

1.5 Access Networks and Physical Media

In sections 1.3 and 1.4 we have examined the roles of end systems and routers in a network architecture. In this section we consider the **access network** - the physical link(s) that connect an end system to its **edge router**, i.e., the first router on a path from the end system to any other distant end system.. Since access network technology is closely tied to physical media technology (fiber, coaxial pair, twisted pair telephone wire, radio spectrum), we consider these two topics together in this section.

1.5.1 Access Networks

Figure 1.5-1 shows the access networks' links highlighted in red.

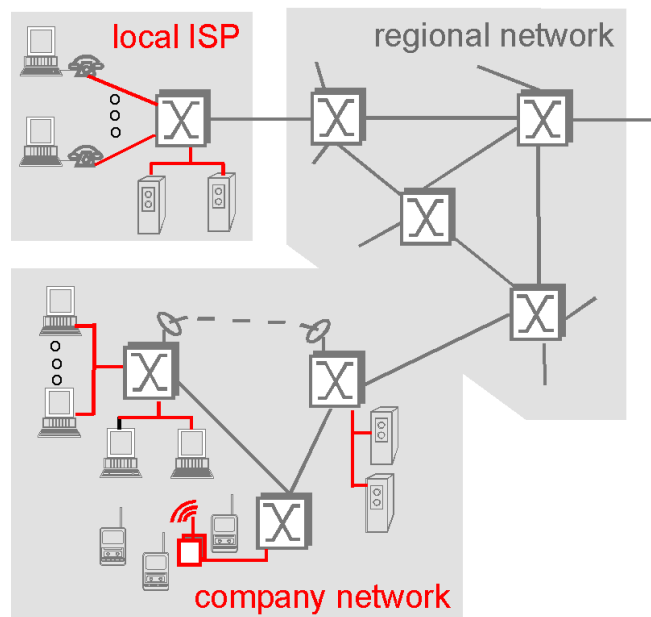


Figure 1.5-1: Access networks

Access networks can be loosely divided into three categories:

- **residential access networks**, connecting a home end system into the network;
- **institutional access networks**, connecting an end system in a business or educational institution into the network;
- **mobile access networks**, connecting a mobile end system into the network

These categories are not hard and fast; some corporate end systems may well use the access network technology that we ascribe to residential access networks, and vice versa. Our descriptions below are meant to hold for the common (if not every) case.

Residential Access Networks

A residential access network connects a home end system (typically a PC, but perhaps a Web TV or other residential system) to an edge router. Probably the most common form of home access is using a **modem** over a POTS (plain old telephone system) dialup line to an Internet service provider (ISP). The home modem converts the digital output of the PC into analog format for transmission over the analog phone line. A modem in the ISP converts the analog signal back into digital form for input to the ISP router. In this case, the "access network" is simply a point-to-point dialup link into an edge router. The point-to-point link is your ordinary twisted-pair phone line. (We will discuss twisted pair later in this section.) Today's modem speeds allow dialup access at rates up to 56 Kbps. However, due to the poor quality of twisted-pair line between many homes and ISPs, many users

get an effective rate significantly less than 56 Kbps. For an in depth discussion of the practical aspects of modems see the Institute for Global Communications (IGC) web page on [Modems and Data Communications](#).

While dialup modems require conversion of the end system's digital data into analog form for transmission, so-called narrowband **ISDN** technology (Integrated Services Digital Network) [[Pacific Bell 1998](#)] allows for all-digital transmission of data from a home end system over ISDN "telephone" lines to a phone company central office. Although ISDN was originally conceived as a way to carry digital data from one end of the phone system to another, it is also an important network access technology that provides higher speed access (e.g., 128 Kbps) from the home into a data network such as the Internet. In this case, ISDN can be thought of simply as a "better modem" [[NAS 1995](#)]. A good source for additional WWW information on ISDN is [Dan Kegel's ISDN page](#).

