UNIT: I; INTRODUCTION TO DATA COMMUNICATIONS

Data communications

Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable. For data communications to occur, the communicating devices must be part of a communication system made up of a com bination of hardware (physical equipment) and software (programs). The effectiveness of a data communications system depends on four fundamental characteristics: delivery, accuracy, timeliness, and jitter.

1. Delivery: The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.

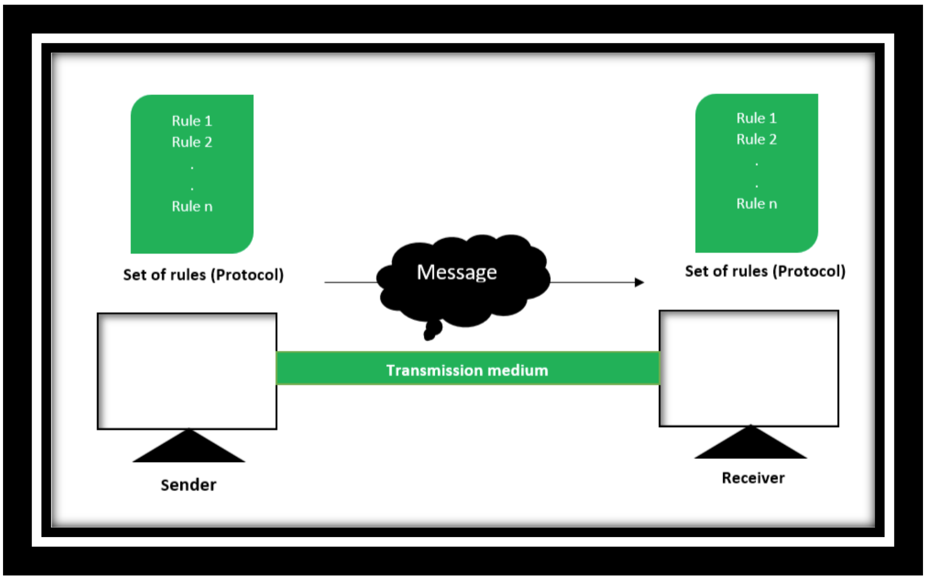
2. Accuracy: The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

3. Timeliness: The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called real-time transmission.

4. Jitter: Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 30 ms. If some of the packets arrive with 30-ms delay and others with 40-ms delay, an uneven quality in the video is the result.

Components:

A data communications system has five components.



1. Message - The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.

2. Sender - The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.

3. Receiver - The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.

4. Transmission medium - The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.

5. Protocol - A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

Data Representation

Information today comes in different forms such as text, numbers, images, audio, and video.

Text

In data communications, text is represented as a bit pattern, a sequence of bits (0s or 1s). Different sets of bit patterns have been designed to represent text symbols. Each set is called a code, and the process of representing symbols is called coding. Today, the prevalent coding system is called Unicode, which uses 32 bits to represent a symbol or character used in any language in the world. The American Standard Code for Information Interchange (ASCII), developed some decades ago in the United States, now constitutes the first 127 characters in Unicode and is also referred to as Basic Latin.

Numbers

Numbers are also represented by bit patterns. However, a code such as ASCII is not used to represent numbers; the number is directly converted to a binary number to simplify mathematical operations. Appendix B discusses several different numbering systems.

Images

Images are also represented by bit patterns. In its simplest form, an image is composed of a matrix of pixels (picture elements), where each pixel is a small dot. The size of the pixel depends on the resolution. For example, an image can be divided into 1000 pixels or 10,000 pixels. In the second case, there is a better representation of the image (better resolution), but more memory is needed to store the image. After an image is divided into pixels, each pixel is assigned a bit pattern. The size and the value of the pattern depend on the image. For an image made of only black and-white dots (e.g., a chessboard), a 1-bit pattern is enough to represent a pixel. If an image is not made of pure white and pure black pixels, we can increase the size of the bit pattern to include gray scale. For example, to show four levels of gray scale, we can use 2-bit patterns. A black pixel can be represented by 00, a dark gray pixel by 01, a light gray pixel by 10, and a white pixel by 11. There are several methods to represent color images. One method is called RGB, so called because each color is made of a combination of three primary colors: red, green, and blue. The intensity of each color is measured, and a bit pattern is assigned to it. Another method is called YCM, in which a color is made of a combination of three other primary colors: yellow, cyan, and magenta.

Audio

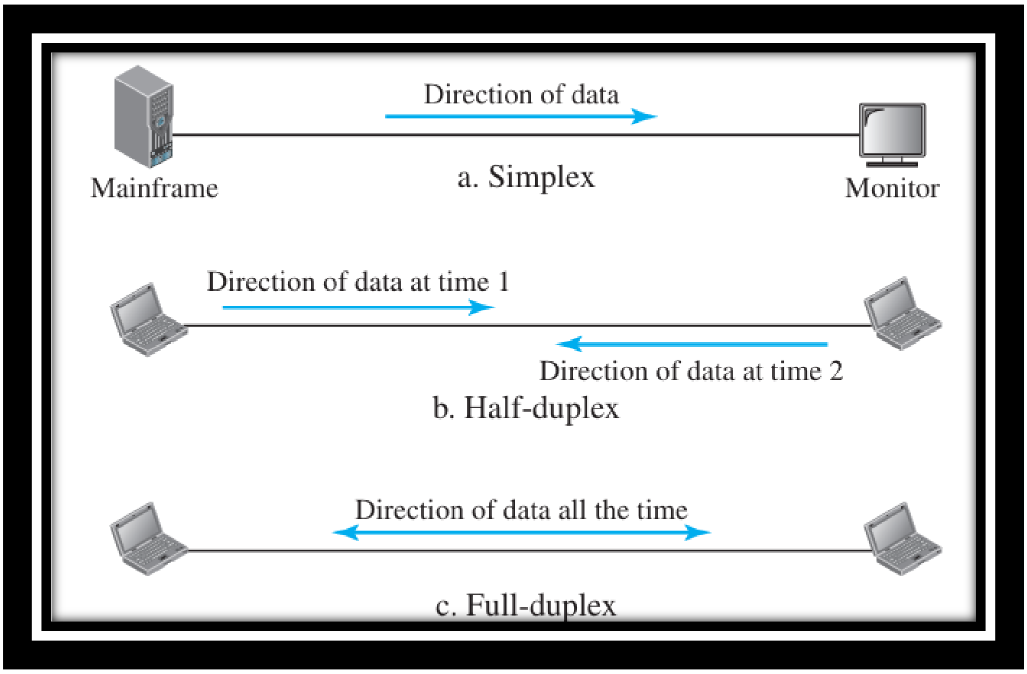
Audio refers to the recording or broadcasting of sound or music. Audio is by nature different from text, numbers, or images. It is continuous, not discrete. Even when we use a microphone to change voice or music to an electric signal, we create a continuous signal.

Video

Video refers to the recording or broadcasting of a picture or movie. Video can either be produced as a continuous entity (e.g., by a TV camera), or it can be a combination of images, each a discrete entity, arranged to convey the idea of motion.

Data Flow

Communication between two devices can be simplex, half-duplex, or full-duplex as shown in Figure:



Simplex

In simplex mode, the communication is unidirectional, as on a one-way street. Only one of the two devices on a link can transmit; the other can only receive (see Figure a). Keyboards and traditional monitors are examples of simplex devices. The key board can only introduce input; the monitor can only accept output. The simplex mode can use the entire capacity of the channel to send data in one direction.

Half-Duplex

In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa (see Figure b). The half-duplex mode is like a one-lane road with traffic allowed in both directions. When cars are traveling in one direction, cars going the other way must wait. In a half-duplex transmission, the entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time. Walkie-talkies and CB (citizens band) radios are both half-duplex systems. The half-duplex mode is used in cases where there is no need for communication in both directions at the same time; the entire capacity of the channel can be utilized for each direction.

