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Media access control protocols in local area networks /

Paresh Shah
Lehigh University

Media Access Control Protocols
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Paresh Shah

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Professor in Charge

CS Division Chairman

CSEE Department Chairman

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Abstract

This thesis is concerned with the standard protocols to gain access to the transmission medium in local area networks. It provides a brief history and an overview of the International Standards Organization Open Systems Interconnection reference model and the local network technology. Three medium access control protocols, namely, Carrier Sense Multiple Access with Collision Detection, and the token methods, the token bus and the token ring, have been discussed. It also describes the activities of the optical-fiber technology and its use in local area networks. Multivendor data communications addressed by General Motors' Manufacturing Automation Protocol and Boeing's Technical and Office Protocols have also been discussed. The multivendor data communication protocols are still undergoing changes and this thesis is provided for current information only.

Chapter 1
Introduction

Local area networks (LANs) are a product of recent advances in technology and the continuing evolution of the computer systems. The need for LANs comes from the growing desire to communicate between small programmable and microprocessor-based devices at a cost consistent with the device cost. Information sharing, inherently provided by centralized systems, can be extended to microprocessor-based devices through the development of convenient communication protocols between such devices. With the tremendous increase in the number of available microcomputers, these communications require agreement on a number of technical points, protocols and conventions -- in order that the information be exchanged. The recognition of these needs and the technological environment led to the formation of the IEEE Local Network Standards Committee, formally known as Project 802.

Local area networks have aroused a great deal of interest among the computer and communication professionals and manufacturers in the last few years because of their potential role in the area of office automation. LANs provide the facility through which microcomputers, word processors, work stations and the like, communicate with one another and with other office technologies such as data storage devices, facsimile devices, intelligent copiers, voice and video handling devices, etc. The availability of computer networks and the evolution of office automation have greatly increased the use of communication in companies and institutions. This development has caused changes in the office environment and necessitates the reorganization of telecommunication systems. The recent introduction of cheap processing equipments has greatly increased the requirements for local area networks. Two primary reasons for this are that computer processing and work stations can now inexpensively be distributed around a local area, such as a factory, an office, a laboratory, a university campus, etc., and very sophisticated techniques be used for processing information required for accessing and transmitting data within the area.

Thus, for many applications, decentralization of computing power is a natural and obvious choice. In many information processing applications, the information itself is distributed in nature and can most appropriately be managed by distributed machines. A local network tends to improve the reliability, availability and survivability of a data processing facility. With the multiple interconnected systems, the loss of any one system has minimal impact. Subject to their geographical limitations, local area networks have a provided a very effective and inexpensive ways of interconnection among various communicating devices. The communication capability made available by local area networks has provided a unified information processing resource.

Since 1980, numerous LAN products have been announced, the more representative ones are: Ethernet, SILK, Wangnet, Data Ring, Polynet, Xinet/Xibus, Cambridge Ring, TransRing 2000, Planet, ODR-1, Net/One, LocalNet, BIS, ARC, etc [6]. Although these local area networks may differ internally in a number of ways, they still some common features. First, they all are restricted to a relatively small geographic area -- usually between several hundred meters and a few kilometers. LANs differ from wide area networks (WANs) or long haul networks in the size of bandwidth offered. LANs offer considerably greater bandwidth than WANs. LANs use a technology which allows very high bandwidths to be implemented economically, thus permitting data rates in excess of 1 megabit per second (Mbps). Thirdly, local area networks are designed to allow a large number of different devices to communicate with one another.

It must be remembered that LAN's power lies not only in the hardware but also in the software. Namely, the LAN is not a device but a system which requires technological integration of physical media transmission and physical media access protocols in connection with the method of data processing. In the design of these integrated communication systems, a layered approach is usually employed, specifically, the International Standards Organization (ISO) standard for Open Systems Interconnection (OSI) consisting of seven layers -- physical, data link, network, transport, session, presentation, and application layers.

1.1 ISO/OSI Reference Model

In 1979, the International Standards Organization (ISO) began development of a computer network reference model. This model for Open Systems Interconnection (OSI) is supported by most of the national and the international standards organizations. The purpose of this International Standard Reference Model of Open Systems Interconnection is to provide a common basis for the coordination of standards development for the purpose of systems interconnection.

The OSI model presumes modularization of the networking support software based on functionality. Each module takes the form of a layer in the model and is responsible for providing selected networking services to the layer above. These services are provided by programs in that layer and through the services available from the layer below.

The seven layers of the OSI Reference Model are as shown in Fig. 1-1. At the highest layer are the application programs and at the lowest layer is the physical media over which the data is transmitted [18].

Application	Provides services to the users; application programs, file transfer, etc.
Presentation	Encodes data to provide common communications services
Session	Provides means of establishing, managing, and terminating connection betn processes
Transport	Provides reliable, transparent data transfer; provides error recovery & flow control
Network	Transmits packets of data; provides routing and congestion control
Data Link	Sends blocks of data-frames; provides error recovery & correction & frame acknowledgement
Physical	Establishes, maintains and terminates physical link; transmits bits through physical channel

Figure 1-1: OSI Reference Model

Each layer provides services to the layer above. Two types of information are passed between layers in providing these services: control and data. The control information is the basis for all the services which are required to process the message. As each layer provides its part of those services, the remaining control information is passed to the next lower layer. The process continues until no control information remains.

The data which is passed down to a layer is generally transported transparently. (An exception is the Presentation Layer which reformats that data). Each layer prefaces that data with a control block prior to requesting the services of the next lower layer. This control block is interpreted by the corresponding layer in the receiving node.

As the data block is passed to successively lower layers, its size increases as shown in Fig. 1-2. As the data is passed to successively higher layers at the receiving node, the control blocks are removed in steps.

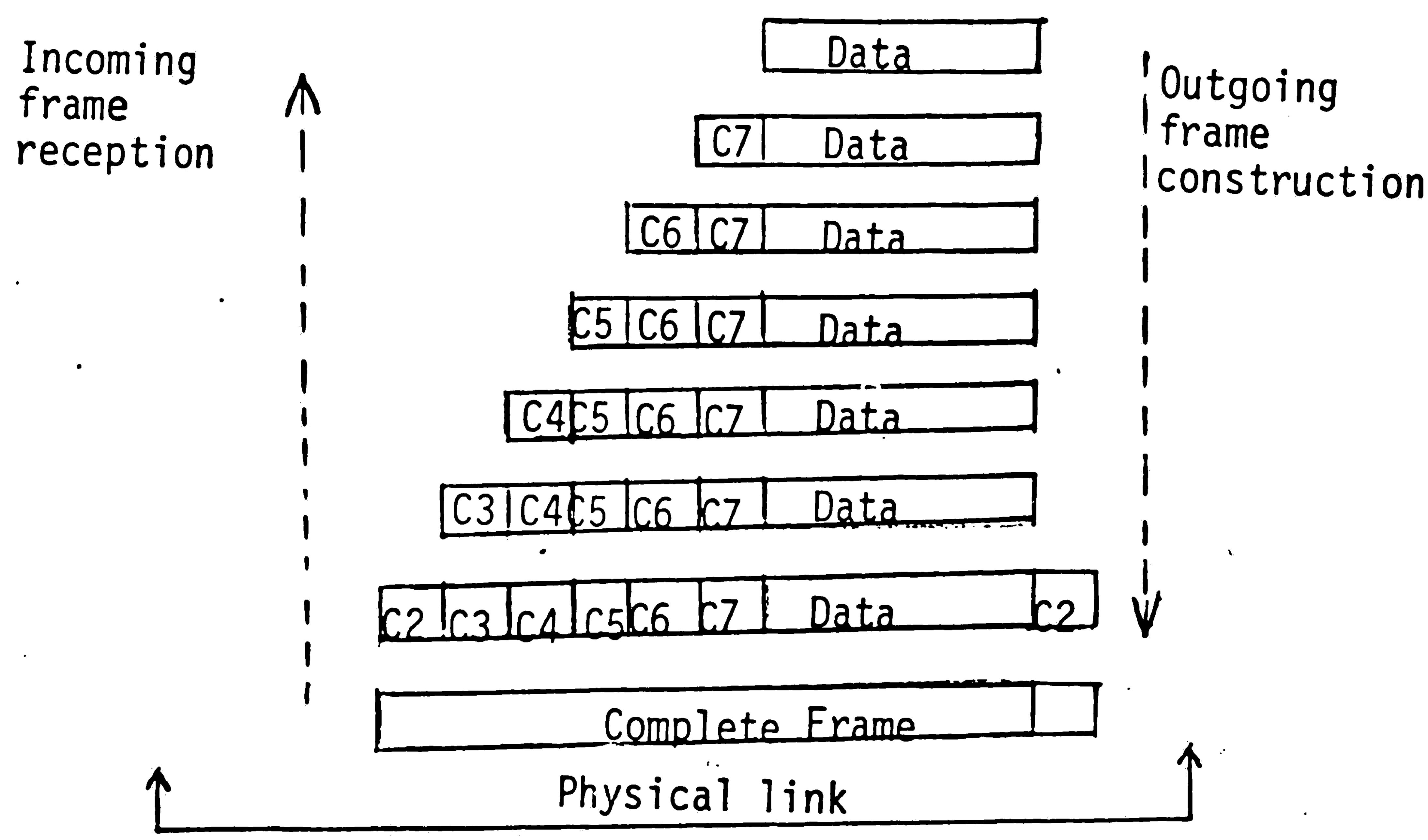


Figure 1-2: Data flow in the network structure

1.2 Local Network Technology

The principle technological alternatives that determine the nature of a local network are its topologies and the transmission medium, which determine the type of data that may be transmitted and the speed and the efficiency of communications [13, 7].

Local networks are often characterized in terms of their topologies, the most common three topologies being: star, ring and bus or tree (bus is a special case of tree with only one trunk and no branches) as shown in Fig. 1-3.

