COMPUTER COMMUNICATIONS: NETWORK DEVICES AND FUNCTIONS

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1. INTRODUCTION

The proliferation of data communications in recent years has stimulated the production of a variety of devices designed to lower cost and improve performance of data communication networks. This tutorial short note provides basic information on the use of three general categories of such devices: (1) devices for interfacing with transmission facilities; (2) devices for cost savings; (3) devices for communications switching. These categories include a major portion of the equipment types found in data communications networks, but are certainly not all inclusive. It should be emphasized that a device may belong to more than one category, and that with proper configurations, almost all the devices can be used for performance improvement such as flexibility, response time, reliability, and expandability.

2. BASIC NETWORK STRUCTURES

There are several communications network structures incorporating a wide range of devices. In order to understand the role of particular devices in networks, it is helpful to identify some basic network architectures and topologies in which the roles of the devices are well defined. These structures are: centralized; distributed store-and-forward (S/F) message or packet switched; and ring-switched. It should be noted that many networks are not of a classic structure; rather, they are more appropriately viewed as hybrid structures mixing variations of the classic structures.

2.1 Centralized Networks

A computer with a small number of terminals connected directly to it forming a star structure is, perhaps, the simplest form of centralized network. Such a network is functionally portrayed in Figure 1. The dotted lines marked A and B represent the boundaries between the computer and transmission facilities and between transmission facilities and terminals. The devices for interfacing with transmission facilities serve to bridge these boundaries. The transmission facilities between boundaries A and B can be of many forms, including the dial telephone network, leased telephone lines, and value added networks oriented specifically towards data transmission services.

Many of the cost-savings devices are located between the boundaries A and B and serve to reduce the cost associated with the transmission facilities.

The centralized network architecture spans many network activities. The computer may be a central processing facility serving remote batch, interactive time-sharing, or inquiry/response terminals. Alternatively, the computer may be a central communications node enabling messages to be sent from any terminal to any other terminal. In this case the computer is usually referred to as a message switch, and the network as a centralized message switching network.

2.2 Distributed Store-and-Forward Networks

A distributed store-and-forward (S/F) message switched network is composed of several geographically dispersed communications processors (CPs) linked together with dedicated transmission facilities (lines), and a user population of terminals and/or computers connected to the CPs. The interconnected CPs are usually referred to as the backbone network or communictions subnet, and serves as a common user service to the terminals and computers. In the classic message switching network, each message is sent in its entirety along a predetermined path from sender to receiver. At each CP (in this case the CP is properly viewed as a message switch) along the path the message is first received in its entirety, then stored until the appropriate outgoing communications facility is available, then transmitted (forwarded) to the next CP. Message storage may be in core, but is often on fast peripherals such as drum or disks to ensure availability of storage for long messages.

A conceptual variation of the message switched network is the packet-switched network in which a message is subdivided into frames or packets before it is transmitted and is reassembled when it is received. Each packet is an independent, self-contained unit for transfer through the network, and thus at each CP smaller units are received, stored, and forwarded than in the message switching case. With proper packet sizes, all storage can be in main core, and because packets are forwarded immediately (without having to wait for reception of the whole message at each intermediate node), the delay time is substantially reduced. The architecture of a distributed store-and-forward network is shown in Figure 2.

2.3 Ring-Switched Network

A ring-switched network is characterized by the ring or loop-type topology of the interconnected CPs. An example is shown in Figure 3. The main function of the CP (Box B in Figure 3) is to interface the terminals and computers with the ring. They will be appropriately called Ring Interface Processors (RIPs) in this paper. The ring is operated as a continuous bit stream circulating in one direction, and a RIP is connected into the ring through a shift register bridging its input and output lines. The channel capacity of the ring is multiplexed into a series of time slots. (To illustrate, assume the channel capacity is 10 Kbps and it is divided into 10 slots. Each slot will then consist of 1000 bits. Bits belonging to the same slot do not have to be continuous. Without loss of generality, for easy understanding, we can assume they are.) The time slots flow through the ring from RIP to RIP, or from station to station, in the same direction (either clockwise or counterclockwise). When a terminal or computer has a message to send, the message is first stored in the RIP. It is then subdivided into blocks or packets that fit into slots. A header is attached to each packet to indicate the origination and destination. The RIP then checks the shift register and waits for an empty slot. When an empty slot is detected, and available for the RIP to use, the packet is shifted onto the ring to occupy the slot. The RIP also has the responsibility to detect the occupied slots that are addressed to it. Sometimes a minicomputer is included in the ring to perform supervisory functions. A ring-switched network may consist of several rings. Two neighboring rings are interconnected by a switching processor. It transfers from one ring to another by comparing a part of the address included in the packets' header with a wired-in address.

3. DEVICES INTERFACING TRANSMISSION FACILITIES

There are two ways in which digital signals are sent down a transmission line: (1) as they are (baseband transmission) or (2) superimposed upon (or "modulate") a higher frequency which "carries" them. Without modification, signals cannot be sent long distances because of distortion on the lines. If the data signals are to be carried by a high frequency, they may either be sent in analog or digital form. A device that interfaces between the baseband signals and the carrier signals is called a modulator-demodulator, or "modem." However, conventionally "modem" refers to devices which interface specifically with analog carriers. Devices which interface with digital carriers have a variety of other names.

