles frame connection matrix and speech exchanges on actual circuits

TELEPHONE SIGNALING : - handles local telephone signaling

SWITCHING PROCESS : - establishes links inside the cluster between software units.

X25 HANDLER : - ensures levels 1-2-3 of X25 for connection with X25 servers or terminals

V24 HANDLER : - ensures asynchronous terminal connection

Handling of the "circuit" subframe

The circuit subframe offers throughputs ranging from 2400 bit/s to 64 Kbit/s. This resource is allocated by a centralized function implemented in the ring controller which holds the map of all the available time slots in the multiframe. The speed conversion between the transmission modulo (nx1200 bit/s v/s px3200 bits) is carried out by a 6+2 envelop as in the X50 CCITT standard; the user interfaces are of the X21 type, also CCITT standardized.

Handling of the packet subframe

The packet/circuit resource sharing gains flexibility through the variable size of the packet resource, which is called the data segment, in the beginning of the frame.

The "packet" subframe carries all packets like data around the ring in 125 us and is used for example by X25 servers and terminal interconnection. Broadcasting uses the DIDON tehcnique and the common signaling channel is used to allocate resources and ensure the integrated service to converse between operators, controllers, gateways and the ring controller.

Access to the packet resource is made by means of a deterministic technique (as apposed to a stochastic technique such as CSMA/CD used for Ethernet) using a token passing scheme with a speech time control mechanism for every controller using the token in accordance with a speech-right rule so as to guarantee a maximum delay for catching up with a free token and sending data for any station.

The token carried by the time slot 1 in the frame (the time slot 0 carries the frames and multiframes synchronization octet) ensures the circulation of the "right of speech" for every segment of data holding this label indicating whether or not the segment occupied with information. Thus when a station has a packet to send, it expects an empty packet (token free) in which it inserts the data and marks "full".

Other functions such as controller supervision and packet-sized allocation are devoted to the packet channel by means of dedicated labels carried by the "token octet". In the same way, the different packets modes such as connectionless, connection and broadcasting (at level 2) are distinguished by this octet.

Main features of the protocols used at level 2 and at level 3 for the packet mode

The main rules which have led to the selection of the technical features of the protocols to be implemented in CARTHAGE used as a Local Area Network (LAN) have been to be deterministic for the delay and the throughput guaranteed at each station that which implies a connection protocol at level 2 and a network level (3) for addressing every terminal.

PROTOCOL IMPLEMENTATION

Data link layer

This layer provides the network with data framing and error detection and recovery.

The "PACKET" resource encapsulates the information in the following format : as shown in fig. 3.

The different fields are detailed below :

TOKEN This field can have several meanings depending on the different functions of the packet :

- EMPTY - the PACKET resource is free,
- FULL - the PACKET resource is full and the TO-ADDRESS is to be matched by all stations,
- LAST-PACKET- indicates to the address that the packet is the last of the transaction (limited by the speech-right-rule),
- RESERVATION- indicates that the data are not significant, but that the ACKNOWLED GEMENT field is used,
- DIDON - indicates that the packet is used for broadcasting and is structured following the DIDON standard,

TO-ADDRESS This field contains the address of the packet's addressee; this address is made with a loop-address concatenated with an "on-the-loop" address. This allows a very easy implementation of the gateway to another CARTHAGE-loop by solving this problem at level 2.

SOURCE-ADDRESS Same as the TO-ADDRESS, but concerns the sender.

SEQUENCING NUMBER This field contains the number of the packet.

DATA This field contains the bytes of information.

CRC This field contains a cyclic redundancy check sequence.

ACKNOWLEDGEMENT This field contains :
- the sequencing number of the acknowledgement packet,
- the flow control code of the addressee station :
  - . RR - station ready to receive more packets,
  - . RNR- station no longer ready to receive additional packets,
  - . REJ- packet erroneous, rejected, must be retransmitted.

In a first step, we have only implemented a point-to point transmission protocol. Broadcasting with acknowledgement is for further study.

Network layer

This layer ensures the routing of information. The field used in the routing process depends on the service :

- datagram : addressee's address enclosed in the DATA field
- broadcast : no field present at level 3
- virtual circuit : reference enclosed in the DATA field
- actual circuit : connection matrix.

VIDEO SWITCHING UNIT

This unit has the same architecture as the cluster and, in addition, is able to handle videocommunications via a dedicated fiber optic broadband network added to the CARTHAGE network.