Full-Duplex

In full-duplex mode (also called duplex), both stations can transmit and receive simultaneously (see Figure c). The full-duplex mode is like a two-way street with traffic flowing in both directions at the same time. In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction. This sharing can occur in two ways: Either the link must contain two physically separate transmission paths, one for sending and the other for receiving; or the capacity of the channel is divided between signals traveling in both directions. One common example of full-duplex communication is the telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time. The full-duplex mode is used when communication in both directions is required all the time. The capacity of the channel, however, must be divided between the two directions.

Computer Networks applications

Business Application

Most companies have a substantial number of computers. For example, a company may have a computer for each worker and use them to design products, write brochures, and do the payroll. Initially, some of these computers may have worked in isolation from the others, but at some point, management may have decided to connect them to be able to distribute information throughout the company. Put in slightly more general form, the issue here is resource sharing. The goal is to make all programs, equipment, and especially data available to anyone on the network without regard to the physical location of the resource or the user. An obvious and widespread example is having a group of office workers share a common printer. None of the individuals really needs a private printer, and a high-volume networked printer is often cheaper, faster, and easier to maintain than a large collection of individual printers. However, probably even more important than sharing physical resources such as printers, and tape backup systems, is sharing information. Companies small and large are vitally dependent on computerized information. Most companies have customer records, product information, inventories, financial statements, tax information, and much more online. If all of its computers suddenly went down, a bank could not last more than five minutes. A modern manufacturing plant, with a computer-controlled assembly line, would not last even 5 seconds. Even a small travel agency or three-person law firm is now highly dependent on computer networks for allowing employees to access relevant information and documents instantly. For smaller companies, all the computers are likely to be in a single office or perhaps a single building, but for larger ones, the computers and employees may be scattered over dozens of offices and plants in many countries. Nevertheless, a sales person in New York might sometimes need access to a product inventory database in Singapore. Networks called VPNs (Virtual Private Networks) may be used to join the individual networks at different sites into one extended network. In other words, the mere fact that a user happens to be 15,000 km away from his data should not prevent him from using the data as though they were local. This goal may be summarized by saying that it is an attempt to end the "tyranny of geography." In the simplest of terms, one can imagine a company's information system as consisting of one or more databases with company information and some number of employees who need to access them remotely. In this model, the data are stored on powerful computers called servers. Often these are centrally housed and maintained by a system administrator. In contrast, the employees have simpler machines, called clients, on their desks, with which they access remote data, for example, to include in spreadsheets they are constructing. (Sometimes we will refer to the human user of the client machine as the "client," but it should be clear from the context whether we mean the computer or its user.) The client and server machines are connected by a network, as illustrated in Fig. Note that we have shown the network as a simple oval, without any detail. We will use this form when we mean a network in the most abstract sense. When more detail is required, it will be provided.

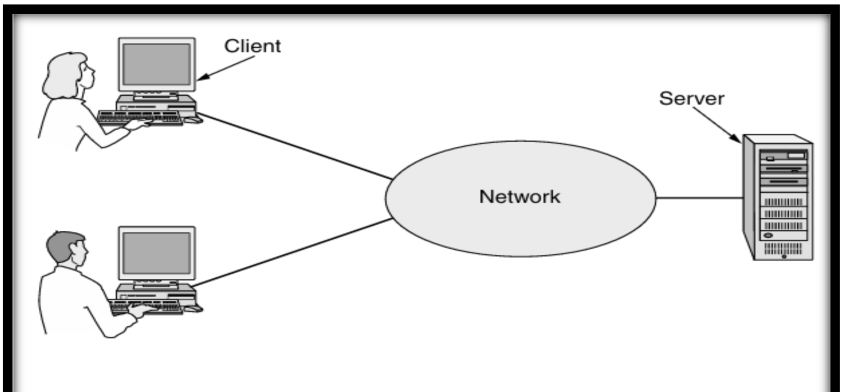


Figure 1-1. A network with two clients and one server.

This whole arrangement is called the client-server model. It is widely used and forms the basis of much network usage. The most popular realization is that of a Web application, in which the server generates Web pages based on its data base in response to client requests that may update the database. The client-server model is applicable when the client and server are both in the same building (and belong to the same company), but also when they are far apart. For example, when a person at home accesses a page on the World Wide Web, the same model is employed, with the remote Web server being the server and the user's personal computer being the client. Under most conditions, one server can handle a large number (hundreds or thousands) of clients simultaneously. If we look at the client-server model in detail, we see that two processes (i.e., running programs) are involved, one on the client machine and one on the server machine. Communication takes the form of the client process sending a message over the network to the server process. The client process then waits for a reply message. When the server process gets the request, it performs the requested work or looks up the requested data and sends back a reply. These messages are shown in Fig.

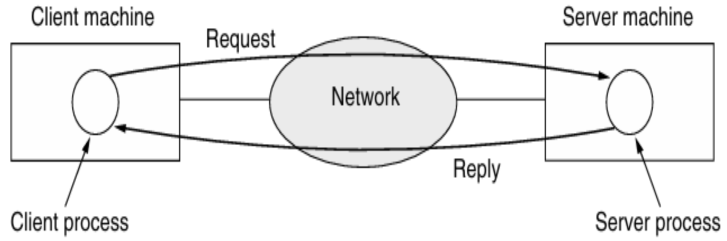


Figure 1-2. The client-server model involves requests and replies.

A second goal of setting up a computer network has to do with people rather than information or even computers. A computer network can provide a powerful communication medium among employees. Virtually every company that has two or more computers now has email (electronic mail), which employees generally use for a great deal of daily communication. In fact, a common gripe around the water cooler is how much email everyone has to deal with, much of it quite meaningless because bosses have discovered that they can send the same (often content-free) message to all their subordinates at the push of a button. Telephone calls between employees may be carried by the computer network instead of by the phone company. This technology is called IP telephony or Voice over IP (VoIP) when Internet technology is used. The microphone and speaker at each end may belong to a VoIP-enabled phone or the employee's computer. Companies find this a wonderful way to save on their telephone bills. Other, richer forms of communication are made possible by computer networks. Video can be added to audio so that employees at distant locations can see and hear each other as they hold a meeting. This technique is a powerful tool for eliminating the cost and time previously devoted to travel. Desktop sharing lets remote workers see and interact with a graphical computer screen. This makes it easy for two or more people who work far apart to read and write a shared black board or write a report together. When one worker makes a change to an online document, the others can see the change immediately, instead of waiting several days for a letter. Such a speedup makes cooperation among far-flung groups of people easy where it previously had been impossible. More ambitious forms of remote coordination such as telemedicine are only now starting to be used (e.g., remote patient monitoring) but may become much more important. It is sometimes said that communication and transportation are having a race, and which ever wins will make the other obsolete. A third goal for many companies is doing business electronically, especially with customers and suppliers. This new model is called e-commerce (electronic commerce) and it has grown rapidly in recent years. Airlines, bookstores, and other retailers have discovered that many customers like the convenience of shopping from home. Consequently, many companies provide catalogs of their goods and services online and take orders online. Manufacturers of automobiles, air craft, and computers, among others, buy subsystems from a variety of suppliers and then assemble the parts. Using computer networks, manufacturers can place orders electronically as needed. This reduces the need for large inventories and enhances efficiency.

