CHAPTER

3

FIBER OPTIC NETWORKS

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One often sees articles written about fiber optic communications networks that imply that fiber optics is "new." That is hardly the case. The first fiber optic telephone network was installed in Chicago in 1976, and by 1979, commercial fiber optic computer datalinks were available. Since then, fiber has become commonplace in the communications infrastructure.

If you make a long-distance call today, your voice is undoubtedly being transmitted on fiber optic cable, since it has replaced over 90 percent of all voice circuits for long-distance communications. Transoceanic links are being converted to fiber optics at a very high rate, since all new undersea cables are fiber optics. Phone company offices are being interconnected with fiber, and most large office buildings have fiber optic telephone connections into the buildings themselves. Only the last links to the home, office, and phone are not fiber.

CATV also uses fiber optics via a unique analog transmission scheme, but they are already planning on fiber moving to compressed digital video. Most large city CATV systems are being converted to fiber optics for reliability and in order to offer new services such as Internet connections and phone service. Only fiber offers the bandwidth necessary for carrying voice, data, and video simultaneously.

The LAN backbone also has become predominately fiber-based. The back-end of mainframe computers is also primarily fiber. The desktop is the only holdout, currently a battlefield between the copper and fiber contingents.

Security, building management, audio, process control, and almost any other system that requires communications cabling have become available on fiber optics. Fiber optics really is the medium of choice for all high bandwidth and/or long-distance communications. Let us look at why it is, how to evaluate the economics of copper versus fiber, and how to design fiber networks with the best availability of options for upgradeability in the future.

IT IS REALLY ALL A MATTER OF ECONOMICS

The use of fiber optics is entirely an issue of economics. Widespread use occurred when the cost declined to a point that fiber optics became less expensive than transmission over copper wires, radio, or satellite links. However, for each application, the turnover point has been reached for somewhat different reasons.

Telephony

Fiber optics has become widely used in telephone systems because of its enormous bandwidth and distance advantages over copper wires. The application for fiber in telephony is simply connecting switches over fiber optic links (Figure 3-1). Commercial systems today carry more phone conversations over a single pair of fibers than could be carried over thousands of copper pairs. Material costs,

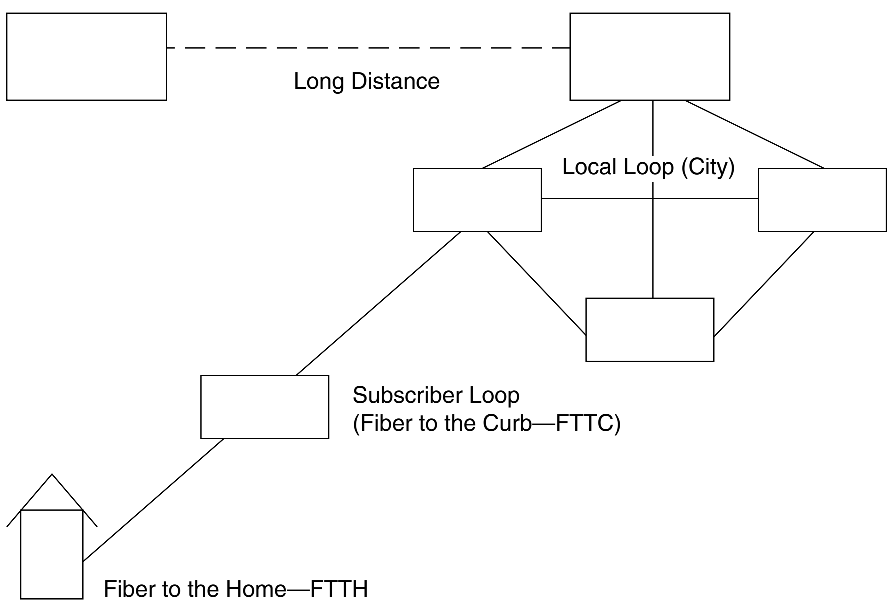

Figure 3-1 Telephone fiber optic architecture.

installation, and splicing labor and reliability are all in fiber's favor, not to mention space considerations. In major cities today, insufficient space exists in current conduit to provide communications needs over copper wire.

