FIBER DEPLOYMENT UPDATE
End of Year 1988

By Jonathan M. Kraushaar

Industry Analysis Division

Common Carrier Bureau

Federal Communications Commission

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Introduction:

The primary purpose of this report is to present current data on fiber deployment in both the local and interexchange markets. The report reflects the results of a recent survey of carrier fiber deployment. It includes data on the interexchange carriers, the Regional Bell Holding Companies, and a number of metropolitan area fiber systems. It supersedes an earlier analysis entitled "Fiber Deployment Update -- End of Year 1987" released in January 1988. Last year's report, which summarized fiber deployment by interexchange carriers and the Regional Bell holding companies, provided a basis for quantitatively evaluating potential network capacity. This report is an update of that study which reviews some of the same background information presented last year, extends the data series, and discusses some of the current developments.

Brief Review of the Technology:

Before discussing the technology itself, it may be useful to briefly review a few terms frequently used in this report. First, the term Gigabit is used to denote Gigabits per second (billions of bits per second). Megabit is used to denote Megabits per second (millions of bits per second). Kilobit is used to denote kilobits per second (thousands of bits per second). These are sometimes referred to as throughput rates or simply throughput. Another important term denoting capacity and used extensively in this report is a DS-3. Before defining a DS-3 it is useful to define a DS-1 which contains 24 equivalent 64 Kilobit channels, each of which can be used to handle a single voice conversation. A DS-3 is a multiplexed bundle of 672 64 Kilobit voice grade circuits (with a present standard bit rate of 44.736 Megabits per second) which contains up to 28 channels operating at the DS-1 rate of 1.544 Megabits per second.

Another acronym, ISDN, which stands for integrated switched digital network, refers to an application of the technology to provide for both newer digital and more traditional telephone services in an integrated network and incorporates a new set of network and interfacing standards which are being adopted worldwide. While the acronym ISDN has been loosely used to describe digital services, it is a term which primarily concerns the overall design strategy, interfacing standards and protocols for evolving the switched public telephone network. The concept as originally planned did not incorporate wideband video capability which has not traditionally been provided by the local telephone carriers. Because ISDN is a digital network concept, it is rapidly becoming a reality with widespread deployment of fiber and will provide the protocols and interfacing standards for the emerging worldwide fiber network.

Fiber is a relatively new transmission medium which uses light rather than electrical or microwave energy to provide for the transmission of intelligence. The light is propogated through thin strands of glass in a similar manner to the propogation of microwaves in a waveguide. The propogation medium can be much smaller for electromagnetic energy in the visual range than for microwaves because of the vastly smaller wavelength of light. Fiber became the medium of choice when losses were reduced to the point where repeater spacings and associated cost became competitive with earlier coaxial, microwave, and copper pair transmission cost. Early fiber transmission systems used multimode fiber which allowed the light to propogate over many slightly different paths through the fiber. Each path had a slightly different length resulting in varying delays for selected portions of the signal. This enhanced a phenomenon called dispersion resulting in limitation of the maximum allowed transmission bit rate for intelligible transmission of signals. Excessive bit rates could not be transmitted because dispersion caused the pulses to spread out and make the transmitted signal unintelligible.

Today, single mode fiber is used in long haul high capacity systems. This type of fiber does not allow the light to propogate in more than one path or mode and significantly reduces the dispersion problem discussed above. As a result, transmission bit rates became limited by the technology used to modulate electrical signals onto the light source. Advances in this technology are gradually pushing up the throughput of optical systems with transmission rates in the Gigabit range already a reality.

The modulation of the light signal may take a number of forms. Traditionally, the highest capacity systems encoded transmitted information on pulses of light, since the lasers producing the light could easily be made to emit light pulses. The use of newer techniques of heterodyning, more analogous to information transfer of information on radio, enable even higher throughput data rates. In addition, wavelength division multiplexing using slightly different colors of light to enable simultaneous transmission of multiple signals, each in the Gigabit range, are being developed. Theoretically, maximum throughputs as high as 25,000 Gigabits or 25 Terabits per second are possible as the transmission rate is limited only by the inherent frequency of the optical energy itself. Present experiments suggest that total system throughputs of about 100 Gigabits on a single fiber are feasible based on known technology. Engineers are investigating new technologies which may eventually make throughputs in the Terabit range (trillions of bits per second) possible.

The highest capacity system presently in use operates at 1.76 Gigabits and has a capacity of 36 DS-3's or 24,192 circuits per fiber pair. Systems using more than one optical wavelength with throughputs of 3.4 Gigabits should be available later in 1989. Research on more advanced systems, both using wavelength division multiplexing and higher bit rates using a single optical wavelength is continuing. AT&T, for example, has reportedly demonstrated 8 Gigabit per second transmission over a 68 kilometer link without any repeaters. In contrast, early multimode systems operated at 45 Megabits and handled a single DS-3 or up to 672 voice conversations. In the somewhat more distant future are systems with throughputs of between 16 and 27 Gigabits which are reportedly being developed or demonstrated in the laboratory by AT&T and Bellcore. These systems will use the wavelength division approach with a separate laser for each optical frequency (color) and will enable hundreds of thousands of telephone conversations to be simultaneously carried over a single fiber pair.

Systems using a single optical wavelength on a fiber with throughputs in the Gigabit range may require a special kind of single mode fiber called dispersion shifted fiber. For this and other reasons a good deal of current investigation to further increase capacity on existing fiber is focusing on wavelength division multiplexing. Because fiber technology has reached the point in which theoretical fiber capacities far exceed present repeater and terminal technology associated with the optical-electronic interface, fiber research activity is focusing on producing fiber with even lower losses which would permit larger spacing between repeaters. In particular, an exciting development in the research stage which will affect the industry within the next 10 to 15 years is ultra low loss halide fiber. This new type of fiber can potentially provide transmission without repeaters over distances exceeding 2,000 miles and undoubtedly will impact future transoceanic transmission systems. Bell Laboratories, Corning and others, including the Japanese, have been investigating halides, but many very difficult problems, including the extreme brittleness of this kind of fiber, are yet to be solved.