3.1 Devices Interfacing with Analog Transmission Facilities (commonly called modems, data sets)

Almost every data and computer communication network relies on the telephone plant's facilities for transmission. Today's telephone facilities have been designed for voice transmission and almost all of them use analog transmission with frequency division multiplexing, requiring analog modulation for carrying and transmitting data signals. A voice grade channel has a bandwidth of approximately 3K Hertz (cycles per second). Theoretically, with proper modulation coding techniques, a maximum bit rate of about 20,000 bps (channel capacity, line speed) can be achieved over a voice grade channel (derived from Shannon-Hartley formula, channel capacity = $W \log_2 (1 + S/N)$, where W is the nominal bandwidth of 3000 Hz and S/N is the signal-to-noise ratio approximately equal to 20 db on a telephone line). Currently up to 4.8 Kbps can be derived from a dial-up line and with proper line conditioning, up to 9.6 Kbps from a voice-grade leased line. It is possible that even higher rates will be achieved in the future. Modem characteristics for common data rates over voice-grade lines are given in Table 1. In general, the higher the bit rate the higher the error rate and the greater the equipment complexity and cost. For data rates greater than 9.6 Kbps, broadband channels are necessary. At present available data rates include 19.2 Kbps over a channel equivalent to 6 voice-grade channels, 40.8 or 50 Kbps over a channel equivalent to 12 voice-grade channels, and 230.4 Kbps over a channel equivalent to 60 voice-grade channels.

3.2 Devices Interfacing Digital Transmission Facilities (commonly called PCM terminals, Data Service Units)

With digital transmission (in contrast to analog), a train of high rate pulses is used to "carry" information (digital information as well as voice), instead of a sinusoidal, or analog carrier. The commonly used technique is called Pulse Code Modulation (PCM). Even though the data signals of the transmission facilities are both in digital forms, there is one major difference. The data from the computers and terminals are in the form of a string of binary pulses, while the signals on the transmission lines are in bipolar forms. In the bipolar transmission format a mark (1) is indicated by presence of a pulse with each mark being opposite in polarity from the preceeding mark. A space (0) is indicated by the absence of a pulse. An exmaple of the different pulse trains is shown in Figure 4. Bipolar transmission requires less power, facilities error detection, and allows transformer coupling at repeaters.

4. DEVICES FOR COST SAVINGS

In order to ship digital information between terminals, computers, and terminals and computers, two major resources are needed. One is the transmission facilities that control the communications, i.e., that provide the orderly flow of the information. Of course, there are costs associated with using the resources. Devices discussed in this section are designed for reducing such costs. However, these devices themselves are an expense. Consequently, quite often the decision of whether or not to use these devices hinges on the tradeoffs between the costs that can be saved by their use and the expense of their acquisition.

4.1 Multiplexers

A multiplexer is a device that allows several terminals to share one line. A multiplexer can be justified if it's cost is less than the savings that can be achieved from line mileage reductions it enables. Figure 5 illustrates this basic concept. The network in Figure 5(a) has five long distance lines and no multiplexers; and the network in Figure 5(b) has one long distance line and one multiplexer. Which network structure is less expensive depends on whether four long distance lines or one multiplexer is less expensive.

We will use "facility" to refer to the part of the telephone plant described in terms of its properties as a transmission medium, and "channel" to refer to a functional communications path. A channel is described by its capacity, i.e., the maximum rate at which information can be acceptably transferred over it. The capacity of the channel, or maximum data rate acceptable, depends on a variety of factors, including the bandwidth of the facility and the hardware characteristics of the modems. The use of one facility to form several separate channels is called multiplexing. A device which combines multiple facilities, each used for one or more distinct channels, into one facility, formed into the same distinct channels, is called a multiplexer. A device performing the reverse process, i.e., transforming one facility, formed into several channels, into multiple facilities, each with one or more of the channels, is called a demultiplexer. Many current hardware devices perform multiplexing in one direction, and demultiplexing in the other direction. Such a device is usually simply called a multiplexer.

The channel is the functional communications path, whereas the facility is part of the hardware used to form a channel. A multiplexer does not alter the channel structure of the network, and thus is functionally transparent. However, the physical facilities from which channels are formed determine a large part of network costs. Multiplexing offers in a way to achieve significant economies in facilities use. To understand these economies, it is helpful to examine the two fundamental approaches to implementing multiplexing.

4.1.1 Frequency Division Multiplexers (FDMs)

One approach is to divide the bandwidth of the facility into several separate segments, and allow each segment to serve a separate channel. This is referred to as a frequency division multiplexing (FDM), and is graphically portrayed in Figures 6 and 7.

An FDM system is comprised of a number of modulator-demodulators, each being a narrowband modem. This accounts for two often cited advantages. First is that since each unit is an independent modem, it can continue to operate regardless of a failure in an adjacent channel. The second is that due to the analog interface with the transmission path there is no need for a high-speed modem, as would be required with a TDM system. Because FDM can be implemented simply with independent narrowband modems, the multiplexed channels can be distributed along a multipoint line.

FDM systems are limited to transmission rates of 1200 bps and are, of course, asynchronous. Since any bit sequence is passed through the system via frequency-shift keying and without manipulation of the data structure, data transparency is assured. This aspect of transparency is critical to the transmission of non-standard code sets.

4.1.2 Time Division Multiplexers (TDMs)

The second approach is to establish a high-speed data stream over the facility and assign periodic time slots or bit positions of the data stream to separate channels. This is referred to as time division multiplexing (TDM). There are several variations on the implementation of these approaches. The basic strategy is graphically illustrated in Figures 8 and 9.

Time division multiplexers construct their high-speed serial outputs either by bit or byte. These two methods account for the commonly accepted terminology, bit-interleaved or character-interleaved TDM. Bit interleave units are generally cheaper than character-oriented systems and propagation delay is considerably less, since buffering occurs on a bit basis. This is an important consideration in Telex or Echoplex applications.

