

Data Communications and Transmission Media

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Abstract

Because of the increasing number of networks and distributed systems, the understanding of data communications and alternatives for the transmission of data is essential for information technology professionals. Systems that are distributed throughout a business must be interconnected to exchange e-mail, share files, and share resources (e.g., printer, database, phone line). The types of information that may be transmitted include voice, data, image and video, and may be sent via analog or digital signals.

A case study of a fictitious company is included that illustrates how a geographically dispersed company with an older system of connectivity can modernize to improve efficiency and reduce costs.

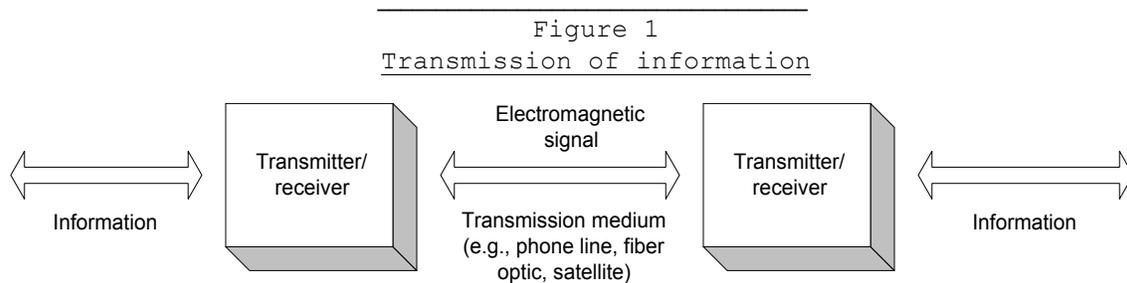
Data Communications and Transmission Media

Civilizations and societies have developed over time through several well-defined periods. Mankind has already passed through the Nomadic Age, the Agrarian Age, the Mercantile Age, and the Industrial Age. There are definitive contrasts between each epoch in how society lived, worked, and interacted with others. We are now in the Information Age, also known as the Knowledge Age, Digital Age, Cyber Age, and Virtual Age (Boar, 1997). In the Information Age, the dominant technology of the era is the computer. Effective management of, and communication of, information is important for businesses to remain competitive in an increasingly competitive marketplace.

Electromagnetic Signals

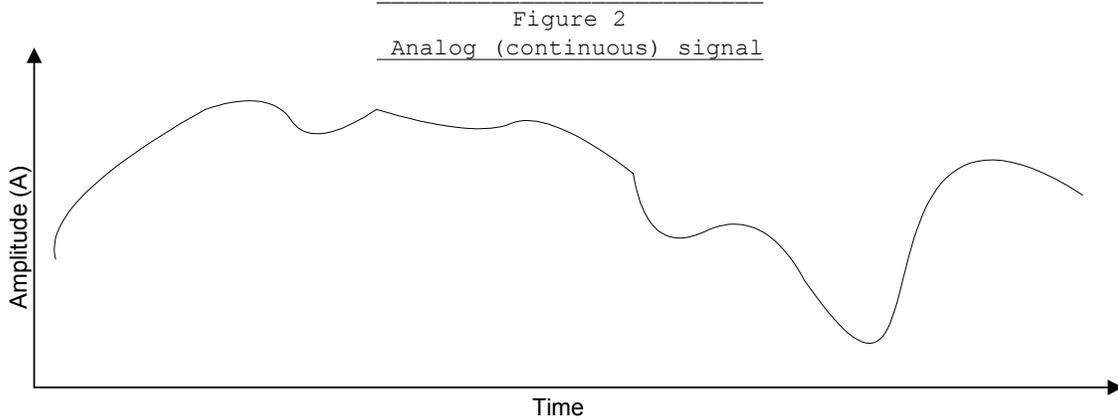
Information is a highly valued commodity and resource in the Information Age, and when two or more users need to communicate or share information at a distance, they engage in data communications via some method of transmission of data signals. Data communications through computers and telecommunications systems includes almost any form of information transfer including text, numerical data, images, and video. Each of these types of information can be represented by electromagnetic signals and transmitted

over a suitable transmission medium. Information is generated by a source (e.g., computer, fax machine) and is then transformed into an electromagnetic signal. The signal is then applied to a transmission medium and transmits from a transmitter to a receiver (Figure 1).

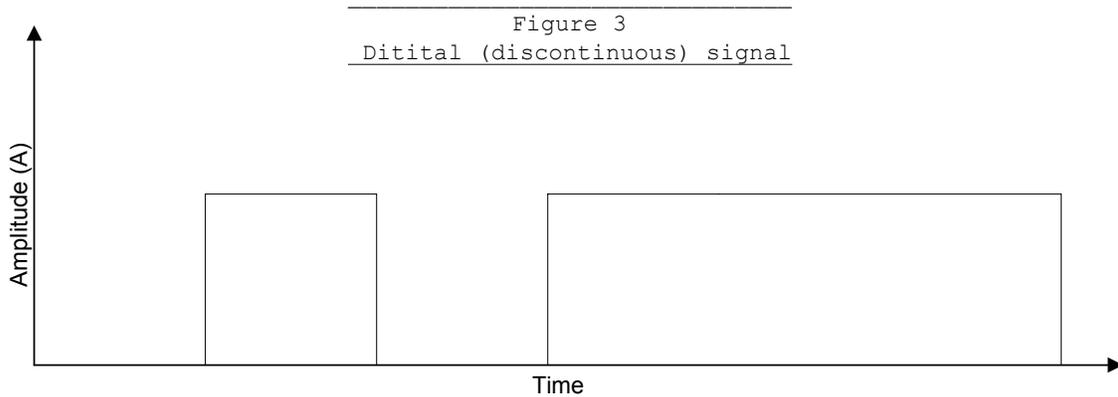


The receiver then “translates” the electromagnetic signal to exactly reproduce (or very closely approximate) the original information.