While fiber carries over 90 percent of all long-distance communications and 50 percent of local communications, the penetration of fiber to the curb (FTTC) and fiber to the home (FTTH) has been hindered by a lack of cost-effectiveness. These two final frontiers for fiber in the phone systems hinge on fiber becoming less expensive and customer demand for high bandwidth services that would be impossible over current copper telephone wires. Digital subscriber loop (DSL) technology has enhanced the capacity of the current copper wire home connections so as to postpone implementation of FTTH for perhaps another decade.

Telecommunications led the change to fiber optic technology. The initial use of fiber optics was simply to build adapters that took input from traditional telephone equipment's electrical signals on copper cables, multiplexed many signals to take advantage of the higher bit-rate capability of fiber, and used high-power laser sources to allow maximum transmission distances.

After many years of all these adapters using transmission protocols proprietary to each vendor, Bellcore (now Telcordia) began working on a standard network called SONET, for Synchronous Optical NETwork. SONET would allow interoperability between various manufacturers' transmission equipment.

However, the telephone companies' (telco's) transition to SONET was slow, a result of reluctance to make obsolete recently installed fiber optic transmission equipment and the slow development of the details of the standards. Progress has been somewhat faster overseas, where the equivalent network standard Synchronous Digital Hierarchy (SDH) is being used for first-generation fiber optic systems. SONET is now threatened by Internet protocol (IP) networks, since data traffic has surpassed voice traffic in volume and is growing many times faster, mostly due to the popularity of the Internet and World Wide Web.

CATV

In CATV, fiber initially paid for itself in enhanced reliability. The enormous bandwidth requirements of broadcast TV require frequent repeaters. The large number of repeaters used in a broadcast cable network are a big source of failure. And CATV systems' tree-and-branch architecture means upstream failure causes failure for all downstream users. Reliability is a big issue since viewers are a vocal lot if programming is interrupted!

CATV experimented with fiber optics for years, but it was too expensive until the development of the AM analog systems. By simply converting the signal from electrical to optical, the advantages of fiber optics became cost-effective. Now CATV has adopted a network architecture (Figure 3-2) that overbuilds the normal coax network with fiber optic links.

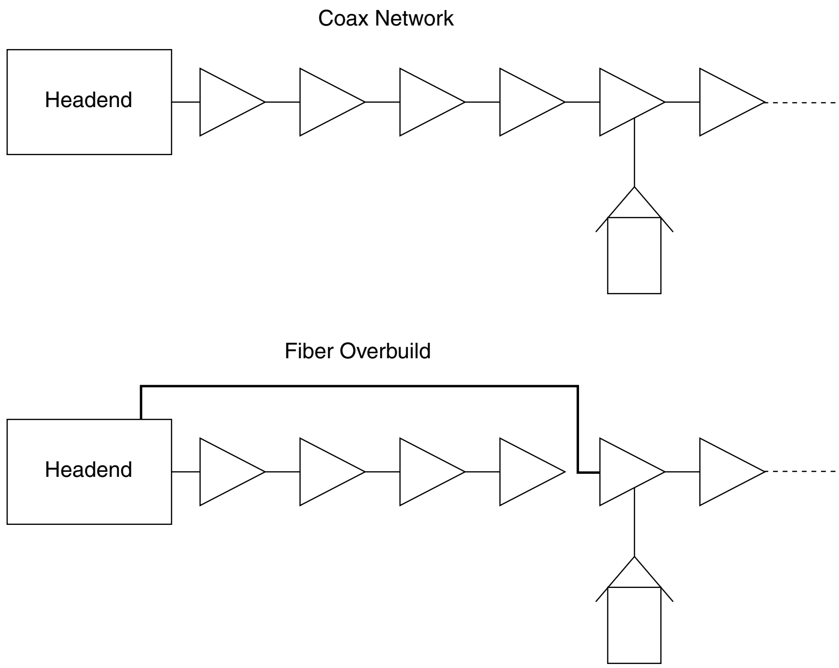

Figure 3-2 CATV architectures before and after fiber overbuild.