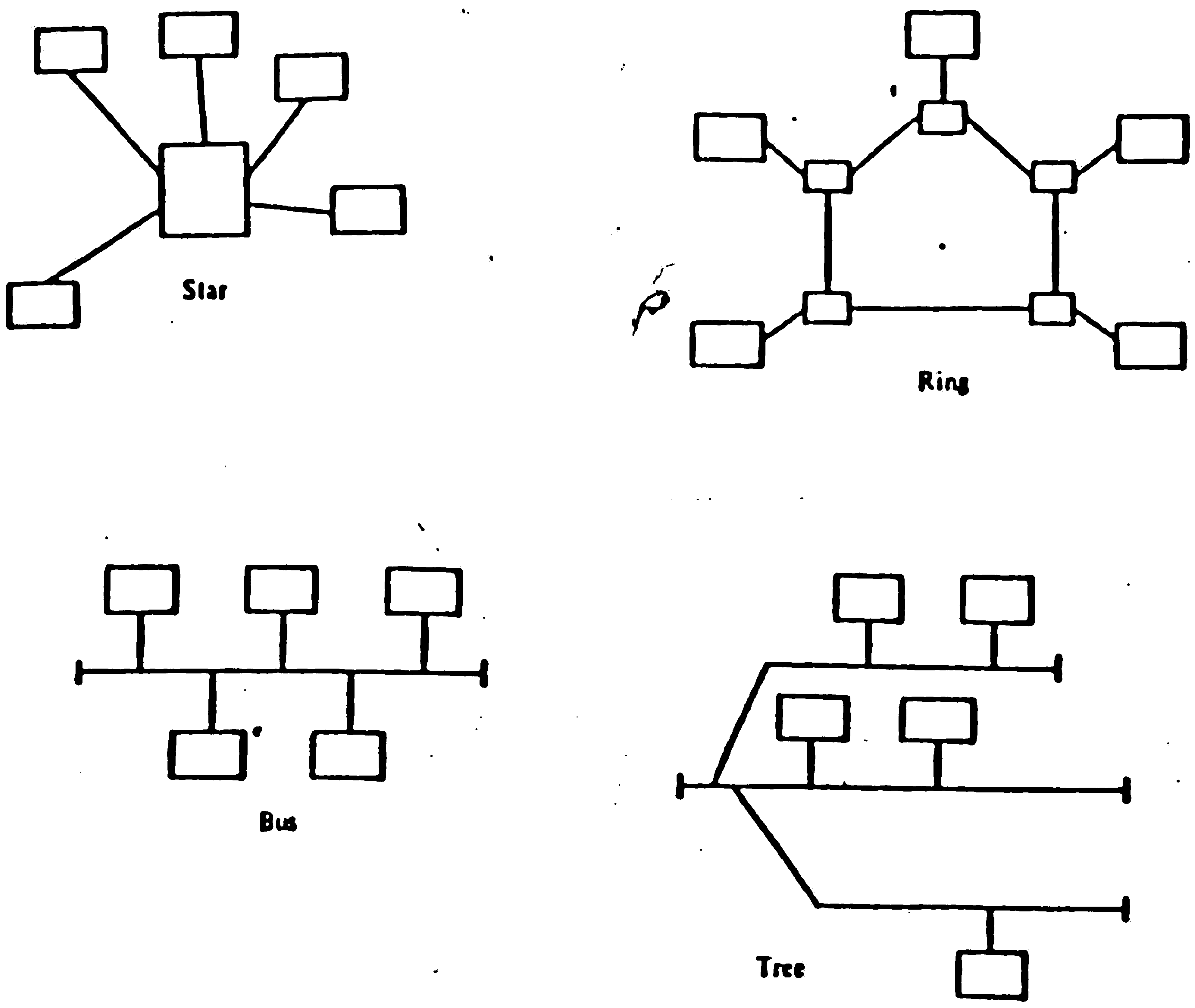


Figure 1-3: Network Topologies

In star topology, a central switching element is used to connect all the nodes in the network. A station wishing to transmit data sends a request to the central switch for a connection to some destination station and the central station uses the circuit switching to establish a dedicated path between the two stations.

The ring topology consists of a closed loop, with each node attached to a repeating element (repeater). Data circulate around the ring on a series of point-to-point data links between repeaters. A station wishing to transmit waits for free token (the right to transmit) and then sends data out onto the ring in the form of a packet, which contains both the source and the destination addresses as well as the data. After one circle, when the packet arrives back to the source node, it provides a form of acknowledgment.

The bus/tree topology is characterized by the use of a multiple access, broadcast medium. Since all devices share a common communications medium, only one device can transmit at a time. Each station monitors the medium and copies packets addressed to itself.

Transmission media used for local networks are twisted pair wire, coaxial cable and optical fiber. Twisted pair wiring (digital signaling wiring) is one of the most common communications transmission media. Although typically used for low-speed transmission, data rates of few Mbps can be achieved. Twisted pair is susceptible to interference and noise but is relatively low in cost.

Higher performance can be achieved by coaxial cable (digital or analog signaling with Frequency Division Multiplexing), which provides higher throughput, can support a larger number of devices and has greater spanning capability. Two transmission methods, baseband and broadband, can be employed on a coaxial cable. The key difference is that baseband supports a single data channel whereas broadband can support multiple simultaneous data channels [12].

Optical fiber is for future local network installations. It has number of advantages over both coaxial cable and twisted pair wire, including light weight, small diameter, low noise susceptibility and no emissions.

1.3 Baseband vs Broadband

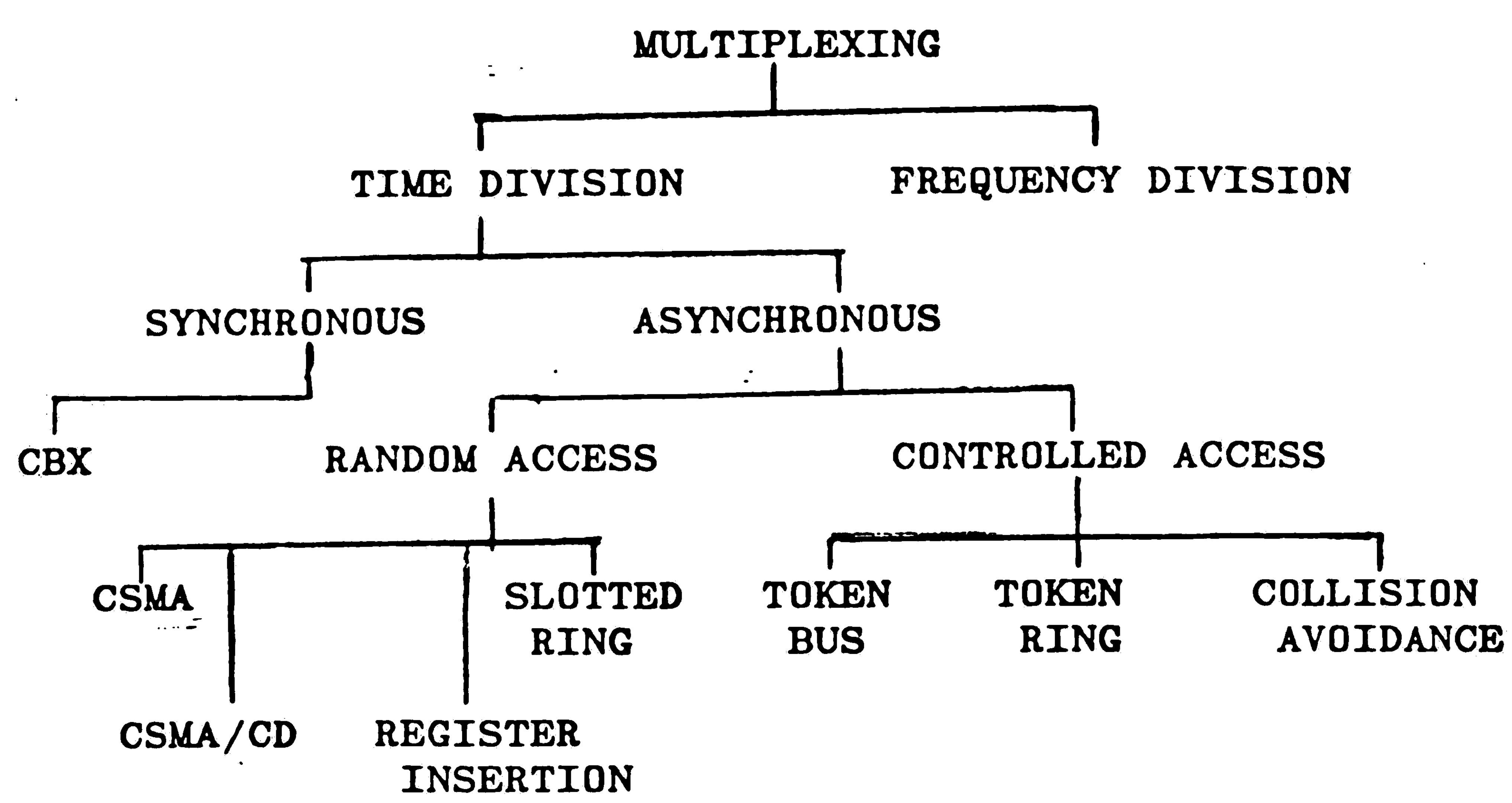
Baseband local networks generally use a bidirectional signal path on which signals are encoded onto the cable using some encoding method. A baseband system by definition uses the digital signaling. A variety of packet-mode media access techniques can be used but the most common implementation is the Carrier Sense Multiple Access with Collision Detection (CSMA/CD). Since numerous devices can share a common cable bus, it is necessary to multiplex the data passing over it. One technique used is Time Division Multiplexing (TDM). The entire frequency spectrum on the medium is used to form the digital signal, which is inserted on the line as a constant-voltage pulse. Baseband systems can extend only about a kilometer at most because the attenuation of the signal causes a blurring of the pulses and a weakening of the signal to the extent that communication over long-distance is impractical. The Xerox Ethernet, for example, is a baseband CSMA/CD channel which operates on a 50-ohm coaxial cable at a system data rate of 10 Mbps.

Frequency Division Multiplexing (FDM) is used in broadband local networks and is much like the multiplexing technique used for years in conventional analog microwave and in CATV. The broadband networks can carry multiple channels and different channels can be used to satisfy different requirements such as a voice, data, and video. One advantage of the broadband network is that, unlike TDM-based networks, it can carry analog as well as digital information. Another advantage is the support of multi-mode communications -- audio, video, and data on the same cable. A disadvantage is the need for radio-frequency (RF) modems, which are often more expensive than the relatively simple transreceivers used in baseband schemes. Another disadvantage is that the propagation delay through a broadband network is likely to be much greater than in a baseband network.

Chapter 2
Standard Accessing Protocols

All local networks consist of a collection of devices that must share the network's transmission capacity. Some means of controlling access is needed so that any two particular devices can exchange data when required.

How access is controlled is constrained by the topology and is a trade-off among competing factors -- cost, performance and complexity. The most common medium access control protocols for local networks are given below [17].



In all cases, multiple data transfer share a single transmission medium. This always implies some form of multiplexing, either in the time or the frequency domain. Within a single channel, some sort of Time Division Multiplexing (TDM) is required. Time division access control techniques are either synchronous or asynchronous. With synchronous techniques, a specific capacity is dedicated to a connection. However, since the needs for the stations are unpredictable, transmission capacity should be allocated in asynchronous (dynamic) fashion. Asynchronous TDM may be random (an algorithm is used to regulate the sequence and the time of station access). The random access category includes, two common bus techniques, carrier sense multiple access (CSMA) and CSMA with Collision Detection (CSMA/CD) and two common ring techniques, register insertion and slotted ring. The regulated access category includes both the token bus and the token ring and collision avoidance, the most common High-Speed Local Network (HSLN) technique.

Local Network Standards Committee of the Institute for Electrical and Electronic Engineers (IEEE) is for defining a standard for local area networks in which "intelligent" terminals and other devices are coupled on a peer-to-peer basis.

This committee is concerned with the lowest two layers of the OSI model, the physical and the data link layer. The OSI recognizes and allows the creation of sublayers by grouping related functions. Due to different options for media access control (MAC), MAC sublayer includes functions associated with both the physical and the data link layer of the OSI. The mapping of the OSI physical and data link layers into the three layered LAN is shown in Fig. 2-1. The three LAN layers are called the Logical Link Control (LLC), Media Access Control (MAC) and Physical layers [10].