Channel capacity is always greater with a character interleaved system since only information bits in a given character are removed from the buffer and transmitted. Despite increased channel capacity, however, few character interleaved systems can claim total pattern insensitivity (transparency) as can "bit" TDM and FDM systems.

The major advantages of TDM stems from its use of one common high-speed bit stream which limits its aggregate bit rate to only that capable of being achieved with the modem (currently 9600 bps). Thus, TDM units can generally handle more and faster devices than FDM (i.e., 8-1200 bps devices for TDM versus 1 for FDM).

4.2 Statistical Multiplexers

The function, configuration, and characteristics of a statistical multiplexer are very similar to those of a regular TDM (and it is usually referred to as an STDM). However, it is distinguished by the following characteristics: the number of channels carried by the facility at the high-speed side of an STDM can be less than the number of channels at the low-speed side. This characteristic is illustrated in Figure 10.

The percent of time a channel is used is called its utilization. Many terminals generate data for transmission at an average rate which is much less than the capacity of the channel, resulting in channels with low utilization. An STDM achieves economic advantage by replacing a larger number of low utilization channels with a smaller number of highly utilized channels. A prerequisite for justifying an STDM is that its output channel capacity must be greater than the sum of the average data rates of the terminals on its input. It is at this point perhaps helpful to examine the difference between a regular TDM and an STDM in more detail.

To each time slot of each channel on the input of a TDM, a time slot is assigned in the high capacity channel on its output. This effectively divides the high capacity output channel into several separate subchannels, each associated with a particular channel on the input. It does not matter whether or not a time slot is being used to transfer information. However, an STDM has more time slots arriving on its input side than leaving on its output side. Each time slot carrying information must be assigned a time slot on the output side. Thus an STDM must be able to identify which time slots are in fact transferring information. Furthermore, it must be able to assign output time slots to this information in such a manner as to be understood by whatever device is on the other end of the output channel. Although the average number of time slots carrying information on the input will be less than the number available on the output, the random nature of terminal use may result in the number of slots carrying information arriving over a brief interval being greater than the number of slots available on the output. Hence, the STDM must also have the ability to buffer the arriving information as it waits for available slots. The requirements of intelligence and storage for STDMs invariably lead to their implementation with microcomputers or minicomputers. The actual operation of STDMs varies considerably, but is usually much more sophisticated than the simple bit packing noted above.

Since STDMs have built-in intelligence, they have other performance features that regular TDMs do not have. When errors occur during the transmission on the high-speed side, regular TDMs do nothing. Since STDMs have intelligence, erred information can be detected with a very high probability and retransmitted. They may also be capable of automatically detecting a variety of terminal codes and converting them to a standard one, and to compress data in order to achieve more efficient transmission. Different manufacturers of these devices assign different names to them. Codex has called their products Intelligent Network Processors; and Digital Communications Associates has termed their products SMART/MUX.

4.3 Concentrators

The word "concentration" appears to have a very broad meaning in data communications. We will discuss only one narrow interpretation of concentration.

A concentrator is also a device mainly for saving line costs. Its operation and structure is very similar to that of an STDM, and differs primarily in its use of greater intelligence and memory to achieve greater concentration and provide more auxilliary services. In essence, there are four major differences between a concentrator and an STDM. (1) In a concentrator, the single facility on the high-speed side carries only one channel. When a message from a low-speed facility arrives at the concentrator, it queues for this single channel at the high-speed side for output. When the channel is available, the whole message is treated as one time slot and is transmitted until completion. This is illustrated in Figure 11. (2) The operation is not transparent to the users. Not every input message from a terminal is being transmitted at the output (e.g. line control messages), and vice versa. (3) An input message may be reformatted before it is sent out. (4) An STDM allows little, if any, software capability for the users, where a concentrator usually has the software development facilities of most minicomputers. This software flexibility gives a concentrator the potential for performing the following communications-related tasks:

- multidrop polling
- error control
- automatic code detection
- code conversion
- handling different line protocols

- data compression
- reliability monitoring
- switching

By performing such local operations, and transferring information to the computer with efficient high-speed transmission techniques, the concentrator can achieve an effective output channel utilization in excess of 100 percent.

Usually, all the communications functions only consume a small fraction of the total processing power available. The residue processing capability in the concentrators has been used in various implementations for the following functions:

- monitoring and control
- message formatting and editing
- local processing (share central computer's load)
- local file maintenance
- journaling and accounting
- software multiplexing and demultiplexing

An example of concentrator useage is shown in Figure 12 showing the network structure of the NASDAQ system.

4.4 Front-End Processors (FEPs)

An FEP is a device used for economizing computer resources needed for data communications. It is inevitably a minicomputer connected between a mainframe computer (or a message-switching computer) and transmission facilities. It may be used simply to interface signals between the mainframe and the transmission facilities, and it may also be used to perform communication control functions. Used in the first role, it replaces the usually more costly hardwired Line Interface Unit (LIU). Used in the second role, it uses its less expensive processing power to save the core and CPU processing overhead, and thus increase the throughput, of the host processor. The FEP usually carries out special communication functions that the host processor cannot cost-effectively handle either because of lacking spare processing capacity or because of extreme complexity involved in implementing them.