Fiber is easy to install in an overbuild, either by lashing lightweight fiber optic cable to the installed aerial coax or by pulling in underground ducts. The technology, all singlemode with laser sources, is easily updated to future digital systems when compressed digital video becomes available. The connection to the user remains coaxial cable, which has as much as 1 GHz bandwidth.

The installed cable plant also offers the opportunity to install data and voice services in areas where it is legal and economically feasible. Extra fibers can be easily configured for a return path. The breakthrough came with the development of the cable modem, which multiplexes Ethernet onto the frequency spectrum of a CATV system. CATV systems can literally put the subscriber on a Ethernet LAN and connect them to the Internet at much higher speeds than a dial-up phone connection. Adding voice service is relatively easy for the CATV operator as well.

Local Area Networks

For LANs and other datacom applications, the economics of fiber optics are less clear today. For low bit-rate applications over short distances, copper wire is undoubtedly more economical, but as distances go over the 100 meters called for in industry standards and speeds get above 100 Mb/s, fiber begins to look more attractive since copper requires more local network electronics and there are many problems installing and testing copper wire to high speed standards. Ability to upgrade usually tilts the decision to fiber since copper must be handled very carefully to operate at speeds where fiber is just cruising along.

Fiber penetration in LANs is very high in long-distance or high bit-rate backbones in large LANs, connecting local hubs or routers, but still very low in connections to the desktop. The rapidly declining costs of the installed fiber optic cable plant and adapter electronics combined with needs for higher bandwidth at the desktop are making fiber to the desk more viable, especially using centralized fiber architectures.

There are a large number of LAN standards today. The most widely used, called Ethernet or IEEE802.3 after its standards committee, is a 10, 100 MB/s or 1 GB/s LAN that operates with a protocol that lets any station broadcast if the network if free. Token ring (most often referred to as IBM Token Ring after its developer) is a 4 or 16 MB/s LAN that has a ring architecture, where each station has a chance to transmit in turn, when a digital "token" passes to that station. These two networks were developed originally based on copper wire standards. Fiber optic adapters or repeaters have been developed for these networks to allow using fiber optic cable for transmission where distance or electrical interference justifies the extra cost of the fiber optic interfaces for the equipment.

Most LANs have been designed from the beginning to offer the option of both copper wiring and fiber optics. Several of these networks were optimized for fiber. All share the common specification of speed: they are high-speed networks designed to move massive quantities of data rapidly between workstations or mainframe computers.

Fiber Distributed Data Interface (FDDI) is a high-speed LAN standard that was developed specifically for fiber optics by the ANSI X3T9.5 committee, and products are readily available. FDDI has a dual counter-rotating ring topology (Figure 3-3) with dual-attached stations on the backbone that are attached to both rings, and single-attached stations that are attached to only one of the rings through a concentrator. It has a token passing media access protocol and a 100-Mbit/s data rate. FDDIs dual ring architecture makes it very fault tolerant, as the loss of a cable or station will not prevent the rest of the network from operating properly.

ESCON (Figure 3-4) is an IBM-developed network that connects peripherals to the mainframe, replacing "bus and tag" systems. ESCON stands for Enterprise System Connection architecture. The network is a switched star architecture, using ESCON directors to switch various equipment to the mainframe computers. Data transfer rate started at 4.5 megabytes/second but was increased to 10 Mbytes/second. With an 8B/10B conding scheme, ESCON runs at about 200 Mbits/sec.

