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ANNABEL Z. DODD

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—William Van Hefner, President, Vantek Communications, Inc.

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—Andrew Allentuck, Columnist, *Financial Post*, Toronto

"Ms. Dodd continues to provide an excellent and thorough text on the telecommunications industry. As in her previous editions, she presents a good balance of technical and business-related information that is readily understandable by anyone with an interest in this key component of today's business environment. In her new edition, she has captured many of the recent changes in this dynamic field, which will affect every company in the years ahead. I strongly recommend her book to anyone who wants a better understanding of telecommunications."

—Joe McGrath, SVP, Information Technologies,
Sunovion Pharmaceuticals, Inc.

"Dodd's work has been very helpful in the past in taking complex technical topics and translating them into actionable business items for my MBA students. Her book doesn't gloss over the details, but rather explains why they are important in the twenty-first century information age."

—Andrew Urbaczewski, Ph.D., Chair, Department of
Management Studies, Associate Professor of MIS,
College of Business, University of Michigan—Dearborn

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To Bob, Judy, Nancy, Laura, Steve, Bobby, Elizabeth,
Julia, Gabriel, Michael, Ari, Moses, Delancey, and Harry.

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Contents

Preface

Innovations in mobile networks and the Internet have eliminated barriers to communications created by geographic distances. People in different countries easily and often inexpensively communicate with one another via mobile devices, computers, and landline phones. Students who travel abroad for their education and workers who relocate for jobs stay in touch with friends and family through social media such as Facebook and Baidu as well as Internet calling services such as Skype.

The widespread availability of Internet access from wireless and wired devices is an important factor in the establishment of new innovative companies.

In the past 20 years, widespread availability of broadband for residential and business computers has enabled the emergence of new businesses that have taken advantage of the lower costs of using the Internet to distribute services. These ventures all have one thing in common: a leader with a vision and drive to succeed. For example, Jeff Bezos, founder of Amazon, developed innovative ways for consumers to read reviews of books and products, and simplified the purchasing process. The vision of Steve Jobs at Apple was for high-quality, innovative, easy-to-use computers, portable music players, and tablet computers. Internet-based companies have forever altered the retail and business-to-business models. Book publishing, book sales, and distribution and sales of music, TV shows, and movies are just a few of the industries that have undergone radical transformations.

The advent of affordable mobile services worldwide has greatly enhanced communications. Before mobile networks achieved global prevalence, many people did not have access to basic telephone service. Communications to Latin America, certain countries in Asia, and Africa were costly and cumbersome.

Mobile networks have made it easier for businesses to operate throughout the world by facilitating the communications among remote staff members and headquarters. However, quite often, poor physical infrastructure such as inconsistent electrical availability and impassable roads, along with corruption, pose barriers to operating businesses in many emerging economies. In addition, high rates of poverty in parts of Latin America, certain Asian countries, and Africa mean that much of the population can only purchases mobile services if they are at extremely low prices. This limits carriers' profits and incentives to upgrade networks.

The expansion of mobile services in emerging markets has created growth opportunities for established carriers from Europe, the Middle East, and certain countries in Asia. Spanish carrier Telefónica is now the second largest carrier in Latin America, where it has experienced high growth because most people have subscribed to mobile services for the first time in the past ten years. By contrast, its European operations have lower profits and little growth.

Mobile networks have had a particularly dramatic effect on countries that previously had scant resources for wired broadband facilities in even the largest cities. In these countries, populations often have mobile phones as their first means of electronic communication. The availability of low-cost mobile devices is also having a positive impact on the economies of developing countries and the lives of their citizens. For example, mobile banking has enabled people who previously had no access to banks to receive money and pay bills via their smartphone handsets.

The popularity of mobile networks for data as well as voice has strained network capacity. In the face of this demand, mobile carriers are upgrading networks to fourth-generation protocols such as Long-Term Evolution (LTE) and Worldwide Interoperability for Microwave Access 2 (WiMAX 2). These upgrades will make available for the first time high-speed Internet access to many small businesses and consumers in emerging countries and rural areas.

However, these network upgrades are costly. For this reason, many carriers have upgraded to intermediate solutions that increase speeds but don't offer as much capacity as LTE and WiMAX. In the long run, most carriers will upgrade to fourth-generation networks as manufacturing costs decrease.

But improvements in Internet capabilities have a dark side: loss of privacy and, sometimes, government surveillance. One of my international students at Northeastern University told the class a chilling incident about how his government monitors the postings of students on social networks from half-way around the globe. One of his friends criticized his country on Facebook while he attended college in the United States. When he went home for a visit, he was arrested at the airport on the basis of these critical remarks. His family has had no information about him since his arrest, and fear that he has been executed. This experience and others like it illustrate the ominous ability of governments to monitor online messages.

However, monitoring behavior on the Internet is an important tool in foiling security breaches that threaten business continuity, national defense, the viability of critical networks, the water supply, and the electric grid. A serious attack on strategic resources has the potential to cripple countries and cause widespread harm.

Another example of monitoring behavior online is when companies track an individual's browsing activities. For example, when consumers download *apps* (applications), browse the Internet, or fill out surveys, companies often collect information, such as age, address, educational level, and gender. Internet companies sell the data, sometimes without obtaining consumers' consent, to marketing companies that use the information to develop advertising strategies that target particular population segments. This results in the loss of consumer control over how their personal information is used.

Internet and wireless services have enabled changes in the ways consumers and enterprises access and store programs and files. In an effort to save staffing and operational costs, enterprises are using cloud computing. With cloud computing, applications such as e-mail, human resources, sales force automation, and accounts receivable are managed at a provider's data centers over the Internet. Residential consumers have also embraced cloud computing and use it to store and play music, create documents, and store backup copies of documents.

Organizations that are hesitant to place critical applications under the control of outside providers are taking advantage of new technologies to support centralized applications that require less space and energy, and fewer full-time staff members to support them.

They make their data center operations more efficient by centralizing services and eliminating those in branch offices, which reduces the required staffing. They have also embraced server virtualization, whereby multiple applications and operating systems are installed on a single server. This decreases the number of servers that need to be supported, which saves space and energy consumption.

Higher-speed, more-reliable networks are important factors that have enabled these efficiencies. As a result of network-based services, network criticality has increased, as have the need for higher speeds and capacity. Consumers and commercial organizations take network availability for granted. However, carriers have invested heavily in upgrading landline networks to meet these demands for capacity and connectivity.

