FIBER DEPLOYMENT UPDATE

End of Year 1991

By Jonathan M. Kraushaar

Industry Analysis Division - Common Carrier Bureau

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Introduction and Overview

This report was first released in December 1986; since then it has been updated annually. Its primary purpose is to document fiber capacity built or used by communications common carriers. It is divided into several sections. The first part reviews the elements of statistical data being collected and discusses the methods, procedures and shortcomings associated with the data and the data collection process. The following parts present key statistics for each of the main categories of carriers along with highlights of important issues and developments. Statistical data illustrating key fiber trends and developments are included in a series of tables following each section of the report.

The scope of this report was originally limited to data on the interexchange carriers and the regional Bell holding companies, but has for the last few years included data on urban fiber systems and non-Bell local operating companies. The report also presents a general review of the technology and associated current developments. A list of references is appended for those wishing to obtain a more in-depth analysis of a specific area of interest.

The interexchange carriers are an important driving force in the industry. Their interest in reliable and low-cost access is impacting the quality of service and development of technology all the way down to the local level. The expansion of their long-haul fiber capacity continues to focus on greater utilization of the existing deployed fiber, either by using technologies with higher bit rates or throughputs, or by equipping previously "dark" fibers. Fiber growth for these carriers has been about 12 percent over the past two years.

The local operating companies have increased their fiber in plant by about 35.4 percent this year compared to a revised growth figure of about 36.5 percent last year. These entities report the use of redundant fiber systems (sometimes called "rings"), fiber-to-the-curb systems in which the fiber does not extend all the way to the customer, and a number of fiber-to-the-home trials. Growth rates are influenced by economic and regulatory developments. However, over the longer term, significant levels of growth will be implemented as local carriers extend fiber closer to the customer by deploying more fiber in the feeder plant.[1] It is also noted that while growth of deployed fiber for many of the companies appears to have declined this year, fiber growth for U. S. West and Bell Atlantic increased significantly. There

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[1] See reference 35.

has generally been increasing interest in fiber architectures and technologies that facilitate economically deploying fiber closer to the customer. This interest is evidenced, for example, by so-called fiber-to-the- curb systems which appear to be supported by Bell Communications Research (Bellcore), at least for near-term use.[2] In addition, fiber configurations featuring redundant access are appearing in metropolitan areas.

Besides the local operating companies, there has also been expansion in the urban or metropolitan fiber systems. While the amount of fiber in these systems continues to be small in relation to the fiber deployed by the local operating companies, this continues to be a dynamic sector of the industry. Furthermore, these companies have attracted the attention of the interexchange carriers, who appear to be interested in efficient, reliable and low-cost alternatives for interconnecting their points-of-presence in metropolitan areas and accessing their customers in large office buildings. The urban fiber carriers have increased their fiber at an even greater rate this year than last. These entities structure their fiber in rings usually around metropolitan areas with high concentrations of businesses. The number of entities covered by this report has been steadily increasing, reflecting the rapid growth of this sector.

Other entities such as electric utilities and cable TV companies have also been deploying fiber. Agreements for joint use or deployment by power utilities and interexchange carriers were discussed in past reports and continue to play a role in new deployments of interexchange carriers. New approaches for providing increased bandwidth capability to residences and businesses continue to be in the spotlight, with attention being placed on cost effective fiber architectures for such deployments. The innovative approaches of these entities should not be overlooked in this quest.

Items of Data Collected

This report summarizes survey data from three categories of carriers: interexchange carriers, local operating telephone companies, and metropolitan or urban fiber carriers.

Carriers were contacted by telephone and a written description of the requested data items was made available to them. These descriptions are summarized in the notes to the accompanying tables and have led, in some cases, to data adjustments for prior years. Five elements of the request are common to all carriers surveyed. These are route-miles of fiber system, fiber miles of fiber deployed, sheath miles of fiber cable deployed, fiber miles of "lit" or equipped fiber, and investment in backbone fiber facilities (i.e., underlying fiber, repeater, and deployment cost). It may be useful to note that two fiber cables extending 100 miles along the same route and each containing 10 fibers would result in 100 route miles of fiber, 200 sheath miles, and 2,000 fiber miles in the statistics collected.

These statistics are useful as an indication of the potential capacity of each carrier's system because the number of circuits that can be multiplexed onto the same fiber can change as terminal and repeater technologies improve. Therefore, the same underlying fiber data can be used in conjunction with updated estimates of available terminal technology to arrive at updated estimates of maximum available capacity. For example, the advent of 1.76 gigabit terminal technology, which supports up to about 25,000 2-way circuits on a single fiber pair,

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[2] See reference 66.

more than tripled the capacity of earlier systems. [3] Many carriers are acutely aware that although up-front costs for fiber deployment in absolute terms are high, a significant portion of the total investment can be deferred until actual demand materializes, thus allowing the use of the most up-to-date equipment available for equipping the fiber.

A number of other items of data have been requested that are tailored to the category of carriers to which the request was made. For the interexchange carriers the total number of points of presence or points of interconnection to local or metropolitan carriers was requested, which was to include interconnection locations which may not be owned by the interexchange carrier. A number of carriers did not provide this data this year. AT&T provided point of presence data only for its switched services. The number of points of presence like fiber route mileage provides a very basic measure of network coverage.

To provide some estimate of the cost of equipping terminal and repeater electronic and optoelectronic equipment on fibers in relation to the underlying fiber investment, data on both backbone fiber investment and DS-3 investment was requested along with DS-3 mileage. Actual DS-3 mileage divided by the potential DS-3 mileage (i.e., assuming all fibers were equipped with the highest capacity systems) would provide an indication of the application of the latest available terminal and repeater technology and would provide a measure of current fiber utilization. Investment per DS-3 mile was calculated based on the limited available data and is listed in Table 4.

Information on fiber facilities leased from other entities was requested to insure that leased fiber capacity would not be included with owned fiber. This should have minimized the chance of double counting of fiber. In at least one instance fiber statistics have been revised to remove leased fiber, which had erroneously been included in prior data submissions. Finally, information on sharing of fiber facilities with electric utilities was requested this year but was not provided by many of the interexchange carriers. Although it is expected that this report has only identified a portion of the total leased and shared capacity, the information on the amount of leased fiber capacity also provides some indication of the amount of interaction among those entities deploying fiber.

Information on the application of fiber technology in several areas was included in the survey of the local operating companies. First, information on fiber-to-the-curb systems allowing residential fiber to be shared to the pedestal or drop wire by several residences was requested. Second, information on fiber technology trials including, but not limited to fiber-to-the-home trials, was requested. Third, information on fiber rings or redundancy arrangements (either dedicated or using a bus structure) was requested. These systems appear to compete with metropolitan or urban fiber systems. Finally, statistics on central office and customer fiber terminations not associated with fiber trials were included in this year's survey.

For metropolitan fiber carriers, information on the number of customer locations and buildings served was requested in addition to the information on the extent of deployed fiber. The information on buildings and customer locations served was provided by nearly all entities and is reported in Table 15.

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[3] The 1.76 gigabit systems can handle 36 DS-3's or 24,192 circuits as compared to 28 DS-3's or 18,816 circuits for the 1.2 gigabit systems.

Source Methods and Data Limitations

This report primarily focuses on domestic common carrier use of fiber and is based on survey work conducted since the fall of 1985. In prior years a significant amount of the data was collected through telephone interviews with key representatives of the carriers. This approach is now supplemented with a written description of the survey items which is made available to each participating carrier. The items of data collected are described with the tables. It was hoped that this procedure would make the reported data somewhat more uniform.

Telephone interviews and a survey item description sheet were used, and follow-up focused on clarification and questions about the responses as well as more general questions on current developments and trends. A number of trade associations including the Utilities Telecommunications Council representing electric utilities, the National Cable Television Association and the Association for Local Telecommunications Services (ALTS) representing urban fiber carriers have also provided input and have been very cooperative and helpful. The Bell Operating Companies were initially contacted by letter. The report has benefitted from the opportunity to talk directly with a variety of industry and industry association contacts. The author greatly appreciates the support and cooperation of all those individuals who made this report possible, especially in view of the fact that the survey was conducted informally and the responses were voluntary.

Most entities provided nearly all of the requested data. In a few instances, provided data may have been excluded from this report where inconsistences were detected or where data items not heretofore requested were not provided by enough of the reporting entities. Several reporting problems have been identified in the past and an attempt has been made to correct these by modifying and augmenting the surveyed items. First, both route and cable sheath mileage were requested of interexchange and urban carriers to insure that carriers with multiple cables in a route make a proper distinction in these data items. Second, the fact that fiber data requested is for owned fiber was reiterated and was further highlighted by separately requesting data on leased fiber. Third, more detailed information on fiber technology trials, fiber-to-the-curb systems and fiber terminations was requested of the Bell operating companies. Urban carriers were asked to supply counts of buildings and customer locations served by fiber. Local operating companies, which in many cases do not track buildings served, were asked to provide data on customer locations served by fiber rings or other forms of redundant access. In some instances their responses were incomplete or limited. Finally, the interexchange carriers were asked to separate backbone investment from the investment associated with DS-3 additions.

With continuing merger and acquisition activity as well as joint ventures, capacity sharing arrangements, leases, etc., it has become increasingly difficult to be sure that no double counting of capacity has occurred. Of particular note is the fact that the interexchange carriers typically have categorized fiber constructed with electric utilities as owned cable even though long-term leases or right to use arrangements may have been used. Since the terms of such shared-use agreements with the electric utilities are confidential and may vary, there was no way of assuring that all such agreements were handled in the same way as they impact the amount of owned fiber. Nonetheless, fiber capacity obtained through long-term agreements with entities which themselves are not interexchange carriers would not lead to double counting insofar as the primary scope of this report is concerned. Thus, inclusion of such fiber as owned capacity of the interexchange carriers was permitted.

Another problem in evaluating the data is the widespread use of redundant paths or routes. Redundancy, in general, makes it more difficult to benchmark utilization levels. Also, mergers compound this problem and may result in situations, due to overlapping of routes, where combined route mileages are less than the sum of the parts. In general, as mergers and overbuilds occur, the likelihood of ambiguity on route mileage data increases. For this reason, all carriers were requested to provide sheath mileage supplementing any route mileage data which was also provided.

Fiber cross section data, calculated by dividing the fiber mileage by the sheath mileage or route mileage, could be a useful check for data errors or misinterpretations. Nonetheless, a tendency to base fiber mileage on route mileage data and an estimated fiber count factor has limited the usefulness of this approach. Similar factors may also have been used in some cases to generate the DS-3 mileages and to provide lit fiber mileages, however there is indication that such problems have been partially addressed this year by the reporting entities. In particular, US Sprint no longer appears to use this approach and revised its previously submitted data with last year's submission to account for this. Williams Telecommunications had indicated that last year's reported data was not consistent with the previously published data series because it had previously included about 1,000 miles of microwave and an unspecified amount of leased fiber in its data. Historical data was therefore adjusted downward last year and again this year to account for the estimated impact of these factors. Also, with last year's report AT&T had eliminated a practice of rounding or estimating components of its totals before arriving at an aggregate. Based upon information provided by the company, downward adjustments to previously reported fiber mileage data were made to make the data more consistent. AT&T's 1989 route mileage was similarly adjusted, although the company could not confirm a similar rounding problem in its route mileage data.