The vast potential capacities of existing fiber will be realized as new repeater and termination technologies are developed. Unfortunately, these developments may not always coincide with practical real world requirements. As a result some carriers will have to weigh strategies involving alternatives of overbuilding existing routes with more fiber, upgrading the electronics on existing routes, and waiting for availability of new generations of electronics.

Background:

Fiber optic communications systems are continuing to play an important role in the networks and strategic planning of all major carriers. Technological developments and associated business decisions are affecting the economic landscape associated with this maturing technology and have attracted the attention of many industry observers.

The cost of electronics, including lasers and receivers, has been declining dramatically, and a 50% decline in the past three years is typical. Even fiber has declined in price by about 50% in the past six or seven years. Changing economies are reducing the prove-in thresholds in both long haul and local applications. Fiber is thus becoming more cost effective for smaller route capacity cross sections and shorter distances. Local feeder plant which provides part of the local loop connection to the central office is becoming a prime area for new fiber deployment. As costs of loop transceivers decline to the $100 range and as demand for new digital and other services increases, significant amounts of fiber will begin to appear in the customer's loop. ISDN services, for example, which have been in the planning stage for some time may begin to make use of fiber in the local loop; however these services were designed to be used with existing copper twisted pairs using a special echo cancelling technology.

Three basic high capacity systems are now in extensive use: the 405 Megabit systems with a capacity of 9 DS-3's or 6,048 circuits per fiber pair, 565 Megabit systems with a capacity of 8,000 circuits per fiber pair and 1.76 Gigabit systems with a capacity of 36 DS-3's or 24,192 circuits per fiber pair. In addition, other systems with various throughputs in the above range, such as systems operating at 1.2 Gigabits have been deployed extensively. The Gigabit systems were deployed about a year ahead of schedule, due to rapid development, and systems operating at up to 3.4 Gigabits are expected to be introduced this year into AT&T's network about a year ahead of earlier expectations. Higher capacity systems are under development and many of them will utilize "wave division multiplexing" techniques mentioned earlier. All these systems utilize the same strands of single mode fiber which have already been deployed by most carriers, allowing for future expansion of existing systems without laying new cable. Single mode fiber allows only one propogation mode which reduces the amount of dispersion or the distortion of signal pulses associated with varying transmission delays of each propogation mode.

Worldwide, there are a number of suppliers of carrier and fiber cable systems. AT&T is a market leader in all areas. Rockwell, NEC, Fujitsu, Northern Telecom, Siecor and Ericsson are other major contenders. While a number of suppliers have introduced products with a throughput exceeding 1 Gigabit, each supplier has its own product line with its own individual bit rate levels. AT&T, for example, uses a 417 Megabit/1.76 Gigabit/ 3.4 Gigabit standard, while Fujitsu uses 405 Megabit/810 Megabit/1.7 Gigabit, and Ericsson uses at 565 Megabit/1.26 Gigabit/2.46 Gigabit. A number of suppliers are now manufacturing repeater and termination systems operating at over 1 Gigabit, including a 1.13 Gigabit Rockwell System deployed by MCI.

Activity this past year appears to have been greatest in the cities and in the transoceanic arena. The TAT-8 cable project across the Atlantic was recently completed and a number of cables connecting various locations in and around the Pacific basin are being deployed. When joined with various U. S. and Canadian systems for transmission across North America, these will provide the basis for a worldwide network of fiber. As noted last year, both AT&T and Cable and Wireless are actively involved in pursuing these activities usually as joint ventures with other parties. The impact of declining transmission costs in high density long haul routes, while significant, will continue to be only one of the many elements affecting interexchange rates. In order for the economies of long haul transmission to be fully realized, the costs of local distribution will have to decline. Unfortunately it is much harder to realize the vast economies of scale inherent in fiber technology in this part of plant. Nonetheless, a number of relatively new domestic ventures at the local level are attempting to exploit, where possible, economies of scale in the medium to large metropolitan areas.

This year's report will briefly touch on activity of the major categories of carriers and will summarize activity at the local level to include a brief discussion of the metropolitan area fiber systems. Although presently small, these systems will attempt to find a niche in the market place and in some cases will compete with both interexchange and local carriers for a share of the interexchange access market. The above developments are partially a result of the changing economies of fiber and transmission relative to switching.

Review of International Developments and Trends

It seems likely that increasing attractiveness of fiber as an alternative to satellite communications will have long term implications. [1] This is becoming more apparent with fiber exhibiting

1 Satellite tends to be a more attractive alternative in networking arrangements involving arrays of receive and transmit locations with lower traffic concentration, while fiber is most attractive in point to point links with a high concentration of traffic.

lower loss and dispersion which allows increased repeater spacings and lower cost undersea cable systems. AT&T's reported plans for a "Worldwide Intelligent Network" with about $2.5 Billion invested in 1987 and $3 Billion to be invested in 1988 and again in 1989 is an important indication of this trend. [2] Cable and Wireless is also taking advantage of this trend. This international venture has assembled a significant U.S. network most of which is leased, rather than owned, capacity.

In the U.S. the Cable and Wireless network utilizes capacity leased from Southern Net, Lightnet, LDX, and Wiltel [3] and some joint owned capacity in a "condominium" arragement with Lightnet. The network reportedly will interconnect worldwide customers of Cable and Wireless, which runs the domestic telephone networks of some 16 countries, including such diverse locations as Hong Kong, Bahrain and Fiji. The network will join Japan, Hong Kong, South Korea and China in the far east with the U.S. and Great Britain. Cable and Wireless has been involved with Pacific Telecom, in a joint venture to build the Pacific fiber system. The cable across the Atlantic Ocean is termed PTAT, a joint venture with Tel optik (now PTAT System). NYNEX has had an interest in this venture for some time but has not been able to obtain the necessary approvals.