Concepts of Time An electromagnetic signal can be described as a function of time. There are two main signal forms that information can take between communication systems: analog and digital. Analog signals (Figure 2) represent data with continuously varying electromagnetic waves, and these signals vary in a smooth fashion. Analog information is a continuous signal (e.g., a voltage) that can take on any number of values within a continuum. Voice and video are examples of analog data, and their signals are described as continuously varying electromagnetic waves that may be transmitted over a variety of media.



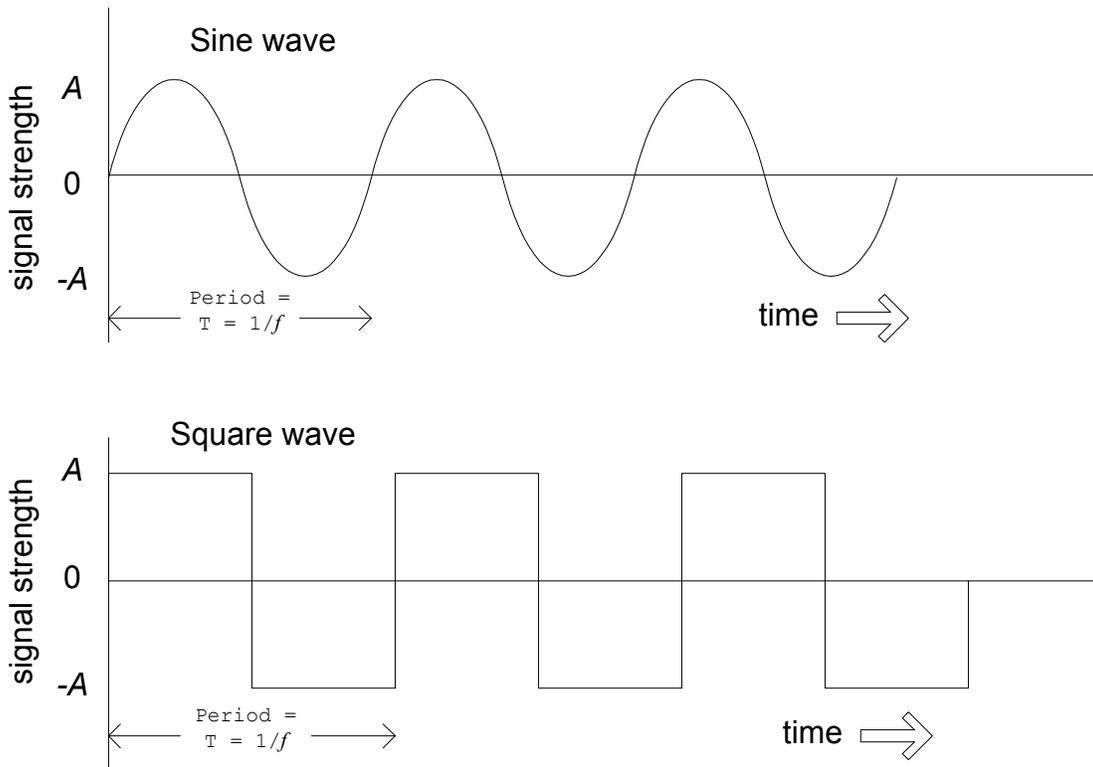
A digital signal (Figure 3) is one in which the signal intensity maintains a constant level for some period of time and then changes to another constant level. Digital signals are also described as discrete or discontinuous signals, and their transmission is possible only over wire media. Whereas the analog signal might represent human speech, the digital signal represents the 1s and 0s of binary notation.



The simplest sort of signal is a periodic signal in which the signal repeats over a period of time. Sine waves

and square waves (Figure 4) are an example of periodic signals, and can be represented by three values: amplitude (A), frequency (f), and phase (ϕ). The amplitude is the peak strength of the signal over time, and is usually measured in volts. The frequency is the rate, measured in cycles per second [or hertz (Hz)], at which the signal repeats. The period (T) of a signal is the time it takes to complete one repetition. Thus, $T=1/f$. Phase is a measure of the relative position in time within a single period of a signal.

Figure 4
Periodic signals: sine wave, and square wave



Mathematically, the formula for the sine wave can be written $s(t) = A \sin(2\pi ft + \phi)$. Graphically, the sine wave takes on

different shapes depending upon the values of amplitude, frequency, and phase. The sine wave also reflects a relationship between time and space. The *wavelength* (λ) of a signal is the distance occupied by a single cycle. If a signal travels at velocity (v), then the wavelength is related to the period in the following expression: $\lambda = vT$. Also, $\lambda f = v$.

Concepts of Frequency Not only is a signal of electromagnetic properties a function of *time*, but it can also be expressed as a function of *frequency*, meaning that an information signal can consist of components of different frequencies. Electromagnetic signals are made up of a compilation of periodic analog signals (sine waves) of differing frequencies. They are also made up of varying amplitudes and phases. The *spectrum* of a frequency is the range of frequencies that it contains. The *bandwidth* of a signal is the range of frequencies that can be accommodated on a particular telecommunications channel (Laudon & Laudon, 2000). The greater the bandwidth, the greater the medium's ability to carry information. For example, if a bandwidth of 4 MHz offered a data rate of 2 Mbps, and broader bandwidth of 8 MHz would offer an increased data rate of 4 Mbps. A given bandwidth can support various data rates, depending on the receiver's requirements.