Dialup modems and narrowband ISDN are already widely deployed technologies. Two new technologies, **Asymmetric Digital Subscriber Line (ADSL)** [[ADSL 1998](#)] and **hybrid fiber coaxial cable (HFC)** [[Cable 1998](#)] are currently being deployed. ADSL is conceptually similar to dialup modems: it is a new modem technology again running over existing twisted pair telephone lines, but can transmit at rates of up to about 8 Mbps from the ISP router to a home end system. The data rate in the reverse direction, from the home end system to the central office router, is less than 1 Mbps. The asymmetry in the access speeds gives rise to the term "Asymmetric" in ADSL. The asymmetry in the data rates reflects the belief that home users are more likely to be a consumer of information (bringing data into their homes) than a producer of information.

ADSL uses frequency division multiplexing, as described in the previous section. In particular, ADSL divides the communication link between the home the ISP into three non-overlapping frequency bands:

- a **high-speed downstream channel**, in the 50 KHz to 1 MHz band;
- a **medium-speed upstream channel**, in the 4 KHz to 50 KHz band;
- and an **ordinary POTS two-way telephone channel**, in the 0 to 4 KHz band.

One of the features of ADSL is that the service allows the user to make an ordinary telephone call, using the POTS channel, while simultaneously surfing the Web. This feature is not available with standard dialup modems. The actual amount of downstream and upstream bandwidth available to the user is a function of the distance between the home modem and the ISP modem, the gauge of the twisted pair line, and the degree of electrical interference. For a high-quality line with negligible electrical interference, an 8 Mbps downstream transmission rate is possible if the distance between the home and the ISP is less than 3,000 meters; the downstream transmission rate drops to about 2 Mbps for a distance of 6,000 meters. The upstream rate ranges from 16 Kbps to 1 Mbps.

While ADSL, ISDN and dialup modems all use ordinary phone lines, HFC access networks are extensions of the current cable network used for broadcasting cable television. In a traditional cable system, a cable head end station broadcasts through a distribution of coaxial cable and amplifiers to residences. (We discuss coaxial cable later in this chapter.) As illustrated in Figure 1.5-2, fiber optics (also to be discussed soon) connect the cable head end to neighborhood-level junctions, from which traditional coaxial cable is then used to reach individual houses and apartments. Each neighborhood juncture typically supports 500 to 5000 homes.