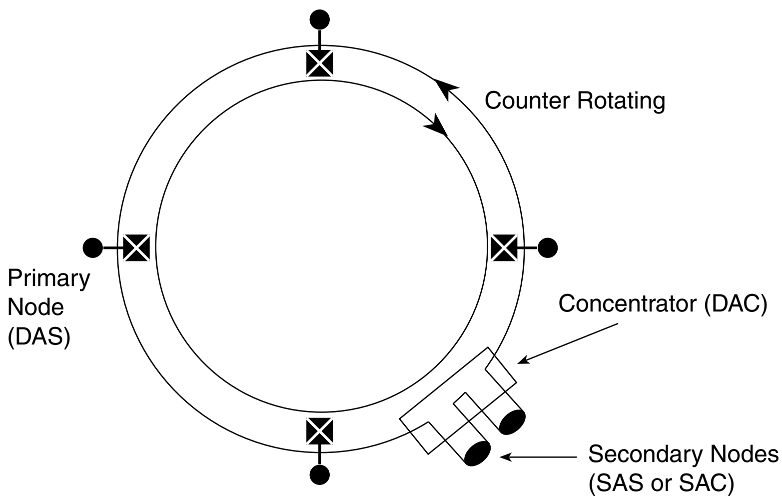

Figure 3-3 Fiber distributed data interface (FDDI).

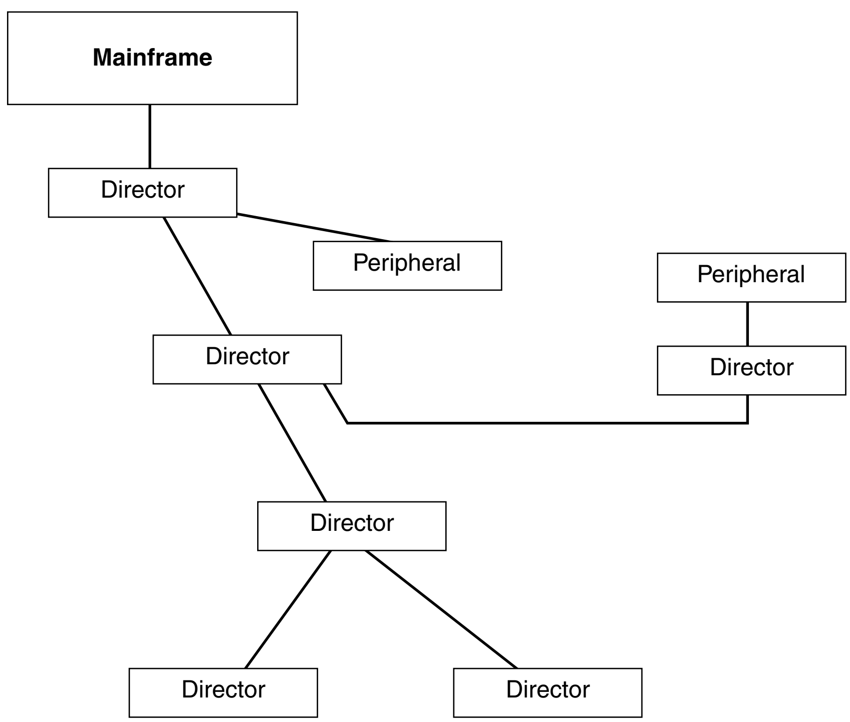

Figure 3-4 Enterprise system connection (ESCON) architecture.

Optically, ESCON and FDDI are similar. They use 1300-nm transmission for the higher bandwidth necessary with high-speed data transfer rates. Both singlemode and multimode cable plants are supported and distances up to 20 kilometers between directors.

Fibre Channel and High Performance Parallel Interface (HIPPI) are both high-speed links, not networks, that are designed to be used to interconnect high-speed data devices. The link protocol supports most fiber types and even copper cables for some short runs.

FIBER OR COPPER? TECHNOLOGY SAYS GO FIBER, BUT . . .

Fiber's performance advantages over copper result from the physics of transmitting with photons instead of electrons. Fiber optic transmission neither radiates radio frequency interference (RFI) nor is susceptible to interference, unlike copper wires that radiate signals capable of interfering with other electronic equipment. Because it is unaffected by electrical fields, utility companies even run power lines with fibers imbedded in the wires!

The bandwidth/distance issue is what usually convinces the user to switch to fiber. For today's applications, fiber is used at 100–200 Mb/s for datacom applications on multimode fiber, and telcos and CATV use singlemode fiber in the gigahertz range. Multimode fiber has a larger light-carrying core that is compatible with less expensive LED sources, but the light travels in many rays, called modes, that limit the bandwidth of the fiber. Singlemode fiber has a smaller core that requires laser sources, but light travels in only one mode, offering almost unlimited bandwidth.

