FIBER DEPLOYMENT UPDATE
End of Year 1989

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Common Carrier Bureau

Federal Communications Commission

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Introduction and Overview

This report was first released in December 1986. Since then it has been updated annually. The primary purpose of this report is to document fiber capacity built or used by common carriers. It is divided into several sections. The first part reviews the elements of statistical data being collected. Important issues and developments associated with each of the main categories of entities deploying fiber are then discussed.

The scope of this report, which originally encompassed data on the interexchange carriers and the regional Bell holding companies, has been expanded to include urban fiber systems, non-Bell local operating companies, and information on the electric power industry's application of fiber to telecommunications. A discussion of the methods, procedures and shortcomings associated with the data and the data collection process is provided at the back of this report along with a discussion of reliability issues. In addition a brief tutorial is provided for individuals who are not familiar with the technical terminology used in this report.

This year, the interexchange carriers have generally been more modest in expanding their fiber networks and there is evidence of further merger and acquisition activity among these carriers. Much of the expansion now focuses on obtaining greater utilization of the existing deployed fiber either by using technologies with higher bit rates or throughputs or by equipping previously dark fibers. Local operating companies have increased their fiber in plant by about 30 percent and now report the use of ring structures and redundancy arrangements. There is every indication that this level of growth will continue for the foreseeable future as local carriers extend fiber closer to the customer by deploying more fiber in the feeder plant. In addition there is evidence of increasing interest in economically deploying fiber closer to the customer using, for example, what are termed "fiber-to-the-curb" systems. There has been significant expansion in some of the urban or metropolitan fiber systems. However, the amount of fiber in these systems is still very small in relation to the fiber deployed by the local operating companies.

Perhaps the most interesting development is the increasing use of fiber by the electric utility companies. In the past, the facilities of the power and telecommunications utilities have been distinct for reasons which were at least partially based on important technical considerations. A realization of the advantage of the nonconductive character of fiber is beginning to change some of this industry structure and there is now significant evidence of agreements for joint use or deployment with interexchange carriers. Despite the potential benefits to the local operating companies, it remains to be seen whether these carriers will also deploy fiber using similar joint agreements with other entities such as the electric utilities. The extent to which such ventures could accelerate the deployment of fiber to the home on an economic basis and provide for capital conservation and greater network redundancy merits further study.

Items of Data Being Collected

A number of statistical elements have been collected and are summarized in the tables accompanying this report. The most significant factor in assessing the amount of potential fiber capacity available is the number of fiber miles deployed. A fiber cable containing 20 fibers and extending 100 miles would, for example, add 2,000 fiber-miles to the total. This parameter is important because it enables one to determine the total number of equivalent voice circuits which can be made available when the terminal technology is specified. The number of voice circuits that can be multiplexed onto a single optical fiber depends significantly on terminal and repeater technologies which are continuing to change. Therefore, the use of circuit mileages based on current technology would provide a misleading picture of capacity. For example, 1.7 Gigabit terminal technology supports up to approximately 25,000 2-way circuits on a single fiber pair, more than three times the capacity of earlier fiber transmission technologies used at repeater and terminal locations. Because many service providers typically initially equip a limited number of fiber pairs initially with transmission electronics and "optronics" (at repeater and terminal locations), it has been possible to minimize initial investment and to take advantage of new transmission technologies as they become available and as future circuit requirements dictate.

Route mileage is also an important factor because it provides a means for estimating the size of each carrier's network. This measure is especially useful for analyzing carriers with relatively simple network structures. However, deployment of multiple cables between locations can result in possible ambiguities regarding what constitutes a distinct route. Despite this potential concern, route mileage can be used to evaluate the overall size of each carrier's network. Route mileage has also been useful for checking the data's validity, particularly for carriers with a simple network structure, since the number of fiber miles divided by the number of route miles gives the average fiber cross section. In a couple of instances this validity check has caused carriers to provide more reliable data. For the local operating companies whose network structure makes it difficult to collect data on route mileage, cable sheath mileage was requested instead of route mileage to ascertain the relative size of the carriers' networks. In the case of the separate metropolitan or urban fiber carriers, both sheath mileage and route mileage were requested as a validity check, but only the route mileage is tabulated in Table 10 of this report.

The third basic item collected is the percentage of fiber miles lit or equipped with basic terminal and repeater hardware. Most systems use a separate fiber pair called a protection pair for added reliability. For this report, a protection pair is considered as lit. In order to better evaluate the impact of new repeater and terminal technology on ultimate system capacity, the DS-3 mile capacity on lit fiber is used to provide an estimate of the new capacity added as the result of new lit fibers in a route or the effect of upgrading electronics. The DS-3 mile measure is also used in some instances to measure the amount of leased capacity. It is likely that the potential for double counting associated with leased fiber is reduced by capturing the leased capacity separately in this manner. However, it is expected that only a portion of fiber capacity obtained through leasing or other agreements has been documented in this report.

The final item which is total fiber system investment is provided as a means to approximate the magnitude of investment in fiber facilities to date. Detailed methodologies for tracking investment vary widely among carriers and available data in this category was sometimes insufficient to establish an adequate commonality. Therefore, data on investment in this report represents a broad estimate and may not accurately portray the identical components for each carrier. Some carriers have included all electronics to initially equip their systems and other smaller carriers reported total company assets, the bulk of which should represent fiber system investment. In other cases, it appears likely that the investment was calculated on the basis of a broad gauge cost per mile of system. For the purpose of Table 3, the fiber investment has been estimated at $75,000 per route mile for carriers not providing any investment data and total investment was rounded to the nearest million dollars. This appears to be fairly consistent with average investment of carriers providing data. In some cases current investment was estimated from data provided previously.