SAFETY

The CARTHAGE network is designed to convey all types of data exchanged inside compagny facilities : a failure of this equipement may have catastrophic consequences on its working. Therefore, during the design phase, a specific effort has been made towards modularity : the different units of the network are build with the same elements and the units that are unique on the loop, such as the loop controller and the gateways, for instance, are duplicated for safety reasons.

In addition, the optical fibers, themselves have been doubled and each cluster unit is provided with an automatic sensor which extracts the signal from the valid fiber.

In addition, the loop controller ensures supervision functions during the life of the network and is able, for example, to stop a chattering station, to stop remotely any station, etc...

STRUCTURE, MODULARITY, COSTS AND FUTURE OF CARTHAGE

If the association of voice and data allows an economical optimum in search of multiservices, it must not compromise the validity of the model if the network is totally telephonic, or totally computer data-based. Each controller has been designed in order to handle a function separately, voice or data.

The central controller (ring controller or RC) is made with 3 boards and must be doubled for safety (6 boards). If the network is only "packet", this controller can be made up of 5 boards.

On a packet network, with 8-16 terminals, we can expect a cost of 600/1000 $ per terminal.

On a circuit network, with 8-16 subscribers, the expected cost would be 1000 $ for voice and data.

These costs clearly make CARTHAGE quite competitive with the classic PABX or Ethernet network with a truely integrated high speed communication structure.

The future lies in the LSI circuit which will be available, and this projects goal to define such structures. We have seen, however that the design was choser in order to use, as close as possible the LSI already available (DIDON, HDLC...).

We are also working on a multiservice multisignaling channel and on a more global integration of video communication functions which presently use a joint fiber optic broadband network using only the switching command facilities of CARTHAGE.

CONCLUSION

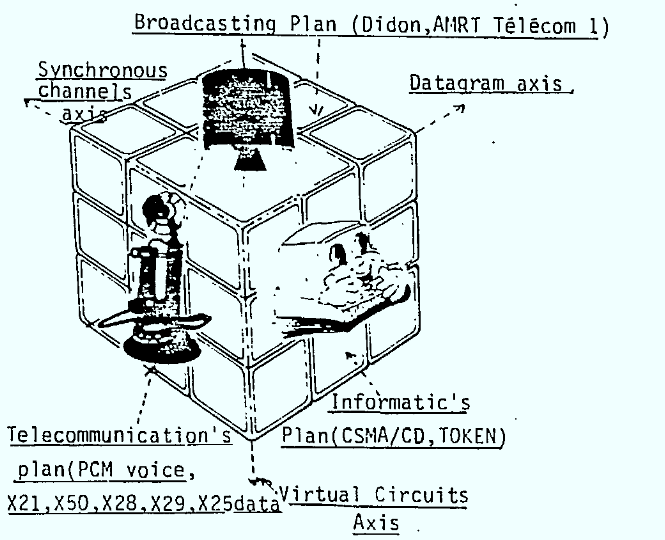
Finally what kind of Network is CARTHAGE ?

Is it a Data Local Area Network (LAN), is it a Integrated Service Local Network (ISLN) or is it a mutliservice PABX (CBX) ? Nobody can say, because as we have noted the ring structure isn't really fixed and a star topology can also be used. In the same order of ideas CARTHAGE can be used only for Voice Switching and Synchronous Data Switching, or for only Packet Switching (in a virtual circuit or datagram mode) or for broadcasting since the boards having been developed with the necessary modularity.

Although the first version of the equipment has been built for a ring topology limited to an 8 Mbit/s rate for technological reasons allowing TTL or MSI LSI, the industrial version will include two such rings around a PABX and the equipment will be structured to enable the building of other configurations such as a star topology using the same hardware and software units. Throughputs eight times higher will be attained (64Mbit/s with the same technology by means of a parallel instead of a serial interconnection between the basic units (controllers), the parallel bus being synchronized as in a TDM switching unit.

At the future, this modular approach will allow optimal configurations (mixed star and ring) adapted to the firm's "topology"; the ring structure being more convenient for high data rates, packet switching requriring distributed processing and the star structure being more effective for voice and data switching in the TDM mode (as in CBX).

To conclude, we might picture CARTHAGE as a "corner" in the magic cube of communications involving three axes : the Synchronized Circuit axis, the Virtual Circuit axis and the datagram and broadcasting axis. So that besides while the project appears very ambitious, its modularity at the cross-roads of different techniques would allow it to become very successfull if we are able to develop the LSI circuits needed to reach very low costs. We are working towards such a goal.



CARTHAGE'S PLACE IN THE TELECOM'S RUBIK'S CUBE