Mobile and landline carrier consolidation is occurring worldwide, and many providers have global and nationwide operations. In parts of the world, two or three large providers control the majority of networks. This low level of competition results in high prices for Internet access and decreases the impetus for network innovation. By contrast, in countries such as India, which has a large number of mobile carriers, competition has resulted in low-priced mobile services. Low prices, however, have led to low profit margins.

The affordability of mobile services and the growing percentage of the population worldwide with access to the Internet pose difficult issues. For example, in countries with robust networks, commercial organizations expect employees to be always available via e-mail and text messaging. It has become more difficult to "tune out" and take a real break from work.

Moreover, it is challenging to balance the need to protect national security and personal financial data from hackers with the need to protect the privacy of citizens from government monitoring. It is additionally challenging to protect the privacy of consumers while recognizing that businesses need to understand market forces by monitoring consumer browsing behavior. These difficult issues won't be resolved by technological solutions alone.

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Annabel Z. Dodd is an adjunct faculty member at Northeastern University's School of Professional Studies, where she teaches courses on wireless mobile services and data communications in the Master's Degree Program in Informatics. She has been an adjunct professor in the Master of Science in Technology Management program at the State University of New York at Stony Brook, where she taught in a joint program with The Institute of Industrial Policy Studies, Seoul, South Korea. In addition, the Fundación de la Innovación Bankinter, selected her to participate in their Future Trends Forum in Madrid in 2004, 2005, and 2007. Formerly in marketing at New England Telephone (now Verizon Communications) and Telecommunications Manager at Dennison Manufacturing Company (now Avery Dennison), Annabel consults with major corporations and institutions and gives seminars to organizations worldwide. The Massachusetts Network Communications Council honored her as the Professor of the Year. *The Essential Guide to Telecommunications* has been translated into nine languages since its first edition, which was published in 1997. You can find more information at her web site, www.doddontheline.com.

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Part I

Enabling Technologies, Data Centers, and VoIP PBXs

1 Computing and Enabling Technologies

In this chapter:

The pace of technological advancement is faster today than ever before. The pace of change in networks began increasing in the late 1980s, and further escalated in the late 1990s with the increase in the number of personal computers at enterprises and homes, growing mobile phone usage, and the growth in both total Internet and multimedia traffic. Unlike earlier improvements during the 1900s, these more recent changes directly impact the way people socialize and how day-to-day business is conducted.

Initially, even with the proliferation of corporate personal computers in the 1980s, electronic communication among staff members was restricted to within the same building. Gradually, increasing speeds of internal networks and affordable fiber links between buildings made it feasible to link all sites within organizations. Later, the advent of powerful microprocessors and manufacturing economies of scale made computer ownership feasible for residential consumers. Affordable, high-speed Internet access for consumers as well as business customers created the tsunami of rapid change.

This escalation was made possible in large part by the introduction of fiber optics, the development of multiprocessing computer chips integrated into various types of network equipment, and the decrease in prices of mass computer storage. These factors along with the shrinking size of components are continuing to lead to vast improvements in mobile networks and mobile devices as well as land-based networks and consumer electronics. Children born in the twenty-first century have trouble imagining a world without e-mail and cell phones. These innovations will lead to even faster changes in the future.

A significant shift in computing is occurring with the introduction of *virtualization*, which came about because of more powerful networks and computers. Server virtualization is the capability of servers to store and run multiple operating systems, each running multiple applications. Servers are specialized computers that host applications such as e-mail or web pages. They can also host applications such as accounting and sales automation packages. The capability of virtualization to consolidate a large number of servers has resulted in the capability of data centers to consume less space and electricity and require fewer administrative tasks. It has also brought down the costs for large third-party providers to manage expansive data centers.

Virtualization and powerful networks are the key factors that have enabled *cloud computing* offerings to be viable. Cloud computing is when consumers, small businesses, and large organizations move some or all of their computing needs to external providers, who typically maintain large data centers. Clients usually access the applications and data that reside in these data centers via the Internet.

Because it is relatively new, most large commercial customers start out by using the cloud for applications that are important but not critical to their core offerings. These include human resources systems such as those designed for expense and vacation reporting. Although institutions have a high degree of interest in cloud computing, concerns about security, control over corporate data, providers' storage and server capacity, and cloud provider stability still exist.

In addition to the aforementioned technologies, Wide Area Network (WAN) acceleration and optimization, compression, and multiplexing increase the functionality of networks. WAN acceleration improves response times in the networks of commercial organizations when staff members access applications and download files from central sites. Without WAN acceleration and optimization, unacceptable delays would occur because of the way these applications are accessed and transmitted, even on high-speed networks.

Another major factor in broadening how mobile networks are used is compression, which uses complex mathematical formulas (algorithms) to decrease the amount of voice, data, and video to be sent over networks. Compression shrinks the amount of data to be sent and re-creates it at close to the same quality at the receiving end. In particular, it enables video and music to be carried efficiently over mobile networks without using up enormous amounts of network capacity. It's an underlying element in the capability of smartphones to download applications (apps) and use them to access services over the Internet.

Finally, multiplexing has enormously increased the capacity of fiber-optic networks. High-speed multiplexers powered by multi-core microchips provide the electronics that increase the capacity of a single pair of fibers by creating multiple streams, transmitting multiple light streams simultaneously rather than just sending a single stream. Without multiplexing, the capacity of the Internet would be vastly lower. Costs to build modern networks would be far more expensive because more cabling would be required to connect continents together, customers to the Internet, and cities to each other.

KEY UNDERLYING TECHNOLOGIES........................

The three technologies discussed in this section—fiber-optic cabling, multi-core processors, and memory—are the building blocks of modern networks. They enable networks to carry more information, faster. Decreasing memory costs have led to affordable personal computers and the ability to store vast amounts of information, accessible via fiber-optic-based networks at lower costs.

Fiber-Optic Cabling: Underpinning High-Speed Networks

Without fiber-optic cabling it would not be possible for the Internet to reach the speed and capacity required to link populations around the globe. Before the introduction of fiber cabling by MCI (now part of Verizon Communications) in 1983 for intercity routing, networks were labor-intensive to build and maintain. Copper cabling is heavier, and has less capacity than fiber cabling, and copper-based networks require more equipment to deploy and maintain.

Electrical signals used to transmit voice and data over copper cabling are subject to fading over relatively short distances. Consequently, amplifiers are needed every mile and a half to boost the electrical signals carried on copper-based networks. It requires many technicians to install and repair these amplifiers.