Interexchange Carriers

Data for the interexchange carriers is shown in Tables 1, 2, and 3. This year, growth in fiber mileage deployed by interexchange carriers was between 15% and 16%, down significantly from last year's growth which was slightly over 27%. Most of the growth this year is accounted for by AT&T's expansion with more than a 35% increase in fiber mileage. Total fiber mileage deployed by the interexchange carriers is estimated at over 2.1 million miles as shown in Table 1. While additional investment to fully equip the 2.1 million fiber miles would be substantial, a rough estimate of the capacity of these facilities, assuming 28 DS-3's or 18,816 circuits per fiber pair suggests that up to about 29.4 million DS-3 miles could eventually be equipped on the existing fiber using present terminal and repeater technology. Even if as much as 50% of the fiber were used for route redundancy, at least 14.7 million DS-3 miles would be available using existing technology carrier and repeater equipment. Presently carriers report having equipped more than 6.3 million DS-3 miles as shown in Table 2.

Over the past few years many of the interexchange carriers have extended their routes and provided route diversity by a multiplicity of agreements among themselves. These kinds of agreements are especially prevalent among the National Telecommunications Network (NTN) companies which have developed a nationwide networking capability by this means. More recently a number of the interexchange carriers appear to have focused greater attention on agreements facilitating joint deployment of fiber and resulting shared use of rights of way with electric power utilities. At least two of the major carriers have accelerated their activities to extend their routes in conjunction with electric power utilities. This activity has been concentrated in the Southeast where population has been growing, and where the local electric utilities have been especially interested in 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 beginning to take 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 still 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. (See the next section on the electric utilities.)

Another continuing activity has been that of mergers and acquisitions. The field of carriers has been consolidating into 4 major entities: U. S. Sprint, the NTN companies, MCI and AT&T. The most recent consolidation activities primarily center on the NTN Consortium of Companies. The largest acquisition was Williams Telecommunications Group acquisition of Lightnet with a fiber network of about 5,300 route miles. Also notable was the merger of Southernet and Teleconnect into a new entity called Telecom USA. In another acquisition, Communications Transmission, Inc. (CTI) owner of the Electra Network, acquired Mutual Signal Corp. In two additional acquisitions which did not involve fiber facilities, Advanced Telecommunications Corp (ATC) acquired the Claydesta microwave network and Litel acquired Charter Communications and Afford-a-Call.

The NTN consortium has also expanded to include RCI in addition to the non-NTN companies acquired by existing NTN companies such as Lightnet and Teleconnect. NTN reports that it is in the process of building a network for signalling system 7, an out of band signalling system which can be used in connection with ISDN services. In addition, NTN reports that it is beginning to offer new switched services and products such as operator services, 800 service, calling cards, video services, and T1 data services.

Table I

Total Estimated Owned Fiber Deployed by Major Interexchange Carriers

	Route-Miles					Fiber-Miles				
Year:	1985	1986	1987	1988	1989	1985	1986	1987	1988	1989
NTN Partners:										
ATC [3]	800	950	967	1,127	1,350	8,000	9,500	9,670	17,158	18,145
Consolidated Network	310	310	352	352	352	3,504	3,504	3,864	3,952	3,952
Litel	881	950	1,210	1,210	1,210	13,720	17,274	22,280	22,280	22,280
RCI [4]	580	580	796	413	415	6,960	6,960	7,202	2,618	2,666
Telecom U. S. A. [2]	465	1,172	1,492	1,492	1,778	4,650	11,720	13,640	14,120	18,599
Teleconnect	*	*	320	400	*	*	*	1,920	2,400	*
SouthernNet	188	895	895	*	*	1,880	8,950	8,950	*	*
Southland Fibernet	277	277	277	*	*	2,770	2,770	2,770	*	*
WilTel (composite) [2]	3,084	9,278	9,544	10,477	11,067	71,020	211,173	232,123	259,065	265,617
LDX Net	670	1,379	*	*	*	16,080	33,096	*	*	*
WilTel	214	2,899	*	*	*	2,140	58,077	*	*	*
Lightnet	2,200	5,000	5,300	5,300	*	52,800	120,000	127,200	127,200	*
NTN Subtotal [1]	6,120	13,240	14,361	15,071	16,172	107,854	260,131	288,779	319,193	331,259
AT&T	5,677	10,893	18,000	23,324	31,871	136,248	261,432	432,000	704,731	956,374
MCI [4]	2,560	5,580	8,775	10,975	11,500	79,200	167,400	245,700	264,680	268,224
U. S. – Sprint [2] [4]	5,300	10,000	18,195	22,090	22,280	122,400	190,000	497,224	575,562	594,876
CTI composite [2]	382	382	803	803	855	9,960	9,960	13,981	13,981	14,653
Electra	382	382	382	382	382	9,960	9,960	9,960	9,960	9,960
Mutual Signal Corp.	*	*	421	421	421	*	*	4,021	4,021	4,021
Diginet [4]	*	*	*	90	95	*	*	*	3,161	3,320
Norlight	*	*	670	670	845	*	*	8,040	8,040	10,140
Valley Net	*	*	*	*	520	*	*	*	*	6,120
Totals	20,039	40,095	60,804	73,023	83,618	455,662	888,923	1,485,724	1,889,348	2,184,966

NOTES: * Data not available or not applicable.

[1] NTN is an acronym for National Telecommunications Network. Data for NTN companies was obtained both from the NTN organization and the individual companies. Where the two sources differed, data selected was the most consistent with previously reported data.

[2] These items represent entities which are the result of mergers and acquisitions. Data is shown for the composite entity from 1985 even if the composite entity did not exist at that time. In 1985 GTE Sprint's Network comprised 1,200 route miles and 24,000 fiber miles. U. S. Telecom Data for that year comprises the balance of the figures shown. As of July 1986 U. S.–Sprint was set up by merger of U. S. Telecom and GTE toll facilities. U. S.– Sprint is now a jointly owned subsidiary of U. S. Telecom and GTE. Data reflecting mergers of Southland Fibernet, SouthernNet, and Teleconnect which is now called Telecom U.S.A. and Wiltel, LDX, and Lightnet are also shown. The Electra network in Texas and Mutual Signal were acquired by Communications Transmission, Inc. (CTI). Data for the Electra and Mutual Signal networks (from 1985) was revised by CTI subsequent to the acquisitions and the 1989 data includes a small amount of unspecified fiber.