The host computer and terminals use the data communications network to interchange information. The general facility of a computer for transferring information between it and the outside world is its input/output (I/O) channel. Particular devices are connected with a hardware interface. In the case of a communications line, the modem terminating the line must be interfaced with the CPU. The overhead required for a large CPU to interact with many communications lines at a modem level is far too great to be economically attractive. Thus, a sophisticated interface is used to handle the modem interaction, and only useful information is transferred through the I/O channel to the CPU. In the early installations, hardwired logic devices called Line Inference Units (LIU) have been used. The LIU's contain logic peculiar to the characteristics of each line and/or terminal they interface, including: the ability to recognize special control characters (such as END OF BLOCK), the capability to assemble and disassemble characters, and limited line monitoring to time out inactive terminals. An FEP used to replace an LIU to perform these functions is called an emulator.

An LIU performs purely "mechanical" functions. The real communications control functions reside in the CPU. These functions include: message formatting (adding or deleting control characters), code conversion (from communication codes to computer codes and vice versa), buffering, queueing, polling, error recovery, etc. A minicomputer that takes over all these functions and appears as a single device on the host computer's I/O channel (regardless of how many terminals are in the field) is a true FEP.

Since most large computers are not designed to effectively handle fluctuating real-time demands, a large overhead, as high as 40 percent in some cases, is often associated with communications processing. The FEP, when designed with real-time schedule in mind, can reduce this overhead to ten percent or less and execute the communication control functions more cost effectively.

Main memory requirements can similarly be reduced. As much as 75K bytes of host processor core has been saved on occasion. Although the same amount of data must be stored, the software requirement associated with buffering, etc. will be much less in the FEP, reducing overall storeage requirements.

In addition to emulation and standard communication control functions, an FEP may also be used to perform functions that usually are not supported in the host processor. These include the ability to accommodate a variety of non-compatible terminals, providing soft-fail capability to prevent loss of data when the host computer malfunctions, message switching, and preprocessing for access to packet-switching networks.

4.5 Modem Sharing Unit

A modem sharing unit (MSU), or multiple access coupler, is a device for connecting several (typically up to six) terminals to a single mode. The terminals are usually restricted to be in the same location (within 50 feet of the MSU). A MSU reduces the number of modems and the number of terminal connections from the telephone company.

4.6 Port Sharing Unit

A port sharing unit (PSU) is a device for connecting several (typically up to six) modems to a single computer port (or concentrator, or multiplexer).

The PSU broadcasts data from the port to all the modems, and delivers data to the port from the first modem to generate an appropriate response.

4.7 Biplexers

A biplexer is a device which uses two voice-grade lines to effectively achieve a single high-speed channel (up to 19.2 kbps). Such a device must be able to compensate for the possible differential delays of the two separate facilities. Typically, acceptable operation can be achieved with the two lines diversely routed with differential delays up to 1/2 second.

The cost effectiveness of a biplexer is principally derived from the current tariff sturcture for high-speed lines versus voice grade lines (i.e., two voice grade lines are typically much less expenseve than one high-speed line).

5. DEVICES FOR COMMUNICATIONS SWITCHING

These devices are divided into three basic types corresponding to the network structures identified earlier: message switching, packet switching, and ring switching. Message switching devices are usually associated with centralized network structures, and packet switching devices with distributed network structures. Ring switching devices are, obviously, associated with ring structures.

5.1 Message Switching Devices

Message switching was an established area of telecommunications before the introduction of the contemporary computer. Many of the service characteristics of message switching networks today reflect their evolution from the earlier years of labor intensive torn-tape operations. Typically, response-time requirements are very lenient (minutes) and availability requirements very stringent (must be operational with probability one). Furthermore, records must be kept of all messages moving through the system, assistance must be provided to terminal operators with problems, and addressing and routing must allow any user to contact any other users. These requirements usually lead to implementation of message switches as computer complexes with substantial peripheral compliments to support journaling, billing, and extensive addressing, and with extensive redundance for high availability. One such complex typically serves the message switching requirements of a corporation or agency, and thus forms the center of a centralized message switching network. Large, typically international, message switching networks have interconnected computer complexes to form a distributed message switching network.

5.2 Communication Devices for Packet Switching S/F Networks

There are three major communication functions that CPs in a S/F packet-switching network must perform: interfacing host computers with the backbone network, interfacing terminals with the backbone network, and managing the packets flowing through the backbone network. It is not necessary to have three distinctive types of CPs to handle these three functions. On the other hand, a host computer or a remote concentrator may perform part of the interfacing functions also.

5.2.1 Packet Switch

A packet switch manages packets in the network. This is the most important function in an S/F packet switching network. Among the tasks that can be classified into this function are:

- Routing input packets to appropriate output lines according to packet destination, traffic condition and routing tables.
- Periodically updating routing tables.
- Detecting network element failures and network disconnection.
- Controlling input rates to avoid traffic congestion.
- Recovering from failure.
- Acknowledging packet receipt
- Controlling errors
- Statistics collection
- Flow control

In the ARPANET, a packet switch is called an IMP (Inter-Message Processor).

5.2.2 Network Access

The following are some of the tasks belonging to this function:

- Recognizing functional applications of the messages, such as file transfer, interactive, RJE, etc., such that appropriate protocols can be applied.
- Breaking long messages (RJE, graphic terminals, etc.) into packets.
- Code-conversion for a variety of different terminals.
- Formatting the packets.
- Attaching the headers and trailers.
- Storing unacknowledged message or packets for possible re-transmission.

- Reassembling receiving packets.

- Acknowledgement.

- Controlling input rate to avoid congestion.

This function can be achieved with the following possible approaches:

- Group the terminal interface function with the traffic managing function, (i.e., make it part of the switching node's responsibilities). (In ARPARET, the CP performing both functions is called a Terminal IMP, or TIP.)