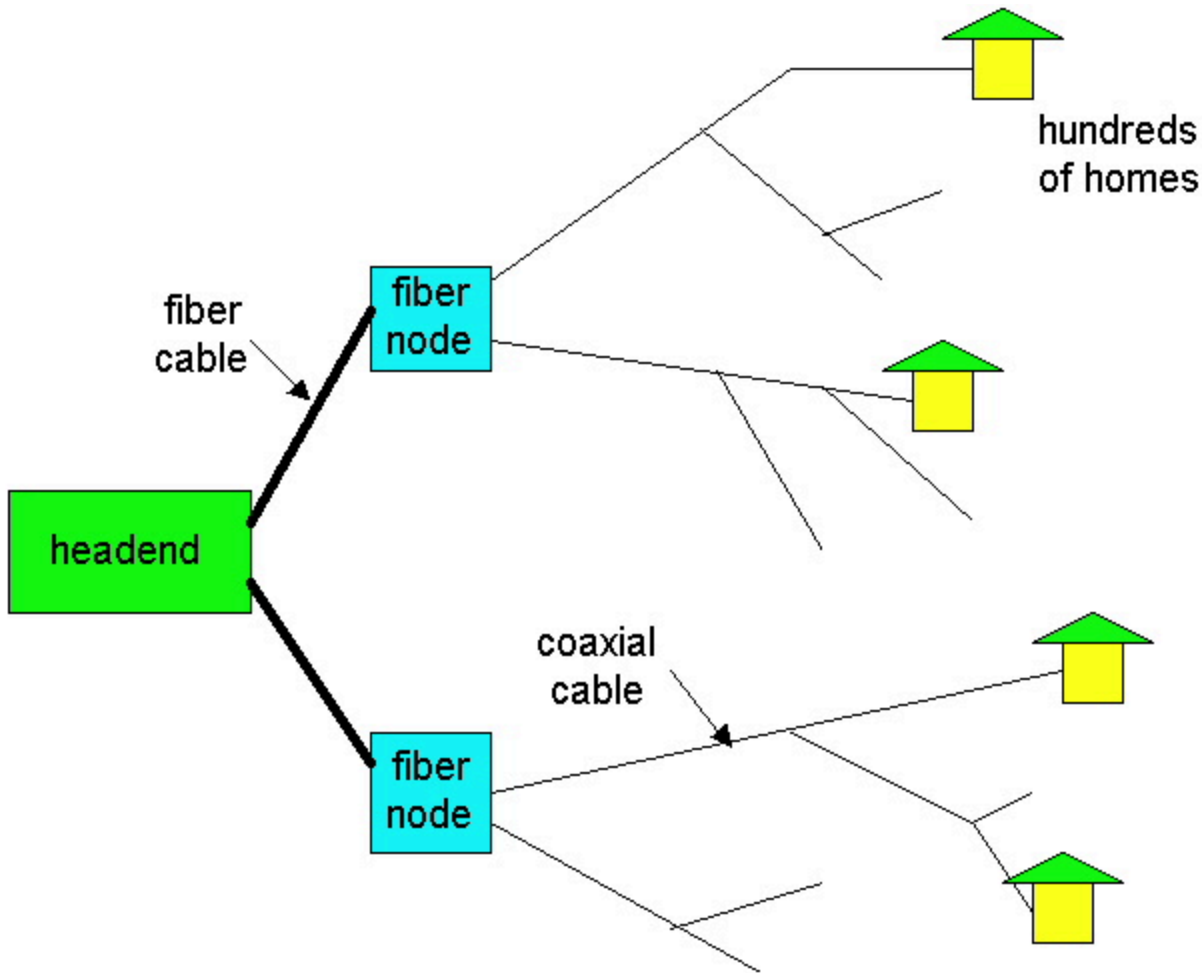


Figure 1.5-2: A hybrid fiber-coax access network

As with ADSL, HFC requires special modems, called [cable modems](#). Companies that provide cable Internet access require their customers to either purchase or lease a modem. One such company is [CyberCable](#), which uses [Motorola's CyberSurfer Cable Modem](#) and provides high-speed Internet access to most of the neighborhoods in Paris. Typically, the cable modem is an external device and connects to the home PC through a 10-BaseT Ethernet port. (We will discuss Ethernet in great detail in Chapter 5.) Cable modems divide the HFC network into two channels, a downstream and an upstream channel. As with ADSL, the downstream channel is typically allocated more bandwidth and hence a larger transmission rate. For example, the downstream rate of the CyberCable system is 10 Mbps and the upstream rate is 768 Kbps. However, with HFC (and not with ADSL), these rates are shared among the homes, as we discuss below.

One important characteristic of the HFC is that it is a shared broadcast medium. In particular, every packet sent by the headend travels downstream on every link to every home; and every packet sent by a home travels on the upstream channel to the headend. For this reason, if several users are receiving different Internet videos on the downstream channel, actual rate at which each user receives its video will be significantly less than downstream rate. On the other hand, if all the active users are Web surfing, then each of the users may actually receive Web pages at the full downstream rate, as a small collection of users will rarely receive a Web page at exactly the same time. Because the upstream channel is also shared, packets sent by two different homes at the same time will collide, which further decreases the effective upstream bandwidth. (We will discuss this collision issue in some detail when we discuss Ethernet in Chapter 5.) Advocates of ADSL are quick to point out that ADSL is a point-to-point connection between the home and ISP, and therefore all the ADSL bandwidth is dedicated rather than shared. Cable advocates, however, argue that a reasonably dimensioned HFC network provides higher bandwidths than ADSL [[@Home 1998](#)]. The battle between ADSL and HFC for high speed residential access has clearly begun, e.g., [[@Home 1998](#)].