[3] ATC refers to Advance Telecommunications Corp. which was formerly known as Microtel.

[4] The data in this table does not include fiber capacity associated with leased fiber but does include joint construction of fiber facilities along power company rights of way. This table reflects corrections made to 1988 data. Note that U.S.–Sprint fiber mi. totals for '87 had been amended from 323,000 and MCI route mileage for '87 was amended from 6,317. U. S.– Sprint reports that its fiber mileage is [illegible]n an estimate of average fiber cross section. See discussion in text. Reduction in the [illegible] RCI's network resulted from sale of Cleveland–Chicago and Toledo–Detroit routes. RCI is now [illegible] with NTN. Fiber shown for Diginet is for Chicago – Milwaukee route only. Diginet's [illegible]itan fiber is shown with metropolitan fiber carriers.

[5] AT&T data in this table includes domestic fiber only.

Table 2

Average Fiber Cross Section and Percent Fiber Miles Lit
Interexchange Carriers

	Average Fiber Cross Section					Percent Fiber Mi. Lit		[2]	Estimated DS-3 Miles [3]		
	1985	1986	1987	1988	1989	1987	1988	1989	1987	1988	1989
NTN Partners:											
ATC	10.0	10.0	10.0	15.2	13.4	80.0%	69.0%	75.0%	*	171,580	*
Consolidated Network	11.3	11.3	11.0	11.2	11.2	33.0%	33.0%	50.0%	*	4,224	7,026
Litel	15.6	18.2	18.4	18.4	18.4	54.2%	54.9%	55.9%	*	52,293	55,869
RCI	12.0	12.0	9.0	6.3	6.4	34.9%	57.4%	56.7%	7,164	5,206	*
Telecom U. S. A. [1]	10.0	10.0	9.1	9.5	10.5	70.0%	80.0%	94.7%	24,829	32,802	*
Teleconnect	*	*	6.0	6.0	*	*	66.7%	*	*	*	4,945
SouthernNet	10.0	10.0	10.0	*	*	60.0%	*	*	*	*	*
Southland Fibernet	10.0	10.0	10.0	*	*	*	*	*	*	*	*
WilTel (composite) [1]	23.0	22.8	24.3	24.7	24.0	42.5%	37.2%	49.0%	201,665	245,869	*
LDX Net	24.0	24.0	*	*	*	39.9%	*	*	*	*	*
WilTel	10.0	20.0	*	*	*	45.5%	*	*	201,665	245,869	*
Lightnet	24.0	24.0	24.0	24.0	*	64.0%	72.0%	*	*	*	*
NTN composite	17.6	19.7	20.1	21.2	20.5	45.5%	45.2%	51.1%	233,658	511,974	62,895
AT&T	24.0	24.0	24.0	30.2	30.0	26.5%	41.6%	45.5% [2]	*	1,294,129	3,024,902
MCI	30.9	30.0	28.0	24.1	23.3	30.0%	40.0%	*	425,000	1,205,357	1,783,342
U. S. – Sprint	*	19.0	27.3	26.1	26.7	30.0%	31.0%	81.6%	865,000	987,000	1,431,985
CTI (composite) [1]	26.1	26.1	17.4	17.4	17.1	52.9%	67.8%	55.1% [2]	*	*	*
Electra	26.1	26.1	26.1	26.1	*	50.0%	71.0%	*	*	*	*
Mutual Signal Corp.	*	*	10.0	10.0	*	60.0%	60.0%	*	*	10,080	*
Diginet	*	*	*	35.1	34.9	*	*	56.0%	*	*	5,400
Norlight	*	*	12.0	12.0	12.0	33.3%	50.0%	41.7%	*	8,040	25,350
Valley Net	*	*	*	*	11.8	*	*	65.0%	*	*	12,250
Composite of Available Data	22.7	22.2	24.4	25.9	26.0	32.3%	38.5%	57.9%	1,523,658	4,006,500	6,346,124

NOTES: (See table 1 for additional notes.)

* Data not available.

[1] Data for composite entity shown where available or where calculated. See notes in table 1.

[2] Data on % of fibers lit may be distorted by route redundancy and method of reporting this data which is described further in text. Considerations affecting when a fiber pair is lit or equipped may vary from company to company and generally does not indicate how many circuits are presently operating. AT&T 1988 data on lit fiber was changed from 20.8%. CTI data for 1989 was recalculated since the acquisition of the Mutual Signal Network.

[3] DS-3 mile capacity on lit fiber was requested based on repeater and terminal technology actually in use. In most instances actual operating DS-3 mileage was reported instead. U. S.– Sprint indicates that its DS-3 mileage is based on an estimate of active DS-3's. MCI's 1988 and 1989 DS-3 mileage was estimated by dividing the number of circuit miles (810 million in 1988 and 1.198 million as of November 1989) by 672, the full capacity of a DS-3. MCI's 1987 circuit mileage was 703 million, but it reported only 425,000 DS-3 miles for that year. Last year MCI had reported 875,000 DS-3 miles for 1988. Multiplying the lit fiber mileage by 28 would provide an estimate of the capacity of lit fiber assuming all lit fiber is equipped with repeaters and terminal gear using current technology. See section in text on technology for further background information.

Table 3

Other Fiber Data

	Estimated [1] Current Fiber Investment Millions $	Estimated Investment per Route mi.	Known Leasing of Fiber [2] DS-3 Mi.	Route Mi.	Fiber Mi.
NTN Partners:					
ATC	90	66,548	*	280	2,460
Consolidated Network	16	45,455	208	330	6,962
Litel	98	80,992	2,400	89	1,734
RCI	7	17,783	6,200	128	632
Telecom U. S. A.	111	62,332	*	732	5,261
WilTel	735	66,414	*	275	1,100
NTN Subtotal	1,057	65,363	8,808	1,834	18,149
AT&T	2,390	75,000	11,281	*	*
MCI	863	75,000	*	5,354	*
U. S. - Sprint	1,671	75,000	*	*	500
CTI	87	102,117	*	*	*
Diginet	7	75,000	*	*	*
Norlight	63	74,627	*	*	*
Valley Net	10	19,231	*	*	*
Totals of Reported Data	6,148	73,075	20,089	7,188	18,649

Notes: * Data not available (See table 1 for additional notes.)