Interexchange Carriers

A number of major nationwide fiber systems have been built. These are NTN (National Telecommunications Network-- a consortium of several regional companies), Lightnet, U.S. Sprint, MCI, and AT&T. There are also a number of statewide or regional systems not associated with the NTN consortium. Data for entities deploying significant amounts of fiber in the interexchange environment are shown in Tables I and II at the end of this report. Table I contains data on network route mileage containing owned fiber, fiber mileage and average fiber route cross sections. The table reveals that while the growth in fiber mileage for the interexchange carriers during 1988 was nearly 30%, it has slowed significantly. Table II provides additional data on DS-3 capacity, investment, leasing and lit fiber and indicates that roughly 5 Billion dollars have been invested in fiber systems to date by the interexchange carriers. Several of these

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2 According to a November 11, 1987 AT&T press release, this plan will expand AT&T's domestic digital network to 60,000 route miles by 1989 and 67,000 route miles by 1990 with 74,000 and 88,000 route miles respectively, worldwide. Much of this digital capacity is associated with fiber systems.

3 LDX has merged with Wiltel.

entities have recently announced the formation of a sharing arrangement called the NSN (National Switch Network). This network incorporates the use of both switching and transmission facilities for termination of traffic from member carriers. Norlight, operating in Wisconsin and Mutual Signal Corp., operating in Michigan, are examples of statewide systems and RCI is a regional system. Thus, the significant amounts of fiber already deployed coupled with their low noise and vast potential capacity will continue to affect the industry.

During the past year in the interexchange market, AT&T, U.S. Sprint, Williams Telecommunications (WilTel), and MCI have undertaken the most significant expansion of their networks. AT&T has again nearly doubled its fiber network size. AT&T's huge fiber capacity increases appear to be related to an number of factors. These are competition, reduction in maintenance costs, the desire for an all digital network without the need for analog to digital conversion, moves toward a global fiber network, and the need for route redundancy and greater network reliability. AT&T has also extensively upgraded the electronics on its higher density routes to operate in the gigabit range. This and the large amount of new fiber deployed last year has actually lowered its percent of lit or active fiber. Most of the other carriers appear to be operating with a much larger percentage of lit fiber than AT&T. [4]

Competition and the desire to generate a favorable customer perception of fiber appears to have been a significant motivating force in the rapidity of deployment in the United States. Although the use of fiber significantly enhances signal quality, fiber is not necessarily required to achieve what a customer may perceive as an improvement. Typically, the transmission quality using equipment operating at engineering specifications associated with older transmission technologies is sufficiently high so that the average customer consistently using circuits designed to these specifications would not notice the difference with fiber. The visibility of fiber technology, however, often tends to overshadow other underlying reasons for its deployment which have less to do with customer perceptions than the real world issues and problems associated with managing large

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4 There are economic considerations which dictate whether overbuilds of new fiber or reliance on future terminal and repeater technologies will be the most cost effective way of handling traffic growth. Where growth exceeds the capacity of present systems, expected future cost of terminal and repeater opto-electronic hardware providing higher system capacities and projected availability dates of that hardware must be weighed against the known cost of deploying new fiber and using existing terminal and repeater hardware.

telecommunications networks. For example, equipment using older technologies is often more expensive to maintain and the quality of circuits derived from this equipment may be less predictable. In addition, fiber and the digital transmission technologies it supports is making the concept of end to end digital connectivity on a worlwide basis and network standardization a reality. Even considering all these factors, deployment activity as large as has been occurring over the past few years is unprecedented.

Many of the smaller regional entities have completed their plans for now and a number of mergers and acquisitions have been consummated. The most significant of these is the merger reported in last year's report of Williams Telecommunications (Wiltel) with LDX to form a new entity with over $250 million in assets and over 4,500 route miles of fiber. Another merger also reported last year between Southern Net and Southland Fibernet resulted in a network of over 1,000 route miles. This regional network is now a subsidiary of Telecom*U.S.A. These merged entities form part of the NTN network. More recently, Microtel has been acquired by Advanced Telecommunications Corp. and is now a wholly owned subsidiary of that company and the Electra Network has been acquired by Communications Transmission, Inc. (CTI). Also of note is Wiltel's acquisition of some of RCI's facilities this past year and its recent offer of $365 million to purchase the Lightnet network. If completed, the purchase will give Wiltel exposure in the East and will establish it as a significant nationwide fiber carrier. In addition, several companies just announced the formation of a traffic sharing arrangement which incorporates the use of switching equipment, called the National Switch Network (NSN). Advanced Telecommunications Corp. which recently acquired Microtel, Litel Communications Corp., RCI, Southern Net and Teleconnect Company are the members of this new arrangement. Teleconnect which initially operated in Illinois, Iowa and eastern Nebraska was not mentioned in last year's report. Teleconnect recently merged with Southern Net and is now a subsidiary of Telecom*U.S.A. It has, however retained its regional identity.

Regional Bell Holding Companies

Besides the interexchange carriers, the Regional Bell Holding Companies have all had extensive deployment of fiber associated with modernization and growth. Tables III and IV at the end of this report provide data on fiber deployed by these entities. The data in Table III suggests that new fiber deployment during 1988 increased the total amount these carriers have deployed by about 30%. A comparable rate of growth was observed last year. Table IV contains data on feeder fiber and fiber to customers. It shows that a significant amount of feeder fiber has been deployed by the Bell Companies. Most of the reported data on fibers to customers only included data associated with current fiber trials. The activities at the local level will in many cases enhance the local operating companies' ability to provide access for advanced digital services employing an integrated switched digital network or ISDN. Although fiber was originally deployed by the local companies for interoffice interconnections, the promise of even lower future fiber cost and less expensive termination technologies is making it an increasingly attractive means to reduce local feeder plant costs and in the future, significant amounts of fiber will even be found in the local loop itself.

On the local level, deployment of fiber generally continues unabated. The Regional Bell Companies appear to be deploying fiber rather than older twisted copper pair plant for growth. There are, however, economic constraints presently limiting deployment of fiber loops which will interface with existing station equipment. The costs of interfacing hardware associated with smaller customers has not yet declined to the point where fiber loops to local residences are cost effective. This has delayed deployment in this portion of plant. Although, a number of local loop trials are now being conducted, it does not appear fiber to smaller customers will be economically attractive in the local loop in its own right for 3 or 4 years without the availability of new revenue from new services. Nonetheless, more significant amounts of loop fiber will probably begin to be deployed beyond the trial stage as early as 1990. It should be noted that even with fiber technology in the local loop, the investment associated with widespread transmission of standard video channels on a point to point basis based on present technology would be prohibitive because transmission of a single standard video channel through the network typically uses the equivalent network capacity of at least an entire DS-3, which can alternatively accommodate 672 voice channels.

