CHAPTER

24

Regional and Metro Telecommunications

About This Chapter

Regional and metro telecommunication systems bridge the gap between the local networks that serve your community and the long-distance telecommunications that form the backbone of the global network. Their function is to collect signals from points across the region and distribute them within the region and to major nodes of long-distance systems. In general, the operation and design of regional and metro networks fall between those of long-distance and local systems: They typically span shorter distances and carry lower-speed signals than long-distance backbone networks, but span longer distances and carry faster signals than local networks. They also differ in connectivity from long-distance and local networks. In this chapter you'll learn about these differences and how regional and metro networks work.

Defining Regional and Metro Telecommunications

The distinction between the terms "regional" and "metro" can be subtle, and may owe more to history and marketing than to different network architectures. Wire-line telephone charges traditionally were split between long-distance calls, listed individually on the phone bill, and regional calls, billed in increments or at a flat rate. The first breakup of AT&T in 1984 split the company between long-distance service (which remained AT&T) and the original seven Bell Regional Operating Companies, which offered services within their own regions. Long-distance and regional services were differentiated on the basis of the area codes existing at the time of the breakup, which have since been subdivided in most states. Those regional phone companies—and competitive carriers formed later—now operate regional networks in their own operating areas.

Metro networks originated more recently, when other companies decided they wanted to carry signals within regional areas. By that time these signals included digital data and video as well as telephone traffic. Not surprisingly, these networks were concentrated in heavily populated metropolitan areas, where demand for transmission capacity was high. As the telecommunications bubble swelled, metro networks were much hyped. The term has survived partly because it sounds more modern, but also because it emphasizes that these networks serve a highly populated metropolitan area with a lot of traffic heavy with data.

Both regional and metro networks consist mostly of fiber. Functionally their main distinction is in how they connect the locations they serve, but this difference is vanishing as networks evolve. Regional and metro networks use essentially the same hardware, and from this point on we'll cover the two networks together, noting differences explicitly.

Regional Distribution

Regional networks are distribution systems.

Regional and metro networks are distribution systems, not information pipelines like links in the long-distance network. Regional networks connect many points; the long-distance system carries large traffic volumes over long distances.

A regional telecommunication system plays the same role as a grid of major streets, which links neighborhood roads to limited-access expressways. Figure 24.1 shows how a regional network in a rural area might look. The network is a grid of cables connecting telephone switching offices in each town. Low-capacity cables (thin lines) run between small towns, and from small towns to their larger neighbors. Larger-capacity cables (thicker lines) connect the larger towns to the regional hub, a small city, where they connect with long-distance lines.

In a sense, this network is a hub-and-spoke system, with high-capacity links spreading from the regional hub to larger towns, and those larger towns, in turn, connecting to small towns. However, the system also includes cross-links between towns, which form rings like those used in SONET systems. If you cut any one cable in the network of Figure 24.1, the towns on both sides of the break would still have connections to all the other towns in the region.

Regional phone networks connect local phone switches with each other and the long-distance network.

Real networks may have more levels of hubs from which lines branch out to smaller hubs, with regional rings providing a backbone to serve the large hubs. Figure 24.2 shows one such network built in Oregon, which covers both the Portland metropolitan area in the northwest and the rural areas in the east. It delivers service to county seats and major towns, connecting to other networks (not shown) that form grids throughout the state. This is only one of the networks serving the region; a separate regional network links telephone switching offices throughout the state, but it's operated by another organization. (Remember that, as with long-distance networks, fibers carrying signals for two different companies may run through the same cable.)

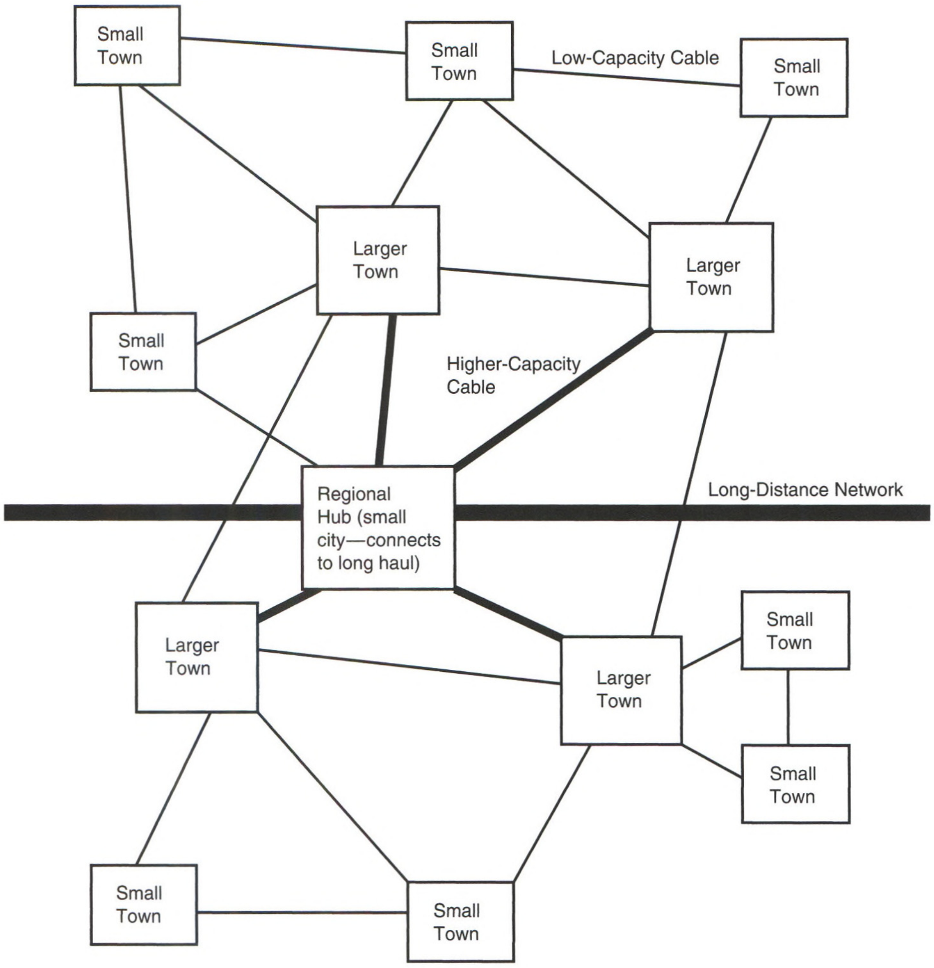

FIGURE 24.1
Regional telecommunication network in rural area.