[1] Investment data has not been provided in the same manner for all carriers. Investment per route mile is calculated from aggregate investment data and route mileage provided. Items included in fiber investment vary among carriers. In cases where data was missing, investment was estimated on the basis of $75,000 per route mile. In some cases current investment was estimated based on last year's investment data and route mile growth. See text for further data qualifications.

[2] Data on leasing of fibers may be rounded or approximated based on data provided in prior years. Data for Telecom U.S.A. does not include revenue sharing agreements but does include sale leaseback and leasing of dark fiber. In some instances leased capacity is reported as DS-3's rather than as entire fibers. Data provided on leased DS-3 miles may not be mutually exclusive with data on leased fiber. Data reflects recent mergers and acquisitions. U. S. Sprint had previously reported 300 route miles as leased.

Electric Utilities

Besides the telecommunications carriers many of the electric utilities are now deploying fiber. Many of these companies have had extensive telecommunications systems for many years which were designed for their own use. These systems, dating back at least 20 to 25 years, typically utilize microwave transmission media. In recent years with the advent of fiber the electric utilities have begun to explore the use of this medium for modernizing and expanding these private telecommunications systems. The attractiveness of fiber from both an economic and technical standpoint has led a number of the electric utilities toward significant deployments of fiber as a means for satisfying their telecommunications needs. Some of the more significant deployments appear to be concentrated in the Southeast where a number of electric utilities have begun to recognize the benefit of arranging construction of facilities for joint use with the interexchange carriers. These facilities are sometimes referred to as enhanced rights of way.

Today a number of major interexchange carriers, including MCI and AT&T and at least one of the NTN companies, have had significant projects with the electric utilities to deploy what is called "ground wire fiber" on the power companies' high voltage lines. The fiber is encased inside the standard ground wire cable and deployed on the high voltage structures. The nonconductive fiber is not vulnerable to electromagnetic currents and fields generated by the high voltage line unless a serious power malfunction shorts the ground wire cable and either heats or melts it. The cable has successfully withstood direct hits by lightning and of course cannot be dug up as buried cable often is. Overhead cable can be affected by storms or hurricanes, but in at least one such case, due to the strength of the cable, the supporting structures were toppled but the cable remained intact. Standard dielectric fiber cable can also be deployed by the electric utilities in local distribution applications. [1]

There are many different types of private agreements being made between the electric utilities and interexchange carriers. While some may resemble a lease, the agreements which are negotiated often are creative and provide for the needs of both parties. Questions of who pays for what construction, the term of facility use by the interexchange carrier, what portion of the facility is used by each party, maintenance, and use fees, if any, are specified by these negotiated agreements. Typically the power company provides the rights of way and its own engineering services, as the deployment of fiber on high tension lines poses special technical problems of its own. Agreements for fiber provide a greater benefit to electric utilities than simple right of way agreements and can also significantly reduce interexchange carriers' deployment costs. In some cases the electric utility has

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1 See reference 5.

established a subsidiary in accordance with state regulation to construct telecommunications facilities from funds coming out of its profits. In such instances the subsidiary would typically resell capacity at the DS-1 or DS-3 level rather than exclusive use of fibers. These facilities are sometimes built as negotiated arrangements between the electric utility and its subsidiary rather than a negotiated arrangement between the utility and a telecommunications carrier. MPX, a subsidiary of SCANA (with South Carolina Electric and Gas as a sister subsidiary) in South Carolina, and IOR Telecom, a subsidiary of Iowa Resources (with Iowa Power as a sister subsidiary) in Iowa, are examples of such telecommunications subsidiaries.

Joint or negotiated arrangements between power companies and telecommunications carriers for deployment of telecommunications facilities are actually a development which is made possible by fiber, which besides microwave and other forms of radio transmission, is the first nonconductive medium for the transfer of large amounts of information. Because it is nonconductive, fiber can be integrated with electric transmission facilities without causing ground potential problems, and problems caused by electromagnetic fields. Any public policy and policy within the power and telephone utilities which developed to keep electric and telephone facilities distinct was at least partially based on this important technical problem. Fiber eliminates this key technical barrier to combining electric power distribution and telecommunications facilities. It remains for the policy and standards issues to be resolved before even more extensive integration of telecommunication plant and electric transmission plant are possible. An early test of some of the policy issues came about as a result of the Norlight network which extensively uses power company rights of way for its deployment of fiber. In this case the FCC preempted the jurisdiction of the states on facilities involving interstate traffic. In another case involving Public Service of Oklahoma some of the same issues have been raised. [2] Also, a number of technical standards activities are underway within the Institute of Electrical and Electronic Engineers (I. E. E. E.).

There now appears to be a general recognition by at least some of the interexchange carriers that a joint project for deploying fiber along a power company right of way is a cost effective alternative to burying fiber, particularly for low density routes, for areas where cable dig up problems exist or for areas where route redundancy is needed. These projects are

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2 In a matter currently pending before the Commission relating to the issue of preemption of state regulatory authority, there is a factual dispute as to whether PSO's system should properly be characterized as a fiber system or should be considered as a hybrid system, since PSO claims both the use of microwave and fiber transmission in its system. See references 16 and 18.

benefiting both the interexchange carriers and the electric utilities and have to some extent eased pressure on the use of scarce microwave frequencies which need to be conserved, particularly in areas of high microwave congestion. Despite the advantages there have been a number of factors inhibiting this kind of activity. One key problem is the number of electric utilities an interexchange carrier would have to negotiate with to deploy a typical long haul network extending beyond the service area of a single electric utility. Also, many complex issues such as maintenance responsibility must be tackled in drawing up joint agreements of this kind. The delay in recognizing the benefits of shared construction with electric utilities and a number of practical problems including the regulatory and standards hurdles have led the interexchange carriers to build the bulk of their networks to this point independent of this option. Thus, this option seems to be coming into its own for shorter distance or more regional systems of the interexchange carriers. Electric utilities which span several states or have large coverage areas in a single large state with extensive transmission networks are prime candidates for this kind of activity, as carriers investigate the possibilities for expanding their regional networks.

