VI

Data Communications and Networking

This introduction explains the basics of data communications and networking. Our ever-increasing ability to transmit data stems from (1) insights into the characteristics of electrical energy (which we express as concepts) and (2) techniques that exploit these characteristics. Each concept is presented as a brief sentence that names and describes it. To help the reader build a mental picture, the concepts are grouped logically.

Readers who master this terminology (thus building the mental picture) and its associated techniques should understand enough not only to be able to use simple data communications equipment (a personal computer loaded with a standard communications software program, for example), but also to solve simple problems, to see new ways to employ data communications, and to carry on informed discussions with data communications experts.

Data communications and networks have existed for over a century and are continually evolving or being replaced. The telegraph, the first electronic communications device, transmitted data using discrete signals in two states; a dot and a dash. Telephones came later and became more widely used because they transmitted the human voice as a continuous range of signals between two limits. (That is, the telephone used continuous or analog signals.) Now computers with their two-state, discrete signals (one and zero) have become widespread, but the only communications system that can serve most of them (the telephone system) still uses some analog signals. The answer has been the modem, which converts analog to digital (two-state) signals and digital to analog. The telephone companies have found digital communications so efficient that they have replaced their analog circuits between their local exchanges with digital circuits leaving analog telephone signals in use only between individual telephones and local signals.

Thus, while analog signals (and modems) are widely used in data communications, digital circuits are being introduced wherever it is economically feasible to do so. Readers who grew up with and now use modems and analog telephone circuits should be aware that they may not need them in a few years. It is, therefore, not enough to know how to use today's data communications and software: you will need to understand the theory on which tomorrow's software and hardware will be built.

BASIC TERMINOLOGY

This section, the first step in presenting the mental picture of data telecommunications and networking, lists the most basic concepts. Terms in **boldface** are the basic vocabulary we are trying to convey.

Telecommunications is passing information over distance. **Data communications** is passing information coded for machine use. Data are represented by binary **values** (1 or 0). Binary values work well for numbers. To represent other things (letters, sounds, and graphics, for example) codes are used. ASCII is the most widely known code. Each binary value is called a **bit.** Bits are strung together to form binary numbers. To form ASCII code, eight bits are grouped together to form a **byte.** Each unique pattern of bits represents a different character (e.g., in ASCII, 1000001 represents the letter A).

Multimedia communications conveys information in multiple forms: audio, video, data, graphics, etc.

A **Network** is a collection of senders and receivers ("nodes") that can communicate to or through each other or through "links." There are two categories of networks: **local area networks (LAN)** and **wide area networks (WAN).** A LAN connects computers in, at most, several buildings that are close to each other. A WAN connects more widely separated computers. Computers that are connected by a LAN or WAN can be formed into a **distributed system,** a group of computers that can operate together sharing data and software capabilities.

The arrangement of computers in networks has been categorized as **network topologies.** The more common topologies are star, ring, tree, and bus (a bus is a data channel that has multiple input/output taps--in essence a piece of wire with multiple connections).

Networks can set up to distribute data in one of two ways: **broadcast--**data are transmitted to more than one recipient at a time and **switched--**data are transmitted to a specific station. (This may and often does require that transmissions be relayed through a series of intermediate nodes.)

The **medium** is anything that can pass information. The medium connects a *sender* to a *receiver* enabling them to communicate. Every medium introduces errors in the data to a greater or lesser degree.

Duplexity describes the capability for data flow. In a **simplex** system, communications can flow in one direction only. In a **half duplex** system, communications can flow in both directions but only one way at a time. And in a **full duplex,** communications can flow in both directions simultaneously.

The terminology presented so far has built a model of a telecommunications, data communications, and the networks over which these activities are conducted. We now turn to the concepts that describe how data are passed between computers.

Bandwidth is the range of frequencies that can pass through a medium calculated as the difference between the highest and lowest frequencies that can be transmitted. This is important because the amount of information a signal can hold is proportional to the signals bandwidth.

Bits per second (bps) describes the rate at which bits are passed over a telecommunications circuit, for example, 2400 bps. **Bytes per second** is the rate in bps divided by eight.

The **signaling rate (Baud)** is the rate at which electronic signals are *sampled each* second. As we will see, this can but need not be equal to the bps.

Data can be transmitted faster if each character follows another without time between them. For this to happen, the sender and the receiver must share common, precise timing. When this happens, the transmission is **synchronous.** For high-speed (and expensive) circuits, the solution often is to let the telephone company provide the clock or "timing." Low cost, low speed circuits use **asynchronous** transmissions. Instead of using a clock, "start" and "stop" bits are included in transmission with a gap between characters. A start bit tells the receiving computer that a data transmission is starting and, therefore, that the sampling should start.