In either fiber type, you can transmit at many different wavelengths of light simultaneously without interference; this process is called wavelength division multiplexing (WDM). WDM is much easier with singlemode fiber, since lasers have much better defined spectral outputs. Telephone networks using dense wavelength division multiplexing (DWDM) have systems now operating at greater than 80 MB/s. IBM developed a prototype system that uses this technique to provide a potential of 300 Gb/s on a LAN!

Which LANs Support Fiber?

That's easy, all of them. Some, such as FDDI or ESCON, were designed around fiber optics, whereas others, such as Ethernet or token ring, use fiber optic adapters to change from copper cable to fiber optics. In the computer room, you can get fiber optic channel extenders or ESCON equipment with fiber built in.

Where Is the Future of Fiber?

The future of fiber optics is the future of communications. What fiber optic offers is bandwidth and the ability to upgrade. Applications such as multimedia and video conferencing are driving networks to higher bandwidth at a furious pace. Over wide area networks, the installed fiber optic infrastructure can be expanded to accommodate almost unlimited traffic. Only the electronic switches need to be upgraded to provide orders of magnitude greater capacity. CATV operators are installing fiber as fast as possible since advanced digital TV will thrive in a fiber-based environment. Datacom applications can benefit from fiber optics also, as graphics and multimedia require more LAN bandwidth. Even wireless communications need fiber, connecting local low-power cellular or personal communication systems (PCS) transceivers to the switching matrix.

The Copper Versus Fiber Debate

Over the past few years, the datacom arena has been the site of a fierce battle between the *fiber* people and the *copper* people. First, almost 10 years ago, fiber offered the only solution to high-speed or long-distance datacom backbones. Although fiber was hard to install then and electrical/optical interfaces were expensive, when available at all, fiber was really the only reliable solution. This led to the development of the FDDI standard for a 100 Mb/s token ring LAN and the IBM ESCON system to replace bus and tag cables.

By 1989, FDDI was a reality, with demonstration networks operating at conferences to show that it really worked and that various vendors' hardware was interoperable. In 1990, IBM introduced ESCON as part of the System 390 introduction and fiber had become an integral part of their mainframe hardware. Everybody thought fiber had arrived.

However, at the same time, the copper wire manufacturers had developed new design cables that had much better attenuation characteristics at high frequencies. Armed with data that their Category 5 unshielded twisted pair (UTP) cables could transmit 100–150 Mb/s signals over 100 meters and surveys that showed that most desktop connections are less than that distance, they made a major frontal assault on the high-speed LAN marketplace. Simultaneously, other high-speed LAN standards, high-speed Ethernet and asynchronous transfer mode (ATM), which deliver FDDI speeds on copper wire, became popular. Now copper manufacturers are offering proprietary designs for copper cables that promise 250 MHz bandwidth, although the designs are years away from standardization. Many potential users continue to postpone making the decision to go to fiber.

So How Do You Decide Between Fiber and Copper?

Some applications are really black and white. Low bit-rate LAN connections at the desktop with little expectation of ever upgrading to higher bit rates should use copper. Long distances, heavy traffic loads, high bit rates, or high interference environments demand fiber. So if you have a backbone and Ethernet or token ring on the desktop, a fiber backbone and Category 5 UTP to the desktop makes good sense. If you already have a mainframe in the computer room and are using channel connections, you probably will use bus and tag cables for connections. But if you are extending those connections outside the computer room or buying a new mainframe, you will be getting fiber optic channel extenders or ESCON.

If either media will work in your application, it really comes down to economics—which solution is more cost-effective. But cost is a combination of factors, including system architecture, material cost, installation, testing, and "opportunity cost."

More end users are realizing that in a proper comparison, fiber right to the desktop can actually be significantly cheaper than a copper network. Look at the networks (Figure 3-5), and you will see what we mean.