As part of this survey several electric utilities in the Southeast, including TVA, Georgia Power, MPX Systems, Carolina Power and Light and Entergy Corporation (formerly Middle South Utilities), were contacted. Approximately 2,900 route miles and about 75,000 fiber miles of ground wire fiber systems for joint use with an interexchange carrier, either completed or nearing completion, were identified. In addition, a project of over 600 miles exclusively for an electric utility in the region was noted. Some less extensive use of ground wire fiber was identified in the Midwest; however, only a relatively small number of electric utilities comprising this region were sampled . While no definitive data on nationwide use of ground wire fiber was developed in this study, it is believed that at least half of deployments to date are in the Southeast.

At the local distribution level similar joint arrangements are also possible. However, the local operating telephone companies in many jurisdictions have been very wary of the activites of the electric utilities and have often used the regulatory process and their clout to inhibit resale of excess power company telecommunications capacity. The electric utilities which are being pressed toward a greater awareness of environmental and conservation concerns are trying to find ways to defer the construction of new power generating facilities. These utilities are beginning to view fiber as one means to facilitate novel time of day pricing schemes through remote meter reading or means to control peak consumption remotely at the source. [3] Of course, fiber can also replace and augment private microwave systems which have been in use for years by the electric utilities to provide for control and telemetry associated with large customers or remotely controlled facilities.

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3 See references 49 and 50.

- The electric utilities have historically needed systems with high reliability and low vulnerability to noise. These requirements are often easily met with fiber facilities. Unlike the interexchange carriers, the local telephone carriers have not generally been in need of new rights of way, and have been very concerned about the potential for lost business through bypass facilities. Nonetheless, their failure to carefully consider the advantages of jointly negotiated agreements for deployment or shared use of fiber with other entities deploying fiber, such as the electric utilities, may inevitably work against the local telephone carriers and their customers in the form of higher rates, less efficient use of capital and greater vulnerability to competition. This is because joint deployments or facility sharing arrangements, in addition to leading toward capital conservation, may also provide valuable redundant facilities to allow for greater system reliability, a feature required by certain customers and sometimes touted by the urban fiber carriers.

It thus appears conceivable that negotiated agreements with some of the very entities that the local Bell Operating Companies may perceive as a bypass threat could potentially turn out to be a benefit. This is especially true given the desire for the Bell Operating Companies to provide fiber facilities to the home. Obviously, the possibilities for joint endeavors brought about by the technology and the nonconductive character of fiber are significant if the right kinds of policy decisions are made in a timely manner by the companies involved and by the regulatory process. The combination of a wide range of interests and opportunities, however, undoubtedly promises to provide for some very interesting but complex regulatory and legal problems, and some form of national policy in this area may be desirable to promote long term national interests.

Local Operating Telephone Companies

In prior years data for the local telephone companies was limited to the regional Bell Holding Companies. This year other categories of local telephone companies have been included. These are the United Companies, the Contel Companies and the GTE companies. In addition, rural carriers which provide data to the Rural Electrification Administration (REA) have been included. Tables 4 through 9 provide data for the local operating companies aggregated to the Holding Company level and rural carriers, but do not include data from all local U. S. telephone carriers.

The plant of the local operating companies can be generally divided into three categories. These are interoffice, feeder and distribution plant. Collectively, feeder and distribution plant is often termed subscriber plant. Interoffice fiber 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. A second part of the local plant is termed feeder plant. This 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 a portion of the loop of numerous subscribers can be handled on a single fiber or twisted wire pair. Sometimes, however, if there are numerous spare wire pairs on a feeder cable, the telephone company will use single pairs for a subscriber all the way to the central office, rather than resorting to multiplexed or carrier systems. In such 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 basic economic considerations are resulting in fiber deployments by all types of local carriers, including carriers operating in rural areas.

While these criteria are often used in deciding when fiber should be deployed, it is expected that other considerations involving company policy are accelerating the rate of deployment of fiber in feeder plant beyond what would be justified solely on the basis of present economic considerations and customer demand. These considerations include a desire to modernize existing plant and not to redeploy technology which is perceived as rapidly becoming obsolete. In addition, many companies would prefer to deploy fiber rather than copper so as not to preclude the possibility of offering wideband services in the future, such as video services. Obviously, one would expect more cases of total feeder systems reaching their capacity in higher growth areas which may partially explain the activity level of fiber deployment in companies such as Southern Bell.

The final portion of local transmission plant is the distribution plant. This is usually dedicated plant in which each subscriber has a single fiber or wire pair connecting the subscriber to a distribution point from which multiplexing or carrier system sharing is feasible. 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.

The local companies were unable to provide data which distinguished 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 were unable to provide data which separated interoffice from subscriber fiber and copper, claiming that many facilities are jointly used for interoffice and subscriber applications and that in some instances no good sources of data in these categories could be located. An attempt was made, however, to obtain estimates, to separate interoffice and subscriber fiber and copper. Several of the companies stated that they used exchange and toll categories as a substitute for the interoffice and subscriber categories which were requested. This would tend to result in an overestimate of the amount of subscriber fiber and copper. The data is displayed in Tables 6 through 9. In the case of the BellSouth companies who did not provide separate data on subscriber fiber, construction budget data was requested to estimate how much fiber is being deployed in subscriber applications. BellSouth projects that 70% of Southern Bell's and 57% of South Central Bell's 1990 fiber construction will be in the subscriber loop. This will increase to about 95% for Southern Bell by 1999 and 70% for South Central Bell by 1993. As more fiber is deployed in the local loop a more clearcut separation of the plant used for subscriber loops from that which is deployed for interoffice applications would be desirable from a regulatory standpoint.