The frequency components of the square wave can be expressed mathematically as: $s(t) = A * \sum_{k=1,3,\dots}^{\infty} \frac{1}{k} \sin(2kf_1t)$. But the amplitude of the k th frequency component (kf_1) is only $\frac{1}{k}$, so most of the energy in this waveform is in the first few frequency components. According to Stallings and Van Slyke (1998), any digital waveform will have infinite bandwidth. But the nature of the medium (e.g., 56 Kbps modem, ISDN line) will limit the bandwidth that can be transmitted. The more limited the bandwidth, the greater the distortion of the signal being transmitted. It is therefore preferable to have broader bandwidth. However, the greater the bandwidth, the greater the cost to the user. Businesses should therefore plan carefully when deciding which mediums to use for data communications and transmissions.

Transmission of images Images may be transmitted as either an analog or digital signal. If they are transmitted as an analog electromagnetic signal (e.g., a television signal), the image is represented as a set of horizontal lines, and each horizontal line is represented by a varying intensity pattern.

If an image is transmitted digitally, it may be done so in the following manner. The image is broken down into

insulated copper wires arranged in a spiral pattern. The two wires act together as a single communication link and are typically bundled together in a protective sheath that also helps to reduce extraneous interference. The "twisting" of the two wires helps to reduce crosstalk interference (Carne, 1999). Twisted pair is the most common medium for both analog and digital signals (Stallings & Van Slyke, 1998). For long distance transmission of analog signals, amplifiers are needed approximately every three miles. For long distance transmission of digital signals, repeaters are needed approximately every one to two miles. For long distance use, twisted pair can be used for data rates of around 4 Mbps, with a bandwidth of 3 MHz. For shorter distances (e.g., within one building) data rates of up to 10 Mbps or more are possible.

Coaxial cable is a cable consisting of one copper conductor that is within, and insulated from, a second copper conductor. This concentric construction allows it to operate over a broader range of frequencies than twisted pair. Also, because it is shielded, it is less likely to experience the interference of extraneous sources from nearby electromagnetic fields. Popular uses of coaxial cable include television signals and long-distance telephone transmission. Like twisted pair, coaxial cable

can be used for both analog and digital signals. It can handle data rates of up to 500 Mbps with a bandwidth of 350 MHz.

Optical fiber is constructed of a thin filament of transparent material (e.g., glass) through which a signal-encoded light beam may be transmitted to send analog signals as optical energy¹. Optical fiber has a cylindrical shape and three concentric sections, and is only about the width of a human hair (Carne, 1999). The two innermost sections are of glass, each with different qualities. The outermost layer is a protective covering. Multiple optical fibers are bundled together to form optical cables. The distinguishing characteristics of optical fiber over twisted pair and coaxial cable are that it (a) has greater capacity—up to 2 Gbps, with a bandwidth of 2 GHz, (b) it is smaller in size and lightweight, (c) it experiences lower attenuation distortion, and (d) it is not affected by extraneous electromagnetic fields.

Unguided Media The atmosphere and outer space are examples of unguided media because they allow wireless transmission. Reception and transmission are possible through the use of an antenna. For transmission, the antenna radiates electromagnetic energy into the air.

¹ Optical fibers conduct optical energy, not electrical energy. (Carne, 1999).

Similarly, a receiving antenna picks up the electromagnetic waves from the surrounding air. The range of frequencies of wireless transmission is from 30 MHz to well over 40 GHz, including all or portions of the broadcast radio, microwave, and infrared² ranges of the frequency spectrum.

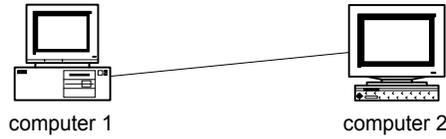
For very long distances, satellites can be used for relaying signals from transmitter to receiver. Important applications for satellite communications include (a) long-distance telephone transmission, and (b) television distribution. The frequency range for satellite transmission is 1 GHz to 10 GHz. While satellites can function in a frequency range higher than 10 GHz, lower ranges are preferred because signals over 10 GHz are increasingly affected by rain and other precipitation.

Connectivity

Data communication between two or more users is not possible without some form of connectivity. Two computers in close proximity can be directly connected with one link (Figure 5). As more computers or workstations need to be

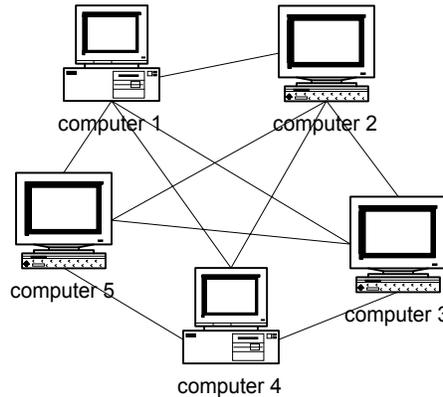
² Infrared signals are typically useful only for point-to-point applications within one room. For example, a computer and printer with infrared capabilities can allow “wireless” communication. Unlike microwaves and radio waves, infrared signals cannot pass through walls.