Home Application

In 1977, Ken Olsen was president of the Digital Equipment Corporation, then the number two computer vendor in the world (after IBM). When asked why Digital was not going after the personal computer market in a big way, he said: "There is no reason for any individual to have a computer in his home." History showed otherwise and Digital no longer exists. People initially bought computers for word processing and games. Recently, the biggest reason to buy a home computer was probably for Internet access. Now, many consumers electronic devices, such as set-top boxes, game consoles, and clock radios, come with embedded computers and computer networks, especially wireless networks, and home networks are broadly used for entertainment, including listening to, looking at, and creating music, photos, and videos. Internet access provides home users with connectivity to remote computers. As with companies, home users can access information, communicate with other people, and buy products and services with e-commerce. The main benefit now comes from connecting outside of the home. Bob Metcalfe, the inventor of Ether net, hypothesized that the value of a network is proportional to the square of the number of users because this is roughly the number of different connections that may be made (Gilder, 1993). This hypothesis is known as "Metcalfe's law." It helps to explain how the tremendous popularity of the Internet comes from its size. Access to remote information comes in many forms. It can be surfing the World Wide Web for information or just for fun. Information available includes the arts, business, cooking, government, health, history, hobbies, recreation, science, sports, travel, and many others. Fun comes in too many ways to mention, plus some ways that are better left unmentioned. Many newspapers have gone online and can be personalized. For example, it is sometimes possible to tell a newspaper that you want everything about corrupt politicians, big fires, scandals involving celebrities, and epidemics, but no football, thank you. Sometimes it is possible to have the selected articles downloaded to your computer while you sleep. As this trend continues, it will cause massive unemployment among 12-year-old paperboys, but newspapers like it because distribution has always been the weakest link in the whole production chain. Of course, to make this model work, they will first have to figure out how to make money in this new world, something not entirely obvious since Internet users expect everything to be free. The next step beyond newspapers (plus magazines and scientific journals) is the online digital library. Many professional organizations, such as the ACM (www.acm.org) and the IEEE Computer Society (www.computer.org), already have all their journals and conference proceedings online. Electronic book readers and online libraries may make printed books obsolete. Skeptics should take note of the effect the printing press had on the medieval illuminated manuscript. Much of this information is accessed using the client-server model, but there is different, popular model for accessing information that goes by the name of peer-to-peer communication (Parameswaran et al., 2001). In this form, individuals who form a loose group can communicate with others in the group, as shown in Fig. Every person can, in principle, communicate with one or more other people; there is no fixed division into clients and servers.

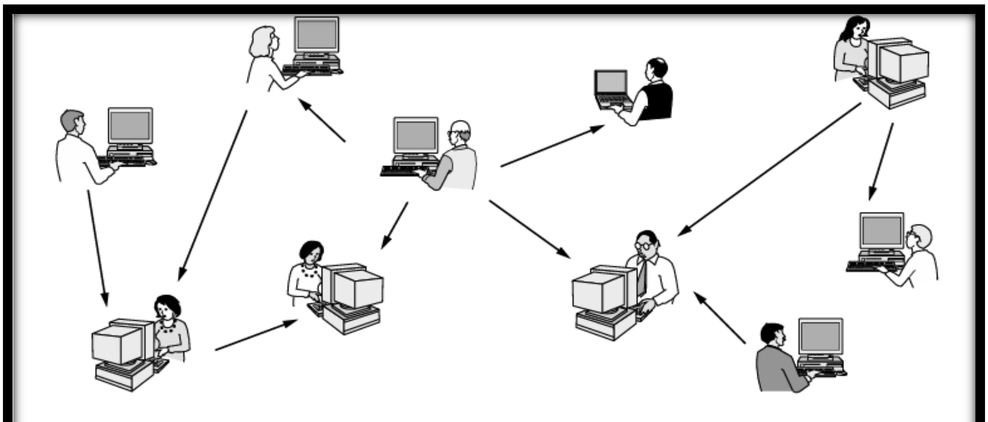


Figure 1-3. In a peer-to-peer system there are no fixed clients and servers.

Many peer-to-peer systems, such BitTorrent (Cohen, 2003), do not have any central database of content. Instead, each user maintains his own database locally and provides a list of other nearby people who are members of the system. A new user can then go to any existing member to see what he has and get the names of other members to inspect for more content and more names. This lookup process can be repeated indefinitely to build up a large local database of what is out there. It is an activity that would get tedious for people but computers excel at it. Peer-to-peer communication is often used to share music and videos. It really hit the big time around 2000 with a music sharing service called Napster that was shut down after what was probably the biggest copyright infringement case in all of recorded history (Lam and Tan, 2001; and Macedonia, 2000). Legal applications for peer-to-peer communication also exist. These include fans sharing public domain music, families sharing photos and movies, and users downloading public software packages. In fact, one of the most popular Internet applications of all, email, is inherently peer-to-peer. This form of communication is likely to grow considerably in the future. All of the above applications involve interactions between a person and a remote database full of information. The second broad category of network use is person-to-person communication, basically the 21st century's answer to the 19th century's telephone. E-mail is already used on a daily basis by millions of people all over the world and its use is growing rapidly. It already routinely contains audio and video as well as text and pictures. Smell may take a while. Any teenager worth his or her salt is addicted to instant messaging. This facility, derived from the UNIX talk program in use since around 1970, allows two people to type messages at each other in real time. There are multi-person messaging services too, such as the Twitter service that lets people send short text messages called "tweets" to their circle of friends or other willing audiences. The Internet can be used by applications to carry audio (e.g., Internet radio stations) and video (e.g., YouTube). Besides being a cheap way to call to distant friends, these applications can provide rich experiences such as telelearning, meaning attending 8 A.M. classes without the inconvenience of having to get out of bed first. In the long run, the use of networks to enhance human-to-human communication may prove more important than any of the others. It may become hugely important to people who are geographically challenged, giving them the same access to services as people living in the middle of a big city. Between person-to-person communications and accessing information are social network applications. Here, the flow of information is driven by the relationships that people declare between each other. One of the most popular social networking sites is Facebook. It lets people update their personal profiles and shares the updates with other people who they have declared to be their friends. Other social networking applications can make introductions via friends of friends, send news messages to friends such as Twitter above, and much more. Even more loosely, groups of people can work together to create content. A wiki, for example, is a collaborative Web site that the members of a community edit. The most famous wiki is the Wikipedia, an encyclopaedia anyone can edit, but there are thousands of other wikis. Our third category is electronic commerce in the broadest sense of the term. Home shopping is already popular and enables users to inspect the online catalogs of thousands of companies. Some of these catalogs are interactive, showing pro ducts from different viewpoints and in configurations that can be personalized. After the customer buys a product electronically but cannot figure out how to use it, online technical support may be consulted. Another area in which e-commerce is widely used is access to financial institutions. Many people already pay their bills, manage their bank accounts, and handle their investments electronically. This trend will surely continue as networks become more secure. One area that virtually nobody foresaw is electronic flea markets (e-flea?). Online auctions of second-hand goods have become a massive industry. Unlike traditional e-commerce, which follows the client-server model, online auctions are peer-to-peer in the sense that consumers can act as both buyers and sellers. Some of these forms of e-commerce have acquired cute little tags based on the fact that "to" and "2" are pronounced the same. The most popular ones are listed in Fig. 1-4.

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books online
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products online
P2P	Peer-to-peer	Music sharing

Figure 1-4. Some forms of e-commerce.