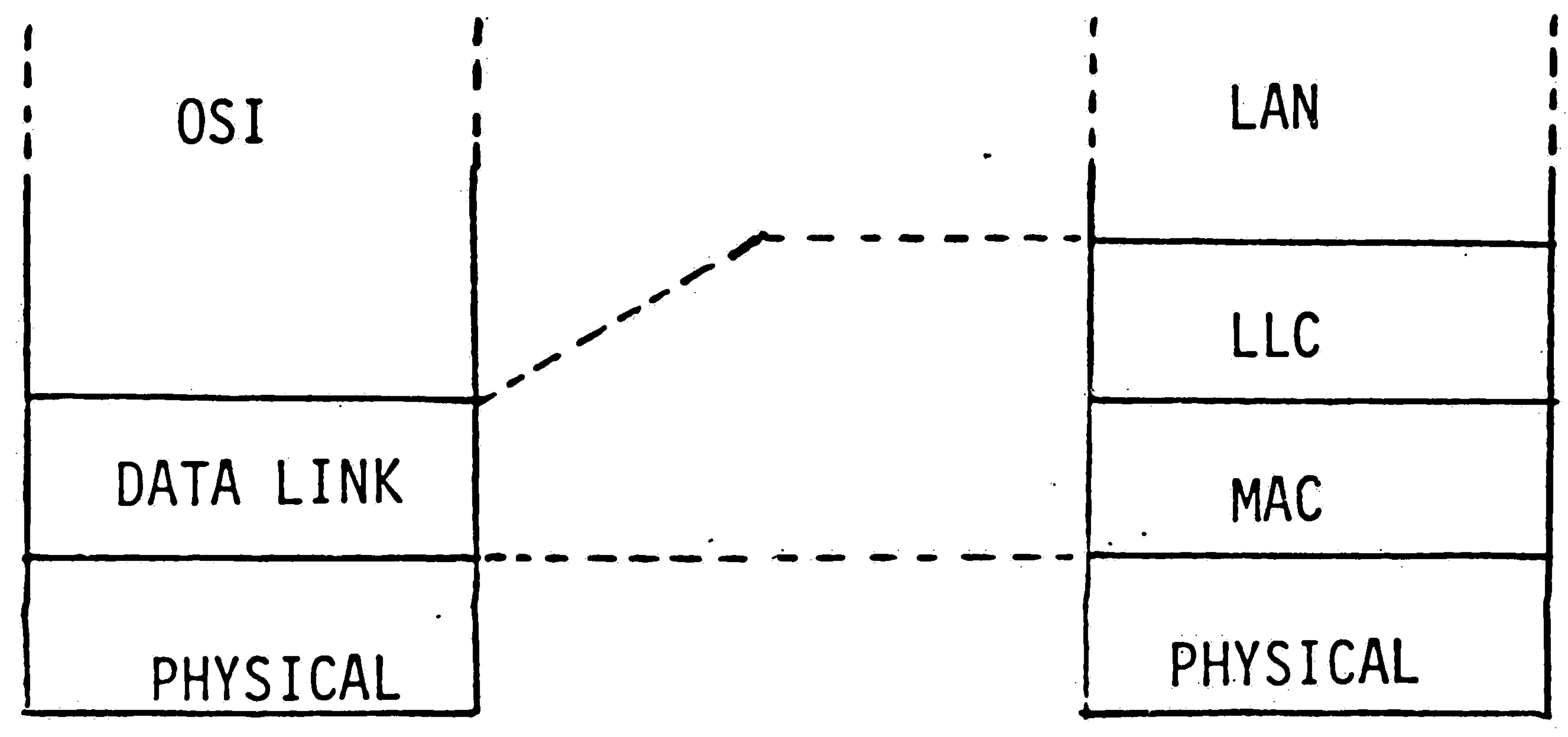


Figure 2-1: OSI-LAN mapping

The Medium Access Control (MAC) sublayer fundamentally provides an application-entity with the ability to "capture" the physical medium for its use. The Logical Link Control (LLC) sublayer performs error checking, addressing and other functions necessary to ensure accurate data transmission between nodes. Three control methods are provided in the standard: Carrier-Sense Multiple Access with Collision Detection (CSMA/CD) [1ANSI/IEEEStd.802.3], Bus Token-Passing [2ANSI/IEEEStd.802.4], and Ring Token-Passing [3ANSI/IEEEStd.802.5].

2.1 CSMA/CD

In Carrier Sense Multiple Access with Collision Detection (CSMA/CD) media access method the basic concept for sharing the physical transmission media by two or more stations is that a station listens for a quiet period on the medium before transmitting (to determine if the line is idle). If it is not, the station waits (defers) until the line is idle (when no other station is transmitting) and then sends its frame (message). If, during the transmission, the frame collides with that of another station, then each transmitting station reinforces the collision signal for a brief period of time (the "jamtime") to ensure that all stations detect it. The stations involved in collision then delay subsequent transmission attempts for a random amount of time (backoff). The CSMA/CD bus operation is shown is Fig. 2-2. The communication can be in one of the three states:

- Successful transmission -- a station has successfully acquired the medium and transmission is in progress.
- Quiescent -- a successful transmission has been terminated and no station has attempted to acquire the medium since that time.

- Collision resolution -- the quiescent state has been ended by a collision and the next successful transmission has not been started.

The CSMA/CD MAC sublayer provides the facility which is medium-independent. However, it is built on the medium-dependent physical facility provided by the Physical Layer. Two main functions, associated with a data link control procedure, must be performed in the MAC sublayer. These functions are presented in IEEE 802.3 standard. They are

1. Data transmission and reception

   a. Frame synchronization and boundary delimitation

   b. Source and destination address handling

   c. Error detection

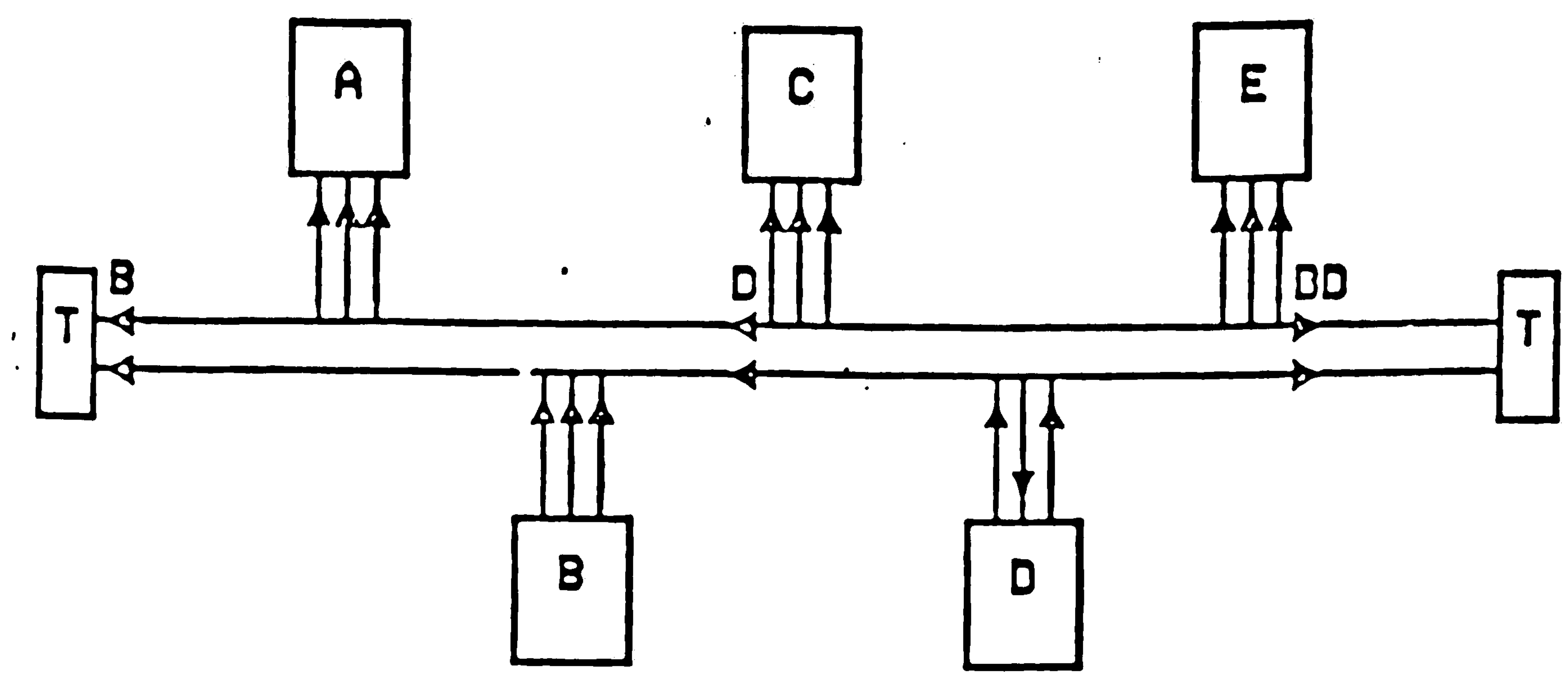
2. Medium Management

   a. Resource allocation

   b. Contention resolution

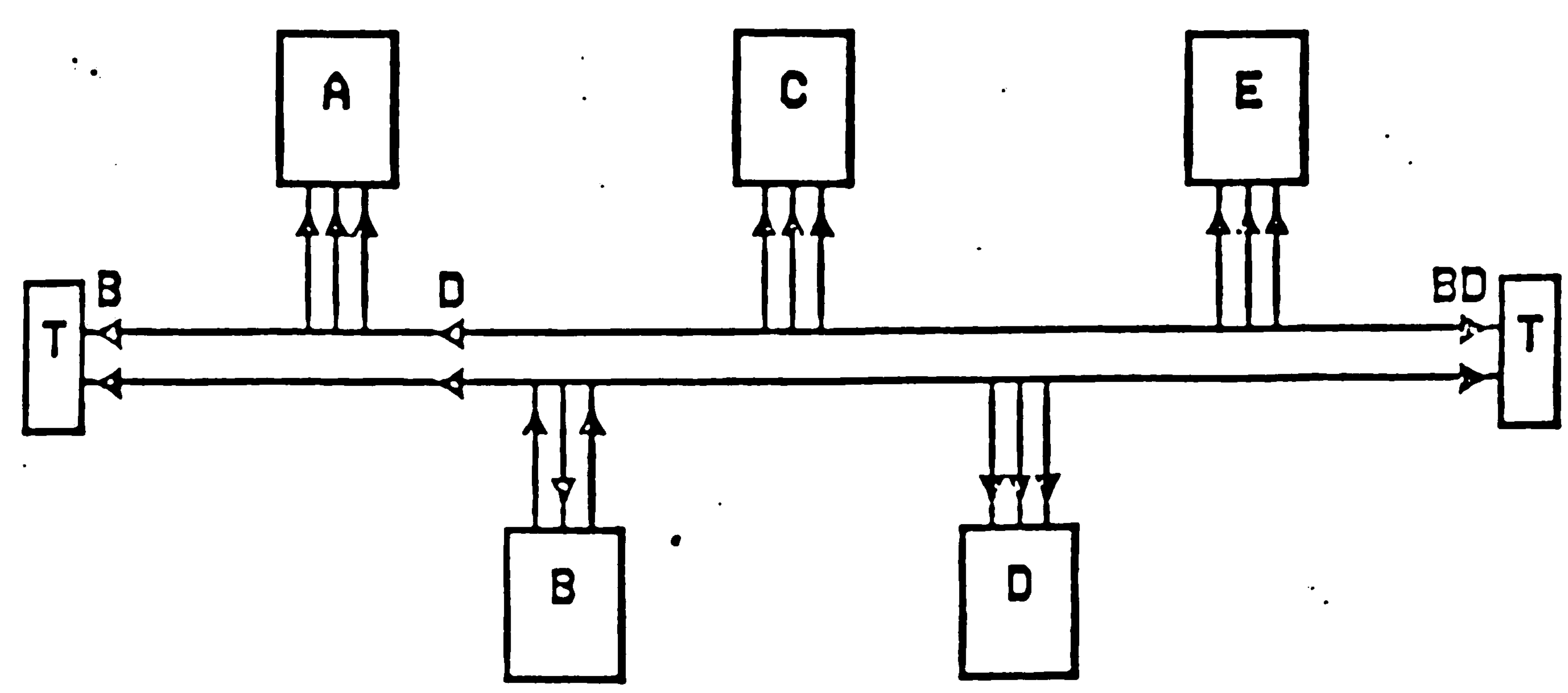
2.1.1 Basic Operation

For the serial transmission of bits on the physical medium, there is a component of the Physical Layer, called, the Physical Layer Signaling (PLS), which provides an interface to the MAC sublayer. Transmission process is initiated by the LLC sublayer which requests for the transmission of a frame. From the data supplied by the LLC, data transmit component of the CSMA/CD MAC sublayer constructs a frame. It appends a preamble (a sequence of bits) and a delimiter, indication of the beginning of the frame. At the end of the MAC information field, a pad of sufficient length is also appended to ensure that the transmitted frame length satisfies a minimum frame size requirement. Control