Lit fiber data may have other pitfalls as well. In particular, route redundancy and backhauling may mask underlying usage levels. Most likely such route redundancy would tend to increase lit fiber percentage over the level which would otherwise exist. In general, abrupt changes in the amount of lit fiber on a year-to-year basis should alert the reader to possible problems with this data element. Some corrections to previously provided lit fiber data are reflected in the tables.

In interpreting data and growth rates from the accompanying tables the reader should be aware that in a number of instances the current year's data was prepared prior to the end of the year and therefore may have been estimated. As such, uncertainty concerning project completion dates may have resulted in data and resulting growth distortions. This may tend to be more of a problem with the metropolitan fiber carriers which are a rapidly growing sector of the industry.

Interexchange Carriers

Data for the interexchange carriers is shown in Tables 1 through 4. This year, growth in fiber mileage deployed by interexchange carriers was about 11.9 percent, down slightly from last year's revised growth of 12.1 percent. AT&T's 11.6% increase in fiber mileage in 1990 included the effect of a downward adjustment of its 1990 fiber mileage and a proportional adjustment to its 1989 fiber mileage to correct for what has been characterized as rounding errors on components making up the total. In 1991 AT&T's fiber mileage grew by about 23%. Total fiber mileage deployed by the interexchange carriers is presently estimated at approximately 2.4 million miles, as shown in Table 2. Much of the long-haul interexchange fiber utilizes railroad rights of way, abandoned pipelines or is simply buried. There are also a significant amount of microwave facilities, particularly in low density routes. In addition, some of the carriers are utilizing fiber built in conjunction with electric power company facilities and rights of way.

A rough estimate of the capacity of all known fiber facilities used by the interexchange carriers, assuming 28 DS-3's or 18,816 circuits per fiber pair, suggests that on the order of 30 million DS-3 miles could eventually be equipped on the existing fiber using 1.2 Gbit/second terminal and repeater technology. Based on data provided this year or in prior years, the carriers have reported equipping more than 7 million DS-3 miles or close to a quarter of the available capacity associated with 1.2 gigabit technology, as determined from Tables 2 and 3. Table 4 summarizes the cost per route mile of fiber backbone and the cost per DS-3 mile. The cost per DS-3 mile was calculated by dividing the total DS-3 investment reported by the carrier by the corresponding number of DS-3 miles reported. This cost is affected by network complexity, system loading, and other factors.

As has been reported in prior fiber reports, a number of the interexchange carriers have been focusing attention on agreements facilitating joint deployment of fiber and associated shared use of rights of way with electric power utilities. This activity has been concentrated in the Southeast, where population has been growing and the local electric utilities have been more aggressive in seeking cost effective means of modernizing their internal telecommunications systems. The non-conductive character of fiber eliminates technical problems in combining electric transmission and communications facilities, such as ground loop, noise, and interference. This has led to the development of ground-wire fiber cable in which the fiber is placed within the core of ground-wire cable and has facilitated the combined construction of regional telecommunications and electric transmission facilities. With the increasing availability of ground-wire fiber and dielectric fiber cable (which can be strapped to existing power lines), utilities are taking advantage of fiber as a means for satisfying their own communications needs. Although the total amount of ground-wire fiber used by interexchange carriers is relatively small in relation to the total amount of interexchange fiber deployed to date, a number of recent construction projects involving interexchange carriers and electric power companies have used ground-wire fiber. Those interexchange carriers reporting data on electric power company facilities report a total of more than 1,100 route miles and 25,000 fiber miles of this type of facility.

Many of the interexchange carriers have extended their routes and provided route diversity by a multiplicity of agreements among themselves. One organization set up early on to facilitate such agreements and to act as a magnet in obtaining capital for small fiber systems was National Telecommunications Network (NTN). NTN is a partnership comprised of Advance Telecommunications Company (ATC), Consolidated Network, Inc. (CNI), Litel, RCI and Williams Telecommunications Group (WTG). Telecom USA which was formerly an NTN partner is now owned by MCI. Its member companies are assessed a fee for the services that NTN provides which are now fairly limited in scope. The NTN companies interconnect directly and adhere to common technical standards that tend to facilitate sharing and other joint arrangements between the member companies.

NTN was originally set up to provide technical coordination, marketing, lobbying, and other administrative services for its member companies. Early on it provided a catalyst for investment in its member companies and gave those companies greater credibility in their financing activities. NTN's technical committee provided for common maintenance interconnection, and redundancy standards for its member companies but this organization has been inactive since early 1990. The original intent of NTN was also to provide for revenue and facility sharing for its member companies. This activity never fully materialized and now the member companies make their own agreements among themselves and with nonmember companies. Much of NTN's role was overtaken by some of the larger partners which have a national presence and do national marketing. The NTN companies are directly interconnected; however, there are now similar interconnection arrangements with nonmember companies.

Another feature of this sector of the industry has been mergers and acquisitions. Very recently Norlight was acquired by Midwestern Relay Co. and is now listed as MRC Telecommunications in the accompanying tables. Previous acquisitions include MCI's acquisition of Telecom*USA during 1990 and Williams Telecommunications Group's acquisition of Lightnet which had reported a fiber network of about 5,300 route miles. Four major entities have emerged: US Sprint, MCI, Williams Telecommunications Group and AT&T. As indicated earlier Williams Telecommunications Group (WTG) and a number of smaller companies for convenience have been previously grouped in this report as NTN companies. Historical data for merged entities shown separately in prior fiber deployment reports has typically been combined in the tables this year for simplicity.

With equal access objectives largely met, the interexchange environment is now characterized by entities facing similar constraints and looking for ways to stimulate traffic and increase their market share. [4] In this environment the impact of differences in long distance rates and service quality resulting from differences in operating efficiencies of the interexchange carriers is reduced or limited by the local network and by local access charges which comprise a significant portion of the cost of a toll call. The interexchange carriers thus have exerted an indirect but important influence on developments in the local environment. They have affected the facility provisioning process and quality of service of the local operating telephone companies and have been relying increasingly on more efficient and lower cost access arrangements and facilities to interconnect their points-of- presence, employing, where applicable, the fiber infrastructure of the metropolitan or urban fiber systems and the local operating companies. The significance of differences in marketing strategies and approaches that will impact local access will continue to be important factors impacting changes in market share and motivations of both interexchange and local carriers.

These effects and competitive pressures may become more pronounced if present economic conditions continue. It is important to note, however, that current trends in fiber deployment activity in the long-haul environment are not simply a function of current economic activity but are also affected by the development of the technology, prior expectations of current economic activity and market share, and competitive effects and mergers discussed above. Capital construction programs for certain fiber backbone facilities of large carriers require significant lead times and thus tend to require longer range forecasting.

[4] See reference 46.

Table 1: Route Miles -- Interexchange Carriers *

	Route-Miles						
Calendar Year:	1985	1986	1987	1988	1989	1990	1991
AT&T	5,677	10,893	18,000	23,324	28,900	32,398	36,871
Electra	382	382	382	382	382	493	493
Mutual Signal Corp.	NA	NA	421	421	421	421	421
CTI (Electra + Mutual)	382	382	803	803	803	914	914
Diginet	NA	NA	NA	90	90	90	90
MCI	3,025	6,752	10,267	12,467	13,839	17,600	19,793
MRC Telecommunications	NA	NA	670	670	844	844	844
ATC	800	950	967	1,127	1,163	1,163	1,163
Consolidated Network	310	310	352	352	352	352	352
Litel	881	950	1,210	1,210	1,210	1,210	1,406
RCI	580	580	796	413	414	415	417
Williams Telecom.	3,084	7,936	8,202	9,135	9,725	9,893	9,930
NTN Total	5,655	10,726	11,527	12,237	12,864	13,033	13,268
US Sprint	5,300	11,915	17,476	21,938	22,002	22,093	22,725
Valley Net	NA	NA	NA	NA	520	570	581
Total Reported:	20,039	40,668	58,743	71,529	79,862	87,542	95,086

* See accompanying notes to the tables and discussion in text.
Also note revisions to historical data.

Table 2: Fiber-Miles and Average Route Cross Section – Interexchange Carriers *

	Fiber-Miles							Average Fiber Cross Section					
Calendar Year:	1985	1986	1987	1988	1989	1990	1991	1986	1987	1988	1989	1990	1991
AT&T	136,248	261,432	432,000	704,731	838,392	935,713	1,146,924	24.0	24.0	30.2	29.0	28.9	31.1
Electra	9,960	9,960	9,960	9,960	9,960	9,960	9,960	26.1	26.1	26.1	NA	20.2	20.2
Mutual Signal Corp.	NA	NA	4,021	4,021	4,021	4,210	4,210	NA	9.6	9.6	NA	10.0	10.0
CTI (Electra + Mutual)	9,960	9,960	13,981	13,981	13,981	14,170	14,170	26.1	17.4	17.4	17.4	15.5	15.5
Diginet	NA	NA	NA	2,890	2,890	2,890	2,890	NA	NA	32.1	32.1	32.0	32.1
MCI	83,850	179,120	259,340	278,800	304,181	424,000	450,000	26.5	25.3	22.4	22.0	24.1	22.7
MRC Telecommun.	NA	NA	8,040	8,040	10,132	10,132	10,132	NA	12.0	12.0	12.0	12.0	12.0
ATC	8,000	9,500	9,670	17,158	18,145	18,297	18,297	10.0	10.0	15.2	15.6	15.7	15.7
Consolidated Network	3,504	3,504	3,864	3,952	3,952	3,952	3,952	11.3	11.0	11.2	11.2	11.2	11.2
Litel	13,720	17,274	22,280	22,280	22,280	22,280	24,740	18.2	18.4	18.4	18.4	18.4	17.6
RCI	6,960	6,960	7,202	2,618	2,654	2,660	2,690	12.0	9.0	6.3	6.4	6.4	6.5
Williams Telecommun.	71,020	181,276	193,829	220,771	227,323	236,274	237,566	22.8	23.6	24.2	23.4	23.9	23.9
NTN Total	103,204	218,514	236,845	266,779	274,354	283,463	287,245	20.4	20.5	21.8	21.3	21.7	21.6
US Sprint	122,400	249,337	343,173	449,490	450,846	453,429	466,677	20.9	19.6	20.5	20.5	20.5	20.5
Valley Net	NA	NA	NA	NA	6,120	6,840	7,196	NA	NA	NA	11.8	12.0	12.4
Total Reported:	455,662	918,363	1,293,379	1,724,711	1,900,896	2,130,637	2,385,234	22.6	22.0	24.1	23.8	24.3	25.1

* See accompanying notes to the tables and discussion in text.
Also note revisions to historical data.

