Chapter 3

REVIEW OF COMPUTER NETWORKS

In this chapter we discuss the issues related to computer networks and concentrate on the concepts and issues that are important for distributed database systems. We therefore omit most of the details of the technological and technical issues in favor of these conceptual presentations.

We define a *computer network* as an *interconnected collection of autonomous computers that are capable of exchanging information among them* (Figure 3.1). The keywords in this definition are *interconnected* and *autonomous*. We want the computers to be autonomous so that each computer can execute programs on its own. We also want the computers to be interconnected so that they are capable of exchanging information. Computers on a network are commonly referred to as *nodes*, *hosts*, or *sites*. They form one of the fundamental hardware components of a network. The other fundamental component is the communication path that interconnects the nodes among them. Note that sometimes the terms *host*

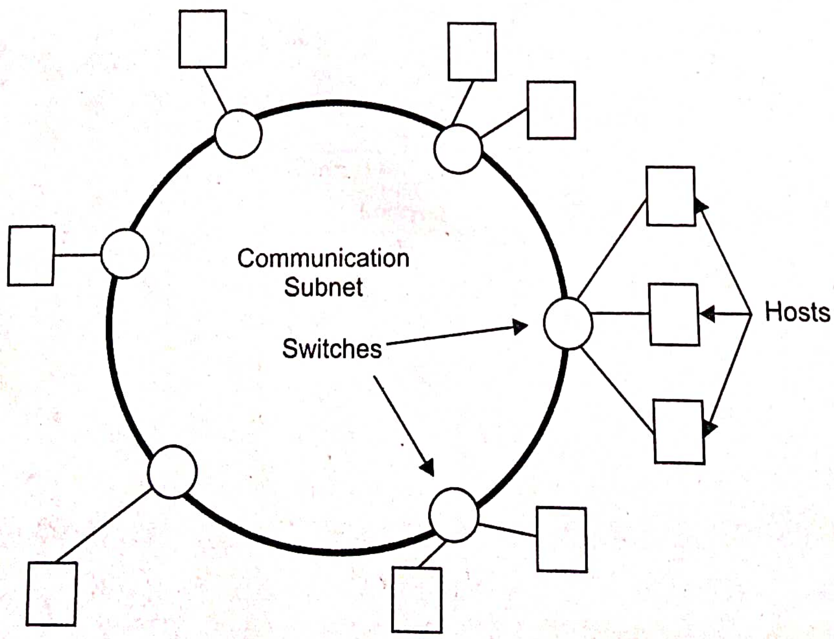

Figure 3.1. Computer Network

and *node* are used to refer simply to the equipment, whereas *site* is reserved for the equipment as well as the software that runs on it.

A computer network is a special case of distributed computing environment where computers are the equipment connected to the data communication channel. In a general distributed environment, though, some of this equipment may be terminals or other specialized devices (such as banking machines). The fundamental data communication concepts discussed in Section 3.1 hold in these environments as well. However, our main interest in this book lies in computer networks since they provide the basic support for distributed database systems.

3.1 DATA COMMUNICATION CONCEPTS

Let us first define a few fundamental terms. To quote [Stallings, 1988]: "... *data* [are defined] as entities that convey meaning. *Signals* are electric or electromagnetic encoding of data. *Signaling* is the act of propagating the signal along some suitable medium. Finally, *transmission* is the communication of data by the propagation and processing of signals."

Equipment in a data communication environment is connected by *links* each of which can carry one or more *channels*. Link is a physical entity whereas channel is a logical one. Communication links can carry signals either in digital form or in analog form. Telephone lines, for example, can carry data in analog form, even though such links are being replaced by ones more suitable to digital transmission. Each communication channel has a *capacity*, which can be defined as the amount of data that can be transmitted over the channel in a given time unit. This capacity is commonly referred to as the *bandwidth* of the channel. In analog transmission channels, the bandwidth is defined as the difference (in hertz) between the lowest and highest frequencies that can be transmitted over the channel per second. In digital links, *bandwidth* refers (less formally) to the number of bits that can be transmitted per second (bps). Three ranges of communication links can be identified according to their bandwidth:

1. *Analog telephone channels*: can carry up to 33 Kbps with suitable modulation techniques
2. *Digital telephone circuits*: can carry 56 or 64 Kbps (referred to as ISDN rates)
3. *Broadband channels*: can carry 1.5 Mbps and above; these form the trunks of digital phone circuits.