Regional networks connect to local phone lines at telephone switching offices, which are the hubs for local phone service. As you will see in Chapter 25, you can trace all local phone lines to a switching office or central office, where they make connections with other local phone lines and with regional and long-distance networks. Regional networks also connect with other local services, including cable television companies, mobile phone systems, and Internet Service Providers that rely on telephone lines for connections with the Internet backbone.

Regional network concepts also apply to urban and suburban areas, but in that case the transmission lines link adjacent suburbs, and feed into the urban center, where they connect with long-distance lines. The result is a network that looks like a more elaborate version of Figure 24.1, but with the nodes labeled suburbs and city center. The city center is the hub, with individual suburbs on spokes, and cross-links between adjacent suburbs.

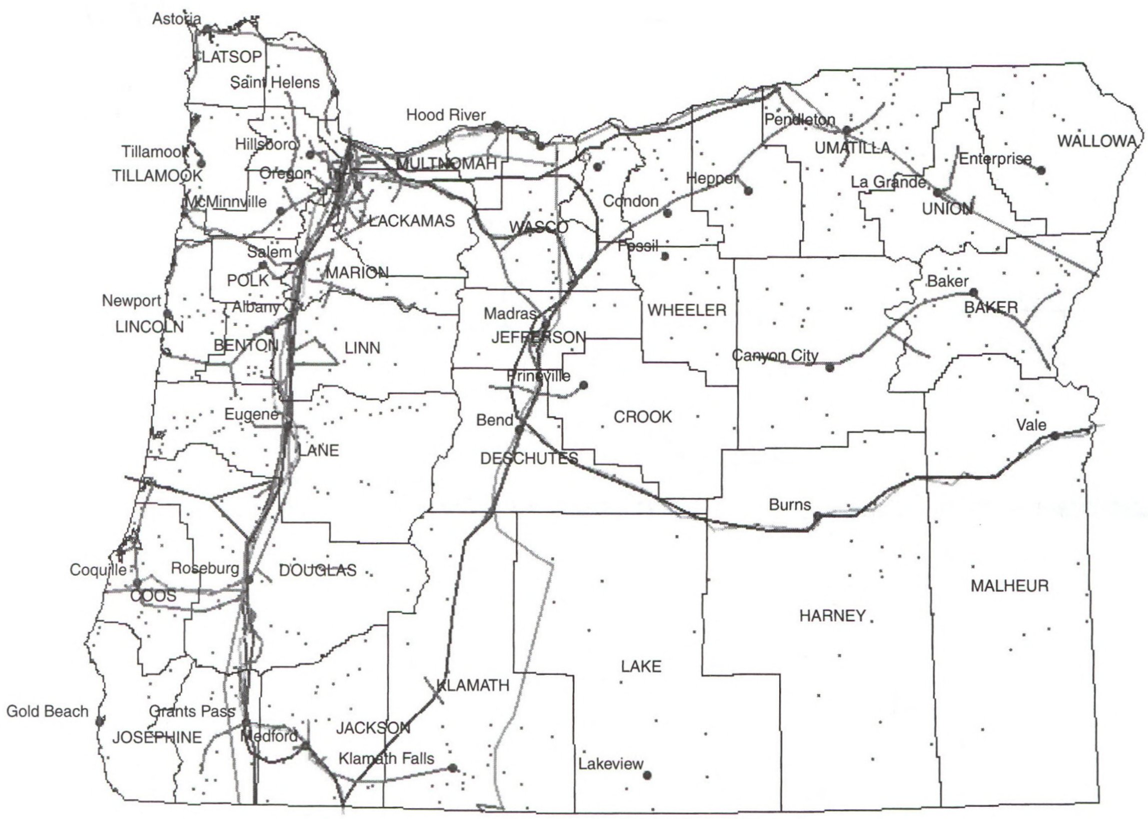

FIGURE 24.2

State of Oregon Enterprise Network provides links throughout the state. (Courtesy of Oregon Economic & Community Development)

Regional phone networks are meshes linking switching offices.

The topology of a network also depends on its history. Established regional telephone companies built their networks piece by piece over many years. As communities grew and traffic increased, the companies expanded their transmission capacity and added new lines. Their networks are meshes that reach throughout the region, but they make their major connections at local telephone switching offices, where signals from each community are collected and organized for transmission to other communities.

New metro networks built by different companies can have different structures. Figure 24.3 shows a metropolitan network built by one company that offers transmission service to everyone in the area. This system is a ring that provides service to many organizations along its route, making links between different points. The dashed line shows a link that carries video signals from a local television station to a cable company's distribution center. Other links could run between city hall and the county office complex at the bottom, and between the mobile phone switching center and the suburban phone company at top. A metropolitan network makes many connections besides those to traditional telephone companies.