In contrast, data on fiber-optic cabling is carried as non-electric pulses of light. These non-electric signals can travel 80 miles before having to be regenerated. This is an enormous savings in labor and allows new organizations to lay miles of fiber between cities, creating competition among local, established telephone companies worldwide.

The most significant advantage of fiber-optic cabling is its enormous capacity compared to copper cabling and mobile services. Light signals on optical cabling pulse on and off at such high speeds that they are able to handle vastly greater amounts of information than any other media.

Once fiber-optic cabling was in place, electronics were developed in the form of *wavelength-division multiplexing*, which further expanded fiber's capacity. These multiplexers essentially split a single fiber into numerous channels, each able to transmit a high-speed stream of light pulses, as shown in Figure 1-1. The current generation of multiplexers are capable of transmitting up to 88 channels of information, each operating at 100 gigabits per second (Gbps).

Fiber optics and its associated electronics have evolved to the point where a consortium of companies including Google, Japanese carrier KDDI, Singapore Telecommunications, and India's Reliance Globalcom are constructing and will operate a six-pair fiber undersea cable with a capacity of 17 terabits per second (Tbps). (One terabit equals 1,000Gb.) That's fast enough to transmit every book in the British Library 20 times per second.

The undersea cable will run from Singapore to Japan, with extensions to Hong Kong, Indonesia, the Philippines, Thailand, and Guam. At the time of this writing, it was scheduled to begin operation sometime in 2012. For older networks, once high-quality fiber is installed in trenches, electronics can be added to increase its capacity

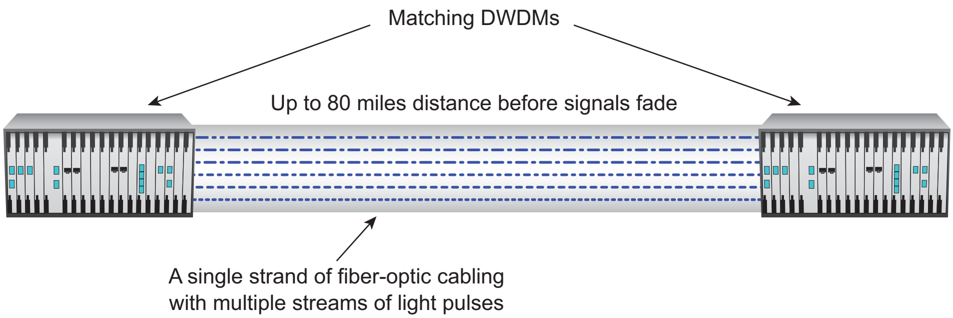


Figure 1-1 *A fiber-optic cable with Dense Wavelength-Division Multiplexers (DWDMs) attached.*

to handle the growing amounts of traffic, including high-definition video transmitted along its routes. The costs to dig trenches and lay fiber are many times higher than the costs to upgrade fiber to handle more traffic. This is why spare fiber pairs are included when new fiber-optic cabling is installed.

Faster, Lower-Priced Processors: Decreasing Memory Costs

Faster multi-core processors, such as those manufactured by Intel, are an integral part of the high-speed electronics used on fiber-optic links. They enable these networks to process multiple streams of light signals simultaneously. They are also at the core of network switches, continually transmitting increasing amounts of data at ever-higher speeds. Additionally, these processors facilitate the capability of personal computers to handle graphics and video transmitted via the Internet.

Many processors used in consumer electronics and mobile phones are based on architecture by ARM Holdings, Plc. This architecture now incorporates 32-bit processing (the ability to process data in chunks of 32 bits), which means that they process data faster. Moreover, they are small and inexpensive, and they use only small amounts of power. Figure 1-2 depicts a prototype of an ARM chip on a circuit board. Low power consumption results in longer battery life in mobile devices. ARM chips are designed by semiconductor firm ARM Holdings, Plc, and are available to electronics manufacturers who pay licensing fee plus royalties up front for each chip designed. According to its web site, 95 percent of mobile devices sold worlwide are equipped with ARM chips.

Figure 1-2 *The ARM chip is 12 millimeters by 12 millimeters. (Twelve millimeters equals .48 inches.) New mobile devices have at least two chips installed. (Photo courtesy ARM Holdings, Plc.)*

Low-cost memory has it made it feasible to embed memory in low-cost consumer electronics and smartphones. It has also enabled enterprises and cloud providers to purchase vast amounts of hard-drive capacity for archival purposes. Thus, companies such as Carbonite, based in Boston, are able to purchase enough memory to offer redundant hard-drive capacity to back up the entire content of a typical consumer computer for less than $30 per year.

SENDING DATA IN PACKETS ....

All Internet traffic, and the vast majority of high-speed data network traffic, is sent in *packets*. Putting data into packets is analogous to packaging it in envelopes. Packet switching was developed by Rand Corporation in 1962 for the United States Air Force and utilized in 1969 in the Advanced Research Projects Agency (ARPANET) of the Department of Defense. ARPANET was the precursor to today's Internet. The Department of Defense wanted a more reliable network with route diversity capability. Developers envisioned greater reliability with packet switching in the ARPANET, where all locations could reach one another.

Packet networks—which includes the Internet—are often more reliable and can better handle peak traffic periods than older, traditional networks, because diverse packets from the same message are routed via different paths, depending on both availability and congestion. In a national emergency such as the September 11, 2001 attacks in the United States on the Pentagon in Washington, DC, and the World Trade Center in New York City, the Internet still functioned when many portions of the public voice and cellular networks were either out of service or so overwhelmed with traffic that people could not make calls.

If one route on a packet network is unavailable, traffic is rerouted onto other routes. In addition, unlike older voice networks, the Internet does not depend on a few large switches to route traffic. Rather, if one router fails, another router can route traffic in its place.

Routing Efficiencies

Packet networks are able to handle peak congestion periods better than older types of networks because traffic is balanced between routes. This ensures that one path is not overloaded while a different route carries only a small amount of traffic. Sending data from multiple computers on different routes uses resources efficiently because packets from multiple devices continue to be transmitted without waiting until a single "heavy user" has finished its entire transmission. Thus, if one route is congested, packets are transmitted on other routes that have more availability.

Packet Contents: User Data versus Overhead

Each packet is made up of user data; data bits, digital voice or video, and specialized header information, such as addressing, billing, sender information, and error correcting bits. Error correction might indicate if the packet is damaged, if the receiver is ready to start receiving, or if the packet has been received. The end of the packet contains information to let the network know when the end of the packet has been reached. Header, end-of-packet data, and other signaling data are considered *overhead*. *User data* (also referred to as the payload) is the actual content of the e-mail message or voice conversation.