Table 3: Percent Fiber Miles Lit and DS-3 Miles -- Interexchange Carriers *

	Percent Fiber Mi. Lit					Estimated DS-3 Miles				
Calendar Year:	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
AT&T	26.5%	41.6%	45.5%	49.6%	44.6%	NA	1,294,129	3,024,902	3,656,642	4,383,896
Electra	50.0%	71.0%	NA	61.7%	64.6%	NA	NA	NA	17,822	28,625
Mutual Signal Corp.	60.0%	60.0%	NA	43.4%	43.4%	NA	10,080	NA	5,944	5,944
CTI (Electra + Mutual)	52.9%	67.8%	55.1%	56.3%	58.3%	NA	NA	NA	23,766	34,569
Diginet	NA	NA	56.0%	50.0%	NA	NA	NA	5,400	NA	NA
MCI	30.0%	40.0%	56.7%	64.3%	NA	449,829	907,802	1,061,143	1,203,458	1,560,000
MRC Telecommunications	33.3%	50.0%	41.7%	65.0%	NA	NA	8,040	25,350	NA	NA
ATC	80.0%	69.0%	75.0%	90.0%	90.0%	NA	171,580	NA	NA	NA
Consolidated Network	33.0%	33.0%	50.0%	53.4%	53.4%	NA	4,224	7,026	12,672	31,616
Litel	54.2%	54.9%	55.9%	60.6%	27.8%	NA	52,293	55,869	43,874	42,081
RCI	34.9%	57.4%	56.7%	56.7%	56.1%	7,164	5,206	10,446	10,446	10,155
Williams Telecommun.	42.5%	37.2%	49.0%	58.5%	58.2%	201,665	245,869	NA	NA	NA
NTN (total)	45.5%	45.2%	62.8%	60.6%	57.5%					
US Sprint	30.0%	31.0%	50.4%	53.9%	55.1%	865,000	987,000	1,431,985	NA	NA
Valley Net	NA	NA	37.3%	50.7%	40.0%	NA	NA	12,250	NA	11,600
Total Reported:	31.8%	38.7%	48.1%	55.0%	49.2%					

* See accompanying notes to the tables and discussion in text.

Table 4: Other Fiber Data -- Interexchange Carriers *

	Estimated Backbone Fiber Investment (Millions $)	Estimated DS-3 Investment per DS-3 mile	Estimated Backbone Investment per Route mi. (Thousands $)	Points of Presence	Previously Identified Leasing of Fiber DS-3 Mi.	Route Mi.	Fiber Mi.
AT&T	2,616	231	71	745	14,502	NA	12,742
CTI	93	NA	102	26	NA	NA	NA
Diginet	7	NA	75	NA	NA	NA	NA
MCI	1,343	NA	68	NA	215,000	5,400	NA
MRC Telecommunications	63	NA	75	NA	NA	155	NA
ATC	90	NA	77	44	NA	280	2,460
Consolidated Network	16	276	45	10	208	180	6,962
Litel	80	1,188	57	30	6,894	90	1,734
RCI	9	754	21	NA	4,809	130	559
Williams Telecommun.	452	NA	45	74	NA	275	1,100
NTN (total)	667	NA	50	158	11,911	955	12,814
US Sprint	1,704	350	75	NA	NA	NA	500
Valley Net	9	NA	16	21	NA	NA	NA
Total Reported:	6,503	265	72	950	241,413	6,510	26,056

* See accompanying notes to the tables and discussion in text.

Notes to Tables 1-4: (NA indicates data was not available)

In some instances carriers may have estimated certain data, such as end of year data received prior to the end of the year. Accuracy may also vary depending on the carrier's method of collecting and assembling its data. Historical data may have been changed from prior reports to reflect adjustments made this year. Also, in some cases historical data for merged entities has been combined. The reader may thus wish to refer to prior fiber deployment reports for previously reported data.

ATC refers to Advanced Telecommunications Corp., which was formerly known as Microtel.

AT&T's 1989 fiber mileage was adjusted downward last year to account for rounding errors in the components making up the total. AT&T's route mileage for 1989 was also adjusted downward from 31,871 to 28,900 even though AT&T could not confirm whether or not similar rounding or estimation problems affected the route mileage figure. Data shown in the tables includes domestic fiber only. Sheath mileage for AT&T was 38,184 as of the end of 1991. Other carriers submitting data indicate that sheath and route mileage are equal. AT&T's point of presence data only includes its switched services. (Also see reference 41.)

The Electra Network in Texas and Mutual Signal Corp. were acquired by Communications Transmission, Inc. (CTI). CTI also identified 52 route miles and 14,653 fiber miles of unspecified fiber in its 1989 data which is not reflected in the tables. Investment data for CTI reflects data which was previously provided.

Litel listed in the tables has very recently changed its name to LCI international.

Norlight was acquired in December 1991 by Midwestern Relay Co. and is now listed in the tables as MRC Telecommunications.

MCI data reflects the acquisition of Telecom*USA which had previously been formed by the merger of Southland Fibernet, SouthernNet and Teleconnect. MCI historical DS-3 mileage had been adjusted to reflect fiber DS-3's only. MCI now reports 2.8 million DS-3 miles on all its facilities (including 13,146 route miles of digital microwave radio). DS-3 mileage on fiber facilities was estimated by the author based on overall DS-3 mile growth rates and data provided last year. Investment per DS-3 mile when calculated from incremental DS-3 mileage and incremental investment data for MCI ranged between $360 per DS-3 mile to about $650 per DS-3 mile, reflecting data provided for the past few years. Overall fiber investment shown in Table 4 for 1991 was estimated from data provided for 1990 and route mile growth for 1991.

US Sprint's historical data has been revised by the company. The reader may wish to refer to prior fiber deployment reports for comparison with previously supplied data. These revisions are shown in Tables 1 and 2 for the period since the merger of US Telecom and GTE toll facilities in 1986. US Sprint now reports 3,152.88 route miles and 64,755.24 fiber miles for 1985.

The composite historical data for Williams Telecommunication Group has been adjusted downward by the author to account for such things as previously included leased fiber and about 1,000 miles of microwave system. Historical data for Williams Telecommunications Group reflects the effect of acquisitions of LDX (1,379 route miles and 33,096 fiber-mi. reported by LDX for 1986) and Lightnet (5,300 route miles and 127,200 fiber mi. reported by Lightnet for 1988) and includes the effect of prior historical data supplied by those companies. Investment has been adjusted downward by the company to include only backbone fiber facilities. Further downward adjustments made this year removed a small amount of previously identified leased fiber from the 1989 to 1991 data. (See prior fiber deployment reports.)

Data on percent of fibers lit may be distorted by route redundancy and method of reporting this data. 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. In a number of instances prior data for percent lit fiber has been recalculated.

DS-3 mileage reflects actual DS-3's in use on fiber facilities only.

Primary investment data was requested for fiber backbone system only. Additional investment for equipping DS-3's was requested separately. Investment per route mile is calculated from aggregate investment data and route mileage provided. In cases where data was missing, investment was either based on previously provided data and system growth or was estimated on the basis of $ 75,000 per route mile.

Data on leasing of fibers may be rounded or approximated based on data provided in prior years. In some cases leased capacity is reported as DS-3's rather than entire fibers. Data provided on leased DS-3 miles may not be mutually exclusive with data on leased fiber.

Except for Valley Net which is a long haul network formed using facilities of several local telephone companies, Tables 1 and 2 reflect owned facilities. Fiber used in long term arrangements with electric utilities may be reported as owned fiber by some of the carriers.

Definitions and descriptions of the items in Tables 1-4:

Route miles of fiber -- The total mileage of fiber routes as would be seen on a network map.

Total fiber miles of fiber -- The number of fiber strand miles used in all routes including both lit and unlit fiber -- the sum of the number of miles of each owned cable weighted by the number of fiber strands. (Also see text of report.)

Sheath miles of fiber -- The total number of miles of fiber cable used in the network. (Typically 12 to 36 fibers are contained in a given sheath.)

Fiber miles of lit fiber -- The number of fiber strand miles activated or equipped with optoelectronic equipment at terminal and repeater sites and capable of providing at least one voice grade circuit .

Investment in backbone fiber facilities -- The total investment in fiber cable, deployment, and repeater sites but not including electronic or optoelectronic equipment.

DS-3 miles carried on fiber -- The number of miles of DS-3 system where each DS-3 system is capable of providing at least one equivalent 2-way voice grade circuit.

DS-3 investment per DS3 mile -- Additional investment for optoelectronic and electronic equipment per mile of DS-3 defined above.

Leased facilities -- Route miles, fiber miles or DS-3 miles leased from other interexchange carriers or resellers as applicable.

Point of Presence -- Point at which an interexchange carrier interfaces with a local operating company or metropolitan fiber carrier for access to its customers.

Local Telephone Companies

This section summarizes data from the Bell operating companies, rural carriers which provide data to the Rural Electrification Administration (REA), and companies affiliated with Contel, GTE, and United. The data is presented in Tables 5 through 13. A number of independent operating companies which together comprise less than 5% of the total fiber have not been included in the accompanying tables. A limited number of companies included in the data for rural companies provided by the REA may also be included in one of the other categories. Data covering the REA companies during 1991 was unavailable.

The plant of the local operating companies can be generally divided into three categories. These are interoffice, feeder and distribution. Interoffice facilities provide for the interconnection of telephone company central offices. Usually these facilities handle traffic from many subscribers and can take advantage of economies of scale.

Collectively, feeder and distribution plant is often termed subscriber plant. The "feeder" portion of plant provides for the part of the local loop which usually is arranged to enable many subscribers to share a common facility. Multiplexed or carrier systems, sometimes called pair gain systems, are used so that on a portion of the loop numerous subscribers can be handled on a single fiber or twisted wire pair. This survey revealed, however, that typically the telephone company will use single copper pairs for a subscriber all the way to the central office, rather than resorting to multiplexed or carrier systems. In many cases, use of existing spare wire pairs would be less expensive than adding a carrier system. However, when all pairs are exhausted, a carrier system is often the least costly way of adding more capacity. Addition of fiber in feeder plant is an attractive alternative in areas where all pairs are exhausted and are already fully equipped with carrier systems. In such cases it usually makes more sense to add a new fiber cable for new capacity rather than a new copper cable. These economic considerations provide the basic justification for fiber deployments by all types of local carriers, including carriers operating in rural areas, and provide a backdrop for other developments. [5]

The final portion of local transmission plant is the "distribution" plant. The distribution plant usually consists of dedicated fibers or wire pairs connecting subscribers to distribution points which are connected to the central office by feeder fiber. Penetration of fiber in distribution plant is the slowest, since there is less opportunity for multiple subscribers to share the cost of the fiber and equipment needed to convert optical signals into electrical signals needed for the typical telephone set or terminal. Deployment of fiber in this portion of the plant has been the most controversial since it may shorten the expected useful life of existing copper facilities and its economic justification typically requires new sources of revenue and new services, some of which may be in competition with existing CATV services.