Our fourth category is entertainment. This has made huge strides in the home in recent years, with the distribution of music, radio and television programs, and movies over the Internet beginning to rival that of traditional mechanisms. Users can find, buy, and download MP3 songs and DVD-quality movies and add them to their personal collection. TV shows now reach many homes via IPTV (IP Television) systems that are based on IP technology instead of cable TV or radio transmissions. Media streaming applications let users tune into Internet radio stations or watch recent episodes of their favourite TV shows. Naturally, all of this content can be moved around your house between different devices, displays and speakers, usually with a wireless network. Soon, it may be possible to search for any movie or television program ever made, in any country, and have it displayed on your screen instantly. New films may become interactive, where the user is occasionally prompted for the story direction (should Macbeth murder Duncan or just bide his time?) with alternative scenarios provided for all cases. Live television may also become interactive, with the audience participating in quiz shows, choosing among contestants, and so on. Another form of entertainment is game playing. Already we have multiperson real-time simulation games, like hide-and-seek in a virtual dungeon, and flight simulators with the players on one team trying to shoot down the players on the opposing team. Virtual worlds provide a persistent setting in which thousands of users can experience a shared reality with three-dimensional graphics. Our last category is ubiquitous computing, in which computing is embedded into everyday life, as in the vision of Mark Weiser (1991). Many homes are already wired with security systems that include door and window sensors, and there are many more sensors that can be folded in to a smart home monitor, such as energy consumption. Your electricity, gas and water meters could also report usage over the network. This would save money as there would be no need to send out meter readers. And your smoke detectors could call the fire department instead of making a big noise (which has little value if no one is home). As the cost of sensing and communication drops, more and more measurement and re porting will be done with networks. Increasingly, consumer electronic devices are networked. For example, some high-end cameras already have a wireless network capability and use it to send photos to a nearby display for viewing. Professional sports photographers can also send their photos to their editors in real-time, first wirelessly to an access point then over the Internet. Devices such as televisions that plug into the wall can use power-line networks to send information throughout the house over the wires that carry electricity. It may not be very surprising to have these objects on the network, but objects that we do not think of as computers may sense and communicate information too. For example, your shower may record water usage, give you visual feedback while you lather up, and report to a home environmental monitoring application when you are done to help save on your water bill. A technology called RFID (Radio Frequency IDentification) will push this idea even further in the future. RFID tags are passive (i.e., have no battery) chips the size of stamps and they can already be affixed to books, passports, pets, credit cards, and other items in the home and out. This lets RFID readers locate and communicate with the items over a distance of up to several meters, depending on the kind of RFID. Originally, RFID was commercialized to replace barcodes. It has not succeeded yet because barcodes are free and RFID tags cost a few cents. Of course, RFID tags offer much more and their price is rapidly declining. They may turn the real world into the Internet of things (ITU, 2005). 1.1.3 Mobile Users Mobile computers, such as laptop and handheld computers, are one of the fastest-growing segments of the computer industry. Their sales have already overtaken those of desktop computers. Why would anyone want one? People on the go often want to use their mobile devices to read and send email, tweet, watch movies, download music, play games, or simply to surf the Web for information. They want to do all of the things they do at home and in the office. Naturally, they want to do them from anywhere on land, sea or in the air. Connectivity to the Internet enables many of these mobile uses. Since having a wired connection is impossible in cars, boats, and airplanes, there is a lot of interest in wireless networks. Cellular networks operated by the telephone companies are one familiar kind of wireless network that blankets us with coverage for mobile phones. Wireless hotspots based on the 802.11 standard are another kind of wireless network for mobile computers. They have sprung up everywhere that people go, resulting in a patchwork of coverage at cafes, hotels, airports, schools, trains and planes. Anyone with a laptop computer and a wireless modem can just turn on their computer on and be connected to the Internet through the hotspot, as though the computer were plugged into a wired network. Wireless networks are of great value to fleets of trucks, taxis, delivery vehicles, and repairpersons for keeping in contact with their home base. For example, in many cities, taxi drivers are independent businessmen, rather than being employees of a taxi company. In some of these cities, the taxis have a display the driver can see. When a customer calls up, a central dispatcher types in the pickup and destination points. This information is displayed on the drivers' displays and a beep sounds. The first driver to hit a button on the display gets the call. Wireless networks are also important to the military. If you have to be able to fight a war anywhere on Earth at short notice, counting on using the local networking infrastructure is probably not a good idea. It is better to bring your own. Although wireless networking and mobile computing are often related, they are not identical, as Fig. 1-5 shows. Here we see a distinction between fixed wireless and mobile wireless networks. Even notebook computers are sometimes wired. For example, if a traveller plugs a notebook computer into the wired network jack in a hotel room, he has mobility without a wireless network.

Wireless	Mobile	Typical applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in unwired buildings
Yes	Yes	Store inventory with a handheld computer

Figure 1-5. Combinations of wireless networks and mobile computing.

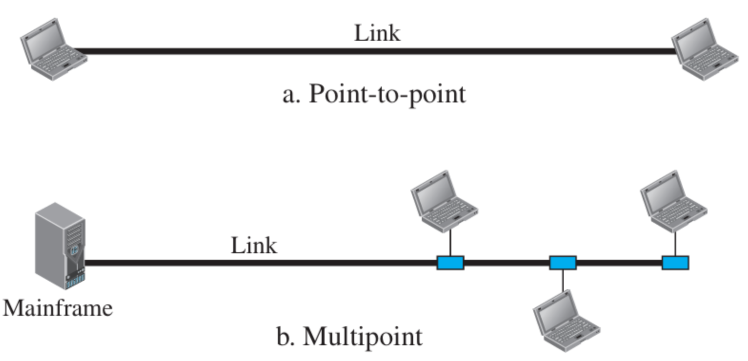
Conversely, some wireless computers are not mobile. In the home, and in offices or hotels that lack suitable cabling, it can be more convenient to connect desktop computers or media players wirelessly than to install wires. Installing a wireless network may require little more than buying a small box with some electronics in it, unpacking it, and plugging it in. This solution may be far cheaper than having workmen put in cable ducts to wire the building. Finally, there are also true mobile, wireless applications, such as people walking around stores with a handheld computer recording inventory. At many busy airports, car rental return clerks work in the parking lot with wireless mobile computers. They scan the barcodes or RFID chips of returning cars, and their mobile device, which has a built-in printer, calls the main computer, gets the rental information, and prints out the bill on the spot. Perhaps the key driver of mobile, wireless applications is the mobile phone. Text messaging or texting is tremendously popular. It lets a mobile phone user type a short message that is then delivered by the cellular network to another mobile subscriber. Few people would have predicted ten years ago that having teenagers tediously typing short text messages on mobile phones would be an immense money maker for telephone companies. But texting (or Short Message Service as it is known outside the U.S.) is very profitable since it costs the carrier but a tiny fraction of one cent to relay a text message, a service for which they charge far more. The long-awaited convergence of telephones and the Internet has finally arrived, and it will accelerate the growth of mobile applications. Smart phones, such as the popular iPhone, combine aspects of mobile phones and mobile computers. The (3G and 4G) cellular networks to which they connect can provide fast data services for using the Internet as well as handling phone calls. Many advanced phones connect to wireless hotspots too, and automatically switch between networks to choose the best option for the user. Other consumer electronics devices can also use cellular and hotspot networks to stay connected to remote computers. Electronic book readers can download a newly purchased book or the next edition of a magazine or today’s newspaper wherever they roam. Electronic picture frames can update their displays on cue with fresh images. Since mobile phones know their locations, often because they are equipped with GPS (Global Positioning System) receivers, some services are intentionally location dependent. Mobile maps and directions are an obvious candidate as your GPS-enabled phone and car probably have a better idea of where you are than you do. So, too, are searches for a nearby bookstore or Chinese restaurant, or a local weather forecast. Other services may record location, such as annotating photos and videos with the place at which they were made. This annotation is known as ‘‘geo-tagging.’’ An area in which mobile phones are now starting to be used is m-commerce (mobile-commerce) (Senn, 2000). Short text messages from the mobile are used to authorize payments for food in vending machines, movie tickets, and other small items instead of cash and credit cards. The charge then appears on the mobile phone bill. When equipped with NFC (Near Field Communication) technology the mobile can act as an RFID smartcard and interact with a nearby reader for payment. The driving forces behind this phenomenon are the mobile device makers and network operators, who are trying hard to figure out how to get a piece of the e-commerce pie. From the store’s point of view, this scheme may save them most of the credit card company’s fee, which can be several percent. Of course, this plan may backfire, since customers in a store might use the RFID or barcode readers on their mobile devices to check out competitors’ prices before buying and use them to get a detailed report on where else an item can be purchased nearby and at what price. One huge thing that m-commerce has going for it is that mobile phone users are accustomed to paying for everything (in contrast to Internet users, who expect everything to be free). If an Internet Web site charged a fee to allow its customers to pay by credit card, there would be an immense howling noise from the users. If, however, a mobile phone operator its customers to pay for items in a store by waving the phone at the cash register and then tacked on a fee for this convenience, it would probably be accepted as normal. Time will tell. No doubt the uses of mobile and wireless computers will grow rapidly in the future as the size of computers shrinks, probably in ways no one can now foresee. Let us take a quick look at some possibilities. Sensor networks are made up of nodes that gather and wirelessly relay information they sense about the state of the physical world. The nodes may be part of familiar items such as cars or phones, or they may be small separate devices. For example, your car might gather data on its location, speed, vibration, and fuel efficiency from its on-board diagnostic system and upload this information to a database (Hull et al., 2006). Those data can help find potholes, plan trips around congested roads, and tell you if you are a ‘‘gas guzzler’’ compared to other drivers on the same stretch of road. Sensor networks are revolutionizing science by providing a wealth of data on behaviour that could not previously be observed. One example is tracking the migration of individual zebras by placing a small sensor on each animal (Juang et al., 2002). Researchers have packed a wireless computer into a cube 1 mm on edge (Warneke et al., 2001). With mobile computers this small, even small birds, rodents, and insects can be tracked. Even mundane uses, such as in parking meters, can be significant because they make use of data that were not previously available. Wireless parking meters can accept credit or debit card payments with instant verification over the wireless link. They can also report when they are in use over the wireless network. This would let drivers download a recent parking map to their car so they can find an available spot more easily. Of course, when a meter expires, it might also check for the presence of a car (by bouncing a signal off it) and report the expiration to parking enforcement. It has been estimated that city governments in the U.S. alone could collect an additional $10 billion this way (Harte et al., 2000). Wearable computers are another promising application. Smart watches with radios have been part of our mental space since their appearance in the Dick Tracy comic strip in 1946; now you can buy them. Other such devices may be implanted, such as pacemakers and insulin pumps. Some of these can be controlled over a wireless network. This lets doctors test and reconfigure them more easily. It could also lead to some nasty problems if the devices are as insecure as the average PC and can be hacked easily (Halperin et al., 2008).