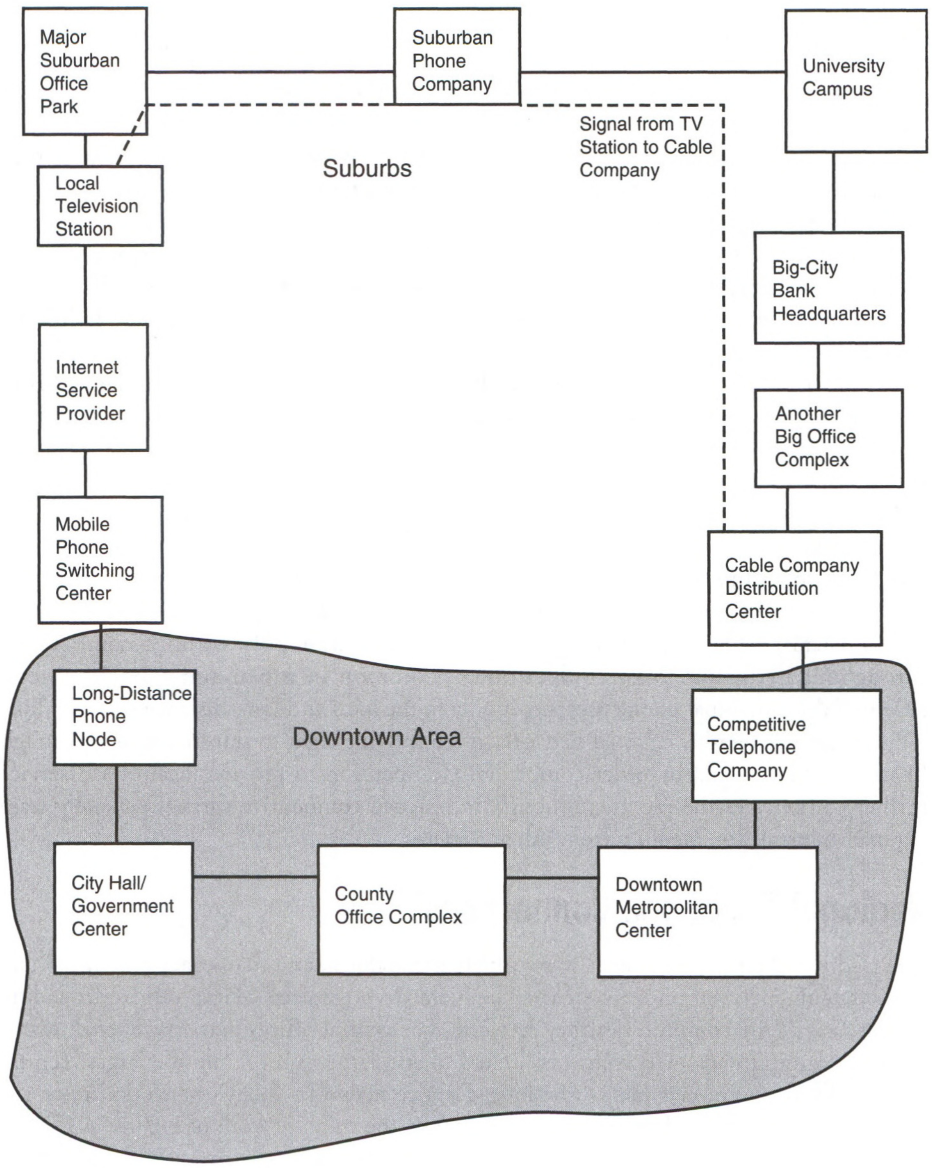

FIGURE 24.3
A metropolitan ring network links many sites.

Other companies may build rings serving other parts of the metropolitan area. These companies can lease capacity to anyone willing to pay for it, including regional phone companies that may decide it's cheaper to rent rather than lay cable along a similar route. The rings and meshes built by all the companies operating in the area combine to form a regional or metropolitan network, carrying a variety of services. However, these networks are not integrated seamlessly, and may operate quite differently, as you will learn later. Let's start by looking at the established regional telecommunications networks.

Regional Telecommunications Networks

Regional phone systems are part of the public switched telephone network.

The well-established regional networks built by telephone companies are part of what is called the *public switched telephone network (PSTN)*, which collects, packages, switches, and distributes telephone signals. This traditional network is a circuit-switched system, which creates voice circuits between individual phones. The switching and packaging are done at local *switching offices*, which digitize voice signals and time-division multiplex the bit streams to create signals at the hierarchy of higher speeds described in Chapter 20. The regional network carries these signals between central offices or from a central office to the long-distance network. You'll learn about connections from the central office to individual phones in Chapter 25.

Recall that this regional phone network is a distribution system with a high level of interconnections that function as a mesh linking many points. It's also a public network, which essentially rents the use of a voice line in time increments to anyone with a telephone connection.

Regional networks also can carry other types of signals. For example, a business may want its own 45-Mbit/s T3 line to carry voice and data signals between its facilities, or may rent a line to an Internet node. The network hardware doesn't care where the signal came from or how it was produced; it just requires a standard data rate along the line.

Historically each regional phone network was a monopoly without competition throughout its region. Now competition is common in urban and suburban areas, although the individual phone user sees it only in the local and long-distance markets. Like long-distance networks, regional networks often buy the right to transmit signals through fibers in cables owned by other companies. Competition to provide local phone service further complicates the picture, although in practice competitive carriers generally lease regional transmission facilities from other carriers.

Regional Telephone Connections

The traditional telephone system was strongly hierarchical, and that legacy remains strong in the circuit-switched phone systems. The hierarchy organized central offices depending on the sizes of the communities they serviced. The central offices that served small towns linked to larger towns, which in turn linked to still larger ones. Only the largest central offices had direct connections to the long-distance network. Today's networks are not as rigidly hierarchical, but that structure is evident in the rural network of Figure 24.1.

Trunk lines connect central offices.

The connections between central offices are called *trunk lines* and today virtually all of them are fiber-optic. In metropolitan or suburban areas, trunks typically run several kilometers between central offices in adjacent communities. Calls made within a region may go through a series of trunk lines. The capacity required depends on the volume of calls on that route.

Legacy and New Networks

Regional networks are upgraded gradually to higher capacity.

Regional networks inevitably contain a mixture of old (*legacy*) and new equipment. The old stuff generally isn't as old as it is in local phone systems, but regional carriers generally do not replace systems in good working condition as long as their transmission capacity is adequate. Normally they replace one segment of the network at a time, both to limit expenses and to avoid disrupting service.