Enterprise Access Networks

In enterprise access networks, a local area network (LAN) is used to connect an end system to an edge router. As we will see in Chapter 5, there are many different types of LAN technology. However, Ethernet technology is currently by far the most prevalent access technology in enterprise networks. Ethernet operates 10 Mbps or 100Mbps (and now even at 1 Gbps). It uses either twisted-pair copper wire or coaxial cable to connect a number of end systems with each other and with an edge router. The edge router is responsible for routing packets that have destinations outside of that LAN. Like HFC, Ethernet uses a shared medium, so that end users share the transmission rate of the LAN. More recently, shared Ethernet technology has been migrating towards switched Ethernet technology. Switched Ethernet uses multiple coaxial cable or twisted pair Ethernet segments connected at a "switch" to allow the full bandwidth of an Ethernet to be delivered to different users on the same LAN simultaneously [Cisco 1998]. We will explore shared and switched Ethernet in some detail in Chapter 5.

Mobile Access Networks

Mobile access networks use the radio spectrum to connect a mobile end system (e.g., a laptop PC or a PDA with a wireless modem) to a base station, as shown in Figure 1.5-1. This base station, in turn, is connected to an edge router of a data network.

An emerging standard for wireless data networking is Cellular Digital Packet Data (CDPD) [Wireless 1998]. As the name suggests, a CDPD network operates as an overlay network (i.e., as a separate, smaller "virtual" network, as a piece of the larger network) within the cellular telephone network. A CDPD network thus uses the same radio spectrum as the cellular phone system, and operates at speeds in the 10's of Kbits per second. As with cable-based access networks and shared Ethernet, CDPD end systems must share the transmission media with other CDPD end systems within the cell covered by a base station. A media access control (MAC) protocol is used to arbitrate channel sharing among the CDPD end systems; we will cover MAC protocols in detail in Chapter 5.

The CDPD system supports the IP protocol, and thus allows an IP end system to exchange IP packets over the wireless channel with an IP base station. A CDPD network can actually support multiple network layer protocols; in addition to IP, the ISO CNLP protocol is also supported. CDPD does not provide for any protocols above the network layer. From an Internet perspective, CDPD can be viewed as extending the Internet dialtone (i.e., the ability to transfer IP packets) across a wireless link between a mobile end system and an Internet router. An excellent introduction to CDPD is [Wang 98].

1.5.2 Physical Media

In the previous subsection we gave an overview of some of the most important access network technologies in the Internet. While describing these technologies, we also indicated the physical media used. For example, we said that HFC uses a combination of fiber cable and coaxial cable. We said that ordinary modems, ISDN, and ADSL use twisted-pair copper wire. And we said that mobile access networks use the radio spectrum. In this subsection we provide a brief overview of these and other transmission media that are commonly employed in the Internet.

In order to define what is meant by a "physical medium," let us reflect on the brief life of a bit. Consider a bit traveling from one end system, through a series of links and routers, to another end system. This poor bit gets transmitted many, many times! The source end-system first transmits the bit and shortly thereafter the first router in the series receives the bit; the first router then transmits the bit and shortly afterwards the second router receives the bit, etc. Thus our bit, when traveling from source to destination, passes through a series of transmitter-receiver pairs. For each transmitter-receiver pair, the bit is sent by propagating electromagnetic waves across a **physical medium**. The physical medium can take many shapes and forms, and does not have to

be of the same type for each transmitter-receiver pair along the path. Examples of physical media include twisted-pair copper wire, coaxial cable, multimode fiber optic cable, terrestrial radio spectrum and satellite radio spectrum. Physical media fall into two categories: **guided media** and **unguided media**. With guided media, the waves are guided along a solid medium, such as a fiber-optic cable, a twisted-pair copper wire or a coaxial cable. With unguided media, the waves propagate in the atmosphere and in outer space, such as in a digital satellite channel or in a CDPD system.

Some Popular Physical Media

Suppose you want to wire a building to allow computers to access the Internet or an intranet -- should you use twisted-pair copper wire, coaxial cable, or fiber optics? Which of these media gives the highest bit rates over the longest distances? We shall address these questions below.