Point-To-Point Networks

A network is two or more devices connected through links. A link is a communications pathway that transfers data from one device to another. For visualization purposes, it is simplest to imagine any link as a line drawn between two points. For communication to occur, two devices must be connected in some way to the same link at the same time. There are two possible types of connections: point-to-point and multipoint.

Point-to-Point A point-to-point connection provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices. Most point-to-point connections use an actual length of wire or cable to connect the two ends, but other options, such as microwave or satellite links, are also possible (see Figure 1.3 a). When we change television channels by infrared remote control, we are establishing a point-to-point connection between the remote control and the television's control system. Multipoint A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link (see Figure 1.3 b).

Figure 1.3 *Types of connections: point-to-point and multipoint*



In a multipoint environment, the capacity of the channel is shared, either spatially or temporally. If several devices can use the link simultaneously, it is a spatially shared connection. If users must take turns, it is a timeshared connection.

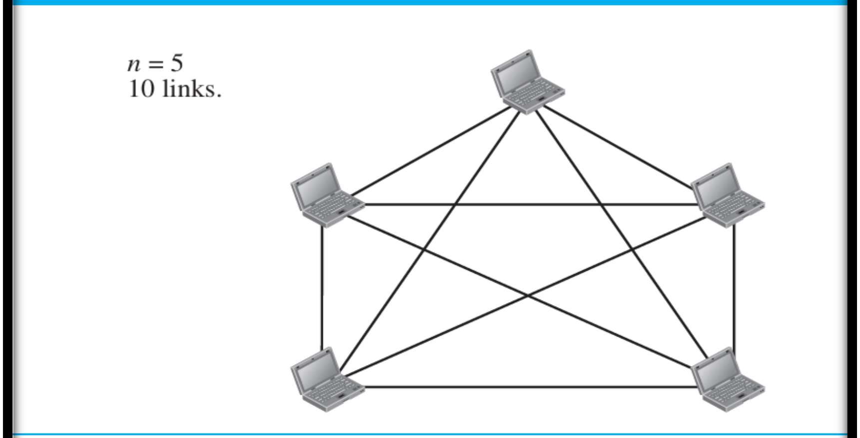
Physical/Network Topology

The term physical topology refers to the way in which a network is laid out physically. Two or more devices connect to a link; two or more links form a topology. The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called nodes) to one another. There are four basic topologies possible: mesh, star, bus, and ring.

Mesh Topology

In a mesh topology, every device has a dedicated point-to-point link to every other device. The term dedicated means that the link carries traffic only between the two devices it connects. To find the number of physical links in a fully connected mesh network with n nodes, we first consider that each node must be connected to every other node. Node 1 must be connected to n – 1 nodes, node 2 must be connected to n – 1 nodes, and finally node n must be connected to n – 1 nodes. We need n (n – 1) physical links. However, if each physical link allows communication in both directions (duplex mode), we can divide the number of links by 2. In other words, we can say that in a mesh topology, we need n (n – 1) / 2 duplex-mode links. To accommodate that many links, every device on the network must have n – 1 input/output (I/O) ports (see Figure 1.4) to be connected to the other n – 1 stations. A mesh offers several advantages over other network topologies. First, the use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices. Second, a mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system. Third, there is the advantage of privacy or security. When every message travels along a dedicated line, only the intended recipient sees it. Physical boundaries prevent other users from gaining access to messages. Finally, point-to-point links make fault identification and fault isolation easy. Traffic can be routed to avoid links with suspected problems. This facility enables the network manager to discover the precise location of the fault and aids in finding its cause and solution.

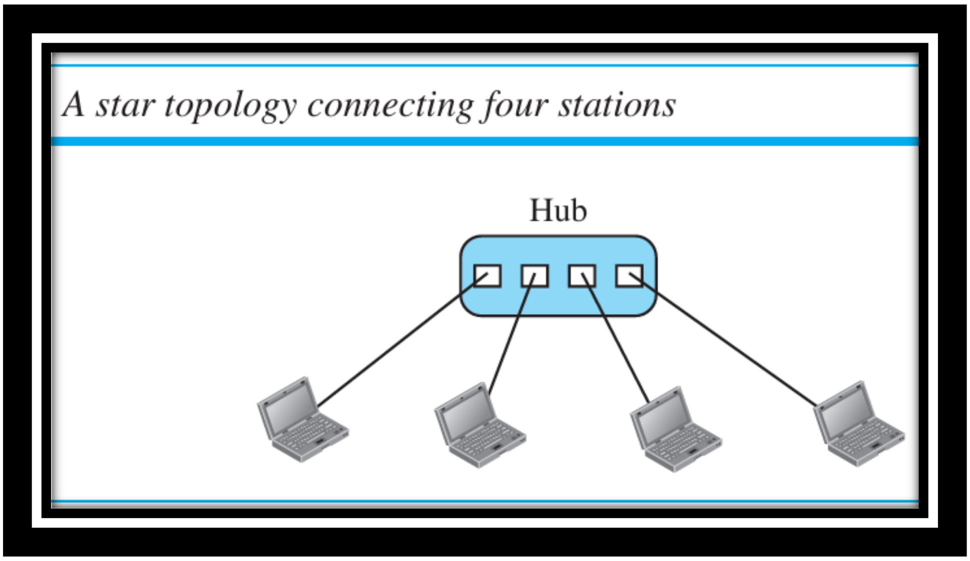
A fully connected mesh topology (five devices)



The main disadvantages of a mesh are related to the amount of cabling and the number of I/O ports required. First, because every device must be connected to every other device, installation and reconnection are difficult. Second, the sheer bulk of the wiring can be greater than the available space (in walls, ceilings, or floors) can accommodate. Finally, the hardware required to connect each link (I/O ports and cable) can be prohibitively expensive. For these reasons a mesh topology is usually implemented in a limited fashion, for example, as a backbone connecting the main computers of a hybrid network that can include several other topologies. One practical example of a mesh topology is the connection of telephone regional offices in which each regional office needs to be connected to every other regional office.