While most fiber currently being deployed by the local operating companies uses the traditional feeder and distribution structure, there are other ways to deploy fiber which may in some cases be more efficient and at the same time provide for greater system reliability. The best known of these is the fiber ring in which a loop or series of loops is used to gather traffic from areas of high customer concentration. Customer access can be achieved from either direction around the loop. The direction of access can be easily modified in the event of a break in the loop. Some of the local companies did not initially respond to a question about any unusual network structures such as fiber rings or have indicated that they do not have such structures in their network. Pacific Bell, Bell Atlantic, and U. S. West however, have specifically reported such network structures in Washington, Philadelphia, Minneapolis, Omaha, and San Francisco. BellSouth initially reported the use of redundancy arrangements and has provided followup information mentioning the use of seven rings, five in Florida, one in Georgia, and one in Mississippi. U. S. West reports in general terms the use of redundancy arrangements. Upon further inquiry, Ameritech has indicated that it presently has no fiber rings in its service areas and S.W. Bell has reported that it is presently building a fiber ring in Houston. NYNEX has also indicated the use of ring or nonstandard fiber architectures in Boston and New York.

Although it is still too costly to justify dedicated deployment of fibers to residences, one proposal which has received some attention is the so called "fiber-to-the-curb" approach. 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 one subscriber fiber by more than one customer beyond this interface point allows fiber penetration to extend to a point closer to the customer. The electronics which convert optical signals into electrical signals required by present terminal devices can thus be shared allowing a large element of the cost to be distributed over more than one customer.

One example of this approach is a field trial which is being made in a residential area near Charlotte, North Carolina where Alltel and Reliance Comm/Tec are installing the system.[4] The trial is initially being set up for standard telephone service but will later facilitate deployment of fiber

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4 See reference 63.

all the way to the residence for video service. Another example is a field trial by New England Telephone Co. in Lynn, Massachusetts, which has been deferred due to the recent telephone strike. In this trial Raynet will provide the fiber to the curb system.

The use of new sources of demand such as video distribution services has been an enticing idea to justify the acceleration of fiber deployment, particularly in feeder and distribution plant. The interest of the local operating telephone companies in providing video distribution services is not new and the companies have been retrofitting their Integrated Switched Digital Network designs to include video. This was discussed in last year's report. Such video applications will require significant investment and have been traditionally kept out of the domain of the regulated telephone based carriers.

Another approach to accelerate fiber deployments to the home which does not yet appear to have been pursued by the local telephone companies includes the possibility of joint use or deployment of fiber facilities with electric utilities which is discussed further elsewhere in this report. Such activities with the electric utilities or other entities deploying fiber would probably only materialize with the prospect of some mutual benefit or with regulatory incentives.

To date there is relatively little distribution fiber in place. There have, however, been a number of trials in which fiber has been deployed all the way to the customer's premises. These trials have been the primary motivation for deploying fiber in the distribution plant to date. Although the local telephone companies have generally opposed the development of bypass systems including the resale of telecommunications capacity built by electric utilities in the local environment, their long term interests might be better served by joint negotiated endeavors similar to those which have been occurring in the interexchange environment. Although the pros and cons of these activities may require further study, such projects if otherwise permitted could provide needed redundant capacity and new kinds of network tranmission structures, as well as an economic means for reaching more local subscribers with fiber and promoting development of new services and capabilities into the next century. In addition, use of fiber in this manner could ease pressure on the limited availability of microwave frequencies. While there are definite advantages to such joint deployment of fiber, evidence of this kind of joint activity at the local level was not uncovered in the preparation of this report.

Table 4

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

	Sheath-Miles						Fiber-Miles [1]				
	1985	1986	1987	1988	1989	[2]	1985	1986	1987	1988	1989
Ameritech	3,200	5,200	6,700	8,700	9,400		77,700	111,100	147,100	177,500	226,300
Bell Atlantic	1,240	4,374	6,730	9,239	12,049		83,085	150,847	227,507	311,022	401,628
BellSouth	3,830	8,694	11,727	15,643	25,048		50,807	170,092	218,489	319,248	470,046
NYNEX	1,606	3,209	4,956	7,413	8,595		83,384	129,743	207,077	290,600	337,662
Pacific Telesis	2,318	2,779	2,964	3,480	4,295		84,310	97,800	101,090	110,273	133,818
Southwestern Bell	1,913	4,374	5,970	7,349	9,050		70,490	151,043	182,911	214,948	253,410
U. S. West	3,527	5,017	6,937	10,030	13,368		47,341	70,082	107,782	163,968	232,139
Regional Bell Totals	17,634	33,647	45,984	61,854	81,805		497,117	880,707	1,191,956	1,587,559	2,055,003
Contel Companies	*	*	*	1,100	11,214	[2]	*	*	*	*	*
GTE Companies	*	*	*	8,999	12,881		*	*	*	134,677	193,325
Rural Companies	*	500	2,584	4,651	6,369		*	2,000	14,236	28,705	42,260
United Companies	*	*	*	2,907	4,453		*	*	*	32,287	60,415
Grand Total	17,634	34,147	48,568	79,511	116,722		497,117	882,707	1,206,192	1,783,228	2,351,003

Table 5

Average Fiber Cross Section

	1985	1986	1987	1988	1989
Ameritech	24.28	21.37	21.96	20.40	24.07
Bell Atlantic	67.00	34.49	33.80	33.66	33.33
BellSouth	13.27	19.56	18.63	20.41	18.77
NYNEX	51.92	40.43	41.78	39.20	39.29
Pacific Telesis	36.37	35.19	34.11	31.69	31.16
Southwestern Bell	36.85	34.53	30.64	29.25	28.00
U. S. West	13.42	13.97	15.54	16.35	17.37
Regional Bell Composite	28.19	26.17	25.92	25.67	25.12
Contel Companies [3]	*	*	*	*	*
GTE Companies [3]	*	*	*	14.97	15.01
Rural Companies [3]	*	4.00	5.51	6.17	6.64
United Companies	*	*	*	11.11	13.57
Composite [4]	28.19	25.85	24.84	22.86	20.81