Replacements generally occur where old equipment fails or more capacity is needed. Carriers try to avoid new construction wherever possible, so they may prefer to lay new cables in existing underground ducts, or add wavelength-division multiplexing and new optical channels to existing systems transmitting only one wavelength.

Generally, regional networks require less transmission capacity than long-distance systems. Thus regional networks make much less use of WDM technology than long-haul systems. Upgrades also are not evenly distributed. Although users are steadily increasing the demand for transmission capacity, the growth is not even. New capacity is most likely to be needed in areas where new development has outstripped existing systems.

Other Connections

Regional networks interconnect with other systems.

The regional networks built for fixed ("wire-line") telephone signals now carry a variety of other signals and must connect with other equipment. Mobile telephones have become common, so regional networks must connect with cell-phone towers and switching centers; this means links in each region ("cell") for each mobile phone carrier serving the region.

Competitive telephone companies also require connections. Many of them use the same local wiring as the dominant local carrier, but have separate switches, either at the dominant phone company's central office or another site. Regional networks also have to connect to telephone services provided by local cable-television companies.

Data services also require special connections. Internet Service Providers need to lease lines to make connections to the Internet. So do data-processing and computer centers at large companies and universities. Large companies also may lease lines to connect with other facilities in the area, which don't have to go directly through the switched telephone network.

Transmission Requirements

Regional networks transmit at a wide range of data rates.

Transmission requirements in regional networks cover a much broader range of data rates and distances than in long-distance systems.

The economics of long-haul transmission dictate that signals be packed as tightly as possible. You trade off the cost of the equipment to package signals against the cost of transmission. That means you have to amortize the extra money you spend at the transmitter and receiver against the money you save on fiber, cable, and optical amplifiers. If you have to send signals 5000 km across the ocean, you can afford to spend much more at the transmitter and receiver end than if the signal is only going 50 km.

Individual telephone circuits are grouped together for efficiency, but the degree of grouping depends on the traffic level. Small towns may generate only enough traffic to fill a few 1.5-Mbit/s T1 lines on the busiest days. Larger towns will generate signals at the 45 Mbit/s T3 rate or higher. Regional networks carry signals at data rates from the 1.5 Mbit/s T1 speed up to 2.5 or 10 Gbit/s, depending on customer requirements. For long-haul systems, it usually makes sense to time-division multiplex slow signals, combining multiple inputs to make a single higher-speed data stream. Regional networks usually multiplex to lower rates.

Metro Networks

Metropolitan networks are similar to regional networks, but specifically serve metropolitan areas with large concentrations of people and industry. There are three basic variations on the concept, and the distinctions can sometimes be hazy:

- *Metro telephone/telecommunications networks* developed by expanding the regional networks of telephone carriers in a metropolitan area. They are basically enhanced regional networks that carry services needed in a metropolitan area. They tend to carry heavier traffic than regional networks and have somewhat different structures.
- *Wholesale metro networks*, run by individual companies, sell service directly to other companies rather than operating a public telephone service.
- *Metro-area networks* (MANs) and wide-area networks (*WANs*) typically serve a single organization spread throughout a metropolitan area, such as a city or county government or a large corporation.

The distinctions between the first two types of networks are caused mostly by differences between the type of carriers that operate them. A metro telecommunications network is run by a company that serves many customers in the region and provides retail public switched telephone service. In general, it has many points of connectivity in the region, as shown in the regional network of Figure 24.1. Many of these connections are made through telephone switching offices.

In contrast, a wholesale metro network generally does not provide retail public switched telephone service, although it may sell bulk capacity directly to large companies. This means it has fewer customers, and thus needs fewer connections through the region. Wholesale networks also tend to have fewer connections throughout the region, and may take the form of a simple ring, as in Figure 24.3. They may have connections to telephone switching offices, as well as other types of connections.

A metro telecommunications network has extensive interconnectivity.

Another important distinction is the degree of connectivity. A metro telecommunications network has extensive interconnection capability because it was built to serve telephone-like functions; each node, as in a switched telephone network, must be able to reach every other node. In contrast, wholesale metro networks only make the connections specified by their customers. You can see the difference by comparing the regional network of Figure 24.1 with the metro ring in Figure 24.3. The regional network can link any pair of towns on the map, although the connection may go through several other towns; however, many customers of the metro ring transmit only between a pair of points. The suburban telephone switch and the bank headquarters in Figure 24.3 don't receive the television signals that go past them on the ring.

Let's look at a couple other key features of these networks.

A metro core ring links metro access loops serving parts of a metro area.

Metro Network Topology

Regional networks have moved away from the hierarchical structure of older telephone networks, in which smaller switches directed signals through larger switching offices. A modern metro telecommunications network in a large city looks more like Figure 24.4, with