Figure 5
One direct link for 2 computers



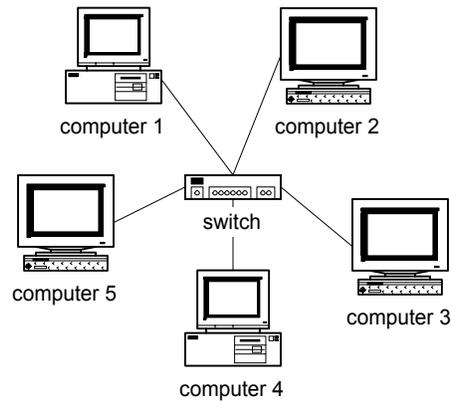
connected, the number of direct links to connect those in close proximity increases markedly. For instance, the number of direct links required to connect three computers to each other is three, and 10 direct links are required to connect five computers (Figure 6). As more computers are

Figure 6
Ten direct links to connect 5 computers



added to a system, it becomes necessary to consider other options. For example, a central switch can be used to connect multiple computers in a local area network (Figure 7).

Figure 7
Full connectivity using a central switch



ISDN, Broadband ISDN, ATM, and Frame Relay

The fields of computing and communications have necessarily overlapped due to the need for companies to connect through networks. Several different connectivity methods have been developed that help companies combine computing and communications, including ISDN, Broadband ISDN, ATM and Frame Relay. *Integrated services digital network* (ISDN) was developed almost two decades ago. ISDN has become popular in recent years as a way to transmit data at rates from 64 Kbps to 1.544 Mbps, and has become the international standard for transmitting voice, image, and other data forms over public telephone lines (Laudon & Laudon, 2000). There are three types of ISDN service: basic rate interface, primary rate interface, and broadband ISDN. All ISDN connections flow through a Class 5 ISDN switch.

Having an ISDN line that would allow quicker access to data may be a good choice for some businesses, especially those that rely on rapid access to data. Benefits of ISDN over slower, dial-up systems are (a) increased speed of access to data, (b) no more being *bumped* or *logged off*, and (c) reasonable rates due to increasing competition among vendors.

For a small to medium-sized business, ISDN is a good choice that management can adopt to make an improvement over slower access speeds. Two major benefits that management can realize with the choice of ISDN are flexibility and cost savings. The ISDN setup is flexible and supports both voice and nonvoice communications. Thus, the company does not have to pay for multiple services to meet a variety of needs. Economies of scale with integrated services allow these services to be provided at lower costs than if they were provided singly. Also, since ISDN is entirely digital, there is no need for analog-to-digital conversion, and users benefit from the full bandwidth of each channel.

One other benefit that companies can realize with ISDN technology is that there are a number of equipment vendors that provide the service. This competition among vendors means that managers can shop for the best combination of

services and equipment and choose what best suits their specific corporate needs.

While ISDN does provide the user with access to both data and voice services in an integrated manner, it suffers from one main problem at the present time. Upgrading a line to ISDN (in some countries) can actually result in the loss of standard voice applications.

The recent interest in high-definition TV has prompted work on a *Broadband ISDN* (B-ISDN) standard. B-ISDN supports fax, video telephone, high-definition TV, and computer networking. In the past audio, video, voice, and data services each needed a different type of communications channel.

B-ISDN is undoubtedly an excellent choice for companies who need data transmission in the hundreds of Mbps. As the name implies, *broadband* ISDN allows transfer of data across much broader bandwidth, and uses packet-switching. Because of the support of universal communications, worldwide exchange is possible with broadband ISDN. One benefit that B-ISDN offers is that data can be transmitted between any medium or combination of media. For instance, large files with both text and graphics can be transmitted and received quickly. Also businesses will find it efficient to share massive amounts

of data from multiple sources. A worldwide investment company may find this technology useful if they need to have up-to-the minute data available as it is collected from dozens of locations throughout the business day across multiple time zones. Another benefit of B-ISDN is that large files can be distributed extremely quickly. For instance, an engineering firm may need to send one complex technical drawing to multiple branch offices so that each may make its respective improvements, suggestions, or modifications to the original file. B-ISDN will also be able to offer video, live television, and CD-quality music, and will be able to do so over the telephone line.

One disadvantage of B-ISDN is that it is not currently available everywhere. Therefore, it can only be a realistic option to consider in geographical locations where it is available.

According to Stallings and Van Slyke (1998), the major contribution of broadband ISDN technology has been *asynchronous transfer mode* (ATM). The B-ISDN technology has resulted in more than just an interface standard. An entirely new network architecture has emerged. ATM is also called *cell relay*, and uses a form of packet-switching, based on the transfer and switching of small fixed-length packets. ATM permits changes once per cell, and after every

48 bytes of payload, the switch is able to do something different, enabling more complex capabilities. ATM is functionally more streamlined than frame relay, and can support data rates much greater than frame relay. ATM's bandwidth is from 25 Mbps to 2.5 Gbps (Laudon & Laudon, 2000). Any company that has massive amounts of data that must be transmitted is wise to consider ATM. Large video and audio files can be sent and received with little or no delay in transmission.

Frame relay is a switched-network technology. Since the frame relay protocol can be used over a dedicated line, it can provide efficient multiplexing ability. The speed of transmission with a frame relay can range from the speed of a T-1 line to a T-3 line, from 1.544 Mbps to 44.736 Mbps, respectively. Some companies prefer to use a frame relay system that is leased, which allows them to keep from having to purchase equipment that a qualified vendor may already have. The vendor would then be responsible for system maintenance, thereby reducing maintenance personnel that would otherwise be required. When using a frame relay system, the user only needs to have line capacity as great as that which is needed to accommodate its needs. If they only need a capacity of 56 Kbps at a certain location, then they only need to pay for the cost of that capacity.