Throughput

Throughput is the amount of user information transmitted, not the actual speed of the line. The disadvantage of frequent error messages and other protocol-related bits is that overhead bits often consume large amounts of bandwidth. Throughput only measures actual user data transmitted over a fixed period of time. Protocols with many bits for error control messages and other types of overhead have lower throughput. Technologies such as WAN optimization are used to mitigate the effect of delays associated with these protocols. (See the section "Wide Area Network Acceleration and Optimization," later in this chapter, for more information.)

So, What Are Carriers, ISPs, and WISPs?

At one time, the term "carrier" referred to local telephone companies, such as Verizon Communications, that carried voice and data traffic for consumers and commercial organizations. Prior to 1996, cable television companies, such as Comcast, were strictly cable television operators. Now, all companies that provide outside cabling or mobile infrastructure and operate networks are generally referred to as carriers. These include cable television operators, mobile telephone companies, long distance providers and traditional local telephone companies. Cable TV operators, mobile carriers, and traditional local telephone companies transmit voice, data, and television signals as well as providing connections to the Internet. To complicate matters further, carriers are also referred to as operators and providers.

Continued

ISPs such as AOL (America OnLine) primarily supply the connections to the Internet and information services over a carriers' cabling, and sometimes provide the switching infrastructure. ISPs also provide wireless services, e-mail hosting, and other services over a carriers' infrastructure. Wireless ISPs (WISPs) offer a variety of wireless services such as Internet access in areas without broadband landline facilities. See Chapter 7, "Mobile and Wi-Fi Networks," for more information on WISPs.

DEEP PACKET INSPECTION: TRAFFIC MANAGEMENT AND MONITORING ....

Deep Packet Inspection (DPI) is one tool that network operators use to manage and understand network traffic. It accomplishes this by analyzing the contents of packets transmitted on network operators' landline and mobile networks. For the most part, DPI examines the content in the headers of packets rather than user content. It inspects and looks for patterns in header information, such as error correction, quality of service, and end-of-message bits, not the e-mail messages themselves.

DPI is an application that can potentially be used by carriers to discriminate against competitors' traffic. For example, using DPI, a carrier can slow down or block traffic generated by competitors' services. See Chapter 6, "The Internet," for information on network neutrality. Network neutrality refers to carriers treating their own and competitors' traffic in an equal manner.

Governments can also use DPI to monitor and censor e-mail messages that they might consider harmful. This can be a double-edged sword, however, as DPI can be used, for example, to track terrorists or people critical of the government.

DPI helps carriers, ISPs, large universities, and enterprises to understand as well as manage their traffic.

Providers can use it to do the following:

- Prioritize traffic
- Maintain control over proprietary information
- Protect networks against hackers
- Block traffic to certain sites
- Plan network capacity requirements

Large, modern packet networks typically carry a mix of rich media traffic, including television, movies, game, voice, and music streams, as well as data. (Previously, packet networks transmitted only data, which requires less capacity and no special treatment.) Faster processers and more affordable memory have led to new DPI switches that enable carriers, large universities, and enterprises to manage congestion in real time as well as offer new services on these diverse mobile and landline networks. In addition, organizations use it to block access to specific non-business-associated web locations such as Facebook (the social network site) to cut down on unnecessary traffic on their networks and increase employee productivity.

Don Bowman, chief technology officer at Sandvine Incorporated, was cited in the article "Flattened networks, creative pricing drives bigger DPI boxes" (Karpinski, Rich, *Telephony Online*, September 9, 2009). The article paraphrased Bowman's statement that DPI is more commonly implemented in countries with mature networks to help them manage their networks than in developing countries where the emphasis is on building new, high-speed networks, not in fine-tuning them. DPI can be used to manage traffic in the following scenarios:

- On a specific carrier's Internet networks
- Between residential customers and their carriers
- On mobile networks
- Between enterprise locations
- On enterprise links to the Internet
- Within the internal networks of an enterprises

It further enables telephone companies to categorize traffic in real time to support more flexible price offerings for mobile carriers' data packages. This is an important competitive advantage, particularly in countries with more than two mobile carriers who compete on pricing and flexibility of the packages that they offer.

DPI systems have the capability to exchange information with a carrier's billing system to support specialized offerings for data plans covering e-mail, songs, games, video, and web browsing. A mobile carrier might offer plans in which customers are allowed to use 300Mb of data for a fixed price, with metered pricing kicking in on anything over 300Mb.

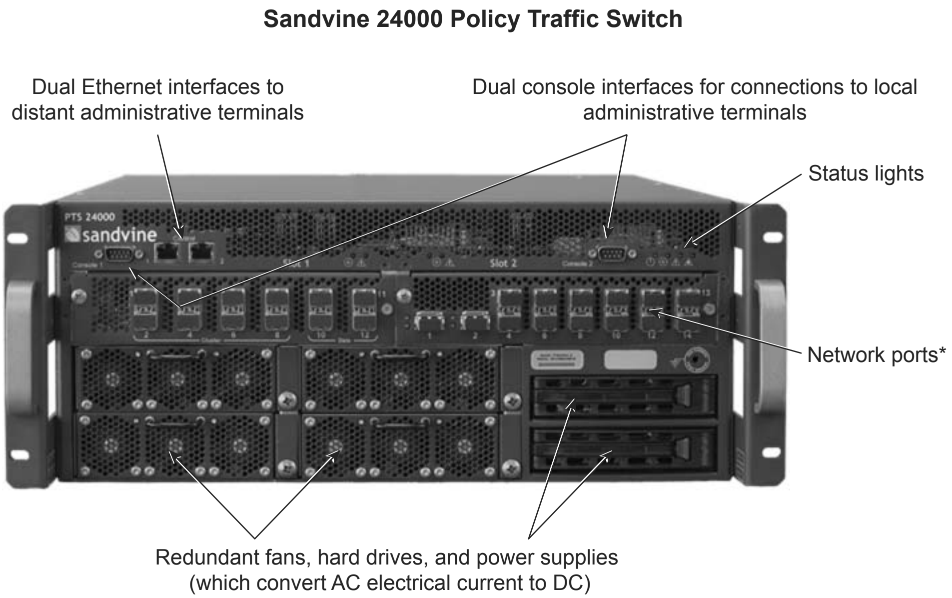
Metered pricing is a billing practice in which customers are charged by usage, rather than a flat rate, for unlimited or predetermined amounts of minutes or data bits. DPI switches tied into a carrier's network can be configured to notify a user when she has used up her plan's allotted minutes or data bits and will be henceforth charged additionally for any additional phone calls or data transmissions.