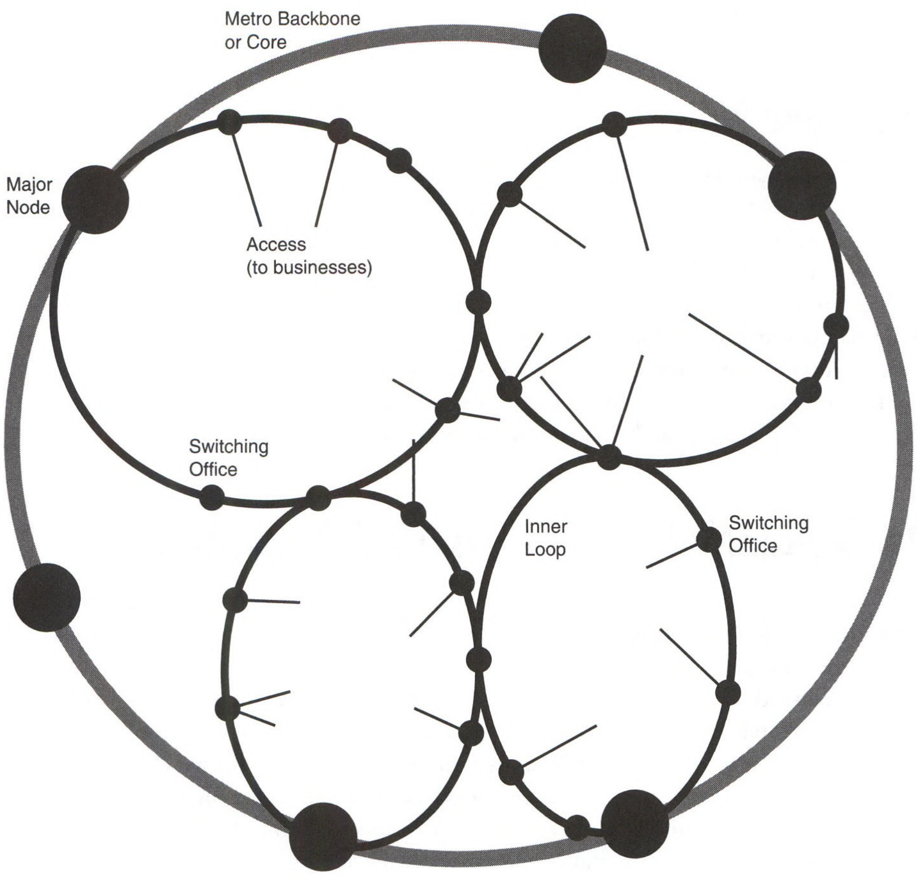

FIGURE 24.4
Metro core and access network in big city.

connections arranged in two sets of rings. The thick outer line is the *metro core* loop, which connects the telephone switches that carry the largest volume of traffic. Nodes on the metro core connect to *metro access* loops, which connect to smaller switching offices that serve parts of the service area. In Figure 24.4 these show as inner and outer loops; they may be arranged differently, but they are always form rings to maintain service in case of a single-point failure.

The same approach could be used in a regional network. In that case, the core connection might be a ring that serves small cities, while the access connections would be the rings connecting the small towns. This highlights an important point—the types of service delivered are as important as the area where they are delivered.

The metro or regional network provides interconnections between two points on the *network edge*. For a telephone network, these points are central offices that make switched connections to individual telephones. For leased lines, they are individual company facilities dedicated to making the same point-to-point connections.

Switching offices are at the network edge.

The network edge or outer part of the metro network is also called the *access network*. In practice, this refers to a connection to a central office or to an organization that buys transmission capacity on the metro network. For example, the suburban telephone office, the big-city bank headquarters, and the university in Figure 24.3 are all part of the access network.

MANs and WANs

MANs and WANs connect organizational LANs.

Both metropolitan telecommunication networks and wholesale metro networks sell transmission capacity to retail or wholesale customers. MANs and WANs do not; they are nominally connections between local area networks (LANs), which organizations use to connect their computers. MANs and LANs often buy or lease capacity on metro networks.

The Internet sometimes is considered a wide-area network, but we won't use that term here because it might muddle the picture. In practice, Internet links run through the same cables as other metropolitan transmission lines but are operated by independent carriers and Internet service providers, which agree to exchange signals with each other. You'll learn more about the Internet and data transmission in Chapter 26.

Regional/Metro Services and Equipment

Regional and metro networks are intermediate between long-haul and local systems in terms of size and traffic volumes. This is evident both in the services they carry and the equipment they use.

Rural regional networks span more territory than do metro networks.

Metro networks usually span no more than about 200 kilometers, and most metro loops are shorter in total length. This means that they require few if any optical amplifiers, except to compensate for lossy components, so they can use wavelengths for which amplifiers are not available. Regional networks can be considerably larger. Functionally a regional network could cover an entire area code, which can span several hundred kilometers in large sparsely populated states, so it may require more amplifiers.

Traffic volumes depend on the population of people and industries. Population density in the United States varies from less than 10 people per square mile in the most sparsely populated states to thousands of people per square mile in major urban areas. Information-intensive industry is concentrated in densely populated areas, so metro networks need much higher capacity than do regional networks in rural areas. Thus unlike long-distance networks, regional and metro networks generally don't have to provide both high transmission capacity and long transmission distances. Traffic volumes are still growing, so metro and regional networks are not as overbuilt as long-distance systems.

Services and Transmission Speeds

As mentioned earlier, metro and regional networks carry both public switched telephone traffic and point-to-point connections between company facilities on leased lines. Thus these networks carry a variety of services at different speeds.

Public networks combine input signals into high-speed data.

Public telecommunications networks are built on the assumption that input from subscribers comes in small chunks, which are combined into larger data flows in a regional or metro network. Public networks combine voice channels using time-division multiplexing to make higher-speed signals. Metro and regional networks see only the combined signals.

Metro and regional networks also receive signals directly from their customers in a variety of formats, depending on customer requirements. Network operators may transmit the signals in the raw input format—a practice called providing "dark fiber" because the customers "illuminate" it with signals in the transmission format they prefer. Alternatively, network operators may merge input signals from multiple access customers into a composite signal at a higher speed, as is done with telephone signals. Signals traveling through the system may come from different standard layers, and the carrier may repackage the signals for transmission on a different layer.

Transmission speeds for regional and metro networks cover a wide range. Small towns have a few T1 connections, larger towns have T3 lines, cities have OC-3 or OC-12 links, and so on up the data-rate hierarchy. The highest rates in regional and metro networks are usually 2.5-Gbit/s OC-48 lines, although higher rates are used in special cases. Generally, most of the transmission lines are at lower speeds, with the high-speed lines concentrated in the most densely populated areas. Metro networks tend to have higher-speed inputs, with switching offices providing input at OC-3 rates or higher.