In computer-to-computer communication, data is usually transmitted in *frames*. Usually, upper limits on frame sizes are established for each network and each contains data as well as some control information, such as the destination and source addresses, block error check codes, and so on (Figure 3.2). If a message that is to be sent from a source node to a destination node cannot fit one frame, it is split over a number of frames. This will be discussed further in Section 3.3.

Later in this chapter we will talk about "packets" and "packet switching". The terms "packet" and "frame" are sometimes used interchangeably, but this is not precisely correct even though they refer to similar concepts. In terms of communica-

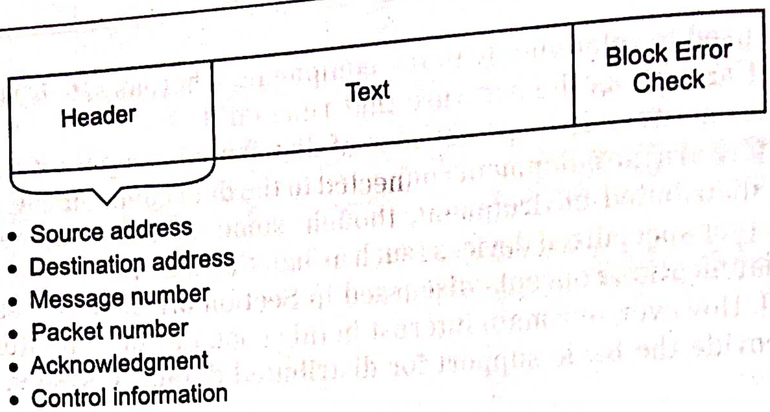

Figure 3.2. Typical Frame Format

tion protocols, they refer to entities at different layers. Specifically, in the ISO/OSI nomenclature that we discuss in Section 3.3, the term packet refers to a unit of transmission at the network layer while frame refers to a unit of transmission at the data link layer. From a practical perspective, the difference between the two often has to do with their formats. A packet format contains in its header network layer information, i.e., information about routing, while a frame includes only information related to the reliability mechanism of the data link layer.

3.2 TYPES OF NETWORKS

There are various criteria by which computer networks can be classified. One criterion is the *interconnection structure* of computers (also called *topology*), another is the mode of transmission, and a third is the geographic distribution (also called *scale* [Tanenbaum, 1997]).

3.2.1 Topology

As the name indicates, interconnection structure or topology refers to the way computers on a network are interconnected. Some of the more common alternatives are star, ring, bus, meshed, and irregular.

In *star* networks (Figure 3.3), all the computers are connected to a central computer that coordinates the transmission on the network. Thus if two computers want to communicate, they have to go through the central computer. Since there is a separate link between the central computer and each of the others, there is a negotiation between the "satellite" computers and the central computer when they wish to communicate.

In ring networks (Figure 3.4), the computers are connected to the transmission medium, which is in the form of a loop. Data transmission around the ring is usually unidirectional, with each station (actually the interface to which each station is connected) serving as an active repeater which receives a message, checks the address, copies the message if it is addressed to that station, and retransmits it.