But before we get into the characteristics of the various guided medium types, let us say a few words about their costs. The actual cost of the physical link (copper wire, fiber optic cable, etc.) is often relatively minor compared with the other networking costs. In particular, the labor cost associated with the installation of the physical link can be orders of magnitude higher than the cost of the material. For this reason, many builders install twisted pair, optical fiber, and coaxial cable to every room in a building. Even if only one medium is initially used, there is a good chance that another medium could be used in the near future, and so money is saved but not having to lay additional wires.

Twisted-Pair Copper Wire

The least-expensive and most commonly-used transmission medium is twisted-pair copper wire. For [over one-hundred years it has been used by telephone networks](#). In fact, more than 99% of the wired connections from the telephone handset to the local telephone switch use twisted-pair copper wire. Most of us have seen twisted pair in our homes and work environments. Twisted pair consists of two insulated copper wires, each about 1 mm thick, arranged in a regular spiral pattern; see Figure 1.5-3. The wires are twisted together to reduce the electrical interference from similar pairs close by. Typically, a number of pairs are bundled together in a cable by wrapping the pairs in a protective shield. A wire pair constitutes a single communication link.



Figure 1.5-3: Twisted Pair

Unshielded twisted pair (UTP) is commonly used for computer networks within a building, that is, for local area networks (LANs). Data rates for LANs using twisted pair today range from 10 Mbps to 100 Mbps. The data rates that can be achieved depend on the thickness of the wire and the distance between transmitter and receiver. Two types of UTP are common in LANs: category 3 and category 5. Category 3 corresponds to voice-grade twisted pair, commonly found in office buildings. Office buildings are often prewired with two or more parallel pairs of category 3 twisted pair; one pair is used for telephone communication, and the additional pairs can be used for additional telephone lines or for LAN networking. 10 Mbps Ethernet, one of the most prevalent LAN types, can use category 3 UTP. Category 5, with its more twists per centimeter and Teflon insulation, can handle higher bit rates. 100 Mbps Ethernet running on category 5 UTP has become very popular in recent years. In recent years, category 5 UTP has become common for preinstallation in new office buildings.

When fiber-optic technology emerged in the 1980s, many people disparaged twisted-pair because of its relatively low bit rates. Some people even felt that fiber optic technology would completely replace twisted pair. But twisted pair did not give up so easily. [Modern twisted-pair technology](#), such as category 5 UTP, can achieve data rates of 100 Mbps for distances up to a few hundred meters. Even higher rates are possible over shorter distances. In the end, twisted-pair has emerged as the dominant solution for high-speed LAN networking.

As discussed in Section 1.5.1, twisted-pair is also commonly used for residential Internet access. We saw that dial-up modem technology enables access at rates of up to 56 Kbps over twisted pair. We also saw that [ISDN](#) is

available in many communities, providing access rates of about 128 Kbps over twisted pair. We also saw that [ADSL](#) (Asymmetric Digital Subscriber Loop) technology has enabled residential users to access the Web at rates in excess of 6 Mbps over twisted pair.

Coaxial-Cable

Like twisted pair, coaxial cable consists of two copper conductors, but the two conductors are concentric rather than parallel. With this construction and a special insulation and shielding, coaxial cable can have higher bit rates than twisted pair. Coaxial cable comes in two varieties: **baseband coaxial cable** and **broadband coaxial cable**.

Baseband coaxial cable, also called 50-ohm cable, is about a centimeter thick, lightweight, and easy to bend. It is commonly used in LANs; in fact, the computer you use at work or at school is probably connected to a LAN with either baseband coaxial cable or with UTP. Take a look at the the connection to your computer's interface card. If you see a telephone-like jack and some wire that resembles telephone wire, you are using UTP; if you see a T-connector and a cable running out of both sides of the T-connector, you are using baseband coaxial cable. The terminology "baseband" comes from the fact that the stream of bits is dumped directly into the cable, without shifting the signal to a different frequency band. 10 Mbps Ethernets can use either UTP or baseband coaxial cable. As we will discuss in the Chapter 5, it is a little more expensive to use UTP for 10 Mbps Ethernet, as UTP requires an additional networking device, called a **hub**.