- Group the host computer interface function with the packet switch.

- Part of the host computer interface function is carried out at the host computer and part at the packet switch (this approach has been adopted by ARPANET).

- Make a distinct CP, specially designed to handle all tasks. This CP will stand between packet switches and host computer and/or terminals. In this fashion, when a packet switch receives a packet, it may not know whether the packet is from a terminal, a neighboring switch, or a host computer. The CP in this case may act like a front-end to a host computer, or a concentrator. (In ARPANET, there is a minihost to interface RJE terminals and IMPs, and there is a special communication processor called ELF to interface a variety of terminals with the IMPs. ELF is a PDP-11 based system.)

5.3 Communication Device for Ring-Switched Network

There are three major communication functions in a ring-switched network: ring interfacing, ring control, and switching between a ring and the rest of the network. Depending on design philosophy, the control function may be distributed among RIPs and switches.

5.3.1 Ring-Interface

A RIP basically consists of a shift register, buffers and an associative store which can be written into by the attached computers or terminals. A RIP can be a minicomputer, microprocessor, or hard-wired device. Among the tasks to be performed are:

- Breaking messages into packets

- Detecting a usable empty slot for sending packets. (An empty slot may not be usable. In a central control system, the assignment of empty slots to users is the responsibility of a central controller.)

- Shifting packets onto the ring
- Detecting arriving packets
- Shifting arrived packets into buffers
- Error control
- Erasing delivered packets from ring slots, if this function is not performed by the ring controller

5.3.2 Ring-Control

Major tasks performed by a CP designated as the ring controller are:

- Maintaining synchronization of the ring
- Preventing the buildup of traffic in the ring because of undeliverable packets. (If a packet tries to pass through the controller a second time, it is either destroyed, creating an empty slot or sent back to its destination.)
- Empty slot assignment upon demand. (This is performed only in a centrally-controlled system in which a RIP cannot shift a packet into an empty slot without permission from the controller.)

5.3.3 Switching Function

Packets destined for a station outside a particular ring have addresses indicating this and are picked off by a switching node in exactly the same way that intra-ring traffic is picked off by the RIPs. This traffic is buffered and shifted onto the next ring in the same way that local traffic is shifted onto a ring by the RIPs.

6. CONCLUSION

Network architectures are seldom of a simple classical structure, but rather are usually of a hybrid form as typified by the network shown in Figure 13. Similarly, the roles of devices in networks are seldom of a simple classical character, but rather are multidimensional in nature, impacting cost, throughput, delay, and availability. In this paper we have briefly described communications devices associated with three basic functional dimensions considered in the network design process. Clearly, many other functional areas can be defined, and many other devices can be examined. However, the areas examined here are perhaps the foremost in consideration of the typical network design process, and the devices considered cover a sufficient range to introduce the reader to the scope of alternatives available.

TABLE 1

Modem Characteristics (voice-grade lines)

Data Rate (bps)	Primary Modulation Technique	Typical Application	Equivalent Data Set Provided By Bell System
Up to 300	Frequency Shift	Low-Speed Terminals	WE 103
300-1200	Frequency Shift	Medium-Speed Terminals	WE 202
1400-1800	Frequency Shift	Remote CRT Terminals, etc.	WE 202
2000-2400	Four Phase, Vestigal AM Duobinary FM	Same as above	WE 201
3600	Four Phase + AM	Same as above	WE 203
4800	Four Phase + AM, Vestigal Sideband AM	Remote Batch Stations, etc. Point-to-Point and High-Speed Polling	WE 208
7200	Multi-Level, Three-Level AM	Point-to-Point Multiplexers, etc.	WE 209
9600	Phase and AM Combined	Point-to-Point Computers and High Speed Terminals	WE 209