Regional links carry data at speeds to 2.5 Gbit/s

Because metro and regional networks carry signals shorter distances than long-distance systems, designers face different trade-offs in selecting transmission speeds and protocols. Expensive transmitters and receivers can be justified in long-haul systems because they can send signals a long distance. However, it's harder to justify purchasing expensive terminal equipment—like time-division multiplexers and demultiplexers—to span the shorter distances in metro networks. That is, for short networks adding extra transmission lines to carry low-speed signals may cost less than installing the electronics needed to time-division multiplex the input to higher speed for transmission over one fiber.

Network Access

There are two distinct ways of accessing a metro or regional network, through a hub and through an add-drop multiplexer. We have glossed over these differences so far, but they impact system function.

A *hub* is a point where all (or most) of the signals in a system are switched and organized. Hubs include local switching offices and correspond to the terminal points on submarine cables or long-distance systems. In the metro network of Figure 24.5, there are two hubs: the network operation center at the top and the urban telephone switching office at the lower right. Other metro networks may include several switching offices.

Hubs or add-drops provide network access.

Add-drops are points where some signals are picked up and others dropped at an attached node. An add-drop multiplexer along the network diverts only part of the signals to the node. In Figure 24.5, the only signal picked up from the television station is one video signal directed to the cable-television company, which will distribute the signal to its subscribers. The figure also shows a two-way link between City Hall and an Internet Service Provider, which operates the city's Web site and provides officials with Internet access.

The metro network in Figure 24.5 is a ring that contains many add-drops and a few hubs. This means it functions largely as a network, interconnecting many nodes and directing signals between pairs of nodes. In a metro network, the signals often are transmitted separately, at different wavelengths or on different fibers. They may pass through add-drops, but not through the nodes attached to the network. In this they differ from

Metro networks typically are rings with many add-drops.

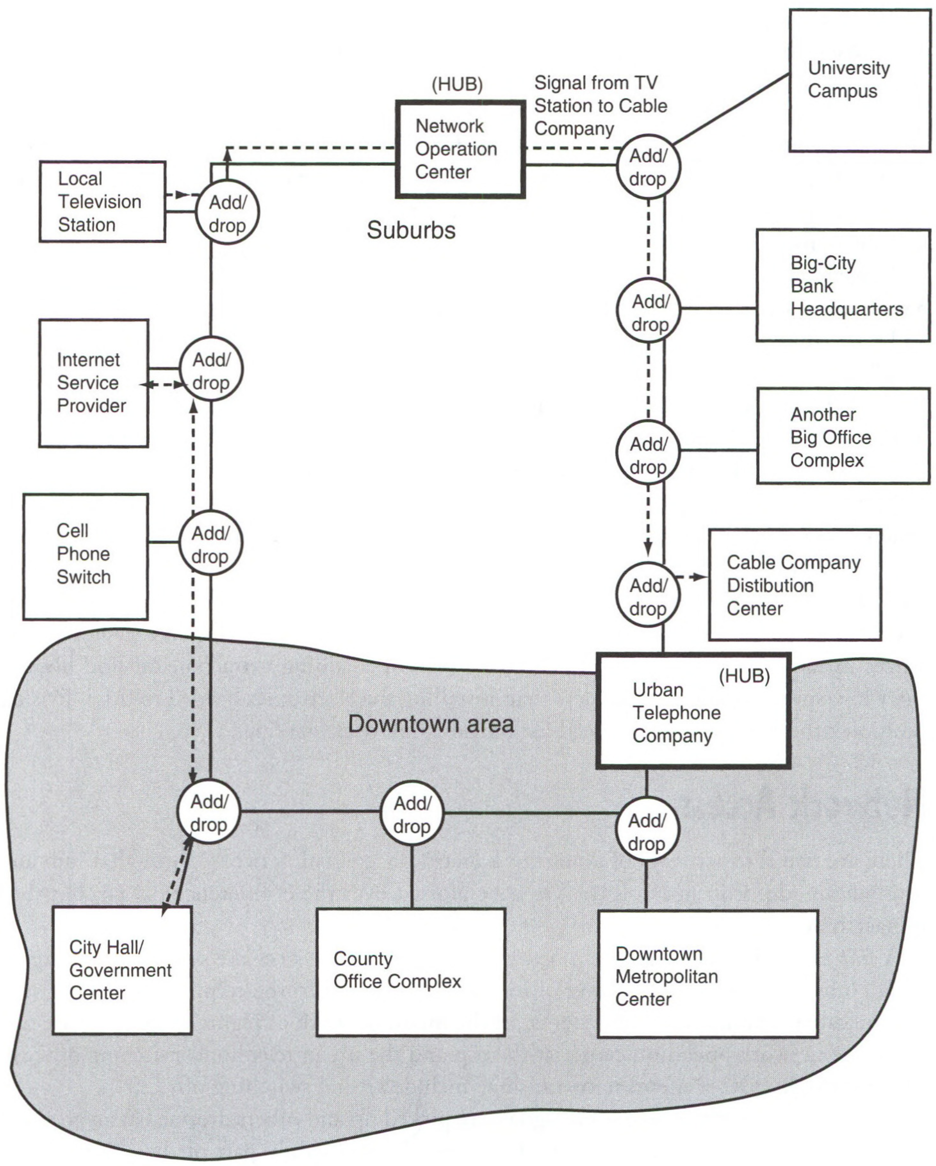

FIGURE 24.5
Hubs and add/drop nodes in a metro network.

other networks, which route a combined signal through all nodes, but each node only receives the signals directed to it. This subtle distinction can be important to some users, such as banks, that are particularly concerned with security.

Other metro and regional networks may contain mostly hubs. In the rural regional network of Figure 24.1, you could consider all the towns to be hubs, some smaller than the others. You can also think of a regional telephone network as an array of point-to-point links, with each terminating at a telephone switch in a different location. Telephone companies often treat their regional or metro networks as a grid of point-to-point links, so they upgrade parts at different times.

Capacity and WDM in Metro Networks

Metro and regional links require lower transmission capacity than long-haul links, a fact that has important consequences. Network operators have installed metro cables with fiber counts up to 400 pairs in highly developed areas, but the cable installations generally were much less costly, and the resulting capacity was not as far beyond real requirements as for long-distance systems.