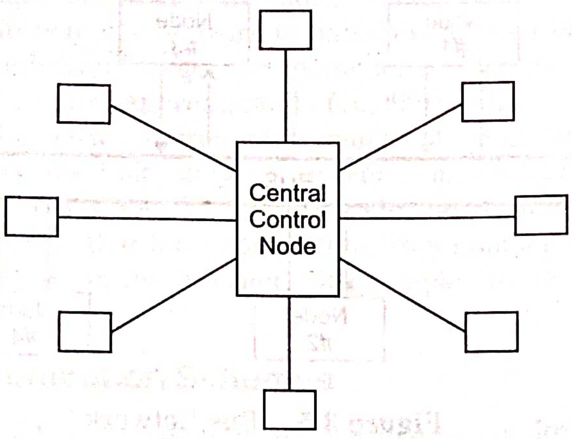

Figure 3.3. Star Network

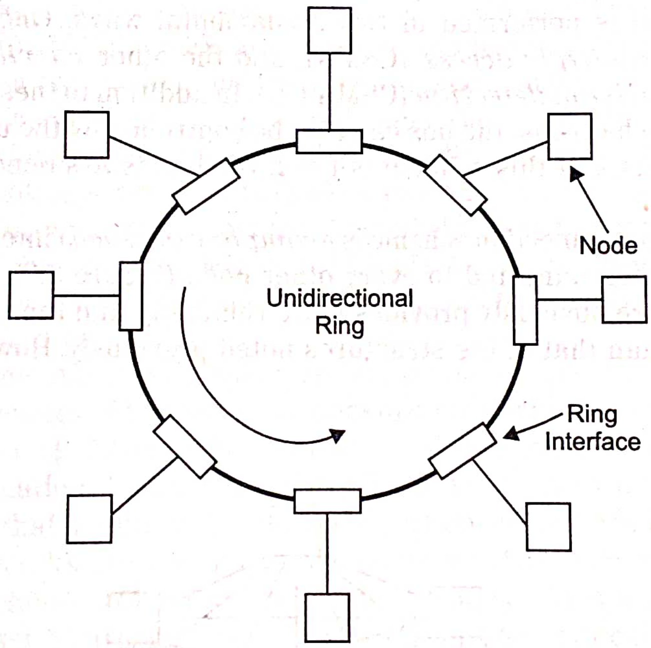

Figure 3.4. Ring Network

Control of communication in ring type networks is generally controlled by means of a *control token*. In the simplest type of token ring networks, a token, which has one bit pattern to indicate that the network is free and a different bit pattern to indicate that it is in use, is circulated around the network. Any site wanting to transmit a message waits for the token. When it arrives, the site checks the token's bit pattern to see if the network is free or in use. If it is free, the site changes the bit pattern to indicate that the network is in use and then places the messages on the ring. The message circulates around the ring and returns to the sender which changes the bit pattern to free and sends the token to the next computer down the line.

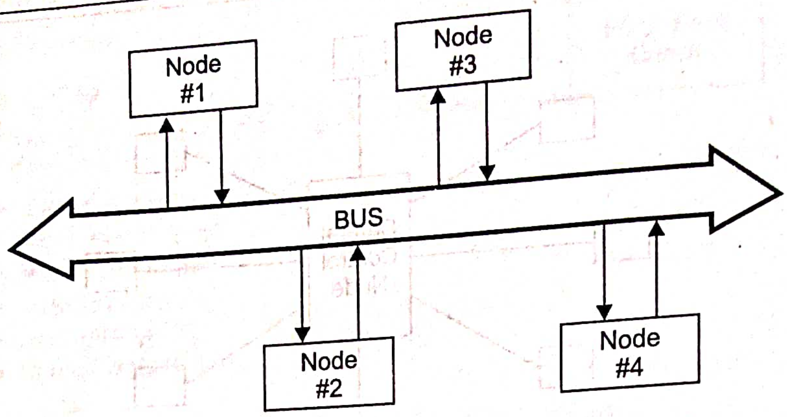

Figure 3.5. Bus Network

Another popular topology is the bus (Figure 3.5), where a common channel used to transmit data is tapped by computers and terminals. In this type of network, the link control is performed in two fundamental ways. One scheme is called *carrier sense multiple access* (CSMA), and the other, *carrier sense multiple access with collision detection* (CSMA/CD). In addition to these two fundamental link control mechanisms, the bus can also be controlled by the use of a token, thus avoiding collisions. If this scheme is used, the bus is assumed to form a logical ring.

Another interconnection scheme is a *complete* (*meshed*) interconnection, where each node is interconnected to every other node (Figure 3.6). Such an interconnection structure obviously provides more reliability and the possibility of better performance than that of the structures noted previously. However, it is also the costliest.

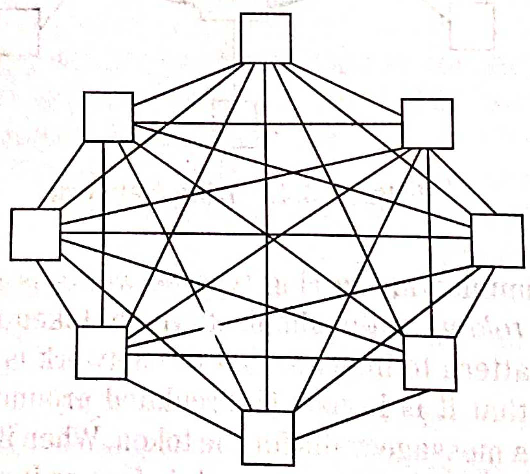

Figure 3.6. Meshed Network

A complete (meshed) interconnection scheme is not very realistic. Even if the number of computers on the network is small, the number of connections that are required are prohibitively large. For example, a complete connection of 10,000 computers would require approximately $(10{,}000)^2$ links.[1]

Communication networks frequently consist of irregularly placed communication links. That is, the links may be neither symmetrical nor follow a regular connectivity pattern. It is possible to find a node that is connected to only one other node, as well as nodes that have connections to a number of nodes. Connections among the computers on the Internet, for example, are irregular.