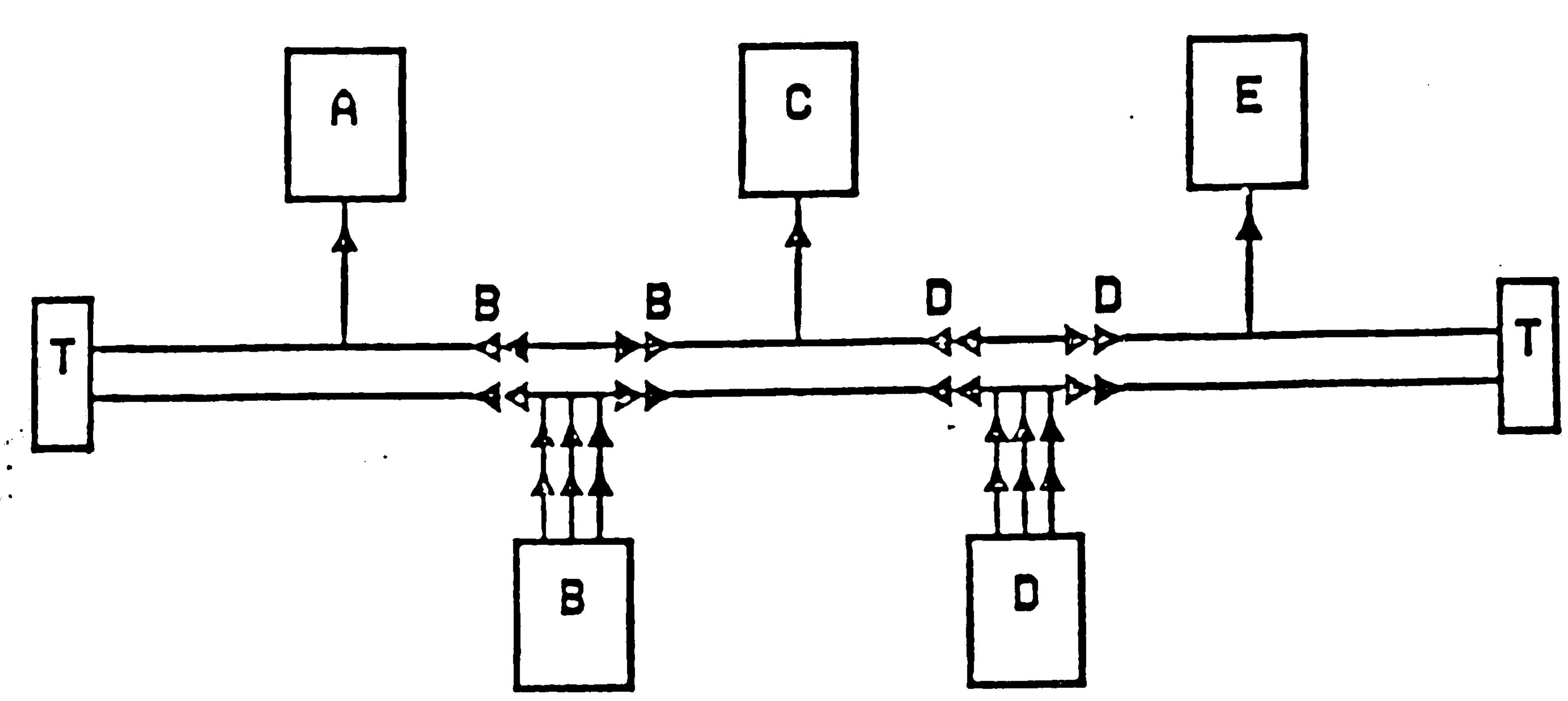


T4. D DETECTS COLLISION AND STOPS TRANSMITTING

B MUST TRANSMIT UNTIL D SIGNAL PROPAGATES TO B

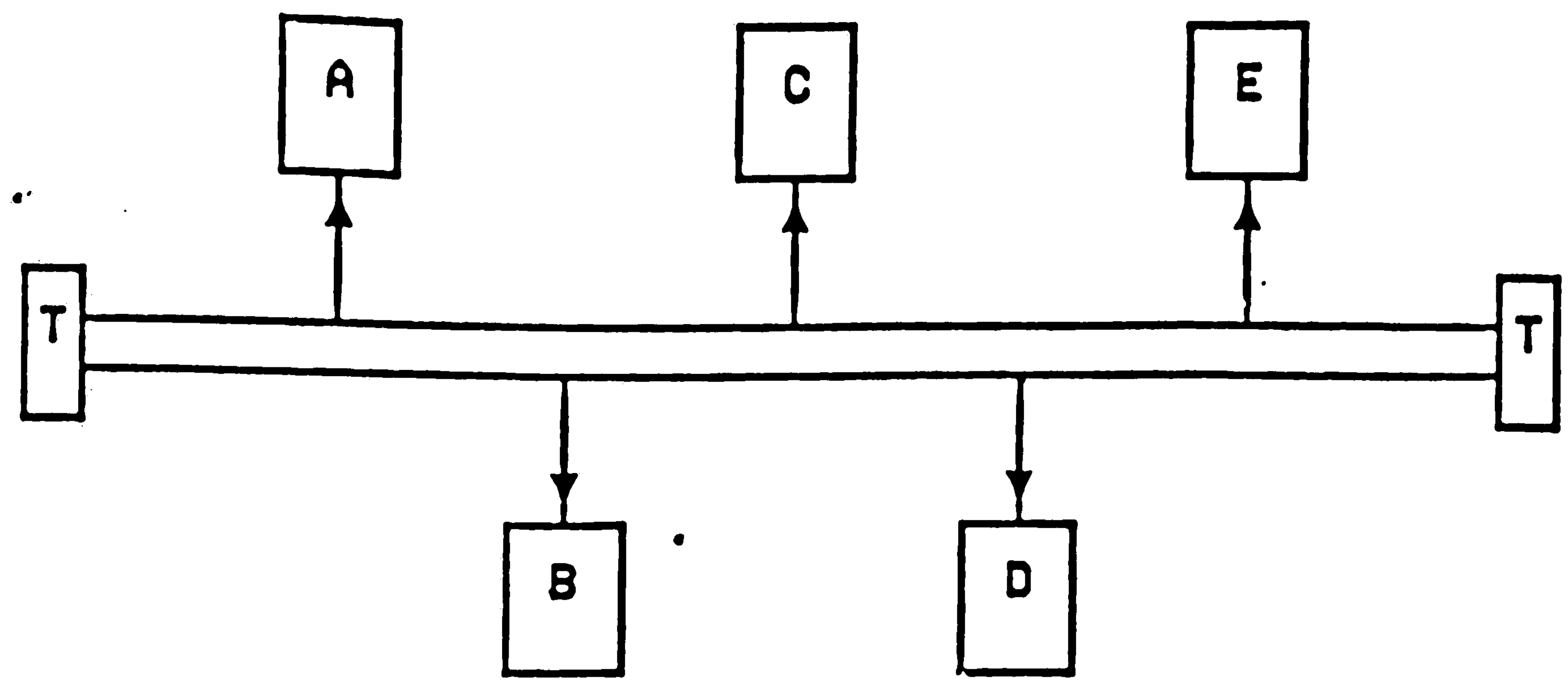


T5. B DETECTS COLLISION AND ALSO STOPS TRANSMITTING

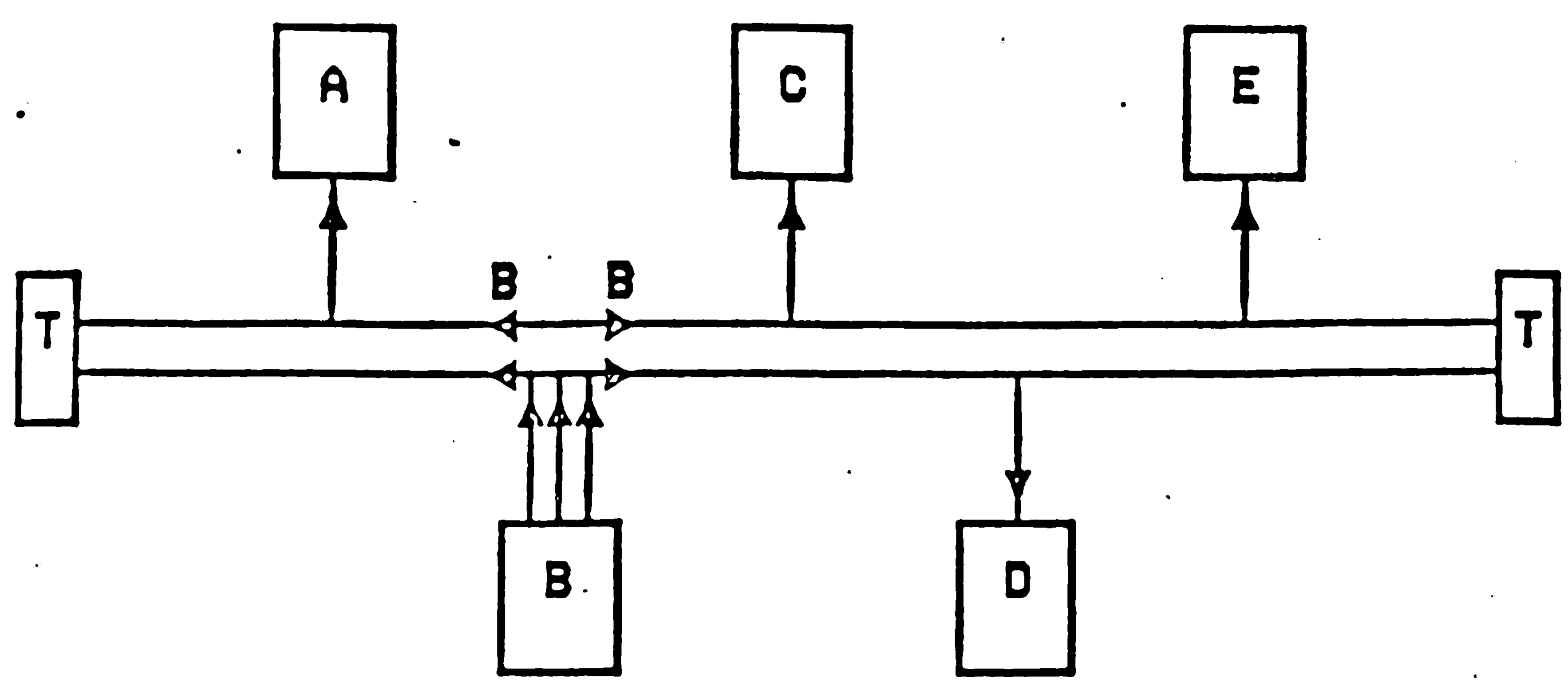


T6. B/D TRANSMIT JAM & PERFORM UNLIKE RANDOM DELAYS

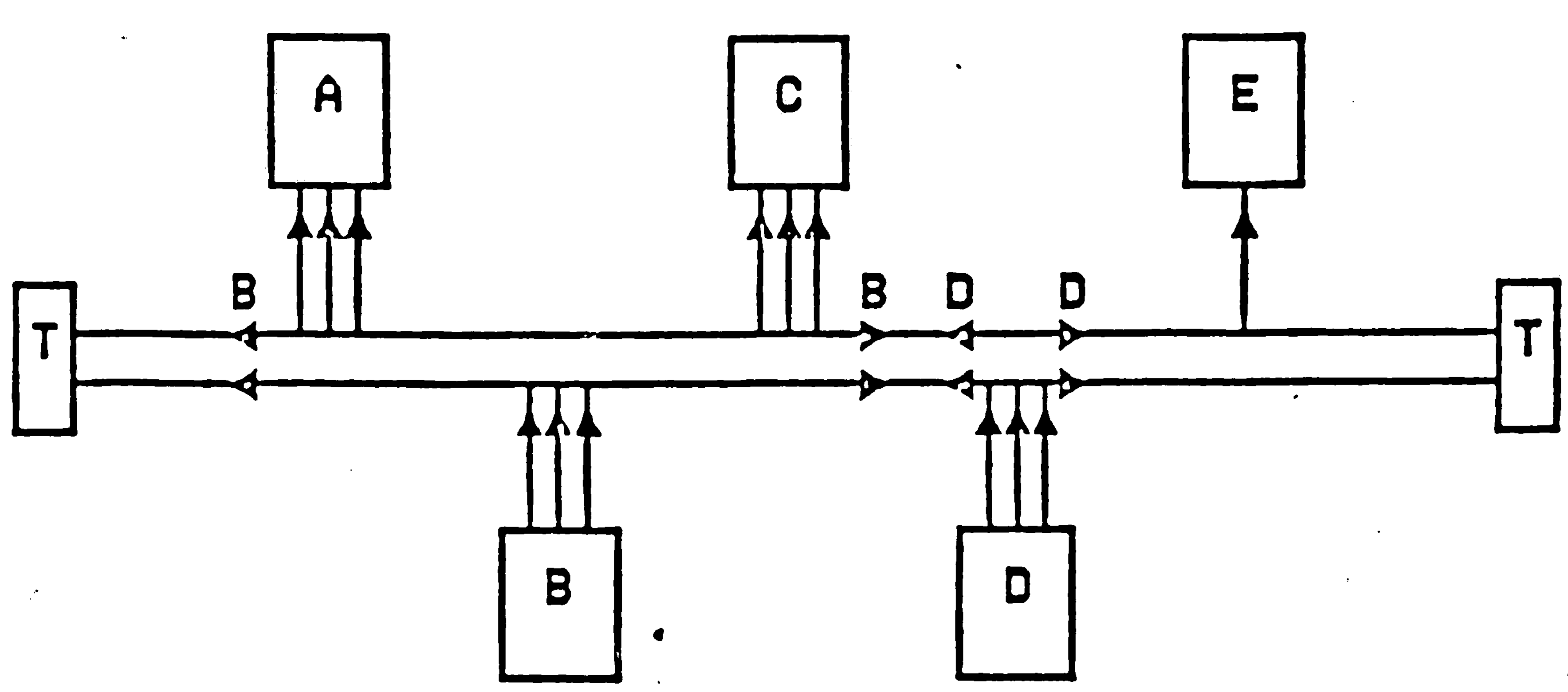
Figure 2-2: CSMA/CD Bus Operation



T1. ALL NODES LISTENING & NO ACTIVITY



T2. B TRANSMITS - ANY OTHER NODE MAY ALSO



T3. B STILL TRANSMITTING

A & C CANNOT TRANSMIT

D STARTS TRANSMITTING

Figure 2-3: Figure 2-2, concluded

information appended to the frame also include source and destination addresses, a length count and a frame check sequence (FCS). The frame is then passed to the Management component in the MAC sublayer for transmission.

The Management component monitors the carrier sense signal provided by the PLS component to determine the traffic on the medium. It avoids contention with the other traffic and defers the transmission if the medium is busy. If the medium is clear (no traffic), then the frame is transmitted. The MAC sublayer sends a serial stream of bits to the PLS interface for transmission.

From the bit stream, the PLS generates the electrical signals. It also monitors the medium during the transmission, detects collision on the medium, if any, and generates collision detect signal, if required. If the transmission takes place without collision, the CSMA/CD MAC sublayer informs the LLC sublayer and waits till another request for frame transmission comes from the LLC sublayer.

At the receiving node (station), the PLS detects the arrival of a frame and it responds by turning on the carrier sense signal. The encoded electrical signal is decoded and translated back into the binary data. The PLS passes all the bits of the data to the MAC sublayer, which discards all the leading control information bits till the frame start delimiter is recognized.

The Management component of the MAC sublayer at the receiving end collect bits from the PLS till the carrier sense signal is on. When the carrier sense signal is turned off, the frame data collected so far, if necessary, is converted to an octet boundary and is passed to receive data component for processing.

Receive data component determines whether the frame is for this station or not by checking the frame's destination address. If the frame is addressed to this station, then it passes the source and the destination addresses and the data to its LLC sublayer. A frame is marked invalid if there is an error either in the frame check sequence value or in the octet-boundary alignment. A transmitted frame addressed to a station will thus be received and passed to the Logical Link Control (LLC) sublayer at that station.

A collision is said to have occurred when the two transmission signals from two stations overlap on the medium. A given station can experience a collision during the initial part of its transmission (the collision window) before its transmitted signal has had time to propagate to all the stations on the medium. Once the collision window has passed, a transmitting station is said to have acquired the medium; subsequent collisions are avoided since all the other stations can be assumed to have noticed the signal (by way of carrier sense) and to be deferring to it. The time to acquire the medium is thus based on the round-trip propagation time of the physical layer.

If the collision occurs, the Physical Layer of the transmitting station recognizes the interference on the medium and turns on the collision detect signal. The Management component of the MAC sublayer notices this and initiates collision handling. First, the transmission station enforces the collision signal by transmitting a bit sequence called the jam signal. This ensures that the time duration of the collision is sufficient to be noticed by other transmitting station(s).

After the jam signal, the transmitting station terminates its transmission and delays next transmission attempt after a pseudo-random time period, so that two stations involved in the collision are unlikely to collide on their next tries. A busy medium results in repeated collisions. The Management component of the MAC sublayer of the transmitting station attempts to adjust to the medium load by backing off (deferring its transmission to reduce its load on the medium). This is accomplished by expanding the time interval for retransmission on each successive transmission attempt. Eventually, either the transmission succeeds, or the medium has failed or is overloaded, in both the cases, transmission attempt is abandoned.

2.1.2 Frame Transmission

Frame transmission includes data transmit and management aspects of a frame.

1. Data transmit includes the assembly of the outgoing frame and generation of frame check sequence.
2. Management of a frame includes carrier deference, interframe spacing, collision detection, random back-off and retransmission.