Video distribution services require significant investment and have been traditionally kept out of the domain of the regulated telephone based carriers. However, declining cost and the prospect of wholly new communications services involving wideband data and perhaps video compression for teleconferencing may prove to be an added future stimulus to the deployment of fiber in the local loop, assuming, of course, that demand for such services develops and there are no regulatory constraints to such services. The operating companies have already been investing significant capital for a number of years towards an integrated voice and data network structure with standardized interface specifications, termed ISDN. Video services were not initially integrated into company plans for this network concept which has already been years in development. There is presently, however, some interest in retrofitting the original ISDN concept to include video.

Despite the fact that fiber is not yet an economic alternative to copper pairs for the local loop, a number of the Bell Operating Companies have been conducting trials in which fiber is extended to the customer both for existing and advanced services. Three such trials have been conducted by Southwestern Bell, Illinois Bell, and Southern Bell. Southwestern Bell and Illinois Bell are using the trials for non video services. Bell South's trial near Orlando, Florida in conjuction with Northern Telecom is being used for cable television and integrated ISDN/voice services. Bell

Atlantic is also conducting trials. Other companies also have plans for future trials or have been studying the feasibility of fiber in the local loop. Each of the Bell Companies was asked to provide data on the number of fibers to customers which is shown in Table IV. However, many of the companies did not provide data in response to this request. The data provided typically includes only fiber associated with fiber trials. It is not clear to what extent fiber is currently being used to serve large customers where the customer does not have direct access to the fiber interface. Of the companies listed, Pacific Telesis reports the largest number of fibers to customers and has included fiber to a number of large customers in Southern California in addition to a trial in Northern California.

Metropolitan Fiber Systems

This year there are a number of developments in the local metropolitan areas which merit discussion. Several companies have begun or will shortly begin to deploy fibers in and around U. S. cities. Compared to the Bell Operating Companies and interexchange carriers these ventures which have been set up to serve large customers and interexchange carriers do not yet have very large amounts of fiber. They are providing both feature group D access and local private line services. Most of the ventures appear to be localized in a single metropolitan area. However, a company called Metropolitan Fiber Systems, Inc., based in Chicago, is constructing fiber "rings" in a number of metropolitan areas through routes designed to maximize the number of large entities which can be served at the minimum cost. By the end of 1989, at least 5 cities will begin to have service and 7-10 other cities are planned for future service. Another active company planning to serve more than one city is the Chicago based company, Fiber Optic Company of the U. S. or "FOCUS." This company is combining its own facilities with capacity leased from the Bell Operating Companies. Its Philadelphia organization presently providing service is a partially owned subsidiary and is called the Philadelphia Fiber Optic Corp.

The single city operations typically serve a medium to large city and some of the surrounding counties. Eastern Telelogic owned by Merrill Lynch is one such company and is based in Philadelphia. The company plans to have a 72 mile backbone system in place by the end of 1990 and will serve 4 counties in and around Philadelphia (Montgomery, Philadelphia, Chester, and Delaware counties), but as of the end of 1988 had no facilities in service. Another single city operation, Institutional Communications Company or I. C. C. is based in Washington, D. C. and is using the subway tunnels for part of its downtown fiber. This company has a number of small rings in areas of high business concentration and is serving areas including Crystal City and Reston in Northern Virginia, and New Carrollton in Maryland. The company appears to have a unique strategy of gathering traffic for its network by leasing DS-3 capacity to a number of distant cities and providing feature group D access on a resale basis to the

Washington area. The company serves both large business customers and interexchange carriers and has been providing service since 1986.

Other companies are presently operating in single metropolitan areas. One is New York Teleport which has deployed a significant amount of fiber in Manhattan both for access to satellite earth terminals outside the city and for digital services within New York City. The earth terminal traffic is associated with analog video services and presently a single broadcast quality channel is operated on a single fiber using analog transmission. Another single city company, Indiana Digital Access, is a small and relatively new Indianapolis based company, which provides service to 20-30 buildings in Indianapolis and which serves the surrounding towns of Muncie, Anderson and Lafayette with digital microwave, all within about 60 miles of Indianapolis. It presently has about 7-8 miles of fiber and 2-14 miles are expected to be added in 1989. Other companies include Public Service of Oklahoma which has bundled fiber in its high voltage power lines for its own use and has attempted to sell its excess capacity and Intermedia Communications Co. of Florida which provides service in Orlando and Tampa.

Metropolitan fiber systems are presently miniscule in comparison to the local operating companies which are continuing to deploy large amounts of fiber. Growth in fiber miles deployed by the Bell Operating Companies during 1988 was in the 30 percent range. While the metropolitan systems may be characterized as innovative facility bypass systems which face stiff competition, many of them are attempting to establish a niche in the marketplace by being in tune with customer needs and serving specialized requirements including those of the interexchange carriers. These companies are attempting to establish a winning mix of business activities so as to effectively compete in the environment of the established local telephone carriers and most regulatory jurisdictions do not appear to be suppressing their activities. Nonetheless, the long term implications of these activities both to the motivations of the local operating companies and to the average telephone subscriber, including smaller and harder to reach customers, will require further study.

Sources, Methods and Data Limitations

This report is based on survey work conducted during the fall of 1985, 1986, 1987 and 1988 and is primarily based on a series of telephone interviews with representatives of the companies shown in the attached tables. The methodologies inherent in this report have not significantly changed from earlier reports, although some of the data items have been modified or clarified somewhat, as noted in the attached tables. The category "key items of construction" has been replaced by the DS-3 capacity on lit fiber in 1987 and 1988 to provide a better handle on the impact of new terminal and repeater technology on fiber capacity. A number of public references which provided useful insights into the promotion and development of fiber by the industry are included in an attached bibliography. Data for the interexchange carriers is summarized in Table I and II and data for the Regional Bell holding companies is summarized in Tables III and IV. Data for a number of metropolitan area fiber systems which have deployed fiber is shown in Table V. These tables should not be viewed as an all inclusive list of companies deploying fiber, but they should provide useful information on significant deployments to date.