The local companies have been unable to provide data which distinguishes between feeder and distribution fiber partly because of problems in defining a uniform demarcation point between shared and dedicated subscriber plant. In addition, several of the companies have difficulty providing data which separated interoffice from subscriber fiber and copper, claimed that many facilities are jointly used for interoffice and subscriber applications and

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[5] See references 35 and 120.

that in some instances no good sources of data in these categories could be located. US West, for example, has stated that it has used exchange and toll categories as a substitute for the interoffice and subscriber categories that were requested. This would tend to result in an overestimate of the amount of subscriber fiber and copper. Ameritech has reported the use of engineering estimates to separate interoffice and subscriber fiber and copper. Other companies either do not provide certain subscriber data or do not indicate whether estimation procedures were used. Subscriber data is displayed in Tables 10, 11, and 13.

The survey of local companies leading to this report focused on a number of aspects of the fiber infrastructure of the local companies. The primary purpose of the survey was to track the amount of fiber in various portions of the operating company plant. While the survey also covered data on the amount of copper in plant which is included in Tables 11 through 13 of this report, the reader should exercise caution when attempting to compare the amount of fiber and copper in plant, since strands of fiber inherently have a much greater information carrying capacity than an equivalent number of copper wires and differing investments and maintenance expenses are associated with activation of comparable capacities on fiber and copper systems.

As part of the infrastructure of local operating company fiber, the survey requested data on interLATA fiber used exclusively for internal company business. These facilities could not be used by the Bell companies under the MFJ for carrying traffic other than official company traffic, and the data indicates the extent of their interLATA facility base associated with such use. This data is summarized in Table 9.

Of particular interest was a determination of how and to what degree new fiber technology was being deployed by the operating companies. Thus, information on fiber rings, fiber-to-the-curb systems and new technology trials associated with fiber was requested. Under the price cap regime instituted in 1991, cost effective applications of new technology should be an increasingly important means by which the local companies will be able to enhance their profitability. Nonetheless, a possible desire to sacrifice long-term goals to short-term profitability by overly limiting the use of new technology or by ineffective or premature applications of technology would significantly mitigate the benefits of the technology or actually make a company less profitable over the long-term. Thus, in the future even greater interest both by regulators and the companies themselves in technology trials, extending beyond the well publicized fiber-to-the-home trials, should emerge. Exploration of more reliable and more efficient plant architectures and electronic configurations should continue to be one important element in such trials.

Some movement in this direction is already evident in response to perceived competitive pressures and a desire to lower the cost of deploying fiber to business and residential customers. In a number of metropolitan areas, local telephone companies are deploying a redundant fiber structure generically known as a "ring," which provides for fiber redundancy by allowing customer access to be achieved from either of two diverse paths. Often fiber redundancy arrangements established by the Bell operating companies differ from the fiber rings of the urban carriers in that they use the existing plant structure with two separate access paths provided to the customer. US West, for example, has tariffed such redundant arrangements. Nonetheless, it should be noted that available data suggests that significantly more fibers appear to have been deployed to date in these arrangements than the number of current customers. For the purpose of this report these redundancy arrangements are all being classified as fiber rings and have been identified by the Bell operating companies in the following metropolitan areas:

Ameritech:

Illinois:	Chicago, Oakbrook, Northbrook
Indiana:	Indianapolis
Michigan:	Detroit, Grand Rapids, E. Grand Rapids, Dearborn, Dutton, Holland
Ohio:	Cleveland, Columbus, Akron
Wisconsin:	Milwaukee

Bell Atlantic:

D. C.:	Washington, D.C.
Delaware:	Wilmington
Maryland:	Baltimore
New Jersey:	Cedar Knolls, Newark
Pennsylvania:	Philadelphia, Pittsburgh, Paoli, King of Prussia, Wayne, Conshocken
Virginia:	Norfolk, Richmond

BellSouth:

Alabama:	Birmingham, Mobile, Montgomery, Huntsville
Florida:	Fort Lauderdale, Jacksonville, Miami, Orlando, West Palm Beach, Daytona Beach, Gainesville
Georgia:	Atlanta, Columbus, Macon, Augusta, Savannah
Kentucky:	Louisville
Louisiana:	New Orleans, Shreveport, Baton Rouge, Lafayette
Mississippi:	Jackson
North Carolina:	Charlotte, Greensboro, Raleigh, Asheville
South Carolina:	Columbia, Greenville, Charleston
Tennessee:	Memphis, Nashville, Knoxville, Chatanooga

NYNEX:

Massachusetts:	Boston, Cambridge, Greendale, Waltham, Worcester
New Hampshire:	Nashua
New York:	New York City, Buffalo
Rhode Island:	Providence

Pacific Telesis:

California:	San Francisco, Los Angeles, El Segundo, Oakland, San Diego, San Jose, Santa Clara, Sunnyvale, El Torro, Berkeley, Anaheim, Sacramento, Irvine
Nevada:	Reno

Southwestern Bell:

Arkansas:	Roger/Springdale
Kansas:	Kansas City

Missouri:	St. Louis
Oklahoma:	Oklahoma City, Tulsa
Texas:	Dallas, Houston, San Antonio

US West:

Arizona:	Phoenix, Tucson, Mesa
Colorado:	Denver
Idaho:	Boise
Iowa:	Des Moines, Waterloo
Minnesota:	Minneapolis, St. Paul, Vadnais Heights
Nebraska:	Omaha
Oregon:	Portland
Utah:	Salt Lake City
Washington:	Seattle

Fiber architectures which would reduce the cost of serving large numbers of residential customers with some form of wide bandwidth service are also being explored. One such application of technology in an architecture which is designed to make deployment of wideband capabilities to residences more cost effective is the use of what is called "fiber-to-the-curb." This approach involves sharing of fiber and equipment to convert optical to electrical signals by more than one residence. In this arrangement fiber is deployed to an interface point near the customer, which in newer construction sites is often referred to as a "pedestal." Sharing of expensive opto- electronic equipment is then possible, and coaxial or other copper wire systems can be used for the short link to the subscriber. Systems of this type have been deployed by some of the local operating companies, as shown in Table 8. Bellcore supports the use of these systems on an interim basis, and it is likely that these systems will evolve as they proliferate further.[6]

Data on fiber technology trials is summarized in Table 8. These are primarily being used to test various fiber-to-residence arrangements and architectures, including systems with limited switched video capability. In some cases other fiber technology trials are also being conducted. BellSouth, for example, has reported trials of its 2.4 gigabit interoffice synchronous optical network (SONET) as well as SONET 150 megabit loop trials. BellSouth also reports a medical information communications application (MICA) which it characterizes as a research project rather than a trial. GTE and BellSouth have also reported an interesting broadband ISDN trial for a research project called VISTANET involving a prototype network for interactive three dimensional medical imaging research. Pacific Bell has reported a technology test of a loop optical carrier system and an associated software support system. Bell Atlantic reports several trials involving bandwidth sharing and voice and video integration capability involving off-the-shelf systems with future broadband upgrading capability.[7]

To better enable assessment of the deployment cost per fiber, investment and fiber count

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[6] See reference 66.

[7] See reference 49.

data associated with fiber trials is also shown in Table 8. Evaluation of this data appears to suggest that per fiber costs of most systems undergoing trial range from $2,000 to an amount in excess of $6,000 per deployed fiber. The cost per fiber of most of the systems appears to fall in the $6,000 range. Aside from the fiber trials and fiber redundancy arrangements alluded to above, there is presently little distribution fiber in place. Nonetheless, the operating companies are generally continuing to deploy significant amounts of new fiber to modernize their plant and at the same time bring fiber closer to the customer. The effective management of rapidly developing fiber and related technologies will pose a major challenge to the operating companies in the years to come.

Table 5: Fiber Deployment by Local Operating Companies

	Sheath-Miles						
Company	1985	1986	1987	1988	1989	1990	1991
Ameritech	3,200	5,200	6,700	8,700	10,800	12,100	14,300
Bell Atlantic	1,240	4,374	6,730	9,239	11,943	14,950	19,380
BellSouth	3,830	8,694	11,727	15,643	19,781	24,181	28,512
NYNEX	1,606	3,209	4,956	7,413	9,221	11,905	14,680
Pacific Telesis	2,318	2,779	2,964	3,480	3,767	5,659	7,024
Southwestern Bell	1,913	4,374	5,970	7,349	9,100	11,700	14,700
US West	3,527	5,017	6,937	10,030	13,425	17,596	22,148
Regional Bell Total:	17,634	33,647	45,984	61,854	78,037	98,091	120,744
Contel Companies				1,100	9,000	12,807	13,107
GTE Companies				8,999	11,855	15,827	17,596
United Companies				2,907	5,002	6,441	8,471
Rural Companies		500	2,584	4,651	6,369	8,689	NA
Total Reported:	17,634	34,147	48,568	79,511	110,263	141,855	159,918

* See accompanying notes to the tables and discussion in text.

Table 6: Fiber Deployment by Local Operating Companies

	Fiber-Miles						
Company	1985	1986	1987	1988	1989	1990	1991
Ameritech	77,700	111,100	147,100	177,500	228,400	285,500	388,900
Bell Atlantic	83,085	150,847	227,507	311,022	373,398	522,970	801,960
BellSouth	50,807	170,092	218,489	319,248	445,452	591,938	734,054
NYNEX	83,384	129,743	207,077	290,600	357,766	473,274	636,954
Pacific Telesis	84,310	97,800	101,090	110,273	126,944	189,077	253,359
Southwestern Bell	70,490	151,043	182,911	214,948	270,300	352,300	453,000
US West	47,341	70,082	107,782	163,968	234,851	351,571	542,308
Regional Bell Totals:	497,117	880,707	1,191,956	1,587,559	2,037,111	2,766,630	3,810,535
Contel Companies						103,603	106,035
GTE Companies				134,677	163,396	213,891	254,720
United Companies				32,287	54,569	87,591	122,525
Rural Companies		2,000	14,236	28,705	42,260	68,237	NA
Total Reported:	497,117	882,707	1,206,192	1,783,228	2,297,336	3,239,952	4,293,815

* See accompanying notes to the tables and discussion in text.

Table 7: Average Fiber Cable Cross Section *

Company	1985	1986	1987	1988	1989	1990	1991
Ameritech	24.3	21.4	22.0	20.4	21.1	23.6	27.2
Bell Atlantic	67.0	34.5	33.8	33.7	31.3	35.0	41.4
BellSouth	13.3	19.6	18.6	20.4	22.5	24.5	25.7
NYNEX	51.9	40.4	41.8	39.2	38.8	39.8	43.4
Pacific Telesis	36.4	35.2	34.1	31.7	33.7	33.4	36.1
Southwestern Bell	36.8	34.5	30.6	29.2	29.7	30.1	30.8
US West	13.4	14.0	15.5	16.3	17.5	20.0	24.5
Average -- Bell Companies:	28.2	26.2	25.9	25.7	26.1	28.2	31.6
Contel Companies						8.6	8.1
GTE Companies				15.0	13.8	12.7	14.5
United Companies				11.1	10.9	12.1	14.5
Rural Companies		4.0	5.5	6.2	6.6	7.9	NA
Average -- All Companies:	28.2	25.9	24.8	22.4	20.8	22.8	26.9

* See accompanying notes to the tables and discussion in text.