The LLC sublayer provides the data to the CSMA/CD MAC sublayer which then sets these data in the fields of the frame. It appends at the end of the frame, padding (if necessary, to meet the minimum frame size requirement) and the frame check sequence, set to Cyclic Redundancy Check (CRC) value generated by the LLC sublayer. The CRC value is used to distinguish an invalid frame from a valid one and is defined by a polynomial which is generated as a function of the contents of the source address, the destination address, the length of the frame, the data, and the pad, if appended at the end.

The CSMA/CD MAC sublayer monitors the physical medium for the traffic all the time by checking whether the carrier sense signal, provided by the PLS, is on or off. If the carrier sense signal is on, the medium is busy and the sublayer waits to the passing frame and delays its own transmission.

The rules for deferring to the passing frames ensure a minimum interframe spacing time. This provides recovery time for other CSMA/CD sublayers and for the physical medium. After deferring its own transmission, when a CSMA/CD sublayer initiates the transmission, it may experience contention for the medium. As a result, collision may occur during this stage until a station accomplishes the acquisition of the network through the deference of all other stations' CSMA/CD sublayers. In case of collision, collision handling process begins.

The dynamics of the collision handling are largely determined by a single parameter called the slot time. The slot time is determined by the parameters of implementation. Collisions are detected by monitoring the collision detect signal provided by the physical layer. If a collision occurs during the transmission of a frame, then the transmission is reinforced by a bit stream called the jam signal. This collision enforcement or jam guarantees that the duration of the collision is sufficient to ensure its detection by all the transmitting stations on the network.

The CSMA/CD MAC sublayer attempts retransmission if the last transmission attempt has been terminated due to collision. Retransmission attempts are either successful, or a maximum number of attempts have been made and all have terminated due to collisions. The schedule of the retransmission is determined by a controlled randomization process called "truncated binary exponential backoff".

2.1.3 Frame Reception

The CSMA/CD MAC sublayer frame reception includes data receive and management aspects of a frame.

1. Data receive includes recognition, frame check sequence validation, and disassembly of the received frame into the fields
2. Management of the frame includes the recognition of collision fragments from incoming frames and frame alignment to octet boundaries

The CSMA/CD MAC recognizes and accepts any frame which contains either an individual address of the station or the broadcast address. At the receiving end, from the bits of the incoming frame a CRC value is generated , and if the generated CRC value does not match the one received, an error has occurred and the frame is marked as invalid. If there are no errors, the frame is disassembled into the fields and is passed to the LLC sublayer.

By monitoring the carrier sense signal provided by the PLS, the CSMA/CD MAC sublayer recognizes the boundaries of an incoming frame. An error in the length of the frame can occur in two ways: the frame may be too long, or its length may not be an integer number of octets. The smallest valid frame must be at least one slot time in length. This determines the minimum frame size. Any frame containing bits less than the minimum frame size is assumed to be a fragment resulting from a collision and is discarded.

2.2 Bus Token-Passing

The basic concept is that the stations on the network are formed into a logical ring irrespective of whether or not the physical topology is ring. The stations are assigned positions in an ordered sequence with the last member of the sequence followed by the first as shown in Fig. 2-4. Control of the transmission medium is passed between stations in an ordered sequence by means of a control packet known as "token". The token represents a "permission to transmit" that grants exclusive use of the transmission medium for a maximum time determined by the "token-holding timer". Depending on the token-holding time and the frame length, a station may transmit multiple frames as opposed to the single frame inherent in the CSMA/CD method. As the token is passed from station to station, a logical ring is formed as shown in Fig. 2-5.

The token access method is sequential in logical sense. During normal steady state operation, token passes from a station to its immediate next station on the ring. The MAC sublayer provides access to the medium by passing the token among the stations in a logically circular fashion. It determines when the station has the right to access the shared medium by recognizing and accepting the token from the predecessor, and when the token shall be passed to the successor station.

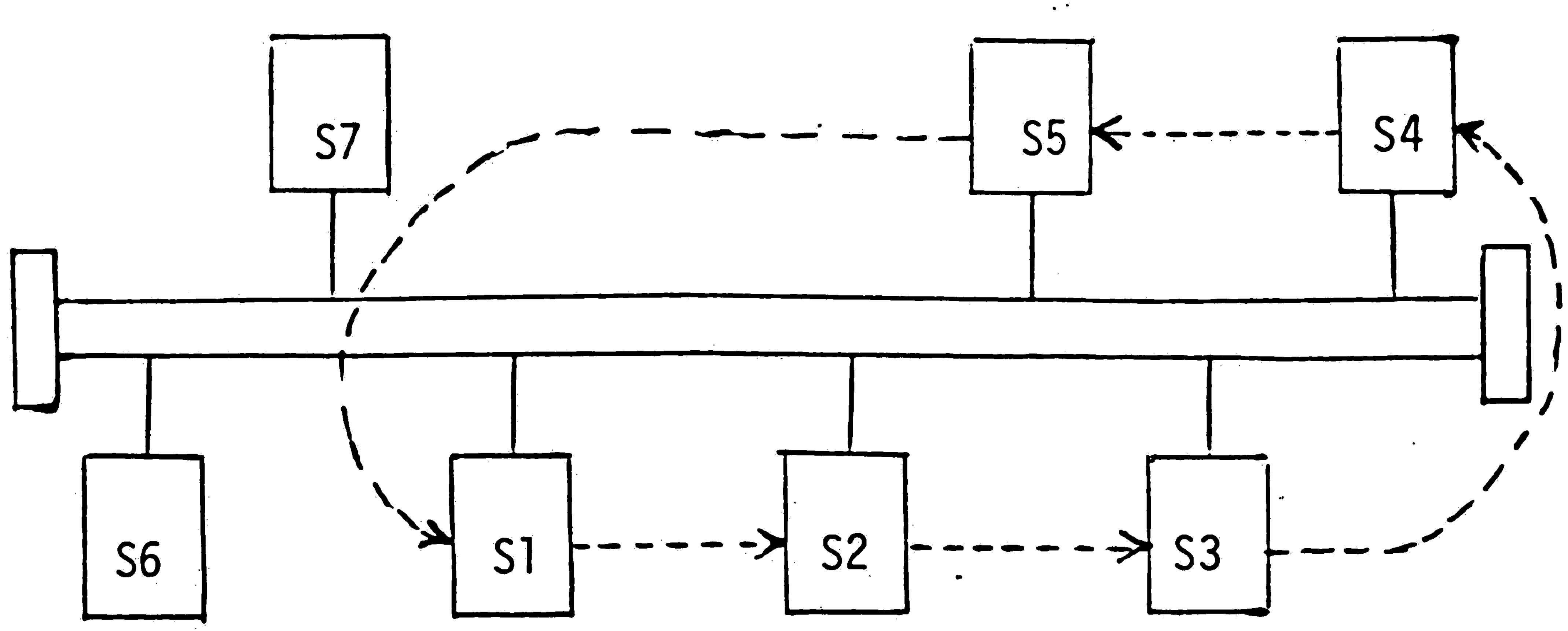


Figure 2-4: Logical Ring on a Physical Bus

The MAC sublayer for a broadcast medium involves specific responsibilities -- creating the logical ring, admitting or deleting the nodes with the necessary adjustment of station addresses (that is, non-participating stations must periodically be granted the opportunity to insert themselves in the ring or a station