3.2.2 Communication Schemes

In terms of the physical communication schemes employed, networks can be either *point-to-point* (also called *unicast*) networks, or *broadcast* (sometimes also called *multi-point*) networks.

In point-to-point networks, there are one or more links between each pair of nodes. There may not be a direct link between each pair, but there are usually a number of indirect links with intermediate connections. The communication is always between two nodes and the receiver and sender are identified by their addresses that are included in the frame header. Data transmission from the sender to the receiver follows one of the possibly many links between them, some of which may involve visiting other intermediate nodes. The intermediate nodes check the destination address in the frame header and if it is not addressed to them, pass it along to the next intermediate node. This is called *switching*. The selection of the links via which frames are sent is determined by usually elaborate protocols which are beyond our scope.

The fundamental transmission media for point-to-point networks are coaxial or fiber optic cables. The telephone network connection to customer equipment traditionally uses twisted pair copper wires. Thus it has limited potential for fast data communication. Instead, the cable TV network uses a coaxial-to-the-home infrastructure that facilitates high speed data networking. Similarly, many existing local area networks are coaxial based. However, these are now being converted to fiber optic cables which provide higher capacity and speed.

In broadcast networks, there is a common communication channel that is utilized by all the nodes in the network. Frames are transmitted over this common channel and received by all the nodes. Each node checks the receiver address within the header and if the frame is not addressed to it, ignores it.

A special case of broadcasting is *multicasting* where the message is sent to a subset of the nodes in the network. The receiver address in the frame header is somehow encoded to indicate which nodes are the recipients.

Broadcast networks are generally radio or satellite-based. In case of satellite transmission, each site beams its transmission to a satellite which then beams it back at a different frequency (Figure 3.7). Every site on the network listens to the

---

[1]The general form of the equation is $n(n-1)/2$, where n is the number of nodes on the network.

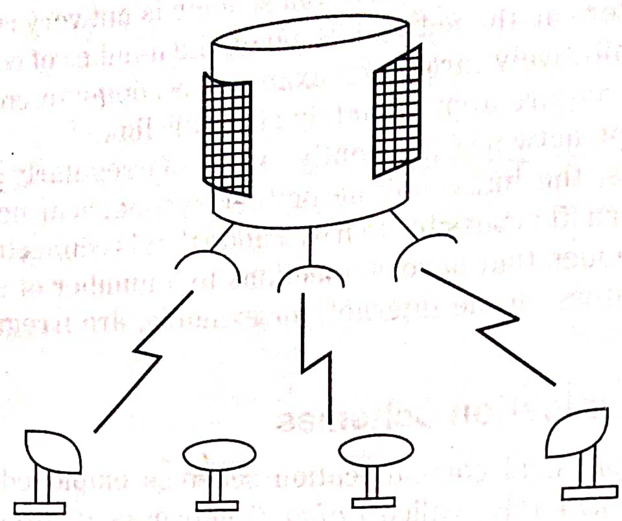

Figure 3.7. Satellite-Based Network

receiving frequency and has to disregard the message if it is not addressed to that site. A network that uses this technique is the SATNET network [Jacobs et al., 1978].

Microwave transmission is another very popular mode of data communication and it can be over satellite or terrestrial. Terrestrial microwave links already form a major portion of most countries' telephone networks. In addition to the public carriers, many companies are making extensive use of private terrestrial microwave links. In fact, major metropolitan cities face the problem of microwave interference among privately owned and public carrier links. An example of a network using satellite microwave transmission as its data communication medium is ALOHA [Abramson, 1973].

3.3 PROTOCOL STANDARDS

Establishing a physical connection between two computers is not sufficient for them to communicate. Error-free, reliable and efficient communication between computers requires the implementation of elaborate software systems that are generally called *protocols*. The complexity of these protocols differ between wide area, local area and metropolitan networks.

Wide area networks commonly have to accommodate equipment that has been manufactured by different companies. This requires that the transmission media be able to handle the *heterogeneity* of equipment and connection. There might be differences in equipment in terms of speed, word length, coding scheme used to represent information, or any other criteria. Therefore, WANs have created a more urgent need for protocols. Thus, we start our discussion with WAN protocols and then move on to LANs. Until recently, the most extensively known WAN protocol is based on the open systems interconnection architecture of the International Standards Organization (commonly referred to as the *ISO/OSI architecture*) [ISO, 1983].