The modest capacity requirements mean that a single channel at 1310 nm can meet the needs of most links in metro and regional networks. This also reduces terminal equipment cost by avoiding expensive WDM optics and costly transmitters in the 1550-nm region.

Most metro links carry one channel at 1310 nm.

Wavelength-division multiplexing may make sense for metro and regional links carrying heavy traffic if no additional fibers are available on the route, the time needed for new construction is excessive, or the cost is higher than installing WDM equipment. Coarse-WDM is preferred over dense-WDM if the transmission distance is short enough to avoid using optical amplifiers and large numbers of channels are not needed. Widely spaced CWDM channels cost less to install than narrow-line DWDM channels, and cover a broader range of the spectrum. Low-water fibers allow use of more wavelengths than older standard single-mode fibers.

Metro systems use CWDM rather than DWDM.

The less-stringent requirements on metro and regional transmission have also reduced the layers of interface electronics. The rationale is that the cost of the electronics needed to convert signals to more efficient formats may be greater than the gain obtained from the higher efficiency. This has led to the development of *protocol agnostic* systems in which carriers assign customers their own optical channel or fiber to use as they see fit. Instead of trying to pack as many channels as possible onto each fiber, the operator reduces the number of layers to cut costs. Figure 24.6 shows an example, where four customers pick different formats: a 2.5-Gbit/s OC-48 line, digital video, Gigabit Ethernet, and Fibre Channel. Using this approach, a video studio can transmit its signal to a cable operator in video format without having to convert the signal.

The shorter links in metro and regional networks also reduce limitations imposed by dispersion and nonlinear effects on system operation. Recall that dispersion is a cumulative spreading of signal pulses that limits maximum transmission speed, so the shorter the distance spanned, the higher the maximum speed. Although very few metro or regional links require 40-Gbit/s transmission, this speed is easier to achieve in metro networks than in long-haul systems.

Shorter spans suffer less dispersion and can transmit higher speeds.

Nonlinear effects also accumulate with distance, so their impact decreases in metro and regional networks. Reducing the cumulative impact of nonlinearities in turn allows transmission of higher optical powers, providing more power per channel in WDM systems. Thus potentially more channels could be transmitted, although at this point there is little interest in increasing the number of optical channels in metro networks.

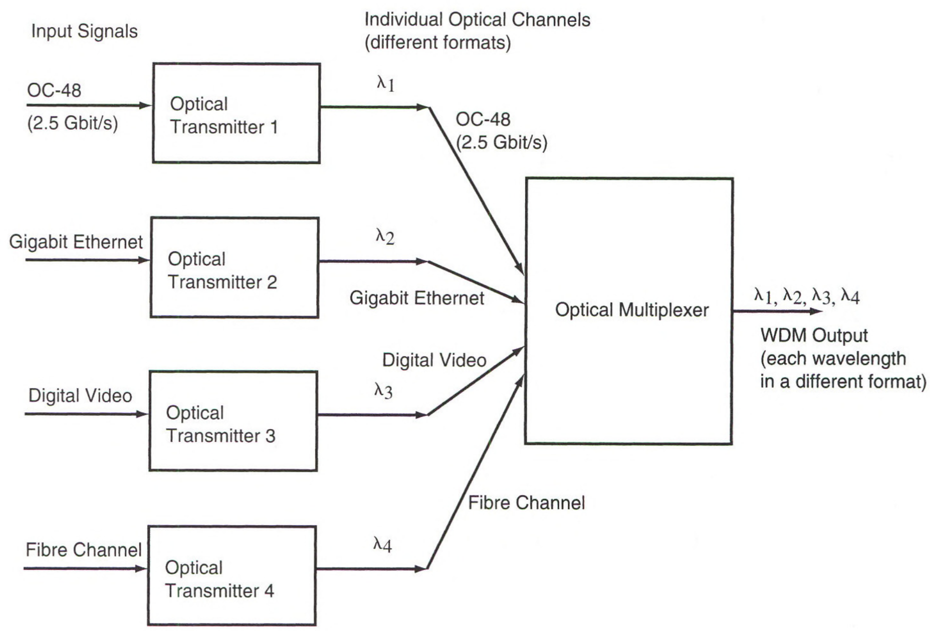

FIGURE 24.6
Metro WDM system transmits optical channels in different formats.

What Have You Learned?

1. Metro and regional networks are distribution systems, not information pipelines. They serve similar purposes, but differ somewhat in detail.
2. Regional phone networks connect local phone switches with each other and long-distance networks. They operate on different levels, ranging from low-capacity connections to small towns to high-capacity connections between suburbs and big cities.
3. A metro network interconnects many points in a metropolitan area. These include telephone switching centers and other facilities that require high-speed connections, such as large businesses, cable television companies, universities, and government offices.
4. Regional networks link switching offices; they tend to concentrate traffic to the largest switches. They transmit signals at a wide range of data rates.
5. Originally built for fixed telephone service, regional and metro networks now carry a variety of other signals and must connect with other equipment, including pagers, cell phones, Internet Service Providers, and competitive phone companies.
6. Regional phone systems are part of the public switched telephone network, which collects, packages, switches, and distributes telephone signals. They carry signals at a hierarchy of data rates.