Star Topology

In a star topology, each device has a dedicated point-to-point link only to a central controller, usually called a hub. The devices are not directly linked to one another. Unlike a mesh topology, a star topology does not allow direct traffic between devices. The controller acts as an exchange. If one device wants to send data to another, it sends the data to the controller, which then relays the data to the other connected device (see Figure)

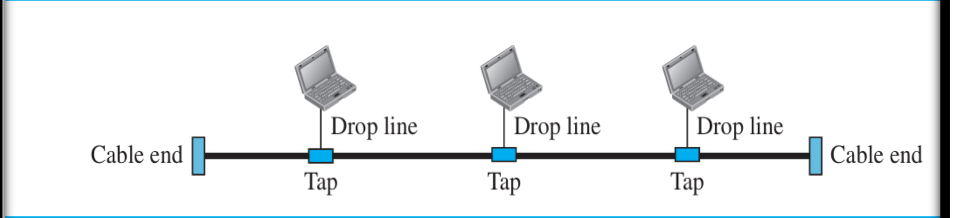


A star topology is less expensive than a mesh topology. In a star, each device needs only one link and one I/O port to connect it to any number of others. This factor also makes it easy to install and reconfigure. Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub. Other advantages include robustness. If one link fails, only that link is affected. All other links remain active. This factor also lends itself to easy fault identification and fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links. One big disadvantage of a star topology is the dependency of the whole topology on one single point, the hub. If the hub goes down, the whole system is dead. Although a star requires far less cable than a mesh, each node must be linked to a central hub. For this reason, often more cabling is required in a star than in some other topologies (such as ring or bus). The star topology is used in local-area networks (LANs). High-speed LANs often use a star topology with a central hub.

Bus Topology

The preceding examples all describe point-to-point connections. A bus topology, on the other hand, is multipoint. One long cable act as a backbone to link all the devices in a network (see Figure 1.6).

Figure 1.6 *A bus topology connecting three stations*

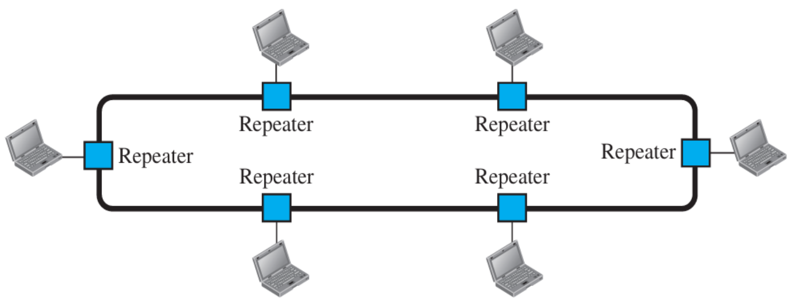


Nodes are connected to the bus cable by drop lines and taps. A drop line is a connection running between the device and the main cable. A tap is a connector that either splices into the main cable or punctures the sheathing of a cable to create a contact with the metallic core. As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker and weaker as it travels farther and farther. For this reason, there is a limit on the number of taps a bus can support and on the distance between those taps. Advantages of a bus topology include ease of installation. Backbone cable can be laid along the most efficient path, then connected to the nodes by drop lines of various lengths. In this way, a bus uses less cabling than mesh or star topologies. In a star, for example, four network devices in the same room require four lengths of cable reaching all the way to the hub. In a bus, this redundancy is eliminated. Only the backbone cable stretches through the entire facility. Each drop line has to reach only as far as the nearest point on the backbone. Disadvantages include difficult reconnection and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number and spacing of devices connected to a given length of cable. Adding new devices may therefore require modification or replacement of the backbone. In addition, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem. The damaged area reflects signals back in the direction of origin, creating noise in both directions. Bus topology was the one of the first topologies used in the design of early local area networks. Traditional Ethernet LANs can use a bus topology, but they are less popular now.

Ring Topology

In a ring topology, each device has a dedicated point-to-point connection with only the two devices on either side of it. A signal is passed along the ring in one direction, from device to device, until it reaches its destination. Each device in the ring incorporates a repeater. When a device receives a signal intended for another device, its repeater regenerates the bits and passes them along (see Figure 1.7).

Figure 1.7 A ring topology connecting six stations



A ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbours (either physically or logically). To add or delete a device requires changing only two connections. The only constraints are media and traffic considerations (maximum ring length and number of devices). In addition, fault isolation is simplified. Generally, in a ring a signal is circulating at all times. If one device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location. However, unidirectional traffic can be a disadvantage. In a simple ring, a break in the ring (such as a disabled station) can disable the entire network. This weakness can be solved by using a dual ring or a switch capable of closing off the break. Ring topology was prevalent when IBM introduced its local-area network, Token Ring. Today, the need for higher-speed LANs has made this topology less popular.

Network Types

Local Area Network

A local area network (LAN) is usually privately owned and connects some hosts in a single office, building, or campus. Depending on the needs of an organization, a LAN can be as simple as two PCs and a printer in someone's home office, or it can extend throughout a company and include audio and video devices. Each host in a LAN has an identifier, an address, that uniquely defines the host in the LAN. A packet sent by a host to another host carries both the source host's and the destination host's addresses. In the past, all hosts in a network were connected through a common cable, which meant that a packet sent from one host to another was received by all hosts. The intended recipient kept the packet; the others dropped the packet. Today, most LANs use a smart connecting switch, which is able to recognize the destination address of the packet and guide the packet to its destination without sending it to all other hosts. The switch alleviates the traffic in the LAN and allows more than one pair to communicate with each other at the same time if there is no common source and destination among them. Note that the above definition of a LAN does not define the minimum or maximum number of hosts in a LAN. Figure 1.8 shows a LAN using either a common cable or a switch.