Interviews with carrier representatives focused on 6 major information categories: number of owned fiber miles deployed, route miles of fiber, percent of fibers "lit" or equipped, total investment in fiber facilites as of end of year 1988, leased DS-3 miles or where applicable leased fiber miles, and total DS-3 mile capacity on lit fiber with present technology. Data requested from the Bell Operating Companies was slightly different as can be seen in Tables III and IV.

While data validation was attempted where possible and comparison was made to data provided last year, reliance had to be placed on the accuracy of data provided verbally. The survey was conducted primarily by telephone, both to emphasize the voluntary nature of the submissions and to avoid placing any unnecessary burden on the carriers. Most carriers were very cooperative and helpful, and they appreciated the general value of the report. A few of the responses were delayed by the number of internal approvals needed. Some of the companies provided written followup and a few carriers went beyond what was required. The responses and effort on the part of the companies were greatly appreciated.

Although this data collection technique appears to give a reliable picture of the amount of fiber deployed to date and as much care as possible has been taken in the preparation of the attached tables, it should be recognized that there are still a number of pitfalls or areas of potential misunderstanding as well as possible human errors in conveying and reporting the data. A significant concern has been the danger of overcounting due to the large number of leasing and cross ownership arrangements in this industry. Data on leased fiber was therefore requested separately so that it was not included in the owned fiber. [5]

Other concerns relate to possible definitional problems. In particular, even the seemingly straightforward term "route-mile" may present a problem for the larger carriers with many redundant paths in their fiber

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5 Information on leased and joint capacity from all the carriers was requested as DS-3 miles and is shown in Table II. Data for known leasing arrangements for fibers is also shown in Table II.

networks. The data accuracy was probably aided by the fact that for many companies this survey has been conducted before and resubmission of the previous year's data was requested to make sure that there was no change in the way data was being provided. This uncovered a few errors or misunderstandings about what was being requested. Another problem is error caused by differences in how data for ongoing projects was reported. This is a problem especially because data for 1988 in many cases represents an estimate of how much capacity was expected to be in place by the end of the year. A few of the carriers adjusted the 1987 data to account for changes in project completion dates near the end of the year. These kinds of changes in previous year's data, while appearing irregular, are quite understandable.

Items of Data Being Collected

A number of data elements have been surveyed and are presented in the tables accompanying this report. While an effort was made to examine what appeared to be data inconsistencies, there are inherent pitfalls associated with each of the data elements. As a check for data consistency, data for 1987 was requested again. While in many cases the corrections were modest, some corrections resulted in values for 1987 more than 25% above previously reported levels. Some of these are highlighted in the following discussion.

Probably the most important parameter in assessing the amount of potential capacity available is the number of fiber miles deployed. A fiber cable containing 20 fibers and extending 100 miles would, for example, add 2,000 fiber-miles to the total. This parameter is important since it enables one to determine the total number of equivalent voice circuits which can be made available when the terminal technology is specified. Because the number of voice circuits which can be multiplexed onto a single optical fiber depends significantly on terminal and repeater technologies which are changing constantly, use of circuit mileages based on current technology would provide a misleading picture of capacity. For example, new 1.7 Gigabit terminal technology which has recently become available supports up to about 25,000 2-way circuits on a single fiber pair, more than 3 times the capacity of earlier transmission technologies. Because many entrants have only equipped a limited number of fiber pairs initially with transmission electronics and "optronics" (at repeater and terminal locations), it has been possible to minimize initial investment and to take advantage of such new transmission technologies as they become available and as future circuits requirements dictate.

Route mileage is also important in that it gives a picture of the overall size of each carrier's network. This measure is especially useful for the carriers with relatively simple network structures. Nonetheless, possible ambiguities in what constitutes a distinct route may begin to result from this measure for carriers deploying multiple cables to cities along an existing route or adding redundant routes. For example, the route mileage for cable between Washington, D. C. and New York City and between Washington, D. C. and Baltimore (where Baltimore is an intermediate point on the Washington-New York route) may be determined differently by different carriers. This should not presently be a significant problem for most of the interexchange carriers, but could begin to pose a problem in interpreting AT&T data which reflects deployment of fiber in multiple redundant network paths. It has been the general intent of this survey to capture redundant network paths as separate routes. While it appears that most carriers, including AT&T, have been consistent in the manner this data was provided, all carriers may not have used the same methodology to capture route mileage. For the Bell Operating companies which typically have the most complex network structure the route mile heading had to be changed to sheath miles as more cables were added in the same paths associated with overbuilds. If this had not been done there would have been a possible distortion of current data as more cables were deployed in the same routes, since the Bell Operating Companies indicate that they have no clear methodology in place to measure route mileage.

Despite these potential shortcomings, route mileage can be used to evaluate the overall size of each carrier's network. Route mileage may also be useful to check data validity, particularly for the carriers with simple network structure, since the number of fiber miles divided by the number of route miles gives the average fiber cross section size. This validity check proved useful in a couple of instances and resulted in what is hopefully more reliable data. For example, corrections to data provided by MCI covering 1987 resulted in the average cross section declining from over 35 to about 24. Similar corrections provided by U. S. Sprint resulted in a higher cross section. Both carriers made corrections to increase both their 1987 fiber mileage and route mileage; however, MCI's route mile correction and U. S.- Sprint's fiber mile correction appear to have been much larger than could have been explained on the basis of projects completed either before or after target dates near the end of the year. In many other instances increases in the average fiber cross section resulted from fiber overbuilds on existing routes and from errors in estimating project completion dates near the end of the year. While the average fiber cross section is of interest in its own right, its use as a validity check now appears more doubtful than it did initially, since many carriers now appear to have obtained the fiber mile figure by estimating their average cross section and multiplying it by the number of route miles.