7. Trunk lines run between switching offices. Switching offices are on the edge of the phone network.
8. Metro telecommunications networks are enhanced regional networks serving metropolitan areas. Like regional networks they have extensive connectivity. Wholesale metro networks sell service to other companies rather than provide public telephone service, and generally have fewer connections.
9. A metro core ring links metro access loops serving a metropolitan area.
10. Metropolitan-area networks (MANs) and wide-area networks (WANs) connect local-area networks (LANs) operated by an organization.
11. Rural regional networks span more territory than metropolitan networks but carry less traffic.
12. Regional and metro networks generally carry signals at up to 2.5 Gbit/s, although higher speeds are technically possible. Traffic demand is lower than in long-haul systems.
13. Network access is provided through hubs or add-drop multiplexers. Many metro networks are rings with many add-drops and few hubs. Regional networks typically have many hubs.
14. Most metro and regional links transmit one channel at 1310 nm and are not long enough to require repeaters. Where WDM is needed, they use coarse-WDM rather than more expensive dense-WDM.
15. Metro networks generally require less expensive terminal equipment than do long-haul networks.
16. Transmission distances in metro and regional networks typically are a few kilometers to about 200 km; most links are shorter than 100 km. Amplifiers are rare, but may be needed in sparsely populated rural areas or if coupling losses are high.
17. Dispersion and nonlinear effects are low because metro and regional systems are short.

What's Next?

In Chapter 25 you will learn about local telephone networks. Chapters 26 and 27 cover video and data networks.

Further Reading

John C. Ballamy, *Digital Telephony,* 3rd ed. (Wiley InterScience, 2000)

Yi Chen et al., "Metro Optical Networking," *Bell Labs Technical Journal* (January–March 1999) pp. 163–186.

Roger L. Freeman, *Fundamentals of Telecommunications* (Wiley InterScience, 1999)

Questions to Think About

1. Telephone calls that go outside of your community pass between your local-telephone switching office and other switching offices on the regional telephone network. What makes some of these long-distance calls?
2. A fire destroys the local switching office in one of the "larger towns" of Figure 24.1. How can the smaller towns connected to it still receive phone service?
3. Your company needs more transmission capacity between two offices 20 km apart. You can lease wavelengths at $20,000 per wavelength per year on a metro network with a five-year lease. You need to transmit three channels, two containing Gigabit Ethernet, and one containing TDM phone signals at 622 Mbit/s. They could fit on a single 2.5-Gbit/s line, but you would need to buy a time-division multiplexer and demultiplexer for the job. What's the most you could pay if you have to amortize costs over 5 years?
4. You're dealing with the same metro network as in Question 3. Their base rate is $1000 per kilometer per wavelength per year. What's the most you would pay for a time-division multiplexer and demultiplexer if you were sending signals only 5 km?
5. A metro network uses low-water single-mode fiber with zero dispersion at 1310 nm, and dispersion of 17 ps/nm-km at 1550 nm. If it transmits signals 100 km, what is the maximum data rate it can handle in the 1550-nm window with a transmitter having linewidth of 0.1 nm? Assume polarization-mode dispersion is insignificant, and that the maximum data rate is

$$\text{Data rate} = \frac{0.7}{\Delta t_{\text{maximum}}}$$

6. You're using nonzero dispersion-shifted fiber in a metro network. If the chromatic dispersion is 1 ps/nm-km and the source bandwidth is 0.1 nm, how far can you transmit signals at 40 Gbit/s? Assume you can neglect polarization-mode dispersion.

Chapter Quiz

1. The best analogy for a regional telephone network is
   a. a pipeline pumping information from coast to coast with no detours.
   b. a superhighway crossing a large unpopulated area with few off-ramps.
   c. surface main streets connecting rural towns.
   d. residential streets in suburbia.
   e. a radio station broadcasting signals in all directions.
2. Which of the following is *not* connected directly to regional telephone networks?
   a. home and office telephones
   b. telephone switching offices
   c. cellular telephone networks

d. long-distance phone lines
e. Internet Service Providers

3. A regional network is a(n)
a. high-speed subway system in Washington, DC.
b. mesh connecting many telephone switching offices.
c. mesh connecting major cities across the country.
d. loop interconnecting many points in an urban area.
e. obsolete concept.

4. The hubs in a regional telecommunications network are
a. connections to international phone lines.
b. points from which cable television signals are distributed.
c. switching offices in towns and cities served by the network.
d. customers connected by add-drop multiplexers.
e. individual phone lines.

5. A regional telecommunications network serves
a. small towns in rural areas.
b. small cities and county seats in rural areas.
c. suburban communities.
d. large cities.
e. all of the above

6. Customers of wholesale metro networks may include
a. cable television operators.
b. regional telephone companies.
c. large businesses.
d. state and local governments.
e. Internet Service Providers.
f. all the above, if they have enough money.

7. A typical distance spanned by a metro network is
a. under 5 km.
b. a few to 200 km.
c. 100 to 200 km.
d. at least 200 km.
e. 200 to 1000 km.

8. Which of the following is true for the structure of signals on a regional network?
a. All signals must be at the same speed.
b. Signals can be transmitted at a hierarchy of speeds from T1 up.

c. Signals cannot be transmitted in different formats on the same fiber.
d. Signals always are transmitted at 2.5 Gbit/s.
e. All signals are time-division multiplexed together for transmission in a single data stream.

9. A metro network operates over a cable containing 864 individual fibers. If the system uses DWDM, each fiber can transmit 100 optical channels at 2.5 Gbit/s. What is the maximum capacity of the entire cable for two-way DWDM transmission?

a. 250 Gbit/s
b. 2.16 Tbit/s
c. 86.4 Tbit/s
d. 108 Tbit/s
e. 216 Tbit/s

10. The metro network described in Question 9 provides broadband service to a community of one million households. If the capacity is divided equally, what capacity can the cable offer to each home?

a. 250 kbit/s
b. 2 Mbit/s
c. 86.4 Mbit/s
d. 108 Mbit/s
e. 216 Mbit/s

11. What type of transmitter is most commonly used in metro and regional networks?

a. 850-nm VCSEL
b. 1310-nm single-channel laser
c. 1550 nm single-channel laser
d. coarse-WDM
e. dense-WDM

12. Which factor is least important in selecting coarse-WDM for use in a metro network?

a. Terminal equipment costs less than that for DWDM.
b. Shorter metro links do not require amplifiers.
c. Metro networks do not require many channels per fiber.
d. Shorter metro links have low dispersion.
e. All are equally important.