The Traditional UTP LAN

The UTP copper LAN has a maximum cable length of 90 meters (about 290 ft.), so each desktop is connected by a unique UTP cable to a network hub located in a nearby "telecom closet." The backbone of the network can be UTP if the closets are close enough, or fiber optics if the distances are larger or the backbone runs a higher bandwidth network than can be supported on copper. Every hub connects to the main telecom closet with one cable per hub.

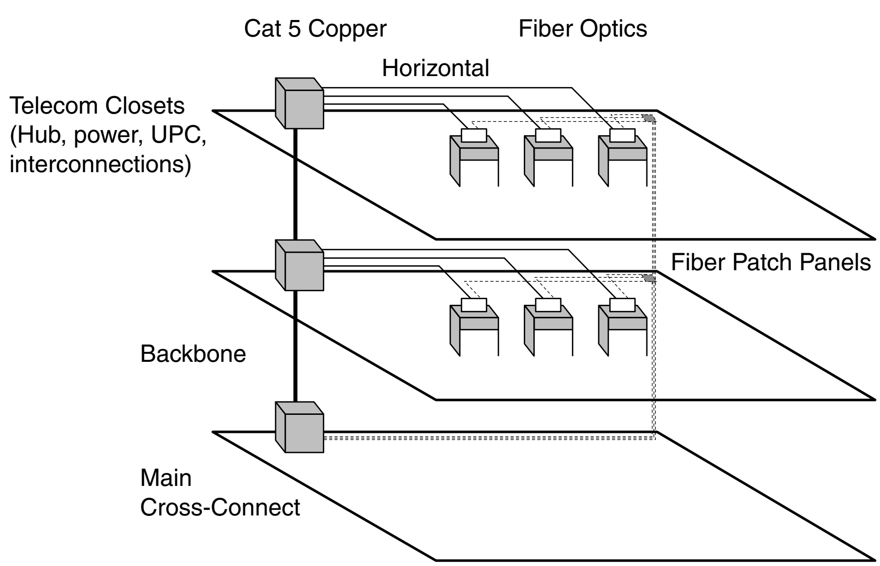

Figure 3-5 Fiber and copper use different network architectures.

In the telecom closet, every hub requires conditioned, uninterruptable power, since the network depends on every hub being able to survive a power outage. A data quality ground should be installed to prevent ground loops and noise problems. It will probably also have a rack to mount everything in (and the rack must be grounded properly.) Cables will be terminated in patch panels and patch cords will be used to connect cables to hubs.

The Fiber to the Desk LAN

Fiber optics is not limited in distance as is UTP cable. It can go as far as 2 kilometers (over 6,000 ft.), making it possible to bypass the local hubs and cable straight to the main telecom closet. It is likely there will be a small patch panel or wall box connecting desktop cables (probably zipcord) to a large fiber count backbone cable. At least 72 desktops can be connected on one backbone cable, which is hardly larger than one UTP cable.

So an "all-fiber" fiber network only has electronics in the main telecom closet and at the desktop—nothing in between. That means we do not need power or a UPS in the telecom closet—we do not even need a closet! Managing the network becomes much easier since all the electronics are in one location. Troubleshooting is simpler as well.

The Myth That Fiber Is More Expensive

The myth that fiber is more expensive has been copper's best defense against fiber optics. In a typical cost comparison, the architecture chosen is the typical copper one, and the cost of a link from the telecom closet to the desk, including electronics, is always higher for fiber—although by less and less each year.

But that is not a fair comparison! In a real comparison, we would price the complete networks shown in Figure 3-5. It would look more like Table 3-1.

So what happens if we total up the costs with this comparison? One estimate on a bank with no building construction costs had fiber costing only about $9 more per desktop. Another estimate had fiber costing only two-thirds as much as UTP. Several new construction projects claimed saving millions of dollars by eliminating all but one telecom closet in a large campus and thereby saving large amounts in building construction costs.

Fiber also saves money on testing. For fiber, it is a simple matter of testing the optical loss of the installed cable plant, including all interconnections to worldwide standards. The test equipment costs less than $1,000 and testing takes a few minutes per fiber.

Testing Category 5 or 6 UTP requires $3,000 to $50,000 in equipment and very careful control of testing conditions. Standards for testing are still continuously developed to keep up with new product development. If you consider the cost of testing, copper will probably cost a lot more than fiber!