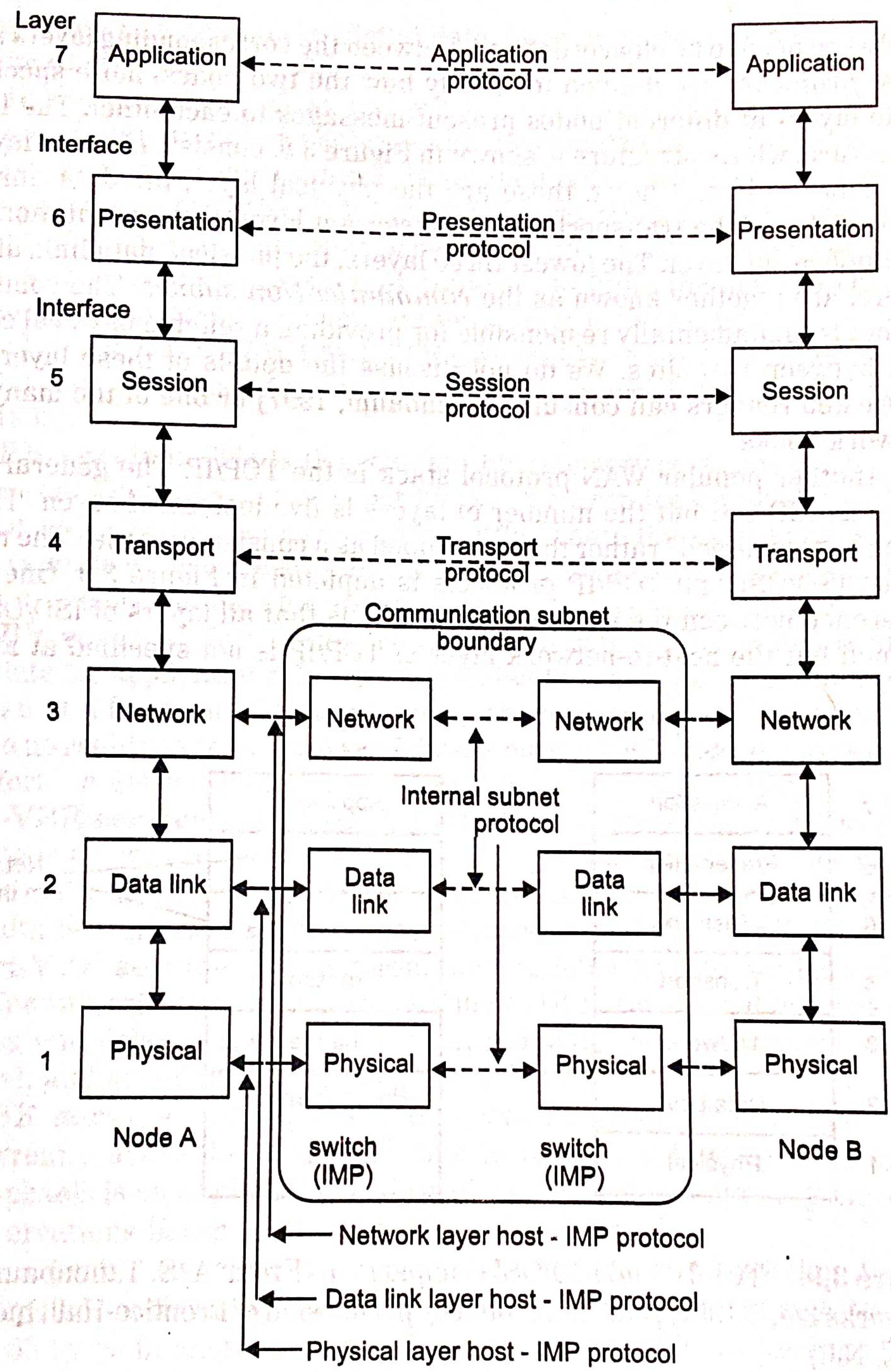

Figure 3.8. ISO/OSI Architecture (From: A. S. Tanenbaum, Computer Networks 3/e, ©1997, p. 29. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

The ISO/OSI architecture specifies that the network is to be built in a layered fashion (thus the term *protocol stack*). Between layers at a given node, *interfaces* that facilitate the passing of information between the layers of software and hardware need to be clearly defined. Between the corresponding layers at different sites, *protocols* are defined to specify how the two nodes, more specifically, the same layers at different nodes present messages to each other. The ISO/OSI architecture, whose structure is shown in Figure 3.8, consists of seven layers. Starting from the lowest layer, these are the physical layer, the data link layer, the network layer, the transport layer, the session layer, the presentation layer, and the application layer. The lowest three layers, the physical, data link, and network layers, are together known as the *communication subnet*. The communication subnet is fundamentally responsible for providing a reliable physical communication between two sites. We do not discuss the details of these layers in detail. Interested readers can consult [Tanenbaum, 1997] or one of the many computer network books.