How Deep Packet Inspection Works

DPI is able to provide information on network conditions because of its capability to see more fields in packets than only the “send to” address. Discerning only a packet’s address is analogous to looking at the address of an envelope. DPI provides the capability to determine which application the packet is using by examining patterns within packets. It can distinguish *Voice over Internet Protocol* (VoIP) traffic from data, gaming, and video traffic so that video or gaming traffic within a carrier network can be given the treatment required to maintain optimum performance.

DPI software develops a database of patterns, also referred to as *signatures*. Each signature or pattern is associated with a particular application such as peer-to-peer music sharing or protocols such as VoIP. It can also be associated with traffic from certain hackers or even terrorists attempting to launch malicious attacks with a goal of disrupting Internet or government sites. The DPI software matches its own database of patterns found in packets to those associated with particular applications, and network attacks.

DPI software can be installed in stand-alone switches connected to an ISP or carrier’s network or as part of routers (see Figures 1-3 and 1-4). Routers are used to connect traffic to the Internet as well as to select routes to other networks.



* Network ports interface with third-party systems, such as billing and charging operations, DPI applications, and subscriber profile databases.

Figure 1-3 *A Sandvine DPI switch. (Courtesy Sandvine, Inc.)*

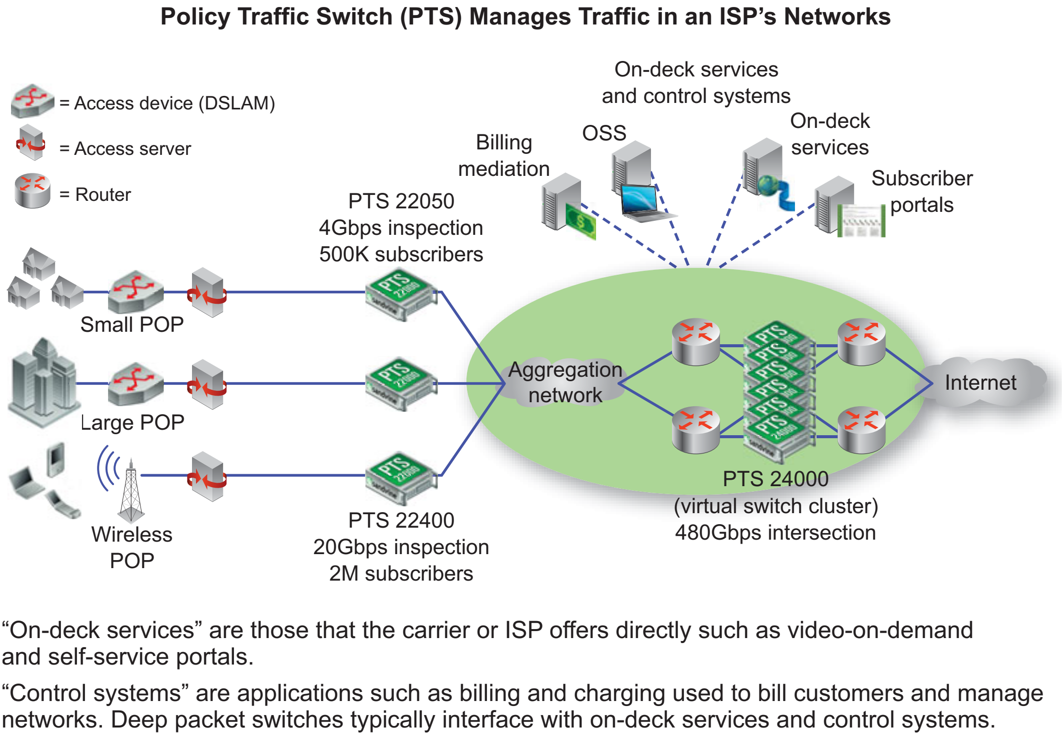


Figure 1-4 *Access devices such as Digital Subscriber Line Access Multiplexers (DSLAMs) connect to customers' modems. The POP (Point of Presence) is the location of the ISP's switching equipment. Managed services include e-mail, text messaging, and content from CNN. (Courtesy Sandvine, Inc.)*

Using DPI to Manage Networks in Private and Public Educational Institutions

In addition to ISPs, universities, colleges, and high schools also use DPI to manage traffic. Large universities often transmit cable TV to dorm rooms and classrooms over the same fiber networks used for all of their data and voice traffic. Educational institutions often carry IP video downloaded from the Internet to classrooms. The DPI software prioritizes video transmitted over these internal networks. Prioritizing video ensures that the video is of acceptable quality. If it's not prioritized, packets might be dropped when the school's network is congested, causing images to freeze.

In other cases, universities and ISPs have been served warrants from law enforcement agencies asking that they turn over the names of students or others who download music illegally from music sharing sites or peer-to-peer Internet sites. These agencies can use DPI services to identify these individuals. In 2009, several music companies sued a 25-year-old graduate student for illegal music downloads and won a $670,000 judgment. In another case, music companies won a $1.2 million judgment case against a single mother. Public sympathy for these defendants has forced music companies to stop suing individuals and begin working with ISPs who can use DPI in an attempt to stop illegal music sharing.

Government Use of Deep Packet Inspection: Packet Capture

Deep Packet Inspection (DPI) is an important tool for managing traffic on complex networks, carrying different types of traffic. However, carriers can also use it to aid government efforts. Some governments have requested that carriers use it to prevent information about political situations from being disseminated to the rest of the world. Many governments have asked that carriers deploy DPI to ferret out terrorist plots, drug trafficking, and other criminal activities.

Depending on how it's configured, most DPI equipment can monitor either the header only or the header plus the user data (payload) of e-mail and instant messages. Capturing the payload of a message is referred to as *data capture*. Data capture can be used to store messages for later scrutiny or to scan messages in real time. Either function requires fast processors and massive storage archives.

With the capability to recognize user data in packets, DPI equipment can be used to monitor e-mail messages by detecting keywords. For example, according to an article in the *Wall Street Journal*, "Iran's Web Spying Aided by Western Technology" (Rhoads, Christopher, June 22, 2009), during its 2009 presidential elections, the Iranian government used DPI to monitor e-mail messages from citizens who they suspected were opposed to the government's candidate. In addition, they attempted to block e-mail messages that contained information about street demonstrations opposing the government's candidate.