Table 3-1. Comparison of Fiber and Copper Networks

	UTP Copper	Fiber
Desktop	Ethernet Network Interface Card for Cat 5	Ethernet Network Interface Card for fiber
Horizontal Cabling	Cat 5 cable, jacks, wall box, patch cord	Fiber zipcord, connectors, wall box, patch cord
Telecom Closet	Patch panel, patch cord, rack, hub, power connection, UPS, data ground	Wall mount patch panel
Backbone Cabling	One Cat 5 cable per connection	One multifiber cable per consolidation point
Main Telecom Closet	Patch panels, patch cords, electronics, power, UPC	Patch panels, patch cords, electronics, power, UPC
Building (relevant for new construction or major renovations)	Space for large bundles of cable, large floor or wall penetrations, big telecom closets, separate grounding for network equipment	Not needed

FUTURE-PROOFING THE INSTALLATION

As fast as networks are changing, always to higher speeds, *future-proofing* is a difficult proposition. When the decision to install fiber is made, follow up is needed in the planning phases to ensure that the best fiber optic network is installed. Planning for the future is especially important. You can easily install a cable plant for your LAN today that will fill your current needs and allow for network expansion for a long time in the future.

Follow industry standards such as EIA/TIA 568 and install a standard star architecture cable plant. Install lots of spare fibers since fiber optic cable is now inexpensive, but installation labor is expensive. Those extra fibers are inexpensive to add to a cable being installed today, but installing another cable in the future could be much more expensive.

What fibers should be installed? For multimode fibers, the most popular fiber today is 62.5/125 micron, since every manufacturer's products will operate optimally on this fiber. However, most equipment is also compatible with 50/125 fiber, which has already been installed in some networks, especially military and government installations in the United States and throughout Europe. All singlemode fiber is basically the same, so the choice is easier, although for most applications the specialty singlemode fibers (e.g., dispersion shifted or flattened) should be avoided.

Paying a premium for higher bandwidth or lower attenuation specifications in multimode fibers can allow more future flexibility. Very high-speed networks have forced fiber manufacturers to develop better fibers for gigabit networks. Installing that fiber today may make migrating to gigabit networks easier in the future.

How many fibers should be installed? Lots! Installation costs generally will be larger than cable costs. To prevent big costs installing additional cables in the future, it makes good sense to install large fiber count cables the first time; however, terminate only the fibers needed immediately, since termination is still the highest labor cost for fiber optics.

Backbone cables should include 48 or more fibers, half multimode and half singlemode. If you are installing fiber to the desktop, 12 fibers, again half and half, will provide for any network architecture now plus spares and singlemode fiber for future upgrades.

The new generation of gigabit networks may even be too fast for multimode fiber over longer distances and they will use lasers and singlemode fiber to achieve >1 GB/s data rates. If you want to use fiber for video or telecom, you may need the singlemode fiber now. But you may not want to terminate the singlemode fiber until you need it, since singlemode terminations are still more expensive than multimode; however, they are getting less expensive over time.

Fiber optics has grown so fast in popularity because of the unbelievably positive feedback from users. With proper planning and preparation, a fiber optic network can be installed that will provide the user with communication capability well into the next decade.

REVIEW QUESTIONS

1. Three areas in which fiber is used:
    1. ________________
    2. ________________
    3. ________________

2. Match the application with the main reason fiber is the choice of transition medium.

______ LAN	a. upgradeability
______ CATV	b. reliability
______ Telecom	c. high bandwidth and distance advantages

3. FTTC stands for ________________ .

4. FTTH stands for ________________ .

5. The development of _______________ made fiber cost-effective for CATV applications.
   a. repeaters
   b. FM systems
   c. AM analog systems
   d. enormous bandwidth

6. Match the following LAN standards with their counterparts in the right column.

______ Ethernet	a. dual counter-rotating ring
______ ESCON	b. most widely used LAN
______ FDDI	c. connects peripherals to a mainframe
______ Token ring	d. originally developed for copper networks