A third basic item reported was the percentage of fiber miles lit or equipped with basic terminal and repeater hardware. Most systems use a separate fiber pair called a protection pair for added reliability. A protection pair was considered to be lit for the purpose of this data item. While information on lit fiber is useful to generally assess fiber utilization, such data may potentially be misleading. First, while it may be simple to calculate the lit fiber mile percentage in homogeneous systems with the same number of fibers throughout, carriers with complex networks may have taken shortcuts in providing this information. In addition, complex protection schemes and the need for backhauling traffic in large networks to enhance system reliability may either artificially inflate the percent lit figure or lead to the conclusion that full exploitable capacity may not always be useable. One large carrier noted that route redundancy and backhauling may cause an extra 10-15% of its capacity to be lit. This will be discussed further in a later section of this report. It should also be noted that the number of lit fibers may have very little to do with the number of active circuits, since additional multiplexing gear is required to derive those individual circuits. In some cases, new construction and upgrading of existing capacity by using newer vintages of electronics may have actually caused the lit fiber percentage to decline.

To better evaluate the impact of new repeater and terminal technology on ultimate system capacity, the DS-3 mile capacity on lit fiber was used to provide an estimate of the new capacity added as the result of new lit fibers in a route or the effect of upgrading electronics. It should be noted that at least one company provided present DS-3 capacity rather than total available DS-3 capacity on lit fiber using present repeater and terminal technolgy equipment. This data item should therefore be used with some caution. The DS-3 mile measure was also used to evaluate the amount of leased capacity. It is expected that the potential for double counting associated with leased fiber was minimized by capturing the leased capacity separately in this manner.

The final data item is total fiber system investment. Detailed methodologies for tracking investment vary widely among carriers and available data in this category was sometimes insufficient to establish an adequate commonality for this data item. Therefore, data on investment in this report represents a broad estimate and may not accurately portray the identical components for each carrier. In the case of AT&T, for example, the increase in outside plant during 1988 was used to estimate fiber construction. This does not include any electronics investment associated with multiplexing or deriving individual channels from the broadband fiber medium. Some carriers have included all electronics to initially equip their systems and other smaller carriers reported total company assets, the bulk of which should represent fiber system investment. In other cases, it appears likely that the investment was calculated on the basis of a broad gauge cost per mile of system. For the purpose of Table II, the fiber investment has been estimated at $75,000 per route mile for carriers not providing any investment data and total investment was rounded to the nearest million dollars. This appears to be consistent with average investment of carriers providing data.

System Reliability

While it is generally agreed that fiber offers maintenance advantages over other transmission media, including coaxial cable systems, there are a number of reliability issues which are important and were discussed in somewhat greater depth in last year's report. It is important to note that primary failure modes of fiber systems are different and potentially more disasterous than microwave and coaxial systems.

Experience to date suggests that failures, while typically infrequent, are catastrophic when they do occur. It is the failure mode and the number of active circuits carried on a typical fiber rather than the frequency of failure which is important. Although this report does not deal with quantitative failure observations, it appears that many carriers in this survey have experienced at least one cable break per year. The impact of these types of occurrences are not offset by the existence of a protection fiber pair in a cable which only protects failure an individual fiber or the electronics associated with it. In contrast to fiber, the primary mode of microwave outages is weather which may be more frequent but generally only affects a single radio channel at a time and usually does not require route diversity. Coaxial cable sheaths are less likely to be totally severed, but individual coaxial tubes within the sheath may easily be damaged. Fiber system (dig up) problems have apparently been aggravated by the fact that some of the cables may not have been buried very deep. These problems appear to be most common in the more densely populated areas such as the Northeast. There are, of course, other failure modes of fiber related to environmental factors. Changes in temperature and stresses on the cable sheath may cause added attenuation in affected sections. While it is expected that these problems can be minimized by proper fiber deployment methods, the long term effects of environmental stresses on fiber should be an important area of continuing study.

While the probability of catastrophic failure is very small, its occurrence requires that traffic be routed around the affected link and often requires elaborate precautionary restoration plans which in some cases may involve significant backhauling of traffic if recovery is possible at all. Small networks without any route redundancy may lose service entirely in such instances. Nonetheless, the desirability of alternate routes will continue to motivate leasing and other joint arrangements between carriers. This has undoubtedly impacted the large number of existing joint ventures, capacity sharing agreements, and leasing arrangements in the industry. Failure to provide route diversity will become an even greater liability as fiber capacities continue to increase with development of newer terminal and repeater technologies.

AT&T, in response to this general problem, is developing restoration plans which will involve switching of fibers at designated nodes. This will eventually be set up so that switching can be done from a centralized location. This process will then be automated and controlled by computer. It is unclear to what extent this problem has affected AT&T's deployment plans. U.S. -Sprint also has restoration plans which appear to involve some backhauling of traffic. Some carriers, including MCI, appear to be relying on leased capacity to provide route redundancy on backbone routes. These situations would distort the measure of lit fiber reported, since spare fibers may have to be dedicated for restoration purposes and thus would not be available for traffic growth. Such factors and the need for system redundancy suggest that some fiber systems may presently be less under utilized than originally thought. Nonetheless, it should be remembered that future terminal and repeater technology advances will increase the potential capacity of existing fiber far beyond what is presently possible.

Conclusions

This report has presented a summary of the amount of domestic fiber deployed to date and has examined some of the recent developments in this industry. Overall construction of fiber cable systems, in percentage terms, has slowed this year. Nevertheless, the local operating companies and the largest interexchange carriers, especially AT&T, are continuing to deploy large amounts of fiber. Declining costs and continuing improvements in the electronics and capacity associated with fiber systems appears to be having an impact, and many carriers are upgrading capacities on existing systems using newer terminal and repeater electronics. New fiber deployment activity is probably more significant now on the international scene and at the local level where a number of metropolitan systems are now on the drawing boards or are being built. Each system seems to be tailored to the market in which it finds itself. For the local operating companies, lower cost electronics is already causing fiber to impact local feeder plant and will probably lead to significant proliferation of fiber in local loop applications within a few years.