Table 8: Data on Fiber Trials of Local Operating Companies *

	Recent Fiber Trial Data									
	Fiber to Home Systems			Fiber-to-Curb Systems			Other Trials			
	Systems	Fibers	Investment Million $	Systems	Fibers	Investment Millions $	Systems	Fibers	Invest-ment	Type
Ameritech	2	266	2.49	0	0	0				
Bell Atlantic	1	250	NA	1	5	NA				
BellSouth	10	2,726	10.38	5	714	3.40	2		0.3	SONET
NYNEX	0	0	0.00	1	216	1.50	1	56	0.2	Dig. Loop Carrier
Pacific Telesis	0	0	0.00	1	288	1.20	3	24	0.168	SONET
Southwestern Bell	2	888	2.58	1	325	0.63				
US West	2	192	0.60	3	384	2.00				
Contel Companies	2	456	2.28	0	0	0.00				
GTE Companies	1	2,406	15.60	0	0	0.00	1			Broadband ISDN
United Companies	5	36	1.63	4	5	0.14				
Rural Companies	NA	NA	NA	NA	NA	NA				
Total Reported:	25	7,220	35.56	16	1,937	9				

* See accompanying notes to the tables and discussion in text.

Table 9: Other 1991 Fiber Data for Local Operating Companies

	* Loop Fiber				Aggregate Fiber Investment (Million $)			InterLata Fiber for Internal Co. Business	
	Fiber Rings-Cities	Cust. Loc. Served by Rings	Fibers termin. at C.O.	Cust. Fibers	Sub-scriber	Total	Percent Lit Fiber	Route Mi.	Fiber Mi.
Ameritech	14	256	26,043	7,700	NA	453.3	57.8%	1	6
* Bell Atlantic	13	NA	12,715	132	NA	581.9	NA	28	4,258
BellSouth	33	NA	50,220	NA	NA	921.2	NA	561	6,713
* NYNEX	9	1,454	35,667	NA	253.7	699.4	NA	154	2,872
* Pacific Telesis	14	280	35,076	NA	108.1	265.9	26.3%	981	10,981
Southwestern Bell	8	82	42,330	18,430	NA	489.6	43.0%	1,593	8,205
US West	14	309	51,363	2,744	200.9	481.4	21.0%	NA	NA
Contel Companies	9	NA	NA	NA	NA	123.3	59.2%	2,622	14,968
* GTE Companies	7	95	NA	NA	NA	307.2	60.0%	8	67
United Companies	6	34	NA	507	NA	173.0	31.2%	93	1,284
Rural Companies	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Reported:	127	2,510	253,414	29,513	563	4,496	40.3%	6,040	49,353

* See accompanying notes to the tables and discussion in text.

Table 10

Fiber Subscriber Plant of Bell Operating Companies *

	Sheath-Miles				Fiber-Miles				
	1988	1989	1990	1991	1987	1988	1989	1990	1991
* Ameritech	*2,800*	*2,600*	*3,300*	*3,500*	*NA*	*56,600*	*69,200*	*84,600*	*144,600*
* Bell Atlantic	*NA*	*4,872*	*6,543*	*NA*	*79,434*	*116,873*	*152,334*	*226,008*	*NA*
* BellSouth	*NA*	*NA*	*NA*	*NA*	*136,807*	*185,795*	*267,271*	*355,163*	*440,432*
NYNEX	*1,935*	*2,656*	*3,995*	*5,388*	*45,938*	*66,823*	*90,027*	*135,876*	*209,716*
Pacific Telesis	*537*	*722*	*1,617*	*2,228*	*15,911*	*22,104*	*30,353*	*64,447*	*97,276*
Southwestern	*NA*	*2,500*	*2,800*	*4,400*	*NA*	*NA*	*95,400*	*135,600*	*174,200*
* US West	*2,816*	*3,484*	*4,714*	*6,593*	*61,616*	*84,824*	*112,373*	*113,795*	*295,192*
Total Reported:	*8,088*	*16,834*	*22,969*	*22,109*	*339,706*	*533,019*	*816,958*	*1,115,489*	*1,361,416*

* See accompanying notes to the tables and discussion in text.

Table 11

Copper Subscriber Plant of Bell Operating Companies *

	Sheath-Miles				Wire-Miles			
	1988	1989	1990	1991	1988	1989	1990	1991
* Ameritech	*242,700*	*245,200*	*244,400*	*325,100*	*139,588,000*	*140,419,900*	*141,930,300*	*142,588,800*
* Bell Atlantic	*280,347*	*290,755*	*291,303*	*288,910*	*187,439,376*	*191,674,222*	*194,425,920*	*194,378,100*
* BellSouth	*559,993*	*564,236*	*566,080*	*570,385*	*238,775,565*	*241,225,031*	*243,457,732*	*243,640,535*
NYNEX	*225,547*	*229,508*	*232,731*	*232,867*	*130,892,737*	*134,247,385*	*137,882,236*	*139,975,586*
Pacific Telesis	*170,267*	*167,522*	*202,465*	*191,015*	*128,766,710*	*127,455,716*	*137,006,786*	*139,054,612*
Southwestern	*NA*	*338,100*	*343,300*	*345,800*	*NA*	*156,900,000*	*159,300,000*	*160,400,000*
* US West	*384,261*	*389,379*	*395,772*	*401,637*	*154,245,455*	*156,228,598*	*158,736,742*	*162,682,600*
Total Reported:	*1,863,115*	*2,224,700*	*2,276,051*	*2,355,714*	*979,707,843*	*1,148,150,852*	*1,172,739,716*	*1,182,720,233*

* See accompanying notes to the tables and discussion in text.

Table 12: Fiber and Copper in Total Plant in Relation to Access Lines -- End of Year 1990 *

Company Name	Access Lines	Total Plant: Strand Miles		Sheath Miles		Per Thousand Access Lines: Miles Copper Wire	Miles Fiber Strand	Miles Copper Cable	Miles Fiber Cable	Percent Fiber	
		Copper Wire	Fiber	Copper	Fiber					Cable	Strand
Ameritech	16,530,254	189,240,300	285,500	325,900	12,100	11,448	17.3	19.7	0.7	3.6%	0.15%
Bell Atlantic	17,905,495	194,425,920	522,970	291,303	14,950	10,858	29.2	16.3	0.8	4.9%	0.27%
BellSouth	17,721,561	243,457,732	591,938	592,424	24,181	13,738	33.4	33.4	1.4	3.9%	0.24%
NYNEX	15,511,119	168,373,472	473,274	263,978	11,905	10,855	30.5	17.0	0.8	4.3%	0.28%
Pacific Telesis	14,558,033	156,536,853	189,077	185,760	5,659	10,753	13.0	12.8	0.4	3.0%	0.12%
Southwestern Bell	11,817,930	169,100,000	352,300	375,200	11,700	14,309	29.8	31.7	1.0	3.0%	0.21%
U. S. West	13,775,772	162,335,227	351,571	424,577	17,596	11,784	25.5	30.8	1.3	4.0%	0.22%
Total reported:	107,820,164	1,283,469,504	2,766,630	2,459,142	98,091	11,904	25.7	22.8	0.9	3.8%	0.22%

* See accompanying notes to the tables and discussion in text.

Table 13: Fiber and Copper in Subscriber Plant in Relation to Access Lines – End of Year 1990 *

	Subscriber Plant					Per Thousand Access Lines				
	Access Lines	Strand Miles Copper	Strand Miles Fiber	Sheath Miles Copper	Sheath Miles Fiber	Miles Copper Wire	Miles Fiber Strand	Miles Copper Cable	Miles Fiber Cable	% Fiber Sheath Miles
* Ameritech	16,530,254	141,930,300	84,600	244,400	3,300	8,586	5.1	14.8	0.20	1.3%
* Bell Atlantic	17,905,495	NA	226,008	NA	6,543	NA	12.6	NA	0.37	NA
* BellSouth	17,721,561	NA	355,163	NA	NA	NA	20.0	NA	NA	NA
NYNEX	15,511,119	137,882,236	135,876	232,731	3,995	8,889	8.8	15.0	0.26	1.7%
Pacific Telesis	14,558,033	137,006,786	64,447	202,465	1,617	9,411	4.4	13.9	0.11	0.8%
Southwestern	11,817,930	159,300,000	135,600	343,300	2,800	13,480	11.5	29.0	0.24	0.8%
* US West	13,775,772	158,736,742	113,795	395,772	4,714	11,523	8.3	28.7	0.34	1.2%
Total reported:	107,820,164	734,856,064	1,115,489	1,418,668	22,969	10,179	10.3	19.7	0.25	1.6%

* See accompanying notes to the tables and discussion in text.

Notes to Tables 5-13:

Several of the initial operating company responses were incomplete, particularly those relating to loop fiber. The companies were generally responsive to further inquiry. In some cases more than one additional attempt was required to obtain the data that was requested. Some of the responses remained incomplete due to time constraints and apparent unavailability of the data.

Ameritech reports subscriber data based on engineering judgment.

Bell Atlantic and BellSouth data on subscriber copper is not available. Total copper is shown in place of subscriber copper. Bell Atlantic indicates that it cannot provide accurate data on lit fiber but references its form M data for 1990 which reported that about 31% of its fiber was lit. Bell Atlantic asserts that the form M data for lit fiber is estimated and not accurately tracked by the company. Bell Atlantic indicates that its only fibers to customers are for trials converted to regular service.

BellSouth subscriber fiber mileage for 1989, 1990, and 1991 as shown in Table 10 was estimated as 60% of the total fiber mileage based upon data provided by the company for 1987 and 1988. Other companies separating subscriber and interoffice fiber show an average of about 33% of the total fiber as subscriber and about 88% of the copper wire as subscriber. BellSouth confirms that its fiber investment does not include electronics at terminal or repeater sites.

GTE and United report customers served by fiber rings rather than customer locations.

NYNEX includes all customer building locations served by fiber, not just those locations associated with redundant configurations or rings.

Pacific Telesis data on customer locations served by fiber rings only includes Pacific Bell.

Data in the tables reflects the fact that prior to 1989 Southwestern Bell used interexchange and toll rather than interoffice and loop subcategories. Southwestern Bell Data for 1989 to the present properly reflects loop and interoffice subcategories which were originally requested.

Total access line counts were taken from the annual Form M submissions of the carriers covering the 1990 calendar year. (See reference 41.)