Because computers work with 1s and 0s, to process continuous or "analog" signals they must sample them to turn them into numbers. The rate at which this sampling occurs is the **sampling rate.** The information a sampled or incoming signal can convey is limited by the frequency with which it is sampled. To capture all information, it must be sampled at the *Nyquist rate,* i.e., at twice the highest analog frequency of the signal. For example, a 300-kHz signal must be sampled 600,000 times a second for all the incoming information to be captured.

In synchronous transmissions, the sending source must provide a whole block of information at once. This block is called a **frame** and is identified by **flag** characters, the beginning and end of the frame. A common flag is the byte (eight bits, an **octet**) 01111110. When the receiver senses this pattern, the receiver knows where to find the incoming data bits without start and stop bits.

A **session** is a continuous period of data exchange among two or more communicating elements on a network.

The **components of electronic signals** are **amplitude, period, frequency,** and **phase.** In the formula *f(t) =* A sin*(2 ft +*), A is the amplitude, *f* is the frequency, and is the phase.

There are two types of current: **alternating (AC)** and **direct (DC).** In AC, current flows in first one direction and then the other. Each change of the direction of flow of the electricity is called a cycle. The number of **hertz** is the number of cycles per second.

We now turn to the terminology used to categorize the equipment for data communications. The **channel** is the medium (e.g., telephone line) over which data are transmitted. A **host computer** is the physical device (computer) in which the data to be transmitted over the channel are located. The host computer or other user equipment connected to the communications circuits is the **data terminal equipment (DTE).** This may or may not be the host computer. Sometimes a special computer is provided for this purpose. Such a computer is called a **front end.** The DTE connects to **data circuit terminating equipment (DCE). Modems,** which convert the digital signals of computers to and from the analog signals used by telephones, are examples of DCE. (The name Modem is a contraction of modulator-demodulator, the functions performed by a modem.) If the computer's digital signals are to be transmitted as digital signals, a **digital service unit/channel service unit (DSU/CSU)** converts a computer's digital signals to the digital signals transmitted over a communications circuit that uses digital signals. A DSU/CSU transmits and receives data at 56 Kbps or faster rates.

A **multiplexer** is used to combine the signals from several inputs and transmit them over one line. This can increases the amount of data that con he transmitted over able communications circuits.

An **internetworking unit** (also called a **bridge** or **router)** connects two or more networks.

STANDARDIZATION ORGANIZATIONS

For data communications to work, myriad specific details must be in order. To facilitate the standardization of all these details, various agreements called protocols been developed, commented on, and published as standards. These agreements cover a wide variety of topics, some of which will be mentioned later. Agencies that publish these agreements or protocols include the International Telecommunications Union (ITU-T, previously known as CCITT), the International Standards Organization (ISO), the American National Standards Institute (ANSI), the Electronic Industries Association (EIA), the National Communications System (NCS), the National Institute of Standards and Technology (NIST), and the Internet Engineering Task Force (IETF).

TRANSMISSION MEDIA

We now turn to the media over which data are transmitted: wire, coaxial cable microwave, satellite, and optical fiber. Information is passed over mediums as bits in the form of "state values." For current this can be as a + or - (flow of charge in "current”). For optical fiber, this can be the presence or absence of light.

Wire is frequently used in twisted pairs, sometimes "shielded" with foil. With wire, the signal is **attenuated** (made weaker) with distance, however, the larger the wire, the less the signal is attenuated. Twisted pairs can handle speeds up to 10 Mbps, however, the lower the speed the further the signal goes without being so degraded as to be useless. To reduce effects of "noise," **balanced** lines can be used.

Coaxial cable is a cable that contains two conducting elements. One is an inner core of wire surrounded by an insulator. The other is an outer wire (usually made of braided metal). Both inner core and outer wire share a common axis, thus the name *co*axial. Coaxial cable are noise resistant, can transmit frequencies to tens of MHz, and handle data rates to hundreds of Mbps.

Microwaves are waves that have a relatively short wavelength (and therefore relatively high frequency), at frequencies of hundreds of millions or billions of cycles per second measured in megahertz or gigahertz. Microwaves are line-of-sight, that is need antenna that can “see" the antenna at other end. This means microwave antennas generally are located on high points. Microwaves can carry a lot of data, tens of Mbps. They require a license and maintenance, and are easily monitored by third parties.

Satellites are microwave transponders (repeaters) in geostationary orbit (22,300 miles above equator). They have high data rates, a broadcast capability, the same cost and delay (about 1/4 second) for sites anywhere in satellite "footprint," and a significant bit error rate--often one in 10^4 or 10^5 (often represented as 10^{-4} or 10^{-5}**).** For some satellite links the sun interferes for 10 minutes per day for two 5-day periods a year.