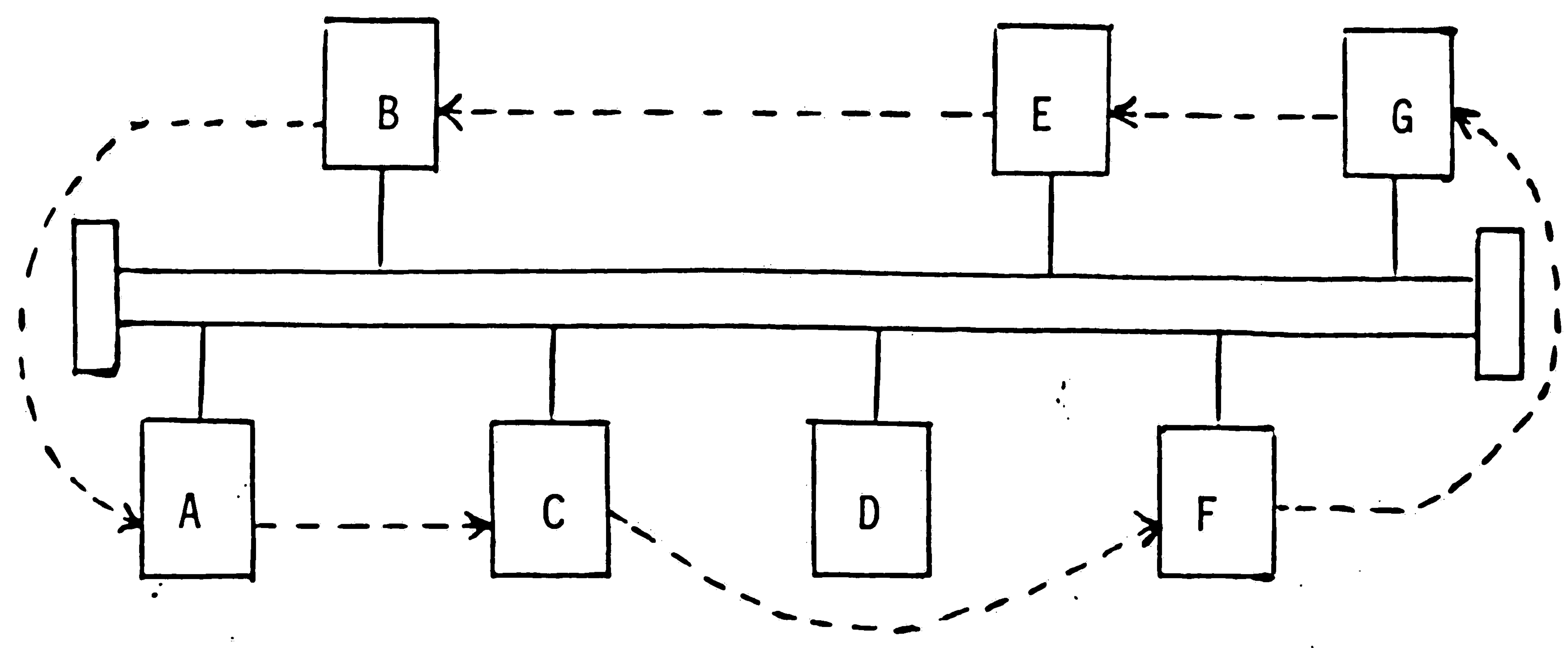


Figure 2-5: Token Passing Bus Operation

can voluntarily remove itself from the ring), fault management and ring initialization.

2.2.1 Normal Operation

When a logical ring on the network has been established and no error conditions are present, the steady state operation begins. Steady-state operation on the ring consists of data transfer and token transfer functions. A station, after its own transmission, passes the token to its successor station. Each participating station on the ring knows the addresses of its predecessor (the station from where it received the token), its successor (the station to which the token should be sent), and its own address.

The maximum time any station need to wait for an access to the medium is referred to as the slot time. The slot time is calculated from several parameters and all the stations in the network use the same value of the slot time before they attempt to transmit. The token passes from station to station in a descending numerical order of station-addresses. When a station receives the token frame addressed to itself, it "possesses" the token and may transmit data frames. When all the information has been send or the time exceeds the maximum token holding time, the station passes the token to the next station in the logical ring.

After a station has transmitted its data, it performs certain maintenance functions and then passes the token to its successor by sending a "token" frame. The station then watches for activity on the line to verify that its successor has heard the token frame. If the sender hears a valid frame, it assumes that the successor has possessed the token and is currently transmitting. If, however, the sender hears a noise-burst or an invalid frame (frame with incorrect frame check sequence), it attempts to assess the state of the network.

The sender in order to decide whether successor has received token or not, continues to listen for some slot times (depending on implementation). If nothing is heard, the station assumes that token transfer to its successor was unsuccessful and retransmits the token frame. If the token sending station does not hear a valid frame after sending the token first time, it repeats the token passing operation once, performing the same monitoring as during the first time.

If the successor does not transmit a frame after receiving the token, the sender assumes that its successor has failed. The sender then attempts to establish a new successor, bridging the failed station out of the ring. If still there is no response for a new successor, the station tries another strategy to reestablish the logical ring. The station now sends a frame to solicit a successor with its own address as both destination and source, asking any station on the system to respond to it. Any operational station that hears the request and needs to be the part of the logical ring responds, and the ring is reestablished using the response window process discussed later.

If all attempts at soliciting a successor fail, the station assumes that a fault may have occurred, and it uses a series of recovery procedures that grow increasingly more drastic as the station repeatedly fails to find a successor station.

The bus token-passing access method is efficient under high loads because the coordination of the stations requires only a small percentage of the medium's capacity. Each station gets an equal opportunity to share the medium's capacity. The stations' transmissions are coordinated so as to minimize their interference with each other. There are no additional requirements on the media and the modem capabilities other than those necessary for transmission and reception of multibit, multiframe sequences at the specified mean bit error rate. The worst-case boundary on access delay can be computed in the absence of the system noise. There are minimum constraints only on how a station which controls the medium may use its share of the medium's capacity. This access method permits the presence of large numbers of low-cost reduced-function stations in the network, together with one or more full-function stations.

2.2.2 Response Windows

New stations are allowed to enter the logical ring through a controlled contention process using "response windows". The response window define the time interval during which a station sending a frame will listen for a response from another station. The frame type to solicit successor indicate the opening of the response windows for stations wishing to enter the logical ring. The frame to solicit successor specifies an address range. Stations whose address fall within this range and who wish to enter the ring may respond to this frame. Responding stations send their requests to become the next station in the ring. If the sender hears a valid request, it allows the new station to enter the logical ring by changing the address of its successor to the new station and passing to its new successor the token.

There may exist a situation where more than one station wishes to enter the ring during one response window. The contention is minimized by the rule that a station only requests admission when a window range is opened for an address range that spans its address.

The maximum delay a station experiences in gaining access to the network defines the worst-case token rotation time. A very long token rotation time may occur if each station attempts to add new stations to the logical ring. The station defers the procedure to solicit successor if the rotation time exceeds the worst-case rotation time.

2.3 Ring Token-Passing

A token ring consists of a set of stations connected in series with the transmission medium. The operation on the "physical ring" is sequential, that is, frames are passed bit by bit from one station to the next station after a short processing delay. Each station receives each and every message (frame), checks it for errors and retransmits it to the next station regenerating the entire message bit by bit. A station has the right to transmit when it acquires the token. Token circulates on the medium after each frame transfer. Any station, wishing to transmit, may capture the token by modifying the appropriate control and status fields. The station possessing the token transmits its frame of information addressed to station(s) [5, 14]. The token passing operation on the ring is shown in Fig. 2-6.

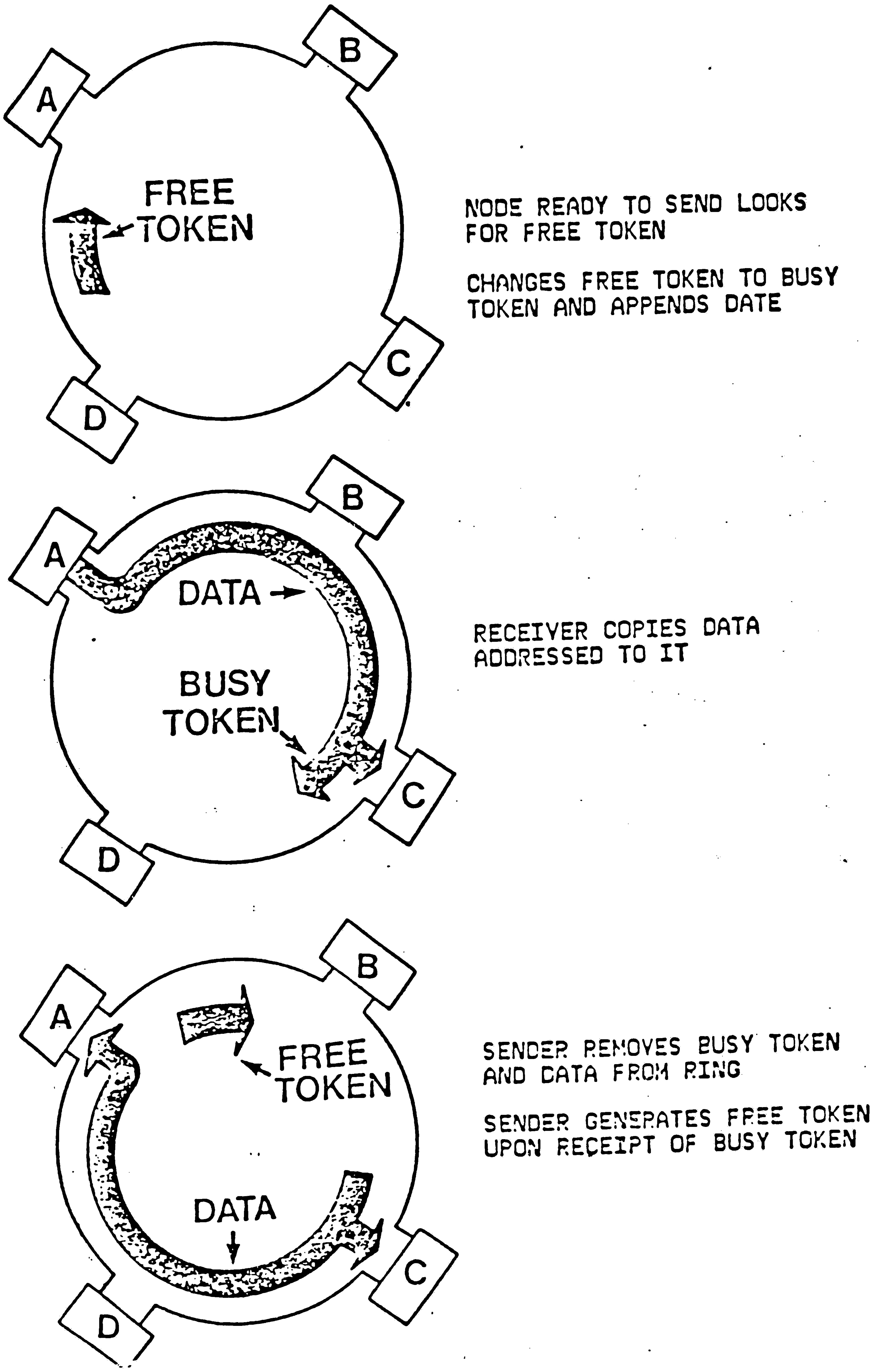


Figure 2-6: Token Passing Ring Operation

The destination station(s) copies the information as it passes. After circulating on the ring, when the frame comes back to the transmitting station, the transmitting station removes it from the ring. The transmitting station may use the medium upto a maximum period of time depending on the token holding timer. After completing the transmission or the time exceeds the token holding time, the sender initiates a new token on the ring to provide other stations opportunity to gain access to the medium. In case of transmission errors, error detection and recovery mechanisms are performed to restore the normal network operations.