On the international scene, fiber is becoming the transmission medium of choice for transoceanic routes. A worldwide network connecting Europe, the Far East and the United States is rapidly becoming a reality and interconnecting transcontinental fiber will become increasingly important as part of that network. AT&T appears to be quite active in this area. Fiber will likely become an even more cost effective alternative when ultra low loss "repeaterless" cables are a reality.

The latest trends in carrier system and repeater costs have contributed to a slowing of demand for domestic interexchange fiber. Adding new capacity to existing systems is not only possible, but the cost of such additions on a per circuit basis should decline. Furthermore, uncertainties in the future availability and cost of improved electronics and optoelectronic hardware may actually offer an advantage to smaller carriers which do not immediately need to increase the capacity of their systems. These trends should continue to put downward pressure on thre cost of providing telephone service. However, as noted last year, there are many other factors which limit significant declines at the consumer level.

Table I

Total Estimated Owned Fiber Deployed by Major Interexchange Carriers

	Route-Miles				Fiber-Miles				Average Fiber Cross Section			
Year:	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
NTN Partners:												
Consolidated Network	310	292	352	352	3,504	3,504	3,864	3,864	11.3	12.0	11.0	11.0
Litel	881	950	1,210	1,210	13,720	17,274	22,280	22,280	15.6	18.2	18.4	18.4
Microtel (see note 2)	800	950	967	1,127	8,000	9,500	9,670	17,158	10.0	10.0	10.0	15.2
SouthernNet	188	895	895	*	1,880	8,950	8,950	*	10.0	10.0	10.0	*
Southland Fibernet	277	277	277	*	2,770	2,770	2,770	*	10.0	10.0	10.0	*
* Southern + Southland	*	*	1,172	1,172	*	*	11,720	11,720	*	*	10.0	10.0
LDX Net	670	1,379	*	*	16,080	33,096	*	*	24.0	24.0	*	*
WilTel	214	2,899	*	*	2,140	58,077	*	*	10.0	20.0	*	*
* LDX + WilTel	*	*	4,244	5,177	*	*	104,923	131,865	*	*	24.7	25.5
NTN Subtotal	3,340	7,642	7,945	9,038	48,094	133,171	152,457	186,887	14.4	17.4	19.2	20.7
AT&T	5,677	10,893	18,000	23,324	136,248	261,432	432,000	704,731	24.0	24.0	24.0	30.2
MCI	2,560	5,580	8,775	10,975	79,200	167,400	245,700	264,680	30.9	30.0	28.0	24.1
GTE-Sprint	1,200	*	*	*	24,000	*	*	*	20.0	*	*	*
U. S. Telecom	4,100	*	*	*	98,400	*	*	*	24.0	*	*	*
U. S. - Sprint	*	10,000	18,195	22,090	*	190,000	497,224	575,562	*	19.0	27.3	26.1
* Electra	493	493	493	493	10,194	10,194	10,194	10,194	20.7	20.7	20.7	20.7
Lightnet	2,200	5,000	5,300	5,300	52,800	120,000	127,200	127,200	24.0	24.0	24.0	24.0
Mutual Signal Corp.	0	0	420	420	0	0	4,200	4,200	0.0	0.0	10.0	10.0
Norlight	0	0	670	670	0	0	8,040	8,040	0.0	0.0	12.0	12.0
**RCI	580	580	796	413	6,960	6,960	7,202	2,618	12.0	12.0	9.0	6.3
Teleconnect	0	0	320	400	0	0	1,920	2,400	0.0	0.0	6.0	6.0
Totals	20,150	40,188	60,914	73,123	455,896	889,157	1,486,137	1,886,512	22.6	22.1	24.4	25.8

Notes:

1 NTN is an acronym for National Telecommunications Network.

* 2 As of July 1986 U. S.-Sprint was set up by merger of U. S. Telecom and GTE toll facilities. U. S.- Sprint is now a jointly owned subsidiary of U. S. Telecom and GTE. Microtel is now a wholly owned subsidiary of Advanced Telecommunications Corp. Data reflecting mergers of Southland Fibernet with SouthernNet which is now called SouthernNet U.S.A. and Wiltel with LDX are also shown. SouthernNet U.S.A. is now a subsidiary of Telecom*USA. The Electra network in Texas was recently acquired by Communications Transmission, Inc. (CTI).

** 3 The data in this table does not include fiber capacity associated with leased fiber or other special agreements shown in Table II. In some instances this may have changed the amount for 1987 from last year's report. This table also relects other corrections in 1987 data. For example, U.S.-Sprint fiber mi. totals for '87 were amended from 323,000 and MCI route mileage for '87 was amended from 6,317. See further discussion in text. SouthernNet U.S.A. reported a small adjustment from last year which is not reflected in the above table. Reduction in the size of RCI's network resulted from sale of Cleveland-Chicago and Toledo-Detroit routes.

4 AT&T data in this table includes domestic fiber only.

Table II

Other Fiber Data

	Approximate Current Investment Millions $	Estimated Investment per Route mi.	Lit Fiber 1987	Lit Fiber 1988	Estimated Total DS-3 Mile Capacity on Lit Fiber 1987	Estimated Total DS-3 Mile Capacity on Lit Fiber 1988	Leased DS-3 Miles 1988	Known Leasing of Fiber Route Mi.	Known Leasing of Fiber Fiber Mi.
NTN Partners:									
Consolidated Network	16	45,455	33.0%	33.0%	*	*	208	330	6,962
Litel	98	80,992	54.2%	59.6%	*	*	2,400	89	1,734
** Microtel	75	61,224	80.0%	69.0%	*	171,580	*	246	2,460
SouthernNet U. S. A.	63	54,010	70.0%	80.0%	24,829	28,502	*		
WilTel	332	64,110	42.5%	41.3%	201,665	245,869	*	275	1,100
NTN Subtotal	584	64,638			226,494	445,951	2,608	940	12,256
AT&T	1,758	75,373	26.5%	20.8%	*	1,294,129	*		
MCI	823	75,000	30.0%	40.0%	425,000	875,000	*	2,704	
U. S. - Sprint	1,670	75,600	30.0%	31.0%	865,000	987,000	21,600	300	
Electra	50	101,420	50.0%	71.0%	*	*	*		
Lightnet	280	52,830	64.0%	72.0%	*	*	*		
Mutual Signal Corp.	32	76,190	60.0%	60.0%	*	10,080	0		
Norlight	50	74,925	33.3%	50.0%	*	8,040	*		
RCI	7	27,638	34.9%	37.5%	7,164	5,206	*	128	632
Teleconnect	30	75,000	*	66.7%	*	4,300	*		
Totals of Reported Data	5,285	72,270	33.6%	32.8%	1,523,658	3,625,406	24,208	4,072	12,888

* Data not available.

