1 Computing and Enabling Technologies

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- Compression
- Increasing Network Capabilities via Multiplexing
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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.

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 inter-city 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 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.

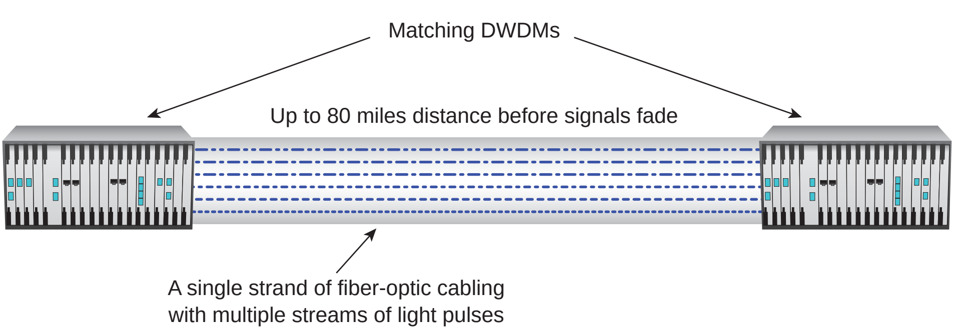

Figure 1-1 *A fiber-optic cable with Dense Wavelength-Division Multiplexers (DWDMs) attached.*

Fiber-Optic Cabling in Commercial Organizations

Because fiber is nonelectric, it can be run in areas without regard to interference from electrical equipment. This is the main reason fiber transmits signals farther than copper before fading. Signals are transmitted along the fiber in the form of on and off light pulses, somewhat similar, in theory, at least, to the operation of signaling lamps that were commonly used in the Navy to transmit Morse code messages.

Although fiber-optic cabling has many advantages for high-traffic areas, the specifications for fiber connections are more exacting, and the fiber itself requires more care in handling and installation. For example, it is less flexible than copper and cannot be bent around tight corners. However, given its greater capacity and cost savings in ongoing maintenance, carriers install fiber in the majority of new apartment buildings and office complexes.

There are two reasons why fiber is typically more expensive than copper to install.

- The electronics (multiplexers and lasers) to convert electrical signals to optical signals, and vice versa, are costly.
- Specialized technicians, paid at higher levels, are required to work with and test fiber cabling.

In addition, the multiplexers and interfaces to copper cabling in the customer's facility requires local power. This adds a point of vulnerability in the event of a power outage.

Fiber-optic cable is made of ultra-pure strands of glass. The narrower the core that carries the signals, the faster and farther a light signal can travel without errors or the need for repeaters. The cladding surrounding the core keeps the light contained to prevent the light signal from dispersing; that is, spreading over time, with wavelengths reaching their destination at different times. Finally, there is a coating that protects the fiber from environmental hazards such as rain, dust, scratches, and snow.

Another benefit of fiber-optic cabling is that eavesdropping is more difficult because the strands have to be physically broken and listening devices spliced into the break. A *splice* is a connection between cables. Splices in fiber-optic cables are easily detected.

Single-Mode versus Multi-Mode Fiber

There are two main types of fiber: single-mode and multi-mode. Single-mode fiber is smaller, is more expensive, and supports higher speeds than multi-mode fiber. Measuring approximately the same diameter of a strand of human hair, it is used mainly in carrier networks and in undersea cabling.

The fact that single-mode fiber carries light pulses faster than multi-mode fiber can be explained by a geometric rule: A straight line is the shortest distance between two points. Light travels faster in a straight line than if it zigzags along a path, which is precisely what happens to light waves if they reflect, or "bounce," off the inner wall of the fiber strand as they travel. These zigzag paths also cause the signals to attenuate, lose power, and fade over shorter distances. The small core of single-mode fiber keeps the light signal from bouncing across the diameter of the fiber's core. Thus, the straighter light signal travels faster and has less attenuation than if it had a bouncier ride through the core.

When the light pulses travel in narrower paths, fewer repeaters are needed to boost the signal. Single-mode fiber can be run for 80 miles without regeneration (boosting). In contrast, signals on copper cabling need to be repeated after approximately 1.5 miles. For this reason, telephone companies originally used fiber for outside plant cabling with cable runs longer than 1.24 miles.

The main factor in the increased expense of single-mode fiber is the higher cost to manufacture more exact connectors for patch panels and other devices. The core is so small that connections and splices require much more precise tolerances than with multi-mode fiber. If the connections on single-mode fiber do not match cores exactly, the light will not be transmitted from one fiber to another. It will leak or disperse out of the end of the fiber core at the splice.

Multi-mode fiber has a wider core than single-mode fiber. The wider core means that signals can only travel a short distance before they require amplification. In addition, fewer channels can be carried per fiber pair when it is multiplexed because the signals disperse, spreading more across the fiber core. Multi-mode fiber is used mainly for LAN backbones between campus buildings and between floors of buildings.

Another factor in the expense of installing fiber cabling systems is the lack of connector standardization. Different fiber system manufacturers require specialized tools and proprietary connectors. Two of the main connector types are the Straight Tip (ST) and the Subscriber Connector (SC). Another is the Small Form Factor (SFF) connector. Each type of connector requires specialized tools for installation.

Making Connections between Fiber and Copper

In enterprise networks, when fiber is connected to copper cabling at locations such as entrances to buildings, at wiring closets, or in data centers, equipment converts light pulses to electrical signals, and vice versa. This requires converters called transmitters and receivers. Transmitters also are called light-source transducers. If multiplexing equipment is used on the fiber, each channel of light requires its own receiver and transmitter. Transmitters in fiber-optic systems are either Light-Emitting Diodes (LEDs) or lasers. There are several reasons for this.