Optical fiber passes light through very thin glass fibers and transmits data at a high rate. For example, OC3 optical fiber passes 155 Mbps. Optical fiber is immune to electrical interference, cannot produce sparks, has low attenuation (repeaters are placed every 20 miles in the best case, compared to the 2.8 miles used on copper T1 lines), and are hard for third parties to tap because there is no radiating signal. Optical fibers are also very thin and very robust, and have a very low error rate: one in 10^9 (or 10^{-9}) or better. There are two versions, multimode and single mode. The latter carries data at higher rates. Optical fiber is used in high-speed LANs and is the carrier backbone of commercial telecommunications operations including submarine cables.

Modems and DSU/CSUs are used to connect computers to wire, coaxial, or microwave circuits: modems for analog circuits, DSU/CSUs for digital circuits. The DSU/CSU may also include a **line driver** to send the digital signal over copper wires (up to a few miles). If external modems (not built into a computer) are used, **interfaces** connect the computers and the modems. The **EIA-232-D (“RS232”)** and **EIA-449 (“RS449”)** are widely used interfaces. Interfaces derive their names from the protocols that describe their specific wiring plans.

PLACING DATA ON THE SIGNAL

Data inside a computer are represented by on and off, 1s and 0s. If the data are to be passed digitally to another computer, the first computer need only send a string of bits in the form of 1s and 0s (current or no current) to the other computer. If, however, the channel between the two computers is an analog circuit, the answer is not so simple because there is a minimum and a maximum (not an on and off) and an infinite number of values between them. The phrase **"modulating the signal'** describes the process by which digital data are represented by an analog signal.

The answer lies in three aspects of a signal that were discussed earlier. amplitude, phase, and frequency. To place digital data on an analog signal using amplitude, high and low amplitude values are established. If a zero is to be transmitted, a low amplitude is transmitted for a specific period. If a one is to be transmitted next, the signal is increased to a high value and held there for a short period. At the receiving modem, the signals are monitored by the periodic sampling mentioned above. Values in the range of the high amplitude value are evaluated as representing a one and values of the low amplitude are evaluated as representing a zero. Similar use is made of the phase and frequency components of the signals. By combining these, a particular signal can convey more than one bit. It has been this ability to combine these components that has enabled modem makers to keep producing faster and faster modems.

ERRORS: THEIR SOURCES AND HANDLING

As has already been noted, errors will be introduced into some data when they are communicated. If the error is in a 25,000 word paper, it may be unimportant, but if the error changes a $100 payment to a $1000, it will be important. The following introduces error sources and handling with a focus on the information that will help readers determine what they need to do about error handling.

Extraneous signals that distort data come under the heading of noise. Types of noise include **White** noise--happens randomly due to the physics of electricity; **Electrical noise--**caused by high-powered electrical sources near signal, e.g., arc welder; **Transients--**short duration changes in circuit (e.g., impulse noise and dropouts); **Cross talk--**interference from other channels in the same transmission medium; **Echos--**signal reflected from the far end of circuit. Also substandard performance from communications components may distort the signal and cause errors. This happens mostly to analog signals.

The **signal-to-noise ratio** is used to state the relationship between a signal and the noise in a channel. Because the signal is usually much larger than the noise, the ratio is often scaled down logarithmically and stated in **decibels,** defined as 10 log (signal power ratio).

Error management methods include sending test signals, measuring the results, and taking appropriate corrective action; doing loop-back tests, tests that send a signal to the far end of the circuit, which is then sent back to the beginning of the circuit; using error detecting codes; keeping statistics on errors (most routers do this today); and using **forward error correction,** the sending of redundant information so the receiving station can make a good guess on what should have been sent if a possible error is discovered.

Digital signals are much less prone to errors than are analog signals.

NETWORK BASICS: SWITCHING AND PACKETS

Data communications requires a means to connect computers, a **connection strategy.** A **direct connection** (e.g., leased line) is the simplest, most expensive, and least flexible approach because there is no switching. **Switching,** the establishment of short-term connections between communicating elements, is the alternative to a direct connection. **Circuit switching** is making and maintaining a connection between two nodes *until one party terminates the connection.* **Packet switching** breaks messages into pieces or **packets,** which are relayed among **packet switches** or **routers** from source to destination. Two methods are usually used to route packets. In the

virtual circuit approach, a route is established and all the packets for a message are transmitted over that route, i.e., through the same sequence of packet switches. In the **data-gram** approach, each packet is transmitted independently. The packet switches are responsible for routing from source to destination, and routes change over time. This approach is different from circuit switching because the route is not reserved exclusively for traffic between the sending and receiving nodes. **Public packet switching** offers packet switching communications for sale as a service, often tied to the Internet.

A **packet** is a string of bits that has been structured for transmission over a network. A packet usually contains only part of a file to be transmitted because files are often divided between many packets before being transmitted and then reassembled at the receiving station. When a packet is built, the information to be transmitted has added to it information required, for example, to route the message, to reassemble the pieces of the message, and to check for errors.

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