Information technology managers who are in a position to make a decision regarding which data transfer technology to use, must first determine the extent for which such a system will be used. In the real estate business, there are numerous one-office companies that need only simple access to on-line information services or to the Internet, and 56 Kbps modems are sufficient. But with companies for which delays in transmission speed would represent an unacceptable slowdown of normal business operations, high-speed transmission is of utmost importance.

Managers would be wise to utilize systems that are not only appropriate for current needs, but are also sufficient to handle future needs. A slightly higher cost to implement a system that exceeds current needs could ultimately provide a cost savings if expected future needs would warrant its adoption. Managers must also consider the routine maintenance needs of any transmission system that would be chosen. Managers should also get multiple equipment bids when possible so that they can ascertain how different vendors' proposals compare in size and scope.

Another concern relates to costs associated with each type of service. With ISDN, there is typically a fixed price per month for service. Also, there is usually a usage charge based on the volume of time connected. Long distance

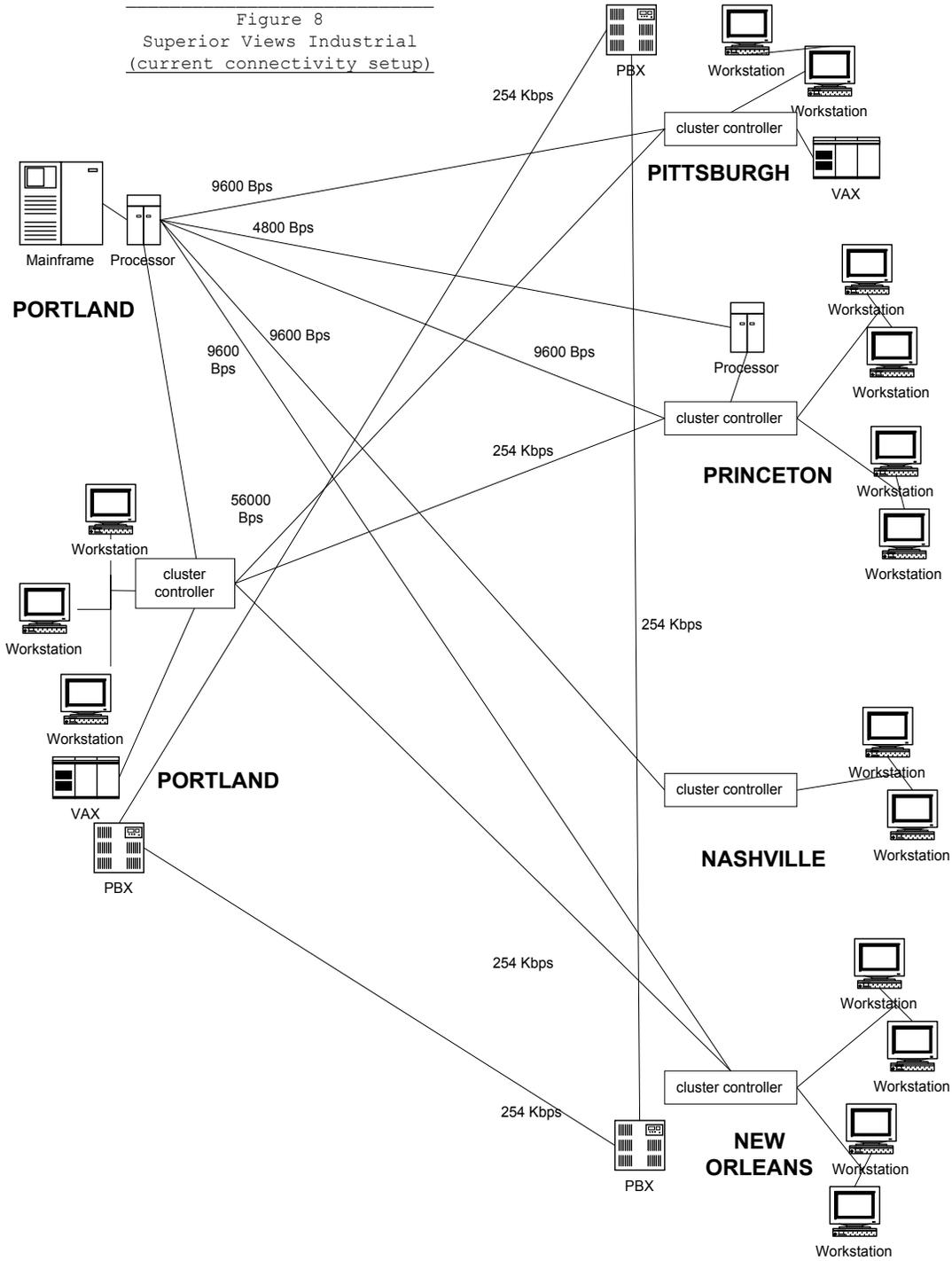
rates apply for long distance communications. Frame relay and ATM do not have separate long distance charges. With these two types of connectivity, there is typically a fixed monthly price for usage based on the capacity of the link. For instance, a line capacity of 128 Kbps would mean a higher monthly fee for a company than would a 56 Kbps-capacity line.