- LEDs cost less than lasers. They are commonly used with multi-mode fiber.
- Lasers provide more power. Thus, less regeneration (amplification) is needed over long distances.
- At the receiving end, the light detector transducers (receivers) that change light pulses into electrical signals are either positive intrinsic negatives (PINs) or avalanche photodiodes (APDs).
- LEDs and PINs are used in applications with lower bandwidth and shorter distance requirements.

7 Mobile and Wi-Fi Networks

In this chapter:

- Introduction
- First-Generation Analog Technologies
- Finite Spectrum for Wireless Networks
- Second-, Third-, and Fourth-Generation Digital Networks
- Fourth-Generation Advanced Mobile Services
- The Streamlined Infrastructure of Long-Term Evolution Architecture
- The Microcell Technology of Picocells and Femtocells
- Handheld Devices and Tablet Computers
- Applications and Services
- Wi-Fi Standards, Architecture, and Use in Cellular Networks
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INTRODUCTION

Mobile networks are critical during personal and national emergencies as well as for day-to-day communications. Worldwide, large percentages of populations that don't have access to affordable wireline broadband services are able to access e-mail with low-cost mobile devices. In addition, mobile networks are becoming an integral part of commercial transactions, and businesses that develop new applications and infrastructure for mobile networks contribute to economic growth by generating revenue and creating employment opportunities. And to a large degree, international enterprises depend on mobile communications to conduct business with mobile staff members and remote customers.

Mobile networks are made up of vast landline networks, switches, and databases. The only portions of these networks that are actually wireless are between a user's device and the mobile network's antennas. Signals to and from antennas are transmitted over landline networks to a carrier's centralized core network.

In addition to their wireless interfaces, mobile providers maintain complex wired networks as well as equipment and databases in core networks. Equipment in the core provides connections to billing systems, various databases, voice switches, and *gateways*. Gateways convert protocols in mobile networks to those compatible with public data networks and the Internet, and vice versa. The mobile core acts as a central site within which these functions are consolidated.

Cellular technology has been transformed from the initial analog systems that were first installed in 1984 to the new, high-capacity digital networks that we use today. Each successive generation has higher capacities, can cram more signals on given amounts of spectrum, and supports additional functions. Mobile networks are primarily based upon second-, third-, and fourth-generation standards. Additional interim standards that are transitions between generations are 2.5, 3.5, and pre-fourth-generation services. The following are the main protocols in mobile networks.

- The second generation, which is still the most common service worldwide, is digital and supports features such as caller ID, voicemail, and Short Message Service (SMS) for texting. Two examples include Code-Division Multiple Access (CDMA) and Global System for Mobile Communications (GSM).
- Third-generation services, which not all carriers have implemented, support higher speeds and packetized data. Wideband Code-Division Multiple Access (WCDMA) and CDMA2000 are among these services.
- When they are fully implemented, fourth-generation protocols will support higher data capacities capable of displacing Digital Subscriber Line (DSL) and cable modem-based broadband Internet access. These protocols include Long-Term Evolution (LTE) and Worldwide Interoperability for Microwave Access 2 (WiMAX 2).

Building, upgrading, and maintaining cellular networks are highly capital-intensive endeavors. Mobile networks require cell sites, switching equipment, and connections to other networks. They also depend on peripheral billing, operations and maintenance, and enhanced services components such as servers that support SMS and e-mail. Further, as a result of the high costs for spectrum needed for new-generation services and additional capacities, usually only the largest carriers have the resources to bid on and purchase spectrum.

Mobile services have already displaced a large percentage of home telephone lines. In the near future, particularly in rural areas and in developing countries, mobile services will be used instead of landlines for Internet access, as well. They are currently replacing DSL Internet access in Scandinavian countries that have high-capacity fourth-generation (4G) mobile networks.

For mobile service to have the capacity to carry this additional traffic, additional spectrum—the portion of the public airwaves over which mobile signals are transmitted—needs to be made available by governments worldwide. However, much of the spectrum is already used for other purposes or for earlier generations of mobile services. Government agencies, broadcasters, and others using this spectrum do not always want to give it up. Freeing up spectrum for next generations of cellular service is often a political issue facing government agencies that control spectrum allocation.

When spectrum is made available at public auctions, governments use the money to supplement tax revenues. High prices for spectrum often shut out smaller, less cash-rich carriers, making it more difficult for them to upgrade their networks. This often makes them less competitive against large, multinational mobile carriers. Availability of spectrum and the ability to use spectrum more efficiently are important issues. Using spectrum more efficiently often depends on having state-of-the-art equipment based on new standards that are better able to carry the large quantities of video and e-mail that are transmitted to and from smartphones and tablet computers.

One way that carriers add capacity to existing networks is by adding additional, smaller cell sites in densely trafficked metropolitan areas. They can also supplement capacity on mobile networks by using Wi-Fi services both within hot spots and in outside areas. (Wi-Fi is is an abbreviated form of the term "wireless fidelity.") Wi-Fi networks have the advantage of operating on unlicensed spectrum that governments make available at no charge. Determining cost-effective ways to add capacity and upgrade networks is the major challenge facing mobile carriers. Maintaining complex infrastructure with many thousands of cell sites is difficult and costly. Moreover, in countries where there are many competitors, prices tend to be lower, resulting in less capital available for carriers to invest in infrastructure.