Broadband coaxial cable, also called 75-ohm cable, is quite a bit thicker, heavier, and stiffer than the baseband variety. It was once commonly used in LANs and can still be found in some older installations. For LANs, baseband cable is now preferable, since it is less expensive, easier to physically handle, and does not require attachment cables. Broadband cable, however, is quite common in cable television systems. As we saw in Section 1.5.1, cable television systems have been recently been coupled with [cable modems](#) to provide residential users with Web access at rates of 10 Mbps or higher. With broadband coaxial cable, the transmitter shifts the digital signal to a specific frequency band, and the resulting analog signal is sent from the transmitter to one or more receivers. Both baseband and broadband coaxial cable can be used as a guided **shared medium**. Specifically, a number of end systems can be connected directly to the cable, and all the end systems receive whatever any one of the computers transmits. We will look at this issue in more detail in Chapter 5.

Fiber Optics

An optical fiber is a thin, flexible medium that conducts pulses of light, with each pulse representing a bit. A single optical fiber can support tremendous bit rates, up to tens or even hundreds of gigabits per second. They are immune to electromagnetic interference, have very low signal attenuation up to 100 kilometers, and are very hard to tap. These characteristics have made fiber optics the preferred long-haul guided transmission media, particularly for overseas links. Many of the long-distance telephone networks in the United States and elsewhere now use fiber optics exclusively. Fiber optics is also prevalent in the backbone of the Internet. However, the high cost of optical devices -- such as transmitters, receivers, and switches -- has hindered their deployment for short-haul transport, such as in a LAN or into the home in a residential access network. AT&T Labs provides an [excellent site on fiber optics](#), including several nice animations.

Terrestrial and Satellite Radio Channels

Radio channels carry signals in the electromagnetic spectrum. They are an attractive media because require no physical "wire" to be installed, can penetrate walls, provide connectivity to a mobile user, and can potentially carry a signal for long distances. The characteristics a radio channel depend significantly on the propagation environment and the distance over which a signal is to be carried. Environmental considerations determine path loss and shadow fading (which decrease in signal strength as it travels over a distance and around/through obstructing objects), multipath fading (due to signal reflection off of interfering objects), and interference (due to other radio channels or electromagnetic signals).

Terrestrial radio channels can be broadly classified into two groups: those that operate as local area networks (typically spanning 10's to a few hundred meters) and wide-area radio channels that are used for mobile data

services (typically operating within a metropolitan region). A number of wireless LAN products are on the market, operating in the 1 to 10's of Mbps range. Mobile data services (such as the CDPD standard we touched on in section 1.3), typically provide channels that operate at 10's of Kbps. See [[Goodman 97](#)] for a survey and discussion of the technology and products.

A communication satellite links two or more earth-based microwave transmitter/receivers, known as ground stations. The satellite receives transmissions on one frequency band, regenerates the signal using a repeater (discussed below), and transmits the signal on another frequency. Satellites can provide bandwidths in the gigabit per second range. Two types of satellites are used in communications: geostationary satellites and low-altitude satellites.

Geostationary satellites permanently remain above the same spot on the Earth. This stationary presence is achieved by placing the satellite in orbit at 36,000 kilometers above the Earth's surface. This huge distance between from ground station though satellite back to ground station introduces a substantial signal propagation delay of 250 milliseconds. Nevertheless, satellites links are often used in telephone networks and in the backbone of the Internet.

Low-altitude satellites are placed much closer to the Earth and do not remain permanently above one spot on the Earth. They rotate around the Earth just as the Moon rotates around the Earth. To provide continuous coverage to an area, many satellites to be placed in orbit. There are currently many low-altitude communication systems in development. The [Iridium system](#), for example, consists of 66 low-altitude satellites. [Lloyd's satellite constellations](#) provides and collects information on Iridium as well as other satellite constellation systems. The low-altitude satellite technology may be used for Internet access sometime in the future.

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