Another popular WAN protocol stack is the TCP/IP. The general idea is the same as ISO/OSI but the number of layers is five instead of seven. The protocol stack has "emerged" rather than developed as a consistent model. The relationship of the ISO/OSI and TCP/IP protocols is depicted in Figure 3.9. One significant difference between the two protocol stacks is that all layers of ISO/OSI are well-defined but the host-to-network layer of TCP/IP is not specified at all.

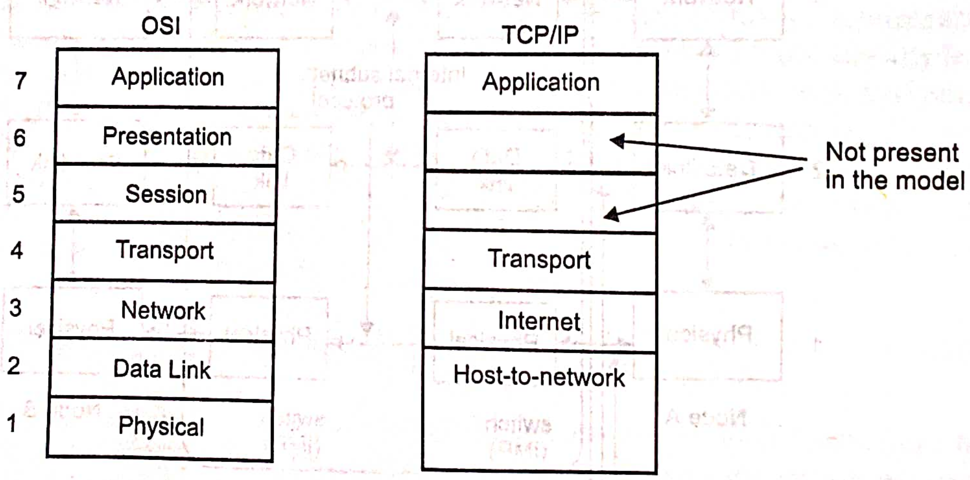

Figure 3.9. TCP/IP and ISO/OSI Comparison (From: A. S. Tanenbaum, Computer Networks 3/e, ©1997, p. 36. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

3.4 BROADBAND NETWORKS

Up to this point, we have concentrated on "data networks," or networks that are specifically configured to carry digital data in either digital form or in modulated analog form. Thus, the data networks are, at least logically, separate from the voice (telephone) networks. However, many of the new applications that use computer networks (e.g., multimedia information systems) require capabilities to transmit other forms of data in addition to digital data, such as video and audio streams with real-time delivery requirements and still images with large bandwidth requirements (a 1024×1024 digital X-ray image with 8 bits/pixel requires 10 Mbps in uncompressed form). Broadband networks are designed to address these requirements in a single network environment. Their identifying characteristics are their high capacity (greater than 150 Mbps), ability to carry multiple data streams with varying characteristics, the possibility of negotiating for a level of quality of service (QoS) and reserving network resources sufficient to fulfill this level of QoS.

The most popular broadband network technology is the Asynchronous Transfer Mode (ATM) networks [ATM, 1996]. ATM networks have been developed for both WAN and LAN applications. At the user level, ATM supports five classes of service [Garrett, 1996]:

1. **CBR service:** This is the constant bit rate service where the network transmits data at an agreed upon bit rate. This service is provided for video and audio transmission (real time traffic) where the source offers traffic constantly at the agreed rate. It does not involve any interactive services, so it is more suitable for applications such as video-on-demand.
2. **UBR service:** This is the unspecified bit rate service which is appropriate for applications that are interested in sending data in units rather than at a fixed rate. Most computer communications are this way; there are no real-time constraints and data is bursty. UBR service makes a "best effort" to deliver data, but does not provide any guarantees.
3. **rt-VBR service:** This service is also for real time traffic, but the source rate is allowed to vary. The variation allows optimizations since sources with varying bit rates can be multiplexed resulting in more efficient bandwidth use. It also accommodates interactive real time applications.
4. **nrt-VBR service:** The non-real time variable bit rate service category is for unit-oriented transmission similar to UBR. However, it improves UBR loss and delay characteristics by introducing QoS parameters such as peak and sustainable rates and the loss rate.
5. **ABR service:** Available bit rate service assigns whatever bit rate is currently available on the network to the requesting application. The emphasis is on minimizing the loss of frames and on adjusting the source reservations based on the variable traffic demand.