Notes:

(1) Investment data has not been provided in the same manner for all carriers. Investment per route mile is calculated from aggregate investment data and route mileage provided.

(2) Items included in fiber investment vary among carriers. In cases where data was missing, investment was estimated on the basis of $75,000 per route mile. See text for further data qualifications.

(3) Data on % of fibers lit may be distorted by route redundancy and method of reporting this data which is described further in text. Considerations affecting when a fiber pair is lit or equipped may vary from company to company and generally does not indicate how many circuits are presently operating.

** (4) Total DS-3 capacity on lit fiber using existing repeater and terminal technology was requested. At least one carrier provided presently operating DS-3 capacity instead.

(5) Data on known leasing of fibers may be rounded or approximated. Data for SouthernNet does not include revenue sharing agreements but does include sale leaseback and leasing of dark fiber. In many instances leased capacity is reported as DS-3's rather than as entire fibers. Data provided on leased DS-3 miles may not be mutually exclusive with data on leased fiber. Data for Wiltel reflects merger with LDX Net.

Table III

Estimated Fiber Deployment by Local Operating Companies
Aggregated to Regional Holding Company Level

	Sheath-Miles				** Fiber-Miles				Average Fiber Cross Section			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
Ameritech	3,200	5,200	6,700	8,500	77,700	111,100	147,100	182,500	24.3	21.4	22.0	21.5
Bell Atlantic **	1,240	4,374	6,730	9,300	83,085	150,847	227,507	314,387	67.0	34.5	33.8	33.8
BellSouth	3,830	8,694	11,727	17,905	50,807	170,092	218,489	337,335	13.3	19.6	18.6	18.8
NYNEX	1,606	3,209	4,956	6,654	83,384	129,743	207,077	260,587	51.9	40.4	41.8	39.2
Pacific Telesis **	2,318	2,779	2,964	3,441	84,310	97,800	101,090	109,826	36.4	35.2	34.1	31.9
Southwestern Bell **	1,913	4,374	5,970	7,217	70,490	151,043	182,911	209,476	36.8	34.5	30.6	29.0
U. S. West	3,527	5,017	6,937	8,665	47,341	70,082	107,782	134,400	13.4	14.0	15.5	15.5
Total	17,634	33,647	45,984	61,682	497,117	880,707	1,191,956	1,548,511	28.2	26.2	25.9	25.1

NOTES:

. **Total fiber mileage installed was requested, including so called unequipped or dark fibers. Pacific Telesis has made a number of significant adjustments to previously provided data. Initially it did not include dark fibers in the data. The company also reported a decline in total fiber mileage due to a "records purification process" in 1986 associated with a loss of approximately 1,100 miles to AT&T at divestiture and almost 100 miles taken out after the 1984 Olympics. This year Pacific Telesis adjusted its previously provided 1987 total of 81,291 fiber miles, indicating that data provided previously only included fiber for interoffice use. Corresponding adjusted data for 1985 and 1986 was provided along with current data. The company had previously indicated that data for dark fiber in 1985 was not available but has reported such data this year. Similar problems in reporting by the other regional holding companies, may have resulted in incorrect assessments of the total amount of fiber in the ground. Note, for example, significant variation in average fiber cross section between 1985 and 1986 as can be seen in the Bell Atlantic data.

2 Data shown for 1988 is estimated. Sheath mileage was provided instead of route mileage. Sheath mileage and route milage would be comparable until more than one cable was placed in a route.

Table IV Fiber in Loop and Loop Feeder Plant

	Fibers to Customers		Fiber Miles Feeder Plant	
	1987	1988	1987	1988
Ameritech	*	*	*	*
Bell Atlantic	*	52	79,434	119,473
BellSouth	220	524	136,807	185,795
NYNEX	*	*	45,938	57,709
Pacific Telesis	2,430	2,766	15,911	16,124
Southwestern Bell	*	*	*	*
U. S. West	*	*	61,616	72,576
Total of reported amounts	2,650	3,342	339,706	451,677

NOTES:

* Some of the Bell Operating Companies report that this data is not tracked directly but derived from other data sources. Bell Atlantic and Bell South data on fibers to customers covers trials only. Other carriers may presently be using fiber to serve large customers' requirements without the customer having direct access to the fiber. It is thus likely that there is significantly more fiber to large customers than reported. Pacific Telesis reports that its data includes a trial in Northern California and service to a number of business customers in Southern California.

Table V Metropolitan Fiber Systems

	Route Miles		Fiber Miles		Percent Lit	
	1987	1988	1987	1988	1987	1988
Eastern Telelogic						
I. C. C.	88.5	108.4	3,059	5,462	*	40%
Indiana Digital Access		7.0		238	*	12%
Inter-Media Communications		5.9		211	*	8%
Metropolitan Fiber System, Inc.	*	4.8	*	344	*	*
N. Y. Teleport	44.5	57.7	4,711	5,433	38%	39%
Philadelphia Fiber Optic		7.0		506	*	42%
Total of Reported Amounts	133.0	190.8	7,770	12,194		

NOTES:

1 Philadelphia Fiber Optic is a partially owned subsidiary of Fiber Optic Company of the U. S. or "FOCUS" which is expected to deploy fiber in Chicago and other cities. Metropolitan Fiber System, Inc. is a Chicago based company which will be deploying fiber in a number of cities.

2 Eastern Telelogic had no facilities in service in 1988.

*3 Data not available.

4 Blank entries denote no known fiber deployed.

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