Case Study

This case study of the fictitious company, Superior Views Industrial, was created to illustrate what a network professional may need to consider to improve connectivity among geographically dispersed locations. Figure 8 describes the current connections among the city branch offices of Superior Views Industrial. The home office of the company is in Portland, and branch offices are located in Pittsburgh, Princeton, Nashville, and New Orleans.

Superior Views Industrial is typical of any company that may have grown through merger or acquisition and needs to improve a system of connectivity that may be outdated or non-optimal. The current system has a number of older 4800 and 9600 Kbps modems.

If the company continues to grow, a properly designed system will allow new sites to be added to the network without affecting the operations of the other sites.



According to Connolly and Begg (1999), companies with a well-planned distributed environment are better able to handle expansion. It is therefore important that the

network and information technology professionals at Superior Views Industrial ensure a sound connectivity infrastructure.

Although there are various costs that must be incurred in any networked system (e.g., maintenance, equipment costs, operating personnel), the most important recurring cost that management must consider is the cost of the actual transmission service. Transmission costs increase with distance (Carne, 1999). Therefore, due to the high cost of voice and data communication facilities and services, multiplexing has become a very practical procedure for reducing costs and improving transmission efficiency. Multiplexing is a procedure where two or more information sources share a larger transmission capacity (i.e., several signal streams are placed on a single bearer), and wherein each information source has its own channel.

In general, multiplexers should be logically placed in areas with a high number of current lines and input/output (I/O) ports. There are two main benefits that Superior Views Industrial will realize upon the implementation of multiplexing. The first benefit is improved efficiency. Efficiency can be improved with statistical multiplexing, which is a method of time-division multiplexing where time

slots on a shared transmission line are assigned to devices on demand, as needed. Arrival time at the multiplexer by signals, not what input line they are on, determines the order in which they are sequenced. As the signals are placed on the multiplexed line, an identifier is added by the multiplexer so that the signals will be forwarded properly.

A second way that the efficiency can be improved is with compression of data. Compression allows fewer bits of data to represent the original amount of data. There are several compression techniques that may be used, depending on the data type. Run-length encoding is one type of compression and is used to compress any form of character sequence that repeats.

The second main benefit that the company will realize with multiplexing is a cost savings, because rather than have to pay for a number of lines with varying capacity, fewer lines will mean less in access costs. Although the proposed lines may be greater in capacity than the sum total of the current line capacity, prices become more cost effective as higher capacity lines are chosen.

Table 1 shows the capacity requirements for Superior Views Industrial prior to the adoption of multiplexers, and the individual line connections are indicated in Figure 8.

After Superior Views Industrial adopts multiplexers, they will be able to reduce the total number of lines, thereby reducing transmission costs. The company is wise to consider the adoption of multiplexers, due to the number of lines that they currently have of varying capacities.

PORTLAND	9,600 bps to Pittsburgh
	9,600 bps to Princeton
	4,800 bps to Princeton
	9,600 bps to Nashville
	9,600 bps to New Orleans
	254,000 bps to Princeton
	254,000 bps to New Orleans
	56,000 bps to Pittsburgh
	254,000 bps to PBX at Pittsburgh & New Orleans
	856,400 bps
PITTSBURGH	254,000 bps to PBX at New Orleans & Portland
	9,600 bps to Portland's mainframe
	56,000 bps to Portland
	319,600 bps
PRINCETON	9,600 bps to Portland's mainframe
	254,000 bps to Portland
	4,800 bps to Portland's mainframe
	268,400 bps
NASHVILLE total	9,600 bps to Portland's mainframe
	9,600 bps
NEW ORLEANS total	56,000 bps to Portland
	9,600 bps to Portland's mainframe
	254,000 bps to Portland
	254,000 to PBX at Portland & Pittsburgh
	573,600 bps