NOTES (Tables 4 and 5) : * Data not available

[1] Total fiber mileage installed was requested, including so called unequipped or dark fibers. Pacific Telesis has made a number of significant adjustments to previously provided data. Initially it did not include dark fibers in the data. The company also reported a decline in total fiber mileage due to a "records purification process" in 1986 associated with a loss of approximately 1,100 miles to AT&T at divestiture and almost 100 miles taken out after the 1984 Olympics. Pacific Telesis had also adjusted its 1987 total of 81,291 fiber miles to 101,090, indicating that data provided previously only included fiber for interoffice use. Corresponding adjusted data for 1985 and 1986 was provided along with 1987 data. The company had originally indicated that data for dark fiber in 1985 was not available but has since reported such data. Similar problems in reporting by the other regional holding companies, may have resulted in incorrect assessments of the total amount of fiber in the ground. Note, for example, significant variation in average fiber cross section between 1985 and 1986 as can be seen in the Bell Atlantic data. NYNEX 1988 data previously reported was for the third quarter.

[2] End of year data for 1989 is estimated. Sheath mileage was provided instead of route mileage. Sheath mileage and route milage would be comparable until more than one cable was placed in a route. Contel sheath mileage was revised from estimated figure of 9,000.

[3] Fiber mileage for the Contel Companies was not reported. The GTE companies had previously reported 8,353 sheath miles and 102,471 fiber miles deployed as of 1988. Data for rural carriers is from REA of which approximately 137 route miles and 869 fiber miles overlaps with Contel companies.

[4] Composite fiber cross section is the total fiber mileage divided by the total sheath mileage.

Table 6

Subscriber Copper and Fiber of Local Operating Companies
Aggregated to Regional Holding Company Level

	Sheath–Miles Fiber		Fiber–Miles Fiber				Sheath–Miles Copper			Wire–Miles Copper	
	1988	1989	1987	1988	1989		1988	1989		1988	1989
Ameritech [3]	2,800	3,100	*	56,600	67,900		242,700	249,200		139,588,000	140,389,700
Bell Atlantic	*	*	79,434	116,873	163,918		280,347	290,344	[1]	187,439,376	194,861,914
BellSouth	*	*	136,807	185,795	242,550	[4]	559,993	565,141	[1]	238,775,565	241,534,024
NYNEX	1,935	2,382	45,938	66,823	80,480		225,547	228,522		130,892,737	133,387,466
Pacific Telesis	537	938	15,911	22,104	33,649		170,267	174,318		128,766,710	129,466,382
Southwestern Bell [2]	3,109	4,143	*	121,135	163,687		373,427	375,700	[1]	167,262,506	168,591,300
U. S. West [2]	2,816	3,484	61,616	84,824	112,373		384,261	389,504		154,245,455	157,117,235
Totals of Available Data	11,197	14,047	339,706	654,154	864,557		2,236,542	2,272,729		1,146,970,349	1,165,348,021

NOTES: * Data not available.

[1] Bell Atlantic, Southwestern Bell and Bell South data on copper cable is for total copper and does not separate subscriber and interoffice.

[2] U. S. West and S. W. Bell provided data for exchange and toll rather than subscriber and feeder. Data shown for these carriers is for 'exchange'. This data will typically overestimate the amount of subscriber fiber.

[3] Ameritech reports subscriber data based on engineering judgment.

[4] Bell South indicates that 70% of Southern Bell's and 57% of South Central Bell's 1990 fiber construction will be in the subscriber loop. This will increase to about 95% for Southern Bell by 1999 and 70% for South Central Bell by 1993. Bell South's 1989 fiber mile data was estimated using the December 1988 view of fiber mile shipments budgeted for 1989.

Table 7

Data on Fiber Trials

	Fiber Trials			Fibers to Customers			
	1988	1989		1987	1988	1989	
Ameritech	0	0		*	*	*	
Bell Atlantic	1	2		*	20	90	[2]
BellSouth	1	8		220	360	569	
NYNEX	0	0		*	*	*	
Pacific Telesis	0	0	[3]	2,430	2,766	*	
Southwestern Bell	1	3		*	50	200	
U. S. West	*	2		*	*	206	[1]
GTE Companies	*	1		*	*	2,204	
Contel Companies	*	*		*	*	220	
United Companies	*	*		*	194	330	
Total of reported amounts				2,650	3,370	3,819	

NOTES: * Data not available

[1] U. S. West reports residences served by fiber rather than number of fibers.

[2] Bell Atlantic data for fibers to customers has been corrected from the the value previously reported for 1988.

[3] Pacific telesis reports that it has not conducted any fiber trials as previously reported and that its data on fibers to customers relates to business customers in Southern California.

Table 8

Fiber and Copper in Total Plant in Relation to Access Lines

End of year 1988 [1]

		Total Strand Miles		Total Sheath Miles		Per Thousand Access Lines					
	Access Lines	Copper Wire	Fiber	Copper Cable	Fiber Cable	Miles Copper Wire	Miles Fiber	Miles Copper Cable	Miles Fiber Cable	Percent Fiber Sheath Miles	Percent Fiber Strand Miles
Ameritech	15,506,716	186,117,400	177,500	323,800	8,700	12,002.4	11.447	20.881	0.561	2.62%	0.10%
Bell Atlantic	16,987,902	187,439,376	311,022	280,347	9,239	11,033.7	18.308	16.503	0.544	3.19%	0.17%
BellSouth	16,472,345	238,775,565	319,248	559,993	15,643	14,495.5	19.381	33.996	0.950	2.72%	0.13%
NYNEX	15,162,797	162,630,997	290,600	258,426	7,413	10,725.7	19.165	17.043	0.489	2.79%	0.18%
Pacific Telesis	13,780,041	149,363,344	110,273	190,088	3,480	10,839.1	8.002	13.794	0.253	1.80%	0.07%
Southwestern Bell	11,002,755	167,262,506	214,948	373,427	7,349	15,201.9	19.536	33.939	0.668	1.93%	0.13%
U. S. West	12,081,921	158,267,424	163,968	415,415	10,030	13,099.5	13.571	34.383	0.830	2.36%	0.10%
Bell Totals	100,994,477	1,249,856,612	1,587,559	2,401,496	61,854	12,375.5	15.719	23.778	0.612	2.51%	0.13%