DPI software that is programmed to only monitor addressing within packet headers can block messages and browsers from accessing particular web sites. This has happened in numerous countries worldwide. However, some citizens figure out ways to circumvent efforts to block them from reaching particular web sites.

COMPRESSION

Compression reduces the size of video, data, image, and voice files. This decreases the amount of network capacity needed to transmit files. Compression increases throughput without changing the actual speed of the line.

NOTE

When compressed music and video files are downloaded from the Internet, video or voice is re-created at the receiving end by using less-powerful, lower-cost but acceptable *asynchronous* compression. Streaming compression algorithms assume that the end user will have less processing power to decode transmissions than the developers and broadcasters that encode the video and audio.

Enterprises typically use *synchronous* compression to re-create text, image and numeric files exactly as they were sent by using web acceleration and optimization. (See the section "Wide Area Network Acceleration and Optimization," later in this chapter.)

With compression, a song can be downloaded in seconds rather than minutes because fewer bits need to be sent. At the receiving end, compatible compression software or hardware re-creates the compressed chunks into close to or the same image or sound that was sent. Text is re-created exactly as it was before it was compressed so that numeric information or product information is not altered. However, when it's received, compression might re-create video and voice in varying degrees of lower video resolution or voice quality with acceptable, often barely noticeable, alterations.

Compression used with text and facsimile often reduces the amount of data to be transmitted by removing white spaces and by abbreviating the most frequently appearing letters. For instance, repeated letters are abbreviated into 3-bit codes instead of 8-bit codes. In a similar fashion, one method of video compression transmits only the changed image, not the same image over and over. In a video conference, nothing is transmitted after the initial image of a person until that person moves or speaks. Fixed objects such as walls, desks, and backgrounds are not repeatedly transmitted.

There are a number of standardized compression *algorithms* (mathematical formulas used to perform operations such as compression) that enable compressed text and video to be transmitted in a format that can be easily decompressed at the receiving end. The following is a list of commonly used compression protocols:

- Various *MPEG* standards are used to compress and decompress audio and video. MPEG stands for Moving Picture Experts Group.
- *MP3* is used for downloading music and other files to iPods.
- Apple's iPod uses *Advanced Audio Coding* (AAC).
- Most Windows-based personal computers have *WinZip* compression.
- *Zipit* is installed on Macintosh computers running OS 10.x.x.

See Table 1-1 in the "Appendix" section at the end of this chapter for a more complete listing of compression standards.

Compression: The Engine behind TV on the Internet

Video and multimedia capabilities have transformed how people use the Internet. Television and movies at sites such as Hulu (a joint venture of Comcast's NBC Universal, News Corporation's Fox Entertainment Group, and Walt Disney Company) and YouTube (a part of Google) enable people to get their entertainment, sports events, and news in video formats from the Internet. Viewers now expect good-quality video over their broadband connections, where in addition to TV and movies, they can view real-time sporting events. To take advantage of these capabilities, broadcasters and cable networks are creating strategic plans to include broadband streaming in their product mix.

In another nod to the future, new television sets have the capability to connect directly to the Web so that people can stream and watch broadband programming more easily on their high-definition, digital televisions. These changes have been made possible by advancements in compression.

Streaming: Listening and Viewing without Downloading

For the most part, when people watch television and movies on the Internet, the content is streamed to them. They do not own or keep copies of what they're viewing.

Streaming is different from downloading. Downloading requires an entire file to be downloaded before it can be viewed or played. With streaming, the user can listen to music or view a video in real time, but cannot store it for later use. When users download from sites such as iTunes, they can store the music files on their computer's hard drive. Spotify is a European site that offers free streaming and monthly subscriptions for €10 to download music. Free streaming music is also available at sites such as Pandora Internet Radio, where users select artists as examples of the type of music they want to listen to. Pandora then streams that genre of music to them.

Streaming and downloading music has caused the music industry and artists' royalties to shrink considerably. Customers now buy their music primarily from vendors such as iTunes, not in the form of CDs, and some users, particularly teenagers, download music without paying from sites such as LiveWire and Kazaa. According to an April 9, 2008 survey by investment bank Piper Jaffray, 61 percent of students surveyed download music illegally. Low royalties have forced popular singers to depend on concert sales for the majority of their income.

Advancements in Compression

Improvements in video compression have been largely fueled by developments in video production hardware, such as faster, multi-processing chips, and by developments in software, such as Adobe's Flash and Microsoft's Silverlight. These new processors along with superior mathematical algorithms enable larger chunks of media to be compressed more rapidly. Flash is a multi-platform software program that developers use to create animation in electronic games, web-based video conferencing, and video. Flash was previously installed on some mobile devices (not Apple tablets or portable music players, which are compatible only with HTML5) and on many video web sites. However, Adobe now uses HTML5 programming techniques for mobile devices. Free versions of the software are often bundled into personal computers so that people can view video created in Flash. Adobe Systems, Inc., owns the rights to and develops Flash.

On2 Technologies, Inc., is the creator of the video compression used in Flash software. According to John Luther, WebM project manager at Google Inc., in the past four years there have been significant developments in video due in large part to improvements in Flash. Now, video downloaded or streamed from the Web works the same on Apple and Windows computers with different types of compression installed. This is because Google has created software extensions that reside on the same chips and support both Apple's QuickTime and Microsoft's Windows Media Player. *Extensions* are add-ons that extend the capabilities of other software or hardware.

Thus, people who download video in the form of movies or sporting events, as an example, are generally no longer aware that they need a special type of compression software. Apple mobile devices are exceptions because they use HTML5 for viewing video. Developers are increasingly using HTML5 programming techniques for compatibility with Apple and other devices.

Using Codecs to Compress and Digitize Speech

Speech, audio, and television signals are analog in their original form. Analog signals are transmitted in waves; digital signals are transmitted as on and off bits. Before they are transmitted over digital landlines or wireless networks, codecs compress (encode) analog signals and convert them to digital bits. Codecs sample speech at different amplitudes along the sound wave and convert it to a one or a zero. At the receiving end, decoders convert the ones and zeros back to analog sound or video waves.

Codecs are located in cellular handsets, telephones, high-definition TV transmitters, set-top boxes, televisions, IP telephones, and radios. Codecs also compress voice in speech recognition and voicemail systems. With compression, codecs do not have to sample every height on the sound wave to achieve high-quality sound. They might skip silence or predict the next sound, based on the previous sound. Thus, fewer bits per second are transmitted to represent the speech.