Figure 1: Centralized Network

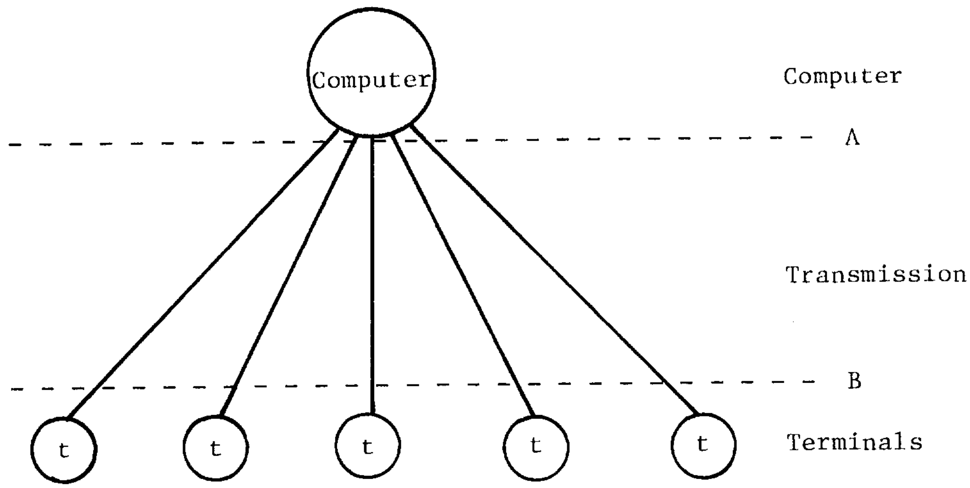


Figure 2 - A Basic Packet Switching Network

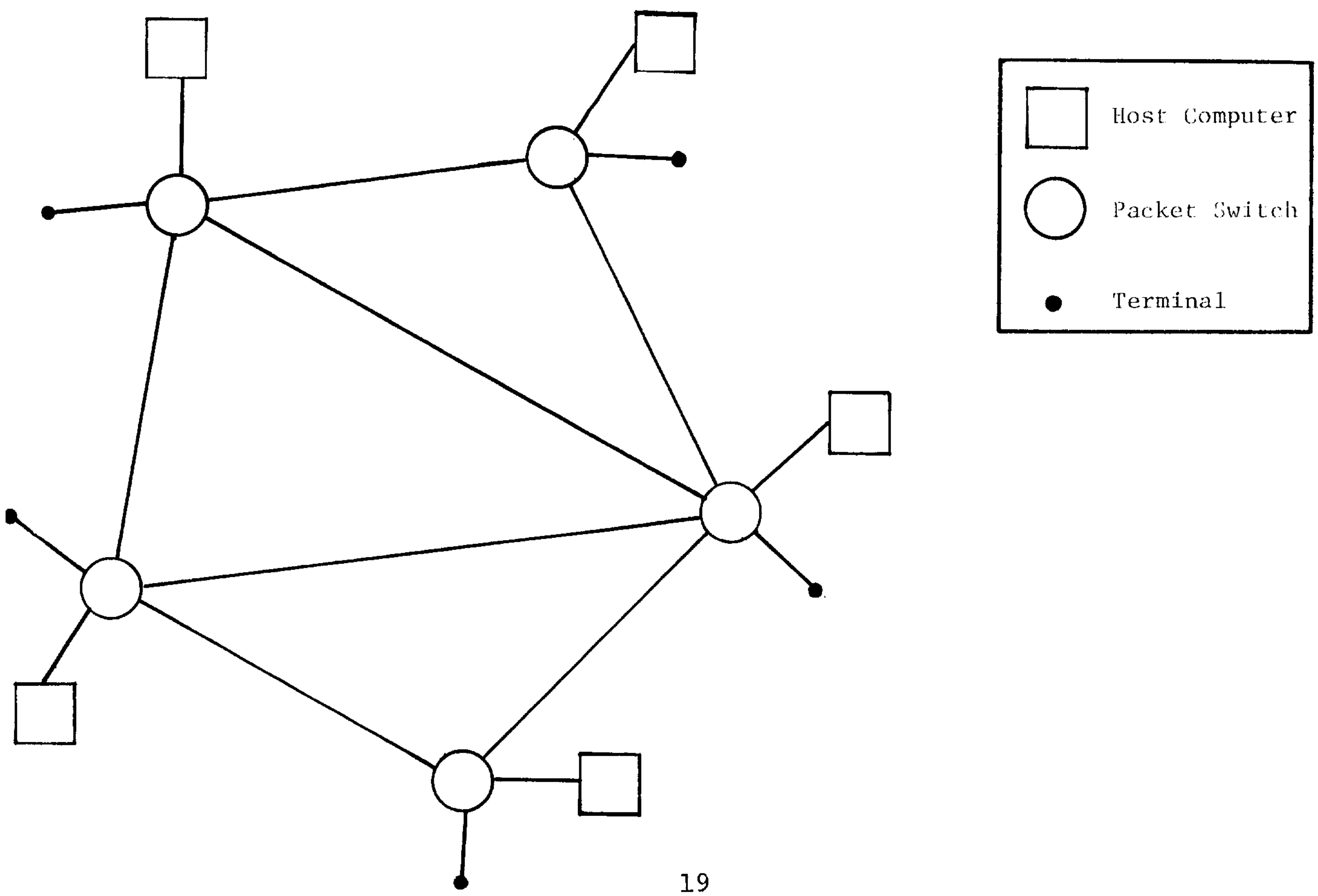


Figure 3 - A Ring Network

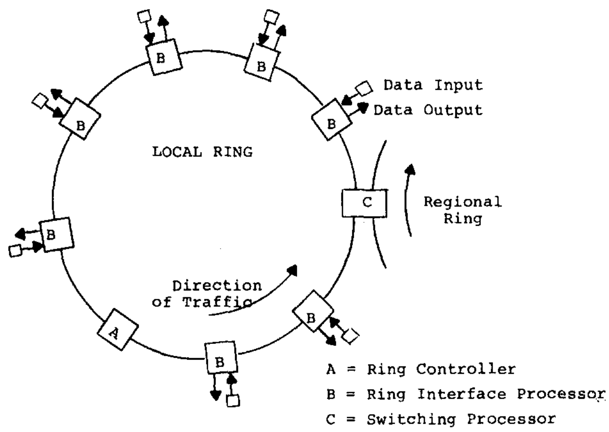


Figure 4 - Binary Code vs. Bipolar Code

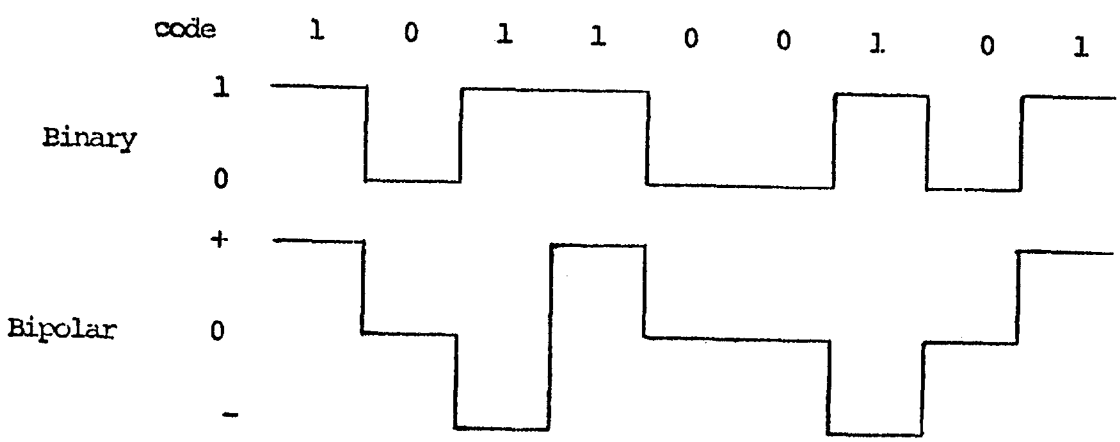
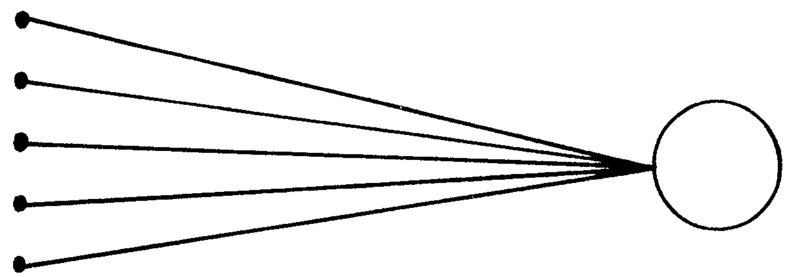


Figure 5 - Multiplexer Configuration



(a) Without a Multiplexer

(b) With a Multiplexer