ATM is a packet switched network with special purpose switches that are connected by fiber optic links. The packets, which are called *cells* in ATM terminology, are 53 bytes in length (48 data, 5 header bytes). ATM technology fits the physical layer of ISO/OSI and TCP/IP protocol stacks (Figure 3.10) and requires an ATM adaptation layer (AAL) to compensate for the differences between ATM technology and the more traditional network technology developed for the upper protocol layers. AAL is responsible for handling lost and misdelivered cells, timing recovery, splitting frames from upper protocol layers into ATM cells at the source and their reassembly at the destination. The cell routing and multiplexing/demultiplexing tasks are accomplished by the ATM layer using the ATM switches.

Current broadband networks operate around 155 Mbps. There are many trial WAN ATM systems in operation and many more ATM LANs have been deployed.

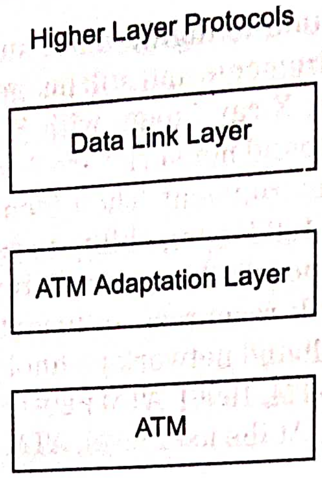

Figure 3.10. ATM Networks

The ability to carry multiple types of data at very high speeds and the opportunity to internetwork with other technology have hightened interest in this technology.

3.5 WIRELESS NETWORKS

Mobility and mobile computing are emerging as major forces. Wireless telephony is now widespread in many parts of the world. The earlier systems were analog and based on frequency modulation. Most of these wireless networks are now being converted to digital which increases the opportunity for mobile computing.

The term "wireless" is used somewhat carelessly. Satellite and microwave-based communications have existed for some time and they are indeed wireless. The current "wireless" networks in support of mobile computing are in fact "cellular" networks. These networks consist of a "wireline" backbone network on which a number of control stations are located. Each control station coordinates the communication from a mobile computer in their respective cell to another mobile computer in the same cell or in another cell or to a stationary computer on the wireline network (Figure 3.11).

In cellular networks, each cell is (logically) organized as a star topology with the control station serving as the central node. Establishment of communication between two mobile stations in the same cell is straightforward. Establishment of communication between stations in different cells involves the coordination of multiple control stations. Since the mobile stations can move, they can cross the boundaries of a number of cells. This requires a "hand-over" process where one control station hands over the mobile station to another control station. Keeping track of this mobility requires some sort of directory management.

There can be a number of different types of mobile stations. One type involves fairly simple computers with limited capabilities. In this case, data are located in computers on the wireline network with the mobile stations "downloading" data as they need them. This scenario is realistic for some applications. However, in this case, the distributed data management problem is not significantly affected