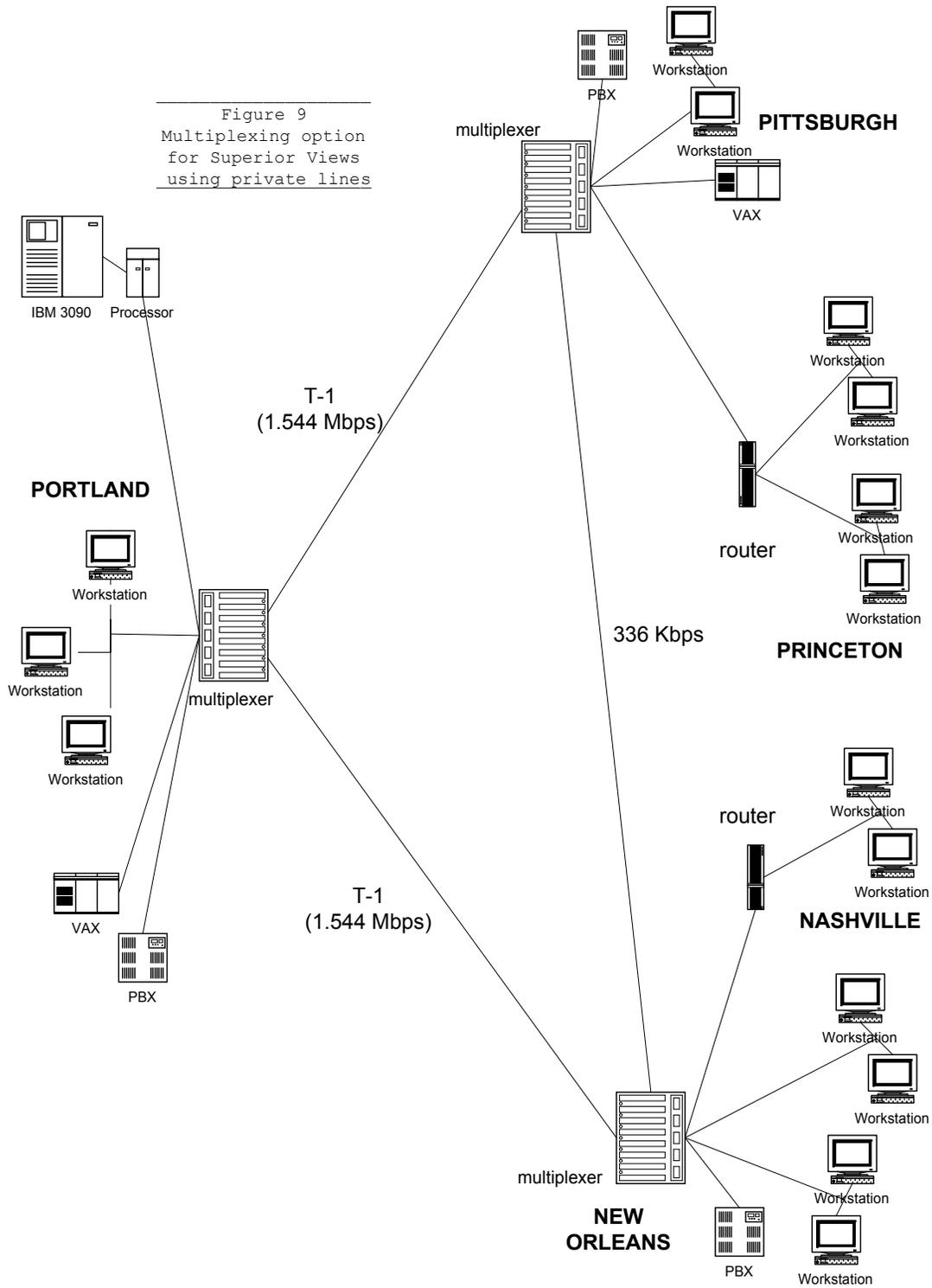
The placement of the private branch exchange³ (PBX) in Portland, Pittsburgh, and New Orleans is an indication of

³ The PBX is an example of circuit-switching, and is used to interconnect telephones within a building. They are typically available with voice message service facilities (Carne, 1999).

the cities that are deemed most important for communications capacity. After multiplexing, these same three cities would maintain their communications importance, and would act as three main hubs, each with one multiplexer. Princeton and Nashville, already having few total number of lines, and needing less line capacity than the other three cities, do not need multiplexers. Princeton and Nashville can be connected through the Pittsburgh and New Orleans multiplexers, respectively, through router connection. The three multiplexers would be placed in Portland, Pittsburgh, and New Orleans. The total number lines needed would be reduced upon implementation of multiplexing.

There are two main ways that the company's lines can be set up using multiplexing. The first option is to use private lines. The second option is to connect through a frame relay. Figure 9 is a depiction of how the company could set up their systems using private lines. A T-1 line is sufficient to handle what Portland's capacity requires, both from Pittsburgh and from New Orleans. The connection between Pittsburgh and New Orleans requires less capacity than do either of those two cities to Portland. Therefore,