INCREASING NETWORK CAPABILITIES VIA MULTIPLEXING

Multiplexing combines traffic from multiple devices or people into one stream so that they can share a circuit or path through a network. Each source does not require a separate, dedicated link.

Like compression, companies and carriers can use multiplexing to send more information on wireless airwaves, fiber networks, and internal Local Area Networks (LANs). However, unlike compression, multiplexing does not alter the actual data sent. Rather, the multiplexer at the transmitting end combines messages from multiple devices and sends them on the same wire, wireless, or fiber medium to their destination, whereupon a matching device distributes them locally.

One important goal is to make more efficient use of the most expensive portion of a carrier's network so that the carrier can handle the vast amounts of traffic generated by devices such as *smartphones* (multipurpose mobile phones with both Internet access and voice capabilities) and computers. Multiplexing is also used by enterprises that link offices together or access the Internet by using only one circuit (a path between sites) rather than paying to lease multiple circuits from their provider. The two most commonly used types of multiplexing are time division and statistical.

Time-Division Multiplexing

Time-Division Multiplexing (TDM) is a digital multiplexing scheme that saves capacity for each device or voice conversation. Once a connection is established, capacity is saved even when the device is not sending information. For example, if a call is put on hold, no other device can use this spare capacity. Small slices of silence with thousands of calls in progress result in high amounts of unused network capacity. This is the reason TDM is being gradually replaced in high-traffic portions of networks by Voice over Internet Protocol (VoIP) technologies, in which voice packets are interspersed with data and video traffic more efficiently, without wasting capacity. Thus, network capacity is not wasted during pauses in voice or data traffic.

Both T1 and T3 use TDM and carry voice, video, and data over a single circuit. In North America and Japan, T3 carries 672 conversations over one line at a speed of 45Mbps. T3 is used for large enterprises, call centers, and Internet access. Small and midsize organizations commonly use T1 for Internet access. T1 carries 24 streams over one circuit at 1.54Mbps. Matching multiplexers are required at the sending and receiving ends of each channel.

Statistical Multiplexing and Achieving Efficient Utilization via Priority Network Services

Unlike TDMs, *statistical multiplexers* do not guarantee capacity for each device connected to them. Rather, they transmit voice, data, and images on a first-come, first-served basis, as long as there is capacity. Ethernet is an example of statistical multiplexing. It can be used in a Wide Area Network (WAN) to connect customers to the Internet. It is also the most common method of accessing LANs within buildings. On Ethernet LANs, if more than one device attempts to access the LAN simultaneously, there is a collision and the devices try again later. Ethernet used for LAN access is located in each network-connected device, such as a printer, computer, or security monitor.

Statistical multiplexers support more devices than TDMs because they don't need to save capacity when a device is not active. Carriers sell WAN Internet access via Gigabit Ethernet offerings, supporting a range of speeds from 10Mbps to 10Gbps. If there is a surge in traffic, such as during peak times, the carrier can temporarily slow down traffic. However, because Gigabit Ethernet's statistical multiplexing has the capability to prioritize traffic, customers who contract for more costly, high-priority service can obtain higher speeds than customers with lower-priority service during traffic spikes.

Bytes versus Bits: Measuring Capacity and Speed

Federal and state requirements mandating retention of e-mail, financial, and other documents as well as corporations retaining all of their files rather than filtering out just what is needed have resulted in computer data storage in the petabytes range. A petabyte equals 1,000,000,000,000,000 characters or 1,000 terabytes.

People often use the terms "bits," and "bytes" interchangeably. Their meanings, however, differ significantly. *Bits per second* (bps) refers to the actual number of bits sent in a given time from point A to point B, or the number of bits transmitted each second. It is also represented as millions of bits per second (Mbps), gigabits per second (Gbps), and terabits per second (Tbps). Simply put, it is the number of bits that can be transmitted in one second.

Continued

Bps (with a capital "B") stands for *bytes per second* by convention. Speeds are represented by the bps acronym. Here are some examples:

- Gigabit Ethernet, used in carrier and enterprise networks, can carry data at speeds of one gigabit per second (1Gbps) to 100 gigabits per second (100Gbps).
- Terabit speed routers deployed on the Internet are capable of transmitting at a rate of 1,000 gigabits or 1 terabit; 10 terabits per second = 10,000,000,000,000 bps.

Bits organized into groups of 8 bits are bytes. Each byte can be a letter character, punctuation, or a space. Computer hard-drive capacity is measured in bytes, but speeds on digital lines are measured in bits transmitted per second. Bytes stored on computer drives and large servers are stored in digital form.

To summarize, a *byte* is a character made up of 8 *bits*. A bit is an on or off electrical or light pulse.

WIDE AREA NETWORK ACCELERATION AND OPTIMIZATION

Lower-cost Wide Area Network (WAN) services and data lines have made it affordable for midsize and some small organizations to link domestic and international offices with headquarters via high-speed data links. (See Chapter 4, "Carrier Networks," for information on carrier network services.) Previously, these organizations only had access to centralized e-mail.

More recently, organizations have centralized an increasing number of IT functions at their headquarters to reduce or eliminate staffing expenses at remote offices. However, when the ability to access applications and files over the WAN is added, linking their remote offices to their headquarters, they often find that users have to sit and wait while files are downloaded.

This becomes a critical issue as organizations grow, centralize IT services, merge with other companies, or add remote sites to their networks. It's not unusual for enterprises to connect their headquarters with as many as 80 remote sites, including branch offices, small sales offices, and warehouses located in their home country, as well as in international locations.

WAN acceleration and optimization, also referred to as application acceleration, improves the performance of data lines between enterprise locations. It is done by a combination of improved compression and the elimination of delays caused by the most commonly used protocols.

Even with high-speed connections, delays can occur when users access data remotely. Certain protocols are at the root cause for many of the long waits for requested documents and applications to download to personal computers. Downloading delays are referred to as *latency*. TCP, HTTP, and HTML are the most commonly used protocols that contain many error control messages that cause latency. (See the Glossary for definitions of HTTP, HTML, and TCP.)

A number of companies, including Cisco Systems, Riverbed Technology, and software start-up Certeon Inc., offer WAN optimization and acceleration. Gareth Taube, former vice president of Worldwide Marketing at Certeon Inc., refers to the aforementioned protocols as being "chatty". Examples of "chatty" messages in protocols include "are you ready?" and "did you get those packets?" Error messaging dialogues create delays because documents aren't downloaded until both ends of the transmission respond to these and other control messages.