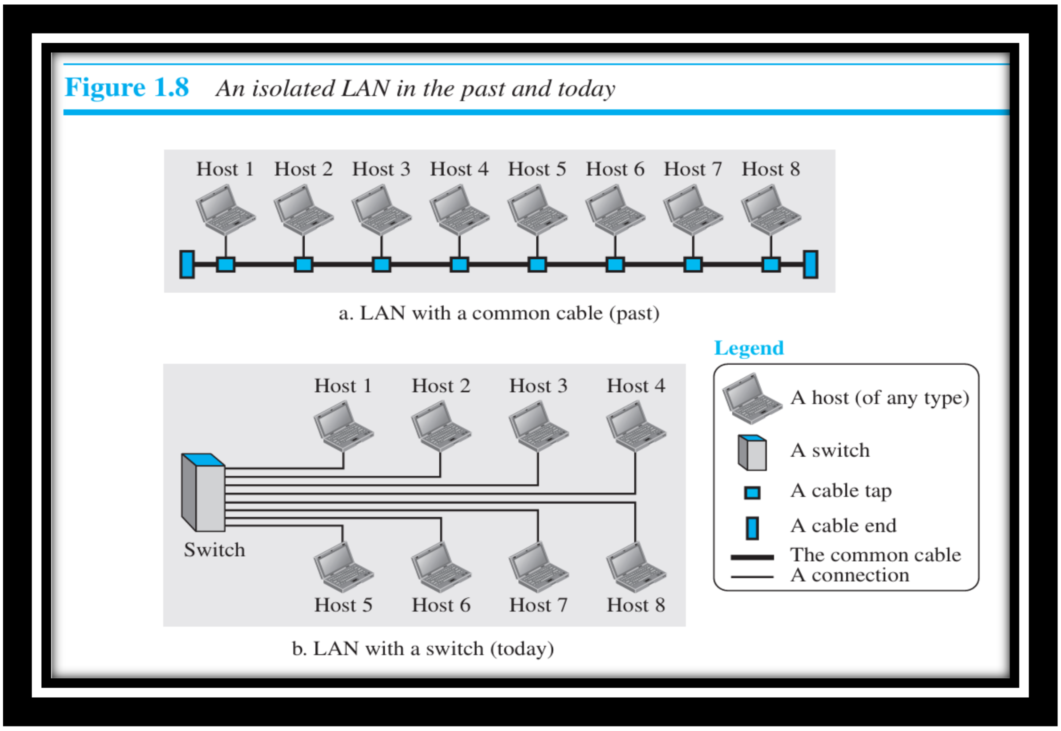
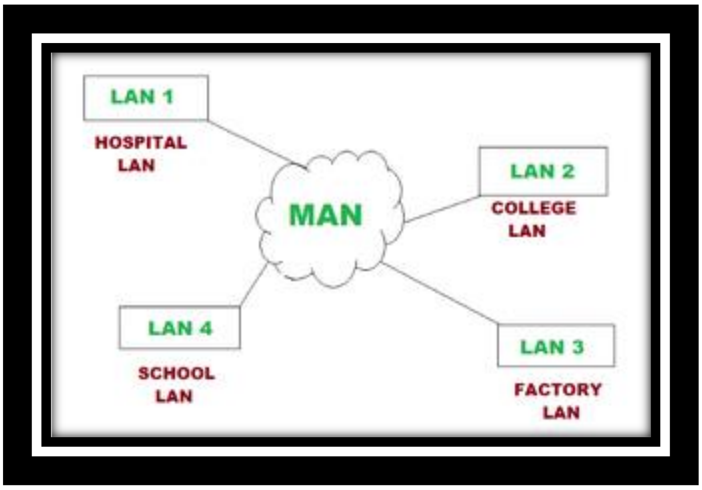


Figure 1.8 *An isolated LAN in the past and today*

When LANs were used in isolation (which is rare today), they were designed to allow resources to be shared between the hosts. As we will see shortly, LANs today are connected to each other and to WANs (discussed next) to create communication at a wider level.

Metropolitan Area Network (MAN) –

MAN, or Metropolitan Area Network covers a larger area than that covered by a LAN and a smaller area as compared to WAN. MAN has a range of 5-50km. It connects two or more computers that are apart but reside in the same or different cities. It covers a large geographical area and may serve as an ISP (Internet Service Provider). MAN is designed for customers who need high-speed connectivity. Speeds of MAN range in terms of Mbps. It's hard to design and maintain a Metropolitan Area Network.



The fault tolerance of a MAN is less and also there is more congestion in the network. It is costly and may or may not be owned by a single organization. The data transfer rate and the propagation delay of MAN are moderate. Devices used for transmission of data through

MAN are Modem and Wire/Cable. Examples of a MAN are part of the telephone company network that can provide a high-speed DSL line to the customer or the cable TV network in a city.

Advantages:

- Provides high-speed connectivity over a larger geographical area than LAN.
- Can be used as an ISP for multiple customers.
- Offers higher data transfer rates than WAN in some cases.

Disadvantages:

- Can be expensive to set up and maintain.
- May experience congestion and network performance issues with increased usage.
- May have limited fault tolerance and security compared to LANs.

Wide Area Network

A wide area network (WAN) is also an interconnection of devices capable of communication. However, there are some differences between a LAN and a WAN. A LAN is normally limited in size, spanning an office, a building, or a campus; a WAN has a wider geographical span, spanning a town, a state, a country, or even the world. A LAN interconnects hosts; a WAN interconnects connecting devices such as switches, routers, or modems. A LAN is normally privately owned by the organization that uses it; a WAN is normally created and run by communication companies and leased by an organization that uses it. We see two distinct examples of WANs today: point-to-point WANs and switched WANs.

Point-to-Point WAN

A point-to-point WAN is a network that connects two communicating devices through a transmission media (cable or air). We will see examples of these WANs when we discuss how to connect the networks to one another. Figure 1.9 shows an example of a point-to-point WAN.

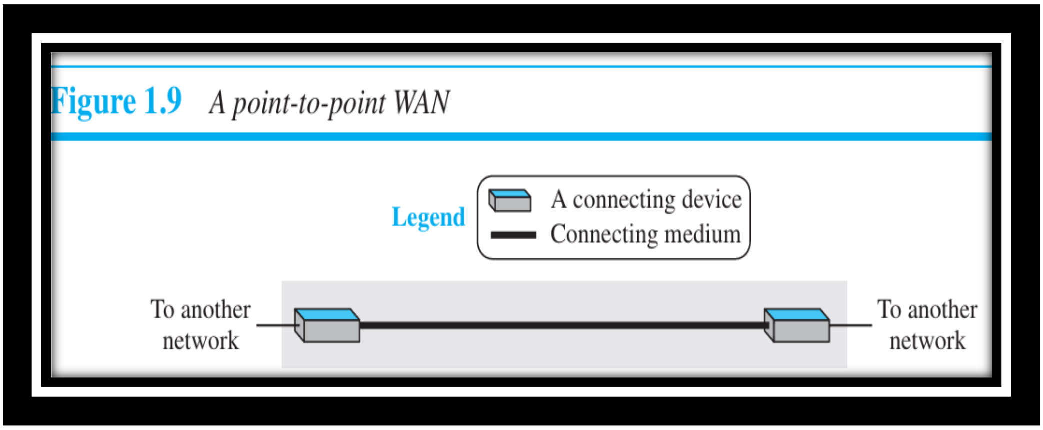
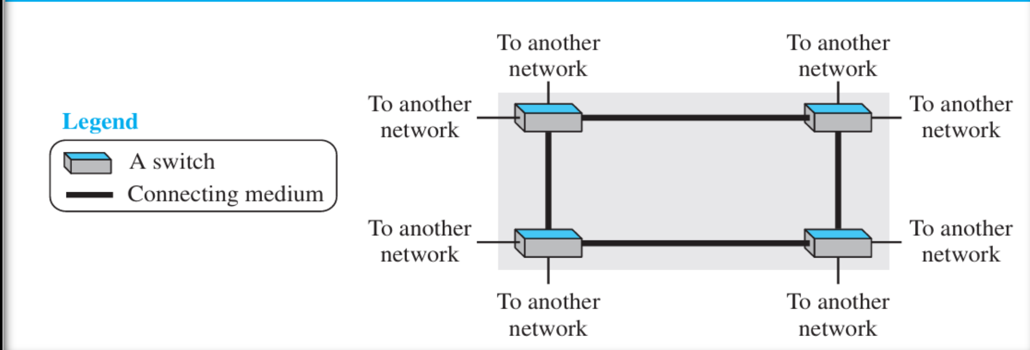


Figure 1.9 *A point-to-point WAN*

Switched WAN

A switched WAN is a network with more than two ends. A switched WAN, as we will see shortly, is used in the backbone of global communication today. We can say that a switched WAN is a combination of several point-to-point WANs that are connected by switches. Figure 1.10 shows an example of a switched WAN.