Fiber rings refer to any form of redundant fiber facilities.

Definitions and descriptions of the items in Tables 5-13:

Total strand miles of fiber and strand miles of copper -- The number of fiber strand miles used in all routes (including both lit and unlit fiber and inactive copper pairs), i.e., the sum of the number of miles of each cable multiplied by the number of strands. The terms "fiber-miles" and "fiber strand miles" are used interchangeably.

Percent lit fiber -- The number of fiber strand miles activated or equipped with optoelectronic equipment at terminal and repeater sites and capable of providing at least one voice grade circuit as a percentage of the total fiber miles of fiber.

Sheath miles of fiber cable and sheath miles of copper cable -- The total number of miles of fiber cable used. (Typically 12 to 36 fibers are contained in a given sheath.)

InterLata fiber Systems -- The route mileage and fiber mileage of owned fiber systems used for internal company business.

Fiber-to-the-curb systems -- The number of fibers and systems employing shared fiber and electronics.

Fiber trials -- The number of recent or current fiber trials with the capital investment and the associated number of fibers.

Fiber Rings -- The number of cities in which fiber rings or other redundant fiber arrangements are in use.

Fibers Terminating at the Central Office -- The number of fibers which terminate on central office facilities used or available for local loops.

Customer Locations Served by Fiber Rings -- The number of customer locations served by rings or other redundant fiber configurations.

Customer Fibers -- The total number of fibers to customers other than for fiber trials.

Investment in fiber backbone facilities -- The total investment in fiber cable, deployment, and repeater sites (outside plant), not including electronic or optoelectronic equipment. Subscriber investment includes that portion of investment associated with subscriber loops.

InterLata fiber for internal company business -- The route and fiber mileage of facilities dedicated to internal company use.

Urban Fiber Systems

For the last few years, this report has included data on a number of entities deploying fiber in metropolitan or urban areas. This rapidly growing group of entities access large business customers using a ring or loop of fiber through areas of high business concentration and are attempting to offer the customer very reliable service with competitive service and maintenance intervals. Table 14 lists the key companies known to be involved in such systems. It is not intended to be an all inclusive list but has been expanded since data on these companies was first reported. It excludes companies that only operate microwave systems or that were constructing fiber plant that was not operational in 1991.

The key targets of the urban systems are large downtown office buildings in cities where the deployment cost and regulatory constraints of new fiber systems are not excessive. Typically a cable several miles in length containing 20 to 200 fibers is deployed in existing conduit or in subway tunnels in a ring structure. The ends of the fiber cable are connected at a hub location. At least one fiber pair in the ring is typically dedicated to a single office building and capacity is often electronically subdivided for customer access within the building. Some carriers are serving more than one customer with each fiber pair, while others have dedicated one or more fiber pairs for a single customer, which is often an interexchange carrier. In either case, the fiber rings afford a simple inherent route redundancy arrangement since traffic can reach the hub in either direction around the loop.

Metropolitan or urban carriers have faced significant barriers to market entry because they must usually negotiate separately with each building owner, as well as obtain municipal franchises and other permits and meet state legal regulatory requirements. Despite the obstacles, a number of entities have successfully established themselves, and at least two are now operating in a significant number of metropolitan areas. There has also been increasing acquision activity with the larger entities purchasing or showing an interest in purchasing a number of smaller entities. Some of the interest in metropolitan fiber systems is evident from Cable TV companies which are also using fiber in their CATV systems. The potential for merger and acquisition activity has thus mitigated to some extent the risk to small startup ventures. An operation in a single city typically involves a $2 million to $10 million investment and serves at least 20 buildings.

The companies typically offer non-switched services, and although they provide end user to end user links, most of their business is either for customer access to a long distance carrier or for links between interexchange carrier points-of-presence. One of the larger entities has established the first 100 Megabit per second network over its facilities. Standards, availability of equipment, and customer requirements should facilitate further development of such networks.

The urban or metropolitan fiber systems have been valuable to the interexchange carriers for providing facilities between their points-of-presence and have reduced the red tape and other problems associated with the facilities the interexchange carriers might otherwise be required to build in metropolitan or urban areas. Besides interexchange carriers, financial institutions are a significant customer category. Despite their touted reliability, cost, and competitive installation and maintenance intervals, customers with multiple sites may for administrative reasons choose not to use urban fiber carriers when some of those sites are not directly accessible to an urban fiber system.

Teleport Communications Group, one of the first urban or metropolitan fiber systems to appear, started in a single metropolitan area, has been expanding to other areas and has also shown an interest in investing in existing entities. It has recently acquired DFW Metrolink in Dallas, Texas which had suffered financial difficulties. Teleport Communications Group initially 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 which have typically used a single fiber for each broadcast quality channel. Its operations have been extended to Boston, Chicago, Los Angeles, San Francisco, Houston, Dallas, and Los Angeles; and it has been attempting to enter the Washington, D.C. market. It also serves a number of smaller cities in New Jersey along the New York- New Jersey corridor, including Garden City, Jersey City, Newark, North Brunswick, Princeton and Weehauken, as well as Cambridge and a few similar sized cities in the Boston, Massachusetts area. Teleport Communications Group operates in each city through wholly owned subsidiaries or through partnerships and indicates that it currently reaches more than 500 buildings.

Another multi-city system, Metropolitan Fiber Systems, Inc. (MFS), is based in Chicago and has been constructing fiber facilities in a number of metropolitan areas through routes designed to maximize the number of large entities that can be served at minimum cost. MFS is 80% owned by Kiewit Communication Company, which had been involved in construction of a number of interexchange carrier fiber networks. This company is deploying fiber in each of its cities based upon a master plan involving one or more rings. The company promotes reliablity with redundant equipment and a backup route as well as a centralized maintenance reporting and deployment system. MFS was operational in 12 major metropolitan areas by the end of 1991 and typically deploys several hundred fiber miles per city.

Metropolitan Fiber Systems presently operates in Chicago, Minneapolis, Boston, Pittsburgh, Philadelphia, Baltimore, Houston, Los Angeles and San Francisco, New York City and Dallas. It has recently acquired Institutional Communications Company (ICC) in Washington, D. C., bringing its total estimated investment to more than $120 million. The Washington, D.C. system uses the subway tunnels as a right-of-way for much of its downtown fiber and has a number of small rings in areas of high business concentration and is serving about 212 buildings in Crystal City and Reston in Northern Virginia and New Carrollton in suburban Maryland. Traffic for its network is increased through leasing of DS-3 capacity to a number of distant cities providing feature group D access on a resale basis to the Washington area. The acquired entity, one of the oldest metropolitan fiber systems, has served both large business customers and interexchange carriers and has been providing service since 1986.

Several operations serve a small number of medium to large cities and sometimes some of the surrounding counties. Eastern Telelogic is one such company and is based in Philadelphia. The company serves four counties in the Philadelphia metropolitan area (Montgomery, Philadelphia, Chester, and Delaware).[8] As of the end of 1991 its full system is estimated at about 140 route miles and it reports serving more than 200 buildings. A second Philadelphia company, Philadephia Fiber Optic Corp., no longer appears to exist and the status of its deployed fiber could not be ascertained. This company had a single city system, which was to have been associated with a larger venture known as Fiber Optic Company of the U.S., which also no longer appears to exist. Another company, Diginet, operates urban systems along the Chicago and Milwaukee corridor as well as a link between the two cities. Indiana Digital Access provides service to a number of buildings in Indianapolis and Terre Haute and serves the surrounding towns of Muncie, Anderson and Lafayette with digital microwave, all within about 60 miles of Indianapolis. Finally, Intermedia Communications Co. of Florida which

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[8] See reference 112.

originally operated in Orlando and Tampa now also operates in Miami.

A number of entities which have recently begun to deploy fiber are identified. Available statistics for those companies which were identified as having operating fiber systems in 1991 are included in Tables 14 and 15. Only companies having fiber systems in operation and providing data were included in the tables.

Companies surveyed include Bay Area Teleport in San Francisco which recently added fiber to an all microwave system; Electric Lightwave which operates in Portland, Oregon, and Seattle, Washington; Metrex which serves Atlanta and Birmingham; City Signal which serves Grand Rapids and Detroit; Penn Access which serves the Pittsburgh metropolitan area; and New England Digital Distribution which serves Boston and Cambridge. A new entity in this year's report is Digital Direct, a subsidiary of Westmarc Communications which began multi-city operations in Seattle, Dallas and Chicago during 1991. Other entities covered for the first time in this report include Ohio Linx in Cleveland, Ohio; Metro Com in Columbus, Ohio; and Fibernet, Inc. which started operation in Rochester, New York and is expanding service to Buffalo, Albany and Syracuse, New York during 1992. Finally, Western Union ATS is operating urban fiber systems in a large number of cities. It was bought from Western Union and is now a subsidiary of MCI. Western Union ATS provides some of MCI's metropolitan conduit and fiber infrastructure in a significant number of cities, in addition to serving other customers.

Of some interest is the fact that the structure of the industry is leading to a greater number of corporate relationships between cable TV companies and urban fiber carriers. A number of the smaller urban systems, for example, are being or have been acquired by a cable TV company. Penn Access is being acquired by Digital Direct, Inc., a subsidiary of Westmar Communications which in turn is owned by TCI, a large cable TV company. The company has recently filed for state regulatory approval for this acquisition. In addition, a cable TV Company, American Cablevision, has established a subsidiary called Kansas City Fiber Net to provide an urban fiber system in Kansas City and Independence Kansas. Another company, Jones International, which already has a cable TV subsidiary called Jones Intercable, has established a sister subsidiary, called Jones Lightwave, to construct urban fiber systems. It now operates a system in Atlanta, Georgia.

Electric utilities are also involved in urban fiber networks. Two such entities, IOR Telecom (a subsidiary of Iowa Resources in the Des Moines, Iowa area) and Public Service of Oklahoma (an electric utility in the Tulsa, Oklahoma area) are providing transmission capacity to their customers as an adjunct to their electric power distribution activity.

As the urban fiber systems extend to more cities and attract more customers, they can be expected to selectively impact growth of demand of the local telephone companies. However, urban fiber systems can only serve those customers they can access. Their customers may, therefore, still be dependent on the local telephone companies. Urban fiber systems appear to have motivated local telephone companies to price special access closer to cost, and to serve larger customers by means of redundant facilities and fiber rings. Of particular note is the fact that a number of fiber rings or fiber redundancy arrangements have been reported by the Bell operating companies in many of the very same cities where urban fiber systems exist.[9]

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[9] See reference 69.