Figure 9
Multiplexing option
for Superior Views
using private lines



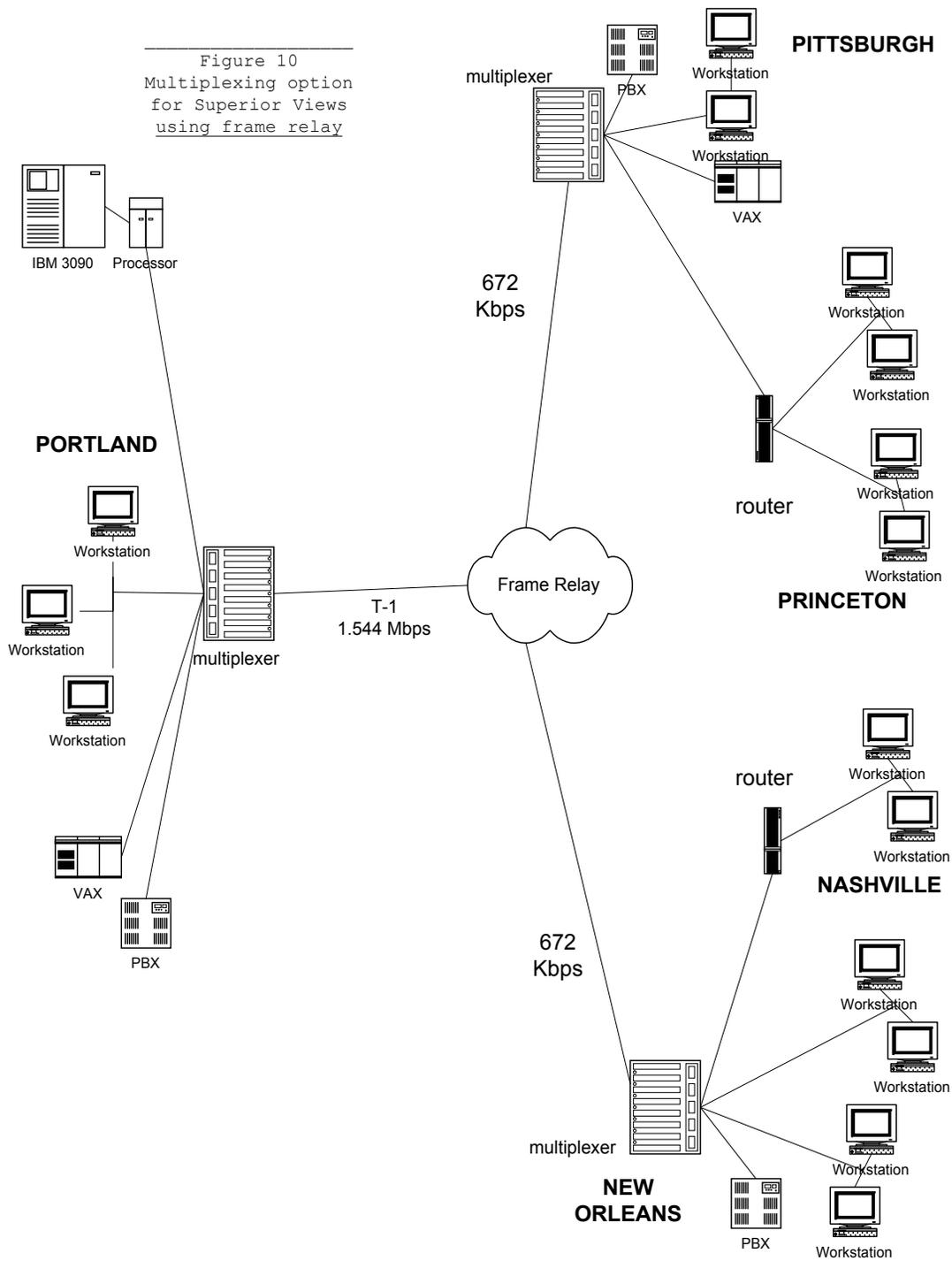
a 336 Kbps⁴ line is sufficient. One advantage of this setup is that if ever the connection from Pittsburgh to Portland, or from New Orleans to Portland, is temporarily down, data may be rerouted back through the system of Pittsburgh or New Orleans to reach its destination in Portland. The most important part of the connection that needs to be accommodated in case of a downed system is the voice connection from the PBX; the employees must be able to verbally communicate with each other. Since the PBX currently requires a 254 Kbps capacity, a capacity for the proposed system must be at least 254 Kbps or greater. A capacity of 336 Kbps was chosen because it is the next available increment above the 254 Kbps capacity of the current system, thereby providing a conservative surplus.

The second main multiplexing option to consider for Superior Views Industrial is to use a frame relay system. One advantage of using a frame relay system is that, unless the company chooses to buy frame relay equipment, another entity is responsible for owning and maintaining the frame system. The line capacity to the frame relay system must accommodate the capacity requirements of each city, and each city would connect via whatever CIR (committed

⁴ I have considered from the port speeds available under US West tariffs in the following incremental choices: 112 Kbps, 224 Kbps, 336 Kbps, 448 Kbps, 672 Kbps, and 1.544 Mbps.

information rate) that they pay for. Three main lines would leave the three main cities and would connect with a frame relay. Portland's capacity requirements would be satisfied with a T-1 line capable of 1.544 Mbps. The line capacity of Pittsburgh and of New Orleans would be satisfied with the choice of 672 Kbps. The choice of 672 Kbps from Pittsburgh and New Orleans accommodates their need for 254 Kbps from the PBX system and the rest of the workstations. Figure 10 shows how Superior Views Industrial's system would be set up using a frame relay system.

One other consideration worth noting is the option of using modems to connect certain aspects of Princeton's and Nashville's systems via the normal phone lines. Nashville and Princeton are currently using 9,600 bps connection speeds for their workstations that are connected through a cluster controller, as is indicated in Figure 8. If modems were actually considered, the company should at least upgrade to modern 56 Kbps modems. However, for the purposes of this case study indicating the benefits of multiplexing, Nashville and Princeton were shown in both Figure 9 and in Figure 10 to connect through New Orleans and Pittsburgh, respectively, via routers. In other words, New Orleans operates as a hub for Nashville, and Pittsburgh operates as a hub for Princeton.



If Superior Views Industrial adopts multiplexing, using either the private line option (Figure 9) or the frame relay option (Figure 10), they will have improvements

in the efficiency of data transmission, and will be able to recognize cost savings. Line capacities were proposed that were greater than their current requirements so that they will have room to "grow" into the new system if they decide to expand operations in the future.

Conclusion

All types of information that can be sent from one place to another can be represented by electromagnetic signals and transmitted over a suitable transmission medium. Depending on the transmission medium and the communications environment, either analog or digital signals can be used to replicate or closely approximate information. Digital signals are less susceptible to noise interference than are analog signals, but are only able to be transmitted over a wire medium such as twisted pair or coaxial cable.

Any electromagnetic signal is made up of a number of frequencies. A key descriptive feature that characterizes the signal is bandwidth, which is the width of the range of frequencies that make up the signal. The greater the bandwidth of the signal, the greater is the information-carrying capacity. Greater bandwidth means higher costs, so users should make certain that the cost is justified.

Information technology managers responsible for setting up a network or communications system should make sure that all relevant criteria are considered before decisions are made. They should understand the fundamentals of data communications, including transmission options and connectivity issues, in order to help their companies maintain competitiveness in the future.

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