2.3.1 Normal Operation

A station gets access to the physical medium (the ring) by acquiring the token. The station possessing the token may transmit a frame or a sequence of frames depending upon the token holding time. A station wishing to transmit requests the MAC sublayer for transmission. The MAC sublayer prefixes the protocol data unit (control information delivered between peer entities) with the appropriate source and destination addresses and then waits to acquire a usable token that is circulating on the ring.

When an appropriate token is recovered, it is modified to a start of frame sequence by setting the token bit. From this point, the station stops regenerating the incoming signal and begins transmitting its own frame. A frame check sequence is appended at the end of the information field.

Each station receives bits from the medium and after delays due to processing, retransmits them back on the medium. Processing of information include check to determine whether a frame is addressed to this station or not. If the frame's destination address match the station address, the group address or the broadcast address, the frame is copied into a buffer and is forwarded to the appropriate sublayer. If the frame is received and copied by the station, then it sets "address recognized" and "copied" bits and retransmits the frame to the next station on the physical ring.

Transmitting frame(s) will make a round trip on the medium and then will be purged by the transmitting station. The transmitting station will insert a new "free" token frame on the ring if the station has completed the transmission of its own frame and the token it used for transmission has returned after one round trip. If a station releases a free token after finishing its transmission but before it receives its own token, then this may complicate error recovery since several frames are on the ring at the same time. Only the source station has the responsibility for removing the circulating frame. The destination station can set bits in the frame as it goes by to inform the sender of the results of the transmission. When a transmitting station releases a new free token, the next station downstream with data to send will be able to seize the token and transmit. In any case, the use of token guarantees that only one station at a time may transmit.

There are two error conditions that could cause the token ring system to break down. One is the loss of the token so that no token is circulating; the other is a persistent busy token that circulates endlessly. To overcome these problems, one station acts as "active monitor". The monitor detects the lost token condition using a time-out, and recovers by issuing a new free token. To detect a circulating busy token, the monitor sets a "monitor bit" to one on any passing busy token. If it sees a busy token with the bit already set, it knows that the transmitting station has failed to absorb its frame and recovers by changing the busy token to a free token. Frame removal procedures are necessary because due to the repeating action, an unclaimed message would circulate on the ring forever. Fault detection algorithms remove frames if the token holding station malfunctions.

Other stations on the ring have the role of passive monitor. Their primary job is to detect failure of the active monitor and assume that role. A contention-resolution algorithm is used to determine which station takes over.

2.3.2 Preemptive Priority Option

Priority preemption can be employed in the ring token-passing method. Two three-bits fields are provided in the access control field of the frame to designate the current priority of the token and to reserve the next free token at a higher priority level. A station having a higher priority than the token-holding station sets the reservation bits to its higher priority level as the frame passes through the station. When the frame returns to the token-holding station, the next free token is issued with its priority bits set to the reserved priority level. Stations of lower priority are prohibited from claiming the token so that it passes to the requesting station or an intermediate station of equal priority that now has frames to send.

The station which upgraded the priority has the responsibility to downgrade the token priority when all higher priority stations have sent their available frames. When the original station sees a free token at the higher priority, it assumes that the higher priority stations have been satisfied and downgrades the token priority before passing it to the next station. This guarantees that the token pass is restarted at the point it was interrupted. Since there are eight levels of priority, the token may be upgraded a number of times before it returns to its original value and restarted around the ring.

Chapter 3
Fiber-optic Networks

Fiber optics, a technology that was still experimental as recently as the late 1970s, is now becoming the medium of choice for sending digital transmissions in communication networks. Its technical and economic advantages are firmly established in existing applications in the U.S. and other industrialized countries. The cost of connections that link computers and terminals to fiber networks has been dropping -- an important factor for LANs [15].

Behind the multiplying applications of fiber optics are several technological advances, such as the advent of "single-mode" fibers that can carry signals of optimal wavelength for long-distance propagation. Many of these applications require transmission speeds of at least 400 megabits per second (Mbps), which single-mode fiber can easily accommodate. Within three or four years, in fact, such fiber optic networks will likely be able to handle greater than 1000 Mbps (1 gigabit per second or Gbps) over distances of 30 or more miles without the need for amplification.

An optical fiber is a hair-thin strand of glass composed of silicon and other materials such as germanium. It consists of a light-transmitting core and a layer of cladding that keeps the light from straying. Optical fiber transmit light using the phenomena of total internal reflection. Reflection takes place when light, traveling through a medium with a high index of refraction, strikes the surface of a medium with a low index of refraction. The core, a material with low refractive index, is surrounded by a layer of cladding, the material with a high refractive index. Light injected into the core reflects off the cladding surface, resulting in total internal reflection.

The earliest fiber optic systems were multimode; they carried several lightwaves down the fiber simultaneously [9]. In case of multimode, with larger core diameter, fibers conveyed signals along many internal paths, or modes. Some of these paths were parallel to the axis of the cable, while others were within the angle of incidence for reflection back into the core at the core-cladding interface (rays at a greater angle passed into the cladding). Thus tendency of signal pulses were to disperse as they travel, because modes with high angles of incidence had to travel a greater optical distance to reach a certain point on the cable than a mode traveling at a lower angle of incidence to the axis. This type of dispersion, called modal dispersion, caused pulses to spread and limit the rate and the distance at which they could be transmitted without regeneration. Thus, multimode cables were plagued by excessive signal attenuation (reduced optical intensity) and dispersion (spreading of the optical pulse). Single-mode fiber, which transmits a single direct beam light, has since been developed. It achieves higher performance, in part because the core diameter has been reduced from 50 microns (standard for multimode fiber) to about 8-10 microns. The smaller diameter permits a single-mode fiber to send a concentrated light beam farther than the multimode, because the light strikes the core/cladding boundary at a much smaller angle, resulting in less attenuation and dispersion.

An optical fiber cable by itself is nothing more than a passive medium through which light travels. Most of the work, then, is performed by transmitting and receiving devices at each end. Digital information is send by a laser or LED optical source device, which then travel through the length of the fiber cable, and is detected at the receiving end by an APD (avalanche photodiode) or PIN-FET (p-intrinsic-n field-effect transistor). An LED/APD combination offers modest performance with the benefit of high reliability with low cost, while the high performance laser/PIN-FET combination costs more and is less reliable.

Optical waveguide cables are distinguished by their great bandwidth, low attenuation, insensitivity to electromagnetic interference, freedom from ground-looping problems, durability, reliability and high flexibility. These properties make optical fibers an attractive transmission medium for the most varied fields of application. Networks based on fiber optics are increasingly being chosen because they offer better control of communication costs and superior performance [11].

Major fiber optic networks are currently being installed by each of the seven regional Bell Telephone companies, and long-distance common carriers such as AT&T Communications, MCI, and GTE Sprint. Some specialized long-haul network providers are also installing fiber capacity, including seven-company consortium called NTN (National Telecommunication Network), headquartered in Washington, D.C. AT&T Communications (Bedminster, N.J.) is modernizing its older analog and digital copper long-haul network with fiber optic systems that can transmit at over 400 Mbps on a single fiber (a rate capable of supporting approximately 6000 voice circuits). United Telecom (Kansas City, Mo.) plans to build a 23,000-mile nationwide fiber optic network to connect all 48 contiguous states. United will build part of its network and lease existing capacity in areas such as the northeastern U.S., where Lightnet (New Haven, Conn.), a joint venture between the CSX railroad and Southern New England Telephone, is already operating high-capacity fiber optics [9, 15].

Unlike AT&T, many other long-haul carriers lack the right-of-way to install miles of fiber cables; this situation explains in part why many AT&T competitors have relied on satellites for long-distance transmissions and microwaves for local traffic. But lately, companies with sizable real estate assets and valuable rights-of-way have begun to play a major role in the telecommunications industry. Railroads, electric power companies, and oil and gas pipeline companies are all leasing their rights-of-way to long-haul carriers for fiber optic networks.

The **fiber-optic local area network** topologies can be classified as the bus, the ring, and the star [16]. Data circulates bidirectionally in the bus. The stations connected to the bus medium feed in and remove data to and from the bus couplers. Power is reduced due to the coupling at each node. In the ring, due to its configuration, the data can travel in one direction only. At each node, the data is generated and retransmitted bit by bit. Although, line loss is substantially greater in the optical bus than in the ring, the bus is less prone to failure.

The star configuration, using optical fiber as the transmission medium, can operate either actively or passively. In the passive operation, the central node splits up the data in terms of power, thus it is available to all the stations. The degree of splitting (the number of nodes on the medium) determines the line loss. In the active operation, line loss is due to fiber attenuation because the data is split electrically in the active node. In terms of the power balance, the active star network behaves like the ring. Via the passive star configuration, at least one order of magnitude more of subscribers can be connected than via the optical bus because line loss increases only logarithmically in the star, but linearly with the number of subscribers in the bus.

The media-access control methods are classified as Time Division Multiple (TDM) access, Carrier Sense Multiple Access with Collision Detection (CSMA/CD), Token Passing or Polling methods, and their variations. The fixed TDM access method is suitable for high-speed file transfer; the dynamic TDM access method for circuit switching services, such as a voice and a video signal, and the CSMA/CD, Token Passing, and Polling methods for packet-switching services. With regard to the relation between physical topologies and media-access control methods, the TDM and Token Passing methods are usually used in a loop-configuration, while the CSMA/CD method is best suitable for star or bus configuration.

Most of the optical LANs in operation today still employ a ring topology and a deterministic access protocol. Since more and more findings indicate for a fairly moderate traffic incidence the CSMA/CD protocols generally involve lower mean network delays than the TDM and token procedures, increasing use is being made of statistical access methods as well.

There is no doubt that the role which fiber optics play in LANs is primarily determined by the insusceptibility of optical fibers to external electromagnetic influences. In process-control systems, the need to combat the electromagnetic combination prevailing in the process environment makes the optical fiber first choice from an economic point of view.

Optical LANs have not yet made a breakthrough on a wide front in the sense of completely replacing electrical systems by optical ones. This is explained not only by psychological inhibitions about new technologies, but also by the lack of optical components with the same degree of sound engineering and proven long-term reliability. The principle obstacle to a more general use, however, has been the material cost. Although installation and maintenance costs are generally comparable to those of competitive media such as baseband or broadband coaxial cable, components such as optical sources, detectors, connectors, and multiplexers boost the cost of fiber optic LANs considerably.

The coming years should bring significant improvement in cost-effectiveness and the optical components will be readily available at a cheaper cost. A number of companies are active in developing and marketing fiber optic components, including AT&T Technologies, Northern Telecom, Siecor Electron Optics Products, General Optronics, Lasertron, Amphenol, and Deutsch.

Chapter 4
MAP/TOP Protocols

Today, a major problem to the effective data communications among various communicating devices is systems incompatibility. The installation of computing and processing equipment from different vendors in today's business and manufacturing environments has led to the need for common communication protocols. In a multivendor computing environment, common communication methods are required for integration and automation of processes. General Motors Corporation developed a specification for a set of communication standards called Manufacturing Automation Protocol (MAP) to provide for multivendor data communications in the factory floor environment [8MAPSpecification]. The Boeing Company's Technical and Office Protocol (TOP) specification is intended to provide multivendor data communications for the technical and office environment [4TOPSpecification]. TOP and MAP, both specifications are based upon the International Standards Organization (ISO) seven-layer Open Systems Interconnect (OSI) model and these protocols will enable pieces of equipment from any vendor -- whether in the office or on the floor -- to communicate with each other.