Figure 6 - Principle of a Frequency Division Multiplexer

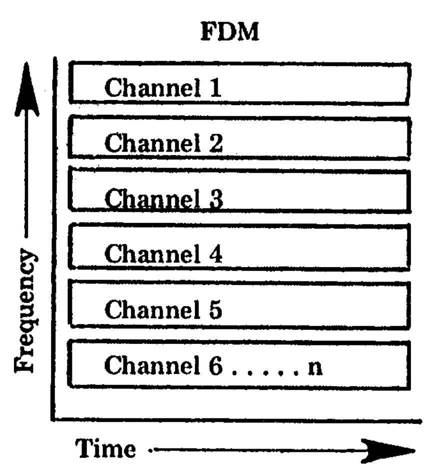
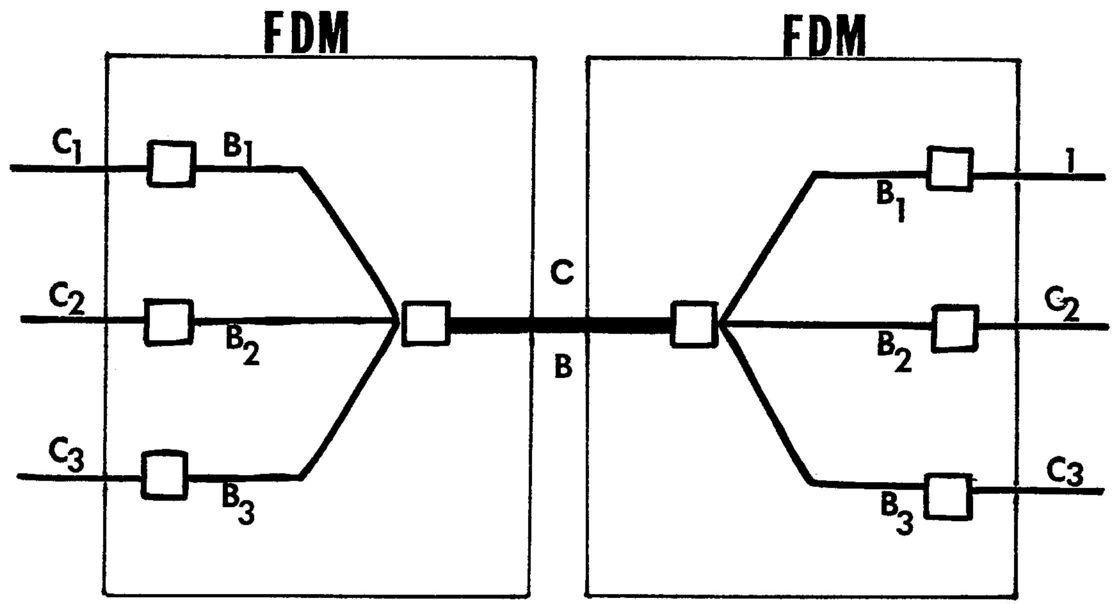


Figure 7 - Principle of an FDM (Frequency Division Multiplexer)



$$B = B_1 + B_2 + B_3$$

$$C = C_1 + C_2 + C_3$$

B's : BANDWIDTH

C's : CAPACITY

Figure 8 - Principle of a Time Division Multiplexer

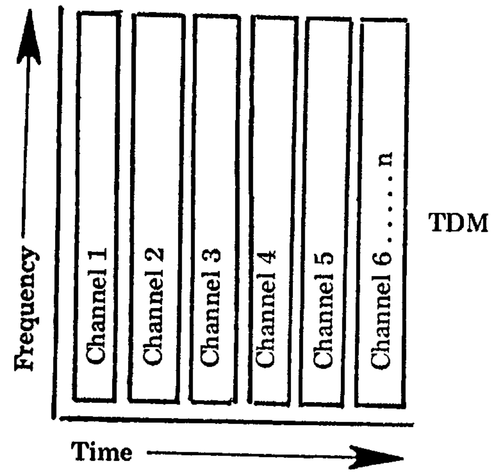


Figure 9 - Principle of a TDM (Time Division Multiplexer)