Table 14 – Urban Fiber Systems *

Company Name	Route Miles					Fiber Miles				
	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
Bay Area Teleport					2.4					85
City Signal				67.0	115.0				5,628	6,280
Diginet			5.4	24.0	26.3			684	1,147	1,160
Digital Direct					118.0					7,144
Eastern Telelogic			68.0	140.0	140.0			2,184	3,666	3,666
Electric Lightwave					6.4					451
Fibernet, Inc.					8.4					388
I. C. C. (Now part of MFS)	88.5	108.4	137.0	148.2	198.0	3,059	5,462	5,877	6,121	7,812
Indiana Digital Access, Inc.		7.0	34.5	59.0	50.0		238	295	469	528
Inter-Media Communications		18.3	78.0	159.0	165.0		579	1,365	2,862	3,000
IOR Telecom (Iowa Resources)			60.0	65.0	75.0			1,284	1,600	1,805
Jones Lightwave					10					80
Kansas City Fiber Net				90.5	93.7				2,534	2,624
Metrex Corporation				7.5	20.0				125	225
Metro Com					36.0					650
MFS (not including I. C. C.)		9.5	62.6	84.1	272.5		399	7,497	12,154	29,089
New England Digital Distribution				10.0	10.0				1,440	1,200
Ohio Linx					2.5					84
Penn Access Corporation				31.0	80.0				1,865	6,800
Phoenix Fiberlink					22.0					968
Public Service of Oklahoma			120.0	109.0	119.0			2,500	2,631	2,855
Teleport Communications Group	44.5	57.7	227.2	273.2	400.8	4,711	5,433	12,346	15,519	20,238
Teleport Denver					100.0					4,800
Total Reported:	133.0	200.9	792.7	1,267.5	2,071.0	7,770	12,111	34,032	57,761	101,932

* See accompanying notes to the tables and discussion in text.

Table 15 Urban Fiber Systems
Other Current Data -- 1991 *

Company Name	Sheath Miles	Average Fiber Count	Investment Millions $	Percent Fiber Lit	Cust. Loc.	Buildings
Bay Area Teleport	3	28.3	0.2	60%	16	9
City Signal	115	54.6	5.0	30%	147	126
Diginet	28	41.0	11.9	32%	80	45
Digital Direct	138	51.7	14.4	6%	30	47
Eastern Telelogic	140	26.2	13.0	65%	NA	230
Electric Lightwave	6	69.6	2.0	17%	24	21
Fibernet, Inc.	8	46.2	NA	NA	NA	35
I. C. C. (Now part of MFS)	198	39.5	19.9	54%	406	212
Indiana Digital Access, Inc.	50	10.6	0.7	61%	16	10
Inter-Media Communications	165	18.2	NA	100%	140	105
IOR Telecom (Iowa Resources)	80	22.6	4.0	61%	50	60
Jones Ligh[illegible]ave	10	8.0	0.5	13%	1	2
Kansas City Fiber Net	131	20.0	NA	51%	41	24
Metrex Corporation	20	11.3	1.2	10%	7	7
Metro Com	36	18.1	NA	NA	18	18
MFS (not including I. C. C.)	273	106.7	NA	67%	3,489	629
New England Digital Distribution	10	120.0	5.0	10%	30	15
Ohio Linx	3	33.6	NA	NA	3	3
Penn Access Corp.	80	85.0	NA	NA	60	60
Phoenix Fiberlink	22	44.0	2.0	27%	12	25
Public Service of Oklahoma	141	20.2	3.0	75%	26	42
Teleport Communications Group	485	41.7	NA	73%	1,295	511
Teleport Denver	100	48.0	NA	NA	NA	NA
Total Reported:	2,242	45.5	82.6	58%	5,891	2,236

* See accompanying notes to the tables and discussion in text.

Notes to Tables 14 and 15: (NA indicates data was not available)

Sheath mileage for Diginet and Metropolitan Fiber System, Inc., Intermedia Corp., Teleport Denver and where otherwise unavailable was assumed to be equal to route mileage.

Statistics shown are for backbone system and reflect owned facilities. Bay Area Teleport, for example operates leased facilities which are not shown in the tables.

Diginet fiber data shown in Tables 14 and 15 does not include fiber connecting Milwaukee and Chicago that is shown in Tables 1 and 2.

Fibernet facilities shown in the tables only include its Rochester, New York operation.

Intermedia Corp. has revised historical route and fiber mile data which had apparently not been reported cumulatively.

Average fiber count is calculated as the fiber mileage divided by the sheath mileage.

Definitions and descriptions of items in Tables 14 and 15:

Route miles of fiber -- The total number of miles of fiber routes as would be seen on a network map.

Total Fiber miles of fiber -- The number of fiber strand miles used in all routes including both lit and unlit fiber -- the sum of the number of miles of each cable weighted by the number of fiber strands.

Sheath miles of fiber -- The total number of miles of fiber cable used. (Equal to or greater than route mileage.)

Fiber miles of lit fiber -- The number of fiber strand miles activated or equipped with optoelectronic equipment at terminal and repeater sites and capable of providing at least one voice grade circuit .

Investment in fiber backbone facilities -- The total investment in fiber cable, deployment, repeater sites but not including electronic or optoelectronic equipment.

Buildings served -- The total number of buildings accessed by fiber where the carrier is capable of providing service.

Customer Locations -- The total number of customer locations or sites in buildings accessed by fiber.

Cities Served -- A list of cities served by fiber facilities. (See text of report.)

Other Entities Deploying Fiber

The electric utilities and cable TV companies have also been deploying fiber. While these entities are beyond the primary scope of this report and are too numerous for a complete survey treatment, they are mentioned here insofar as they have introduced innovative and cost effective approaches in their deployments.

Previous reports highlighted joint deployments of electric utilities and interexchange carriers which typically use what is called "ground-wire fiber" in which the fiber is encased inside the standard ground-wire cable and deployed on the high voltage structures. Use of fiber electrically isolates the power facility from the communications link, and ground-wire fiber is believed to be less vulnerable to direct hits by lightning than to very serious power malfunctions that could melt the cable. Such risks, however, are expected to be lower than the outage risk of buried fiber associated, for example, with the fiber cables being accidentally dug up. Ground-wire fiber deployments involving long-term use agreements with interexchange carriers have provided a very cost effective means for many electric utilities to upgrade their own communications facilities, and a number of electric utilities, especially in the southeastern U.S., have been fairly active in promoting this approach. The deployments are also useful in that they may have a limited impact on future microwave frequency requirements associated with private microwave systems used by the electric utilities. Microwave systems, however, will often still be used for backup and to reach areas not accessible to fiber systems.

There are a number of different types of arrangements which have been used by the electric utilities in deploying fiber with the interexchange carriers. Typically the facilities are built under a negotiated long-term agreement sometimes characterized as an "enhanced right-of-way" or the utility leases or negotiates capacity built by a subsidiary. The details of these arrangements are beyond the scope of this report. As part of last year's survey several electric utilities or their subsidiaries in the Southeast, including TVA, Georgia Power, Alabama Power, MPX Systems, Carolina Power and Light and Entergy Corporation (formerly Middle South Utilities), were contacted. Last year's report identified about 3,400 route miles and about 65,000 fiber miles of ground-wire fiber systems for the above entities, either completed or nearing completion. All but about 675 route miles of this appeared to be associated with interexchange carriers. Continuing construction plans of these utilities through the 1992-93 time frame included an additional 770 route miles and about 18,800 fiber miles associated with interexchange carriers by three of the above entities. This year's survey focused on the interexchange carriers rather than the electric utilities to determine the extent of their joint facilities with electric utilities. A limited response by the interexchange carriers only identified a total of only about 25,000 fiber miles of such facilites which is far below the total known to have been deployed. [10]

Besides the electric utilities, several cable TV companies have been fairly active during the past few years in fiber deployments. These include ATC, Jones Intercable, TCI, Continental Cable and American Cablevision. While a number of CATV companies use microwave systems for the backbone portion of their networks, other companies have concentrated on deploying fiber in the "trunking" or backbone portion of their plant which is shared by the largest number of subscribers and which most affects service quality. Last year's report documented more than 25,000 fiber miles which had been deployed by ATC and Jones

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[10] See references 101-103.

Intercable in what may be characterized as hybrid fiber/coax systems. The mode of deployment used takes advantage of the one-way character of transmission and is cost effective because fiber repeaters are not used. Rather, input power at the source or head end is repeatedly split in fiber structured as a tree until power budgets are fully met. [11] This approach retains the coaxial cable nearest the subscriber with a minimum number of repeaters, and the costly coaxial investment associated with accessing individual homes is retained in its existing form. These deployments of fiber are of interest in that they are primarily passive systems which are targeted to result in the greatest impact for the smallest incremental capital investment.

Tutorial Review of the Technology

Before discussing the technology itself, it may be useful to briefly review a few terms which have been 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 effective data rates are sometimes referred to as throughput rates or simply throughput. Another important term denoting capacity and used extensively in this report is the term DS-3. Before defining a DS-3 it is useful to define the term DS-1, a unit of capacity consisting of 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 contain up to 28 channels operating at the DS-1 rate of 1.544 megabits per second.

Several acronyms relating to a number of fiber and digital standards are in common use in the literature. Two such terms, SONET and FDDI, refer to synchronous optical network standards and fiber distributed data interface standards respectively. [12] SONET standards will impact a significant part of local operating company networks and will affect, for example, digital cross connects associated with switched or reconfigurable DS-1 and DS-3 links. Equipment for local operating company applications is presently in greatest demand. Fiber distributed data interface standards will probably have greatest initial applicability to personal computer networks and metropolitan or urban fiber systems. [13]

Another acronym, ISDN, which stands for integrated switched digital network, refers to an overall application of the technology to provide for both newer digital and more traditional telephone services in an integrated network and incorporates the new 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 that 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, an overall ISDN network capability, with widespread deployment of fiber is rapidly becoming a reality which will provide the protocols and interfacing standards

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[11] See references 21-23.

[12] See references 107 and 132.

[13] See reference 74.

for an 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 visible 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 propagate 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. 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 propagate 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 techniques of heterodyning, more analogous to information transfer of information on radio that is also under development, may 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 (trillions of bits 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 possible based on extensions of known technology. Engineers are investigating new technologies which may eventually make throughputs in the terabit range possible. However, the future application of higher system data rates may require smaller repeater spacings until further problems with dispersion are solved.

Technological Developments

Developments in fiber technology are occurring in several areas. The ongoing research typically has a long-term horizon. Fiber (optical) amplifiers, ultra low loss fiber, increases in information handling capability, and new network electronic configurations and fiber architectures are all areas under investigation. This section will briefly highlight some of the developments in these areas.

A basic interest in further lowering the cost of fiber systems on a per-circuit basis and extending their useful life has centered on increasing fiber system capacities and reducing the number of required repeaters. This will require higher speed laser emitters, use of multiple wavelengths or "rails," advances in repeater technology and solutions to problems of dispersion. The highest capacity systems using a single optical wavelength, typically operate in the one to two gigabit range and handle between 28 and 36 DS-3's per fiber pair. AT&T's 1.76 gigabit systems, for example have a capacity of 36 DS-3's or 24,192 equivalent voice circuits per fiber pair. AT&T also uses a 2 wavelength or "rail" system which can handle two 1.76 gigabit systems on a single fiber pair. Research on more advanced systems, both using wavelength division multiplexing and higher bit rates using a single optical wavelength is continuing. Those systems using the wavelength division approach will require 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.