Certeon's software improves transmissions by substituting a proxy that emulates these error messages at the receiving end. The sending end removes most of the error messages. At the receiving end, the proxy performs the error control locally so that transmissions are not delayed by control messages. This technique works effectively on high-quality links such as those made up of fiber-optic cabling.

Because most WAN traffic is identical to previous transactions, Certeon's patent-pending de-duplication (a type of compression) sends only changes in data exchanges, not the entire file each time. As an example, when two offices collaborate on a Microsoft PowerPoint presentation, the software learns what is in the file the first time it is sent. When a person resends the file with edits, only the changes are transmitted, thus decreasing the file size from perhaps 5 megabytes to 10 kilobytes. The software at the receiving end reassembles the file with the changes included.

In addition to latency elimination and compression, some WAN optimization software can prioritize certain types of data traffic. For example, for a financial institution, it can give priority to customer web transactions over internal communications. This speeds up money transfers to the institution.

Streamlining protocols and using compression increases throughput on enterprise data links and creates more capacity for current and future applications. An important capability makes it possible to utilize an organization's data links to electronically back up corporate data to other sites. If the main data center is destroyed by fire or a natural disaster, the organization's data is preserved. This is possible because WAN acceleration software and compression technology free up bandwidth capacity for data backup.

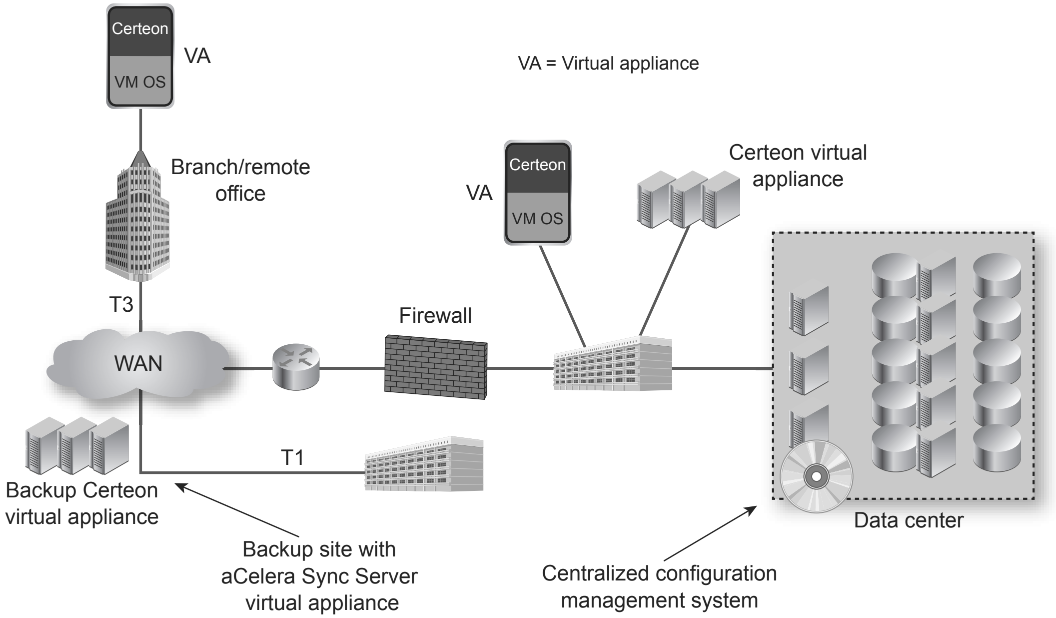


Figure 1-5 *Certeon aCelera Virtual Appliance software loaded onto a virtual computer on a physical server at headquarters and at remote branches. Proprietary hardware is not required. (Courtesy Certeon)*

WAN acceleration software is often installed on standard computers at the customer's locations. Certeon's software is downloaded onto virtual servers (servers that can run multiple operating systems and applications), in data centers, and at remote locations. (See the section "Single Servers Functioning As Multiple Servers via Virtualization," later in this chapter, for information on virtualization.) Additionally, the software can be downloaded to a desktop computer for remote employees. Figure 1-5 portrays an example of WAN acceleration and optimization software installed at headquarters and branch offices.

USING PROTOCOLS TO ESTABLISH A COMMON SET OF RULES

Protocols enable disparate devices to communicate by establishing a common set of rules for sending and receiving. For example, TCP/IP is the suite of standard protocols used on the Internet with which different types of computers, running a variety of operating systems, can access and browse the Internet. TCP/IP is a prime factor in the Internet's widespread availability.

The fact that protocols used on the Internet are available for free in their basic form and work with a variety of browsers, operating systems, and computer platforms makes them attractive interfaces for enterprises, hosting, and cloud-computing sites that support remote access to services such as Microsoft Office documents. A web-based interface compatible with many types of computers and operating systems enables enterprises to support software at a central site.

Installing software at a central site minimizes support requirements. When an IT department supports applications such as the Office suite that are installed on each user's computer, it must download software and updates to every computer and ensure that each has a compatible hardware platform and operating system. By locating the software at a central site rather than on each user's computer, updates and support are simpler. In addition, fewer IT employees are required to maintain servers with applications on them in remote offices.

However, many of these frequently used protocols are structured in such a way that they add a great deal of overhead traffic to the Internet and enterprise networks. This is because these protocols require numerous short signaling messages between the user and the Internet for functions such as identifying graphics, checking for errors, and ensuring correct delivery and receipt of all the packets.

The following protocols are used on the Internet and on corporate networks that have a web interface to information accessible to local and remote users.

- **Ethernet** This is the most common protocol used in corporate Local Area Networks (LANs). It defines how data is placed on the LAN and how data is retrieved from the network. Wi-Fi wireless networks are based on a different form of Ethernet.
- **Hypertext Markup Language (HTML)** This is the markup language used on the Internet and on enterprise networks. It is often used by employees who write web pages for their organization. HTML commands include instructions to make text bold or italic, or to link to other sites. Instructions, known as tags (not visible on Internet documents), are bracketed by open and closed angle brackets (< and >), otherwise simply known as the less-than and greater-than symbols. Tags indicate how browsers should display the document and images within each web page. For example, <bold> is a command for bolding text. Tags are delivered along with the web page when users browse the Internet and access information through web interfaces at enterprises. They are good examples of overhead bits.
- **Extensible Markup Language (XML)** This is another markup language based on elements surrounded by tags that identify fields requiring user input. The tag <name> is an example of a tagged label; it is not visible to users, but labels the field. Other variable labels might include quantity,