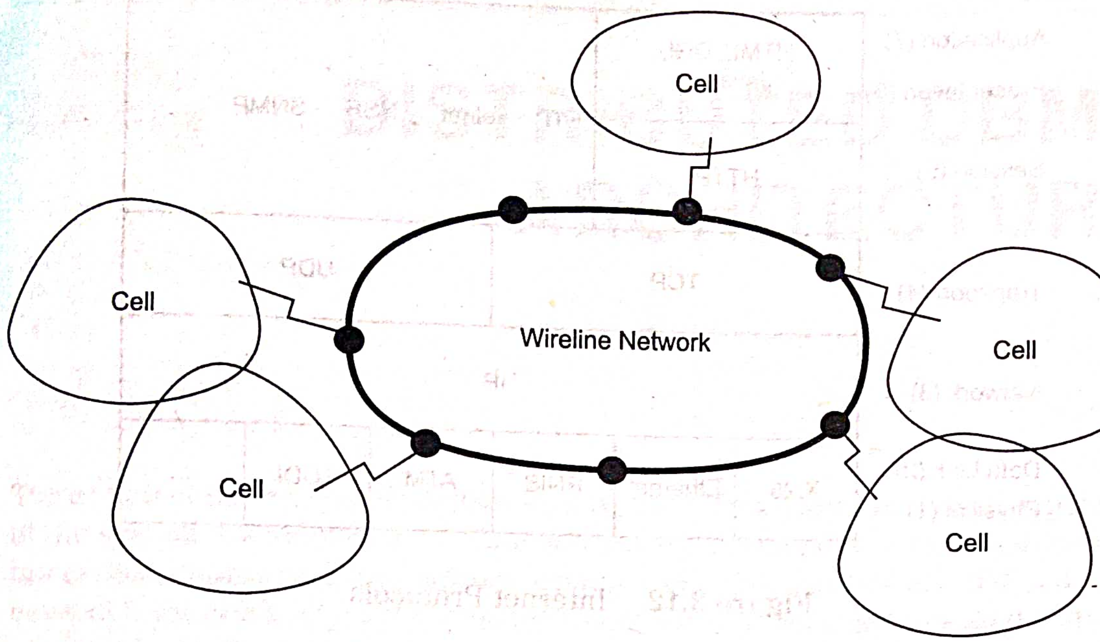

Figure 3.11. Cellular Networks

by mobility because data resides primarily on wireline computers. More interesting is the environment in which the mobile stations are more powerful and store native data that may need to be shared by others—the so-called "walkstation" case [Imielinski and Badrinath, 1994]. This approach causes significant difficulties for data management due to the communication, mobility, and portability characteristics of the mobile environment [Forman and Zahorjan, 1994].

Communication is over wireless networks which are prone to disconnection, noise, echo, and low bandwidth. Mobility of some of the equipment on the network causes static data in stationary networks to become dynamic and volatile in wireless networks. Mobility raises issues such as address migration, maintenance of directories and difficulty in locating stations. Finally, portability places restrictions on the type of equipment that can be used in these environments. For example, easy portability and the desire for long operation between battery recharges usually restrict the type and size of storage that can be used.

3.6 INTERNET

Internet is the term used to refer to the world-wide network of computers. In fact, it is a heterogeneous federation of networks, each with its own characteristics and protocols. The connections to Internet are voluntary and in most cases ad hoc in the sense that there is no controlling entity that enforces policies and guidelines for the communication of these networks. There is an Internet Engineering Task Force (IETF) but its effect has so far been minor.

The number of nodes on the Internet is growing very fast with more than 100 million connected computers expected by 2000. Perhaps the primary impetus for

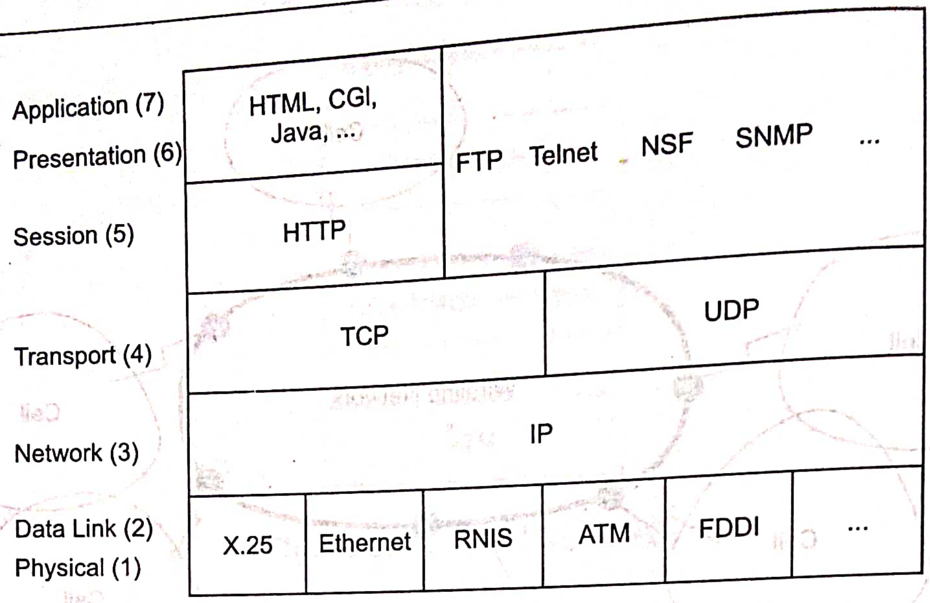

Figure 3.12. Internet Protocols

the fast growth of Internet has been the adoption of TCP/IP as the primary protocol. TCP/IP is now bundled with virtually all the operating systems, making it easier to connect to the Internet which can accommodate a variety of protocols (Figure 3.12).

Internet poses significant challenges, in particular due to the heterogeneity of the equipment and the networks. These are not issues that we will go into in this chapter.

REVIEW QUESTIONS

3.1 Explain data communication concepts.

3.2 What are the various types of networks? Explain in detail.

3.3 Explain the terms: protocol standards, broadband networks, wireless networks and Internet protocols.