Figure 1.10 *A switched WAN*



Internetworks

Many networks exist in the world, often with different hardware and software. People connected to one network often want to communicate with people attached to a different one. The fulfilment of this desire requires that different, and frequently incompatible, networks be connected. A collection of interconnected networks is called an internetwork or internet. These terms will be used in a generic sense, in contrast to the worldwide Internet (which is one specific internet), which we will always capitalize. The Internet uses ISP networks to connect enterprise networks, home networks, and many other networks. We will look at the Internet in great detail later in this book. Subnets, networks, and internetworks are often confused. The term "subnet" makes the most sense in the context of a wide area network, where it refers to the collection of routers and communication lines owned by the network operator. As an analogy, the telephone system consists of telephone switching offices connected to one another by high-speed lines, and to houses and businesses by low-speed lines. These lines and equipment, owned and managed by the telephone company, form the subnet of the telephone system. The telephones themselves (the hosts in this analogy) are not part of the subnet. A network is formed by the combination of a subnet and its hosts. However, the word "network" is often used in a loose sense as well. A subnet might be described as a network, as in the case of the "ISP network". An internetwork might also be described as a network, as in the case of the WAN in Fig. 1-10. We will follow similar practice, and if we are distinguishing a network from other arrangements, we will stick with our original definition of a collection of computers interconnected by a single technology. Let us say more about what constitutes an internetwork. We know that an internet is formed when distinct networks are interconnected. In our view, connecting a LAN and a WAN or connecting two LANs is the usual way to form an inter network, but there is little agreement in the industry over terminology in this area. There are two rules of thumb that are useful.

First, if different organizations have paid to construct different parts of the network and each maintains its part, we have an internetwork rather than a single network. Second, if the underlying technology is different in different parts (e.g., broadcast versus point-to-point and wired versus wireless), we probably have an internetwork. To go deeper, we need to talk about how two different networks can be connected. The general name for a machine that makes a connection between two or more networks and provides the necessary translation, both in terms of hardware and software, is a gateway. Gateways are distinguished by the layer at which they operate in the protocol hierarchy. We will have much more to say about layers and protocol hierarchies starting in the next section, but for now imagine that higher layers are more tied to applications, such as the Web, and lower layers are more tied to transmission links, such as Ethernet.

Since the benefit of forming an internet is to connect computers across networks, we do not want to use too low-level a gateway or we will be unable to make connections between different kinds of networks. We do not want to use too high-level a gateway either, or the connection will only work for particular applications. The level in the middle that is ‘‘just right’’ is often called the network layer, and a router is a gateway that switches packets at the network layer. We can now spot an internet by finding a network that has routers.

Protocols and standards

Definition of a Protocol

In computer networks and communications, a **protocol** is a set of rules or standards that define how data is transmitted and received between devices in a network.

Functionality Includes:

- Data formatting and encoding
- Message transmission rules
- Error detection and correction
- Flow control and synchronization

Examples:

- **HTTP (Hyper Text Transfer Protocol):** Used for web communication.
- **TCP/IP (Transmission Control Protocol/Internet Protocol):** Foundation of internet communication.
- **FTP (File Transfer Protocol):** Used for transferring files.

Protocol Standards: De facto and De jure

In networking and technology, **protocol standards** ensure interoperability between different systems and devices. These standards can be categorized as **De facto** or **De jure**.

◈ De facto Standard

- **Meaning:** "In fact" or "by practice"
- **Definition:** A protocol or technology that becomes a standard through **widespread use and acceptance**, even if it is **not officially approved** by a standards organization.
- **Adoption:** Emerges from **market dominance** or community use.
- **Example:**
  - **TCP/IP** – Initially adopted as a de facto standard before formal standardization.
  - **Microsoft Office file formats** – Widely used before formal standardization.

◈ De jure Standard

- **Meaning:** "By law"
- **Definition:** A protocol that is **officially recognized and approved** by a formal **standards organization**.
- **Adoption:** Established through **regulatory or official bodies** like ISO, IEEE, ITU, etc.
- **Example:**
  - **OSI Model (by ISO)**
  - **JPEG (Image format standard by ISO/IEC)**

☑ Comparison Table

Feature	De facto Standard	De jure Standard
Based on	Common usage / Market acceptance	Official approval by standards bodies
Formal approval	No	Yes
Speed of adoption	Faster	Slower (due to review processes)
Stability	May vary	More stable and reliable

- **De facto** standards are accepted through usage.
- **De jure** standards are enforced through formal ratification.
  Both play important roles in shaping how technologies develop and interoperate.

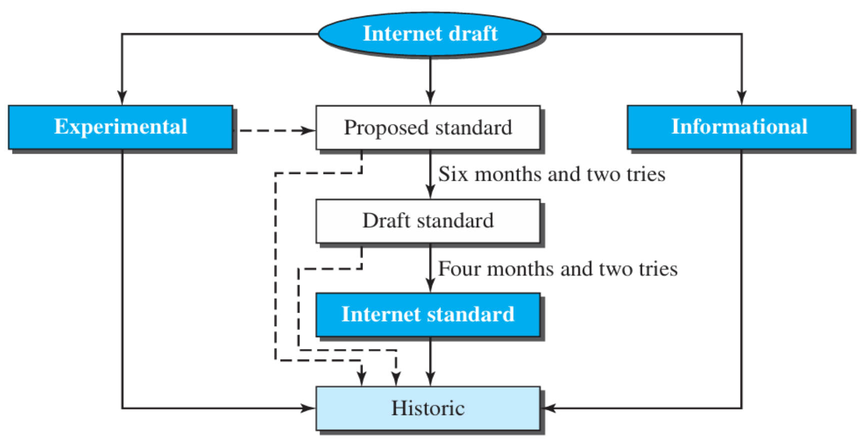
RFC

An Internet standard is a thoroughly tested specification that is useful to and adhered to by those who work with the Internet. It is a formalized regulation that must be followed. There is a strict procedure by which a specification attains Internet standard status. A specification begins as an Internet draft. An Internet draft is a working document (a work in progress) with no official status and a six-month lifetime. Upon recommendation from the Internet authorities, a draft may be published as a Request for Comment (RFC). Each RFC is edited, assigned a number, and made available to all interested parties. RFCs go through maturity levels and are categorized according to their requirement level.

Maturity Levels An RFC, during its lifetime, falls into one of six maturity levels: proposed standard, draft standard, Internet standard, historic, experimental, and informational (see Figure 1.16).

❑ **Proposed Standard-** A proposed standard is a specification that is stable, well understood, and of sufficient interest to the Internet community. At this level, the specification is usually tested and implemented by several different groups.

Figure 1.16 *Maturity levels of an RFC*



❑ **Draft Standard-** A proposed standard is elevated to draft standard status after at least two successful independent and interoperable implementations. Barring difficulties, a draft standard, with modifications if specific problems are encountered, normally becomes an Internet standard.

❑ **Internet Standard-** A draft standard reaches Internet standard status after demonstrations of successful implementation.

❑ **Historic-** The historic RFCs are significant from a historical perspective. They either have been superseded by later specifications or have never passed the necessary maturity levels to become an Internet standard.

❑ **Experimental-** An RFC classified as experimental describes work related to an experimental situation that does not affect the operation of the Internet. Such an RFC should not be implemented in any functional Internet service.

❑ **Informational-** An RFC classified as informational contains general, historical, or tutorial information related to the Internet. It is usually written by someone in a non-Internet organization, such as a vendor.

Requirement Levels

RFCs are classified into five requirement levels: required, recommended, elective, limited use, and not recommended.

❑ **Required-** An RFC is labelled required if it must be implemented by all Internet systems to achieve minimum conformance. For example, IP and ICMP are required protocols.

❑ **Recommended-** An RFC labelled recommended is not required for minimum conformance; it is recommended because of its usefulness. For example, FTP and TELNET are recommended protocols.

❑ **Elective-** An RFC labelled elective is not required and not recommended. However, a system can use it for its own benefit.

❑ **Limited Use-** An RFC labelled limited use should be used only in limited situations. Most of the experimental RFCs fall under this category.

❑ **Not Recommended-** An RFC labelled not recommended is inappropriate for general use. Normally a historic (deprecated) RFC may fall under this category.