Since the ISO OSI model specifies functions rather than protocols, compliance with the model does not ensure multivendor communication. During AUTOFACT '85, an industry trade show, both, The Boeing and General Motors sponsored the demonstration of TOP and MAP protocols (refer Fig. 4-1) and received a great deal of interest and encouragement from the computer industry professionals and manufacturers. MAP is an application subset of OSI and allows information exchange pertaining to factory floor computer data communications among diverse intelligent devices. TOP, also an application subset of ISO OSI protocols, is designed to complement the MAP specification and addresses data communication needs in an office, which include applications such as electronic mail, word processing, editable text and nontext document exchange, file transfer, graphics interchange, data base management, distributed batch jobs, videotext and business analysis. TOP and MAP networks are based on existing and proposed national standards for Local Area Networks and will interconnect freely as required. This interconnection includes computer-to-computer transaction processing, and application-to-application process initiation, transfer, and completion.

AUTOFACT '85 OSI IMPLEMENTATIONS

TOP END SYSTEM	TOP/MAP INTERMEDIATE SYSTEM		MAP END SYSTEM
ISO FTAM			NETWORK MANAGEMENT, DIRECTORY SERVICES, MMFS SUBSET, ISO FTAM & ISO CASE KERNEL
NULL			NULL
ISO SESSION KERNEL			ISO SESSION KERNEL
ISO TRANSPORT CLASS 4			ISO TRANSPORT CLASS 4
ISO CLNS	ISO CLNS		ISO CLNS
IEEE 802.2 LINK LEVEL CONTROL CLASS 1	IEEE 802.2 LINK LEVEL CONTROL CLASS 1	IEEE 802.2 LINK LEVEL CONTROL CLASS 1	IEEE 802.2 LINK LEVEL CONTROL CLASS 1
IEEE 802.3 CSMA/CD BASEBAND MEDIA	IEEE 802.3 CSMA/CD BASEBAND MEDIA	IEEE 802.4 TOKEN ACCESS on BROADBAND MEDIA	IEEE 802.4 TOKEN ACCESS on BROADBAND MEDIA

Figure 4-1: AUTOFACT '85 OSI Implementation

The objective of the **Physical Layer** is to provide a physical connection for transmission of data between data link entities, and means by which to activate and deactivate the physical connection.

Broadband coaxial cable has been recommended as the standard media for MAP networks. It not only supports the high speed data requirements of a local area network, but can also handle voice and video requirements and allows multiple networks to exist simultaneously on the same media. Broadband technology is a part of the IEEE 802.4 (Token passing on a bus configuration) communications standard. Although the network is a bus topology, it is a logical ring for the purpose of passing the token.

The physical medium selected as the TOP standard is a shielded 50-ohm coaxial cable (known as 10Base5 version of IEEE 802.3). This cable provides a 10 Mbps data rate limited to 500-meter network segments. The primary reason for choosing IEEE 802.3 (Carrier Sense Multiple Access with Collision Detection access method) as the initial physical layer protocol is the ease of migration from the Ethernet (Xerox Corporation). However, the intent of the TOP is not to limit the physical layer to IEEE 802.3 but may expand to include other media and access methods.

The objective of the **Data Link Layer** is to provide for and manage the communication linkage between any two end systems. It may also detect and correct errors in the physical layer and perform other functions necessary for accurate data transmission.

The IEEE 802.2 specification is the preferred standard for the logical link control sublayer. It defines a multipoint peer-to-peer protocol. There are two types of service within this sublayer, connectionless-oriented (type 1) and connection-oriented (type 2). Connectionless-oriented service allows for the exchange of data between two logical link control entities without the establishment of a data link connection. It does not provide for message sequencing acknowledgment, flow control or error recovery. Connection-oriented service, on the other hand, does establish a data connection and does provide the aforementioned functions. There are also two classes of service, that which supports type 1 operation only (class 1) and that supports both types of operation (class 2).

The preferred protocol at the data link layer for both TOP and MAP is the IEEE 802.2 Logical Link Control (LLC) standard using type 1 systems and class 1 services to provide connection-less mode network services.

The purpose of the **Network Layer** is to provide message routing between end nodes, independent of the transport protocol used. It also provides network service enhancements, flow control, and load leveling.

MAP accomplishes end-to-end routing function using a global routing function. The network layer is divided into four major sublayers. ISO developed these sublayers to perform functions that the network layer needs to perform. They are

1. Inter-Network sublayer
2. Harmonizing sublayer
3. Intra-network sublayer
4. Access sublayer

The Internet sublayer of the OSI Reference Model's network layer contains the information for end node-end node information flow/exchange. This allows messages/packets to traverse multiple local area networks without regard for the routing methodology of each network.

Harmonizing sublayer, also known as Network Interface Sublayer, provides enhancements to lower layers and sublayers and provides uniform support services to the Internet sublayer. This layer, generally, is an implementation specific sublayer.

Intra-network sublayer contains an intra-network routing protocols. It performs all routing and switching of messages to, from, or through this node within the set of interconnected nodes communicating with a common routing protocol.

Link Access sublayer provides the necessary interface to the Data Link layer.

These sublayers are concerned with converting global address information into routing information, maintaining message routing tables and/or algorithms, establishing and terminating network connections when appropriate, and switching each incoming message to its proper outgoing path.

The network layer functions of TOP are same as MAP.

The task of the **Transport Layer** is to provide a network-independent transparent transfer of data between cooperating session entities.

The services of the transport protocol can be thought of as fitting into two general types: transport-connection management and data transfer. Connection management services allow a transport-user to create and maintain the data path to a correspondent transport-user. Data transfer services provides the means for exchanging data between the pair of transport-users.

Connection management is composed of four services. The 'establishment' service provides for the establishment of transport-connections. The NBS 'close' service provides for the graceful termination of a connection. The 'disconnect' service also terminates a connection, but with the possible loss of data (an 'abort' service). The 'status' service provides a mechanism for the user to be informed about the attributes and status of a transport-connection.

Data transfer is provided by three services. The 'data' service allows a user to transfer data to a correspondent user on a connection (a 'normal data' service). The 'expedited-data' service allows for the transfer of a limited amount of data outside of normal data stream (an 'urgent data' service). The 'unit-data' service allows for the transfer of data to a correspondent user without the need to first establish and later terminate a transport-connection.

The MAP standard for the transport layer is the ISO compatible subset of the National Bureau of Standards, Class 4 Transport Protocols (NBS-Class 4). Class 4 is the largest and most complex class of transport. It provides flow control and ability to multiplex user transmissions to the network. In addition, class 4 adds error detection and recovery by checking for out-of-sequence, lost, or damaged packets. Only class 4 supports a datagram-oriented network.

TOP will also use the most reliable transport service, Class 4.

The task of the **Session Layer** is to manage and synchronize the reliable data transfer between the presentation entities.

A session-connection may be structured so that interactions between the two users occur:

1. two-way alternate (half-duplex)
2. one-way interaction (simplex)
3. two-way simultaneous (full-duplex)

The MAP standard for the session layer follows the ISO Session standard which achieved International Standard status in 1984. The minimum subset of the ISO Session International standard for MAP connectivity is specified by the Kernel function unit and the Duplex functional unit.

TOP will follow ISO Session protocol. The initial implementation of the ISO session will be the session kernel and the full-duplex subset of the basic combined subset.

The purpose of the **Presentation Layer** is to provide a negotiated representation of data in order that the application entities can communicate. The presentation layer is concerned with the syntax and representation of the transferred data. Only binary and ASCII data can be exchanged by applications.

No Presentation Layer protocol control information will be present for MAP implementation.

Currently, the presentation layer is also null in TOP until a standard(s) is accepted. This is consistent with the MAP specification. The intent of TOP is to support a full presentation layer protocol. (The presentation layer protocol being developed by ISO is known as Abstract Syntax Notation One.)

The purpose of the **Application Layer** is to provide services to allow application programs to access and use the network services provided by the lower layers.

MAP file transfer will reflect the two phase implementation cycle. Phase 1 will include implementation of the file transfer Kernel, read, write, and limited file management functional units and the Kernel group of the virtual filestore attributes.

Phase 1 supports the transfer on both binary and ASCII text file formats and the remote creation and deletion of files. It is expected that Phase 2 will include implementation of limited file access capabilities and an enriched set of file formats.

The network applications addressed by TOP specification include file transfer, electronic mail, document exchange, servers, job transfer and manipulation, and virtual terminals.

Phase 1 of TOP implementation will cover file transfer. The protocol used for file transfer, ISO file transfer, access, and management (FTAM), is the same protocol that is used in MAP. (The file transfer protocol deals with the way a file is moved from one open system to another. File access and management deals with file attributes and protection.)

Chapter 5
Conclusion

Local area networks use low-cost, high-speed transmission capability as the basis for a general-purpose data transfer network. There are two basic issues in local area network design. First, how should the hardware realizing the network be organized to provide reliable high-speed communication at the minimum cost? Second, what protocols should be used for the operation of the network? An effective communication among various devices would require agreements on number of technical points and IEEE Local Network Standard Committee have so far approved three standards for medium access control protocols: Carrier Sense Multiple Access with Collision Detection, the Token Bus and the Token Ring.

This thesis has described in detail the proposed standards. The important characteristic of CSMA/CD is that every station equally attempts for access, it is simple, easily implemented access algorithm and is quite efficient when traffic load is low. However, it can not be discriminatory, a desirable feature when some traffic is of higher priority. Access time and response time are statistical rather than deterministic. CSMA/CD is directly applicable to bus topologies and therefore, does not satisfy applications where other topologies may be more appropriate.

Priority option can be implemented in the token-passing methods. They are deterministic, that is, there is a known upper bound to the amount of time any station must wait before transmitting. The methods are very efficient under heavy load conditions. Efficiency is insensitive to both the number of stations and the length of the medium. The principle disadvantage is their complexity. Another disadvantage is that under lightly loaded conditions, a station may have to wait through fruitless token passes for a token. The requirement of token maintenance can also lead to complexity.

In the transmission of physical signals, fiber-optic trunk line systems have definite advantages over the conventional coaxial cable and and twisted wire systems. Generally, in the fiber-optic trunk line systems, two offices are just connected, while, in fiber-optic LAN, many user terminals are connected to share a common data. Therefore, multi-accessing is the most significant feature of the fiber-optic LAN. However, optical LANs have not yet made a breakthrough on a wide front in the sense of replacing electrical systems by optical ones.

Today, office automation is rapidly becoming popular with advanced computer and communication technology. The LAN has appeared as one of the most important technologies to enable a variety of terminals to communicate with one another more efficiently. Certain groups in Japan, Europe and U.S.(including General Motors Corporation and The Boeing Company) have already started LAN standardization activities to enable users to easily interconnect products from different vendors.

Sophistication in networking today is achieved through integrated-software development. In a network architecture, networking software is at the lowest level, high-level languages and the operating systems are at the next-higher level, and the application software is at the highest level. Integrated software results in each level being transparent to all levels above and being able to embed in itself the next lower level. Network manufacturers are attempting to produce competitively priced components that can handle high level languages and operating systems and can share mass storage and expensive peripherals.

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Vita

Paresh Shah, the son of Anantrai and Pushpa Shah was born on October 12, 1960 in Calcutta, India. He attended the Birla Institute of Technology & Science, Pilani, India and received his Bachelor of Engineering Degree with Honors in Electrical and Electronics Engineering in June of 1984. While pursuing his Master's Degree in Computer Science at Lehigh University, he has served as a teaching assistant in the Computer Science and Electrical Engineering department and programmer for the IBM funded research at the Computer-Integrated Manufacturing Laboratory. His professional experience includes trainings with the several leading computer firms in India.