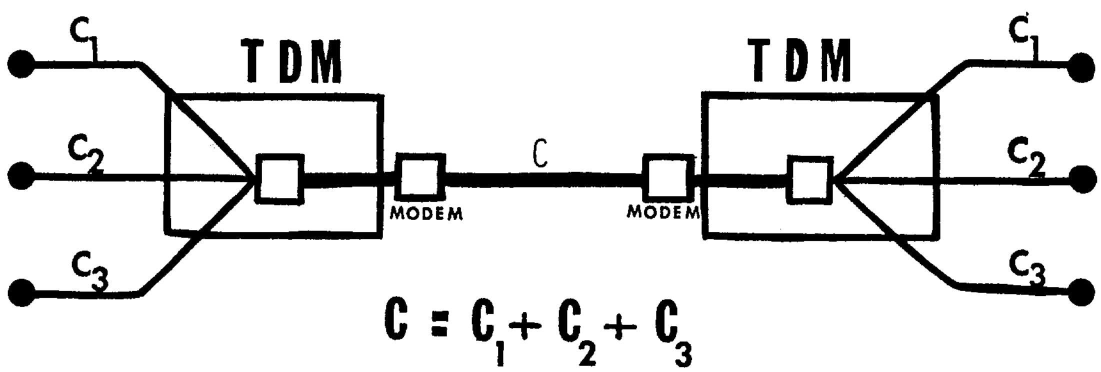
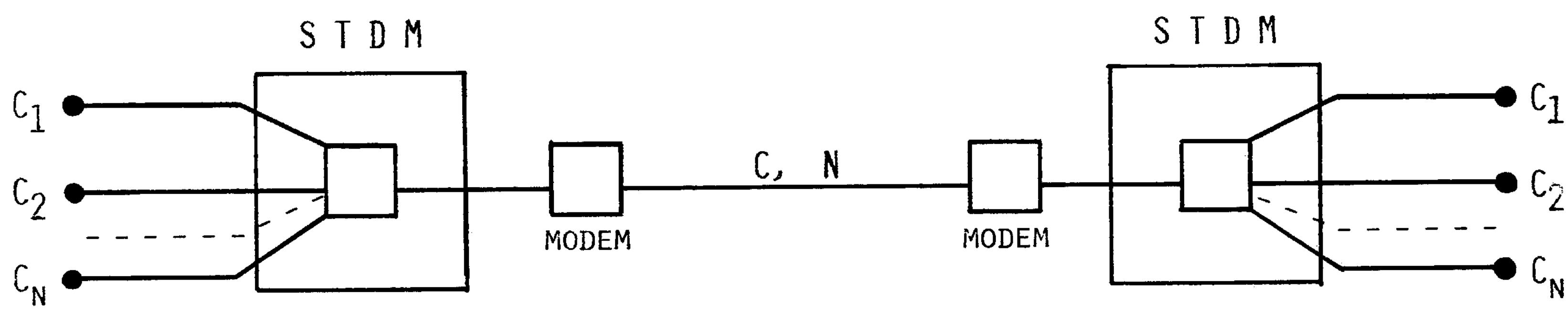


Figure 10 - <u>STDM</u>



CAPACITY: $C < C_1 + C_2 \ldots + C_N$

NUMBER OF CHANNELS: $N < n$

Figure 11 - Principle of a Concentrator

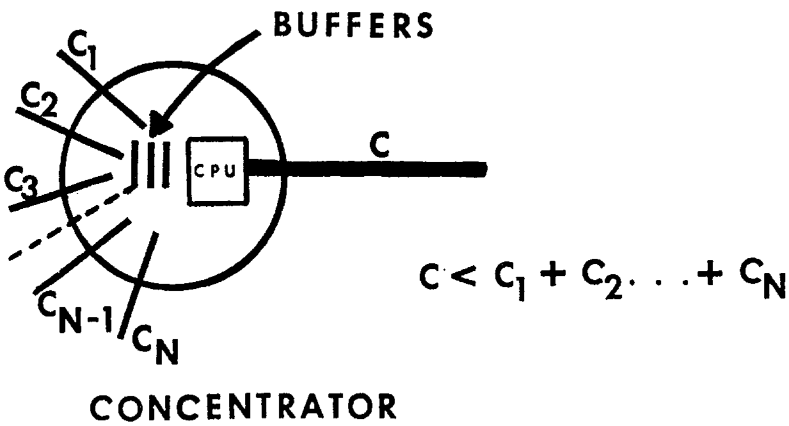


Figure 12 - An Example of a Centralized Communication Network

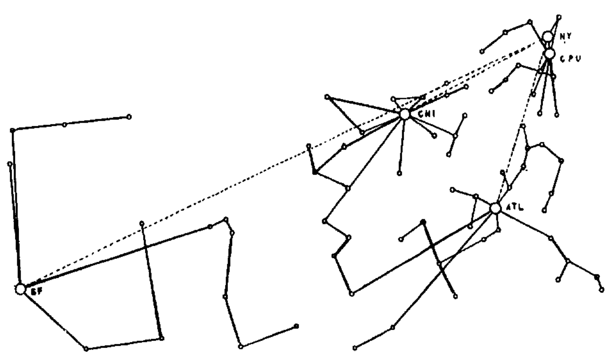


Figure 13 - A Hybrid Network Structure