Developments to more fully exploit the vast potential capacities of the fiber medium itself have focused on the need to improve repeater and terminal technology, since existing single mode fiber is operating well below theoretical capacity limits of the fiber itself, even when systems in the 1 to 2 gigabit range are employed. Use of multiple optical wavelengths or rails has been demonstrated in the laboratory and in field tests and appears to provide the basis for the most immediate capacity increases. Other types of modulation including forms of analog modulation are also under investigation. Systems with throughputs of between 16 and 27 gigabits are also reportedly being developed or demonstrated in the laboratory by AT&T, Bellcore, British Telecom, NTT, and others.

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 by looking for other phenomena that could amplify light signals directly and cancel the effects of dispersion. This would permit larger spacing between repeaters, as well as boost potential capacities. As should be evident, accomplishments of greater spacing between repeaters is usually accompanied by lower bandwidth capability and vice versa, which is due partly to the phenomenon of dispersion. Thus, maximizing the product of the bandwidth and repeater spacing becomes the ultimate objective.[14]

An exciting development in the research stage that may 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.

To further enhance the capability of existing fiber, work on laser amplifiers which can be placed in line with fiber is another area of interest. Such devices are just now becoming available but cost may be prohibitive for many applications. Optical amplification offers interesting possibilities because the greatest limitation in transmitting data over fiber is the limitation in existing repeaters and terminal devices which must convert optical signals to electrical signals and back again. With optical repeaters the full capability of fiber would not be limited by the need to develop new generations of optoelectronic conversion devices. Such developments would be particularly advantageous in undersea fiber systems where capacities of systems could be increased with new terminal devices as technologies associated with the electro-optical interface improve, and the repeaters would not have to be touched. With optical repeaters, new generations of terminal electronics could thus increase system capacities without

[14] See reference 11.

requiring new repeaters that effectively require a new cable to be laid. [15] AT&T and KDD in Japan expect to use fiber amplifiers in transoceanic cable in as little as three to four more years with capacity more than an order of magnitude greater than existing systems.[16]

Repeaters are required in fiber systems for two reasons. First, and most obvious, is the effect of attenuation or loss in the fiber. The second but equally critical effect of dispersion limits transmission bandwidth and repeater spacing. As propogation distance increases, light pulses on fiber tend to spread out due to this phenomenon. Dispersion is caused by very slight differences in distance traversed by different portions of the optical signal that affect bandwidth characteristics through constructive or destructive interference. This can be a critical problem, since it limits the maximum data rate which can be transmitted or the allowable distance between repeaters.

Single mode fiber now in use vastly reduces dispersive effects over multimode fiber since only one mode or characteristic propogation path is allowed. Nonetheless, even further reductions of dispersion are required for fiber systems to support higher data rates over significantly longer distance, as would be encountered in underseas cables or in terrestrial systems with larger repeater spacing.

One very interesting approach has been the use of what is called "soliton pulse transmission". A soliton is a pulse that remains unchanged by dispersive fiber effects during its transmission. Nonlinear quantum effects are employed to both amplify the signal and cancel the effects of dispersion. A continuous (non- pulsed) laser provides a background light level of sufficient power which, through a phenomenon described by quantum physics called "pumping," causes a transfer of energy to the propagating lower power pulsed optical signal. [17] The propogation velocity can be altered by changing the light intensity through what is known as the Kerr effect which can be used to control dispersion. [18] This would allow transmission at very high data rates without the need for repeaters which require conversion of optical to electronic signals and vice versa. Fiber systems operating with background laser pumping over their entire length could totally eliminate the need for repeaters, or this effect might be used over selected fiber sections to regenerate pulses optically. Further research in this area is going on at Bell Laboratories and elsewhere.

To date very long high capacity systems employing laser amplification techniques have been demonstrated including a recent coherent system demonstrated by NTT with 2.5 Gigabit data rates over distances approaching 1,400 miles. Such a system can be rated by multiplying the maximum system length by the bandwidth which in this case is over 5,500 gigabit-kilometers per second. An experimental high capacity system demonstrated at AT&T reportedly achieved transmission up to 50,000 gigabit-kilometers per second. In the future, when remaining problems are solved, fully optical working systems extending over 4,000 kilometers will be deployed. Transmission up to 9,000 kilometers would then only depend on proper control of the jitter of pulses due to quantum effects. These developments demonstrate

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[15] See reference 89.

[16] See reference 34.

[17] See reference 119.

[18] See reference 34.

hat many current fiber system technologies, as amazing as they seem, are still only in their infancy.[19]

Soliton pulse transmission and related technologies typically first find application in undersea environments where extending the useful life of cables by allowing future enhancements of their capacity will justify the expected higher early costs of these systems. Eventually, such technologies will significantly reduce the cost of building terrestrial systems by eliminating many costly repeaters.

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 are beginning to weigh strategies and costs associated with alternatives of overbuilding certain existing routes with more fiber, upgrading the electronics on existing routes, and waiting for availability of new generations of electronics. It appears that those developments which will increase fiber capacities over current maximum levels using significantly higher bit rates are far enough in the future to constrain the potential capabilities of existing systems, at least for the time being. In the immediate future, systems with multiple wavelengths or rails appear to be most likely. Availability of new capacity enhancing technologies and expected demand growth will impact the degree of new fiber deployments and overbuilds.

Another important area of interest has to do with electronic configurations and fiber architectures which would both minimize the cost of fiber deployment in the loop plant and improve overall network reliability. The portion of the plant closest to the customer is inherently the most costly, since opportunities for exploiting economies of scale in the loop environment are limited. Novel fiber architectures are important when trying to reach end users with fiber in a more cost effective manner with lower chances of failure. For this reason, more attention is being placed on new approaches for configuring fiber and electronics. Fiber-to-the-curb systems have stood out as one obvious cost reducing configuration and a group of vendors already manufactures equipment for such systems.[20] Fiber rings, which can be used to serve end users or to interconnect central offices, have stood out as one means for addressing reliability issues.

The fiber rings used by local operating companies and urban fiber carriers are one example of fiber configurations or architectures typically used for large businesses or downtown office buildings. Using this approach, fiber can access many large customers with system redundancy in a cost-effective manner. To share the available capacity on fibers used in fiber ring arrangements, the capacity is often subdivided by means of multiplexing and demultiplexing equipment, or a so-called bus structure has been used. This allows a customer to only access a portion of the fiber bandwidth on an as-needed basis. Further development and exploration of such approaches may eventually lead to more cost-effective ways of providing high bandwidth capabilities to residences as well as improving overall network reliabiliy.

In addition, new fiber configurations associated with fiber to the home trials of the operating telephone companies are emerging. In an attempt to reduce the cost of video to the home, system bandwidth is sometimes sacrificed by using a switched optical signal allowing the

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[19] See references 34 and 134.

[20] See reference 80.

user to remotely control the video signal reaching the customer. Such switched systems when used for home entertainment are incompatible with existing CATV systems which provide all signals (up to about 80 channels) to the customer simultaneously. Switched video systems also require extra equipment on the customer's premises and do not appear to allow the customer to simultaneously record one channel and watch another. Presently, optical switching technologies are at an early stage of development, which will probably constrain the early possibilities of such systems. [21] Developing video and data compression technologies may also find application in video to the home systems. These technologies may also provide an impetus toward greater use of narrowband ISDN and may spur development of a variety of novel services to customers over existing facilities. One relatively promising compression technique based on fractal mathematics may provide compression ratios needed for transmission of television signals over narrowband ISDN lines. Such approaches in some form would allow more time for the economic development of broadband systems while stimulating demand for narrowband ISDN whose development extended over many years but whose use has been retarded by lack of such a stimulus and by preoccupation with wideband systems. [22]

The cable TV industry has only recently begun to use fiber (since about 1988); however, early developments suggest that it has developed cost effective methods of deploying fiber in video applications that provide wide bandwidth for one-way communications. [23] Use of fiber in the backbone or "trunk" portion of the CATV service provider's network, with a wide bandwidth coaxial transmission system in the portion of the network nearest the subscribers, eliminates a large number of amplifiers which are currently associated with coaxial CATV systems, thus resulting in more uniformly reliable service to all customers with improved signal quality. The repeaterless backbone fiber network "feeds" a series of small cells each of which uses a small existing coaxial network. The coaxial cable going to the customer is unchanged, and no expensive and high maintenance equipment is required in the customer's premises for conversion of optical and electronic signals. The customer thus continues to receive the full set of channels, and the cable operator can justify the investment on the basis of improvement in service and reduction in system operating and maintenance costs. CATV operators using such systems are clearly interested in new developments associated with optical amplifiers which will enable further use of fiber in their systems.

The portion of plant closest to the customer is generally the most costly because there are fewer opportunities for sharing that generally makes fiber systems so attractive. The fact that residential customers don't necessarily require the same bandwidth in both directions suggests that benefit may be derived by focusing on the expected evolution of bandwidth and switching requirements in both directions for residences and businesses, rather than on the fiber medium or conveyance itself. From a technical viewpoint, a facility combining a fiber "trunked" one-way wideband video capability with a return narrow band channel might be one means to accelerate the development of sophisticated communications services to residences on a cost-effective basis. Planned evolution of such a facility would allow exploitation of new technology as it became cost effective. [24]

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[21] See reference 30.

[22] See references 7,62 and 148.

[23] See references 21, 22, and 80.

[24] See references 22 and 89.

Despite practical regulatory issues as well as issues involving the structure of very different utilities, it is natural to consider the embedded investment of existing CATV coaxial systems, which either serve or pass most U.S. households in the country and are designed primarily for one-way transmission, as part of an integrated system for residential use. Use and further development of such existing facilities together with telephone company facilities could permit new services to develop with less extensive commitments of new capital, than might be envisioned by early deployment of fiber to customers on a large-scale basis. Present industry and regulatory structure, however, does not appear to be leading to this kind of result. Instead, there have been a number of corporate relationships linking Cable TV and Urban fiber operations and a sense of some in the industry that competition will solve all the problems of introducing new technology into the local loop. More effective ways of utilizing new technology in the local loop will involve new ways of dealing with complex regulatory, management, and technical issues. New approaches both to develop and effectively manage deployment of innovative network architecture and technology merit continued investigation and highlight the need for careful and thorough planning prior to significant commitments of capital. [25]

This section has only touched on some of the ongoing developments in fiber technology. Further information is contained in a number of references listed on the following pages. To better evaluate technological developments by the operating companies, a question on fiber trials, fiber-to-the-curb systems, and fiber ring architectures was asked in the survey. Data received is summarized in Table 8 of this report. Information of this kind may be useful in evaluating the awareness and responsiveness of the local operating telephone companies to the latest and most cost-effective technologies available to them.

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[25] See reference 135.

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