Table 9

Fiber and Copper in Subscriber Plant in Relation to Access Lines

End of year 1988 [1]

		Total Strand Miles		Total Sheath Miles		Per Thousand Access Lines				
	Access Lines [5]	Copper Wire	Fiber	Copper Cable	Fiber Cable	Miles Copper Wire [4]	Miles Fiber	Miles Copper Cable	Miles Fiber Cable	Percent Fiber Sheath Miles
Ameritech [3]	15,506,716	139,588,000	56,600	242,700	2,800	9,001.8	3.650	15.651	0.181	1.1%
Bell Atlantic	16,987,902	*	116,873	*	*	*	6.880	*	*	*
BellSouth	16,472,345	*	185,795	*	*	*	11.279	*	*	*
NYNEX	15,162,797	130,892,737	66,823	225,547	1,935	8,632.5	4.407	14.875	0.128	0.9%
Pacific Telesis	13,780,041	128,766,710	22,104	170,267	537	9,344.4	1.604	12.356	0.039	0.3%
Southwestern Bell [2]	11,002,755	*	123,135	*	3,109	*	*	*	*	*
U. S. West [2]	12,081,921	154,245,455	84,824	384,261	2,816	12,766.6	7.021	31.805	0.233	0.7%
Bell Totals	100,994,477	553,492,902	656,154	1,022,775	11,197	9,790.9	6.497	18.092	0.166	0.8%

NOTES: * Data unavailable.

[1] This Data is presented for 1988 because 1989 access line data is not yet available.

[2] U. S. West and S. W. Bell provided data for exchange and toll rather than subscriber and interoffice. Data shown for these carriers is for 'exchange'. This data will typically overestimate the amount of subscriber fiber. An estimate based on U. S. West construction budget data suggests that approximately 28% of its total fiber is subscriber fiber rather than the 51.7%, as suggested by the 'exchange' category used above.

[3] Ameritech reports subscriber data based on engineering judgment.

[4] Although each non-fiber access line requires a wire pair, the amount of subscriber copper per access line appears larger than expected and may be explained by a large number of spare copper pairs or inaccurate estimates of subscriber copper. (Also see note 2.)

[5] Source of Access Line Data: Annual Form M reports for 1988 filed with the Federal Communications Commission.

Urban Fiber Systems

Last year's report covered a number of urban fiber systems which typically involve the deployment of a ring or loop through areas of high business concentration in major cities. Table 10 lists the key companies involved in urban fiber systems. It is not intended to be an all inclusive list and is being expanded as new entities are discovered. Two 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. They are being classified for the purpose of this report as urban fiber systems. Public Service of Oklahoma (PSO) has deployed fiber along its power distribution lines for its own use and has been actively selling its excess capacity. [5] Another company, Diginet is involved in both urban fiber systems and an intercity fiber system between Chicago and Milwaukee.

A number of companies were introduced in last year's report. One of the larger systems, Metropolitan Fiber Systems, Inc., (MFS) is based in Chicago and is constructing fiber "rings" in a number of metropolitan areas through routes designed to maximize the number of large entities which can be served at the minimum cost. It appears that MFS is now operating in the largest number of cities. This company is deploying fiber in each of its cities based upon a master plan usually involving a ring or figure eight shaped route. The company promotes reliablity with a backup route and a centralized maintenance reporting and deployment system. While MFS is or will be operational in up to eight cities shortly and typically deploys several hundred fiber miles per city, the route mileage of each system is relatively small.

Another entity, Teleport Communications Group, which started in a single metropolitan area, is expanding to other areas. 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, it is constructing systems in San Francisco, Houston, and Los Angeles, and it is now attempting to enter the Washington, D. C. and Chicago markets which will put it in a total of seven markets. Teleport Communications Group operates in each city through wholly owned subsidiaries or through partnerships.

Several operations typically serve a medium to large city and sometimes include some of the surrounding counties. Eastern Telelogic is one such

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5 See footnote 2.

company and is based in Philadelphia. The company plans have included a 72 mile backbone system by the end of 1990 to serve four counties in and around Philadelphia (Montgomery, Philadelphia, Chester, and Delaware counties). As of the end of 1989 its full system is estimated at about 68 route miles. A second Philadelphia company, Philadephia Fiber Optic Corp., which has a single city system, had been associated with a larger venture known as Fiber Optic Company of the U.S. or FOCUS which is no longer in existence. Another entity, Institutional Communications Company or I. C. C. is based in Washington, D. C. and is using the subway tunnels for part of its downtown fiber. This company has a number of small rings in areas of high business concentration and is serving areas including Crystal City and Reston in Northern Virginia, and New Carrollton in Maryland. The company appears to have a unique strategy of gathering traffic for its network by leasing DS-3 capacity to a number of distant cities and providing feature group D access on a resale basis to the Washington area. The company serves both large business customers and interexchange carriers and has been providing service since 1986. Another single city company, Indiana Digital Access, provides service to a number of buildings in Indianapolis and serves the surrounding towns of Muncie, Anderson and Lafayette with digital microwave, all within about 60 miles of Indianapolis. It presently reports a system comprising 34.5 miles. Finally, Intermedia Communications Co. of Florida provides service in Orlando and Tampa.

The present impact on the local telephone companies of urban fiber systems generally appears to be relatively small but as these systems expand to more cities and attract more customers, they can be expected to selectively impact growth of demand of these companies. However, urban fiber systems can only serve those customers they can access and may themselves be dependent on the local telephone companies for "bottleneck" and sometimes backup facilities. For example, in a recent development MFS has expressed an interest in colocating its facilities with the local operating telephone companies, which could facilitate expansion of its customer base.[6] Of particular note is the fact that a number of fiber rings have been reported by the Bell Operating Companies in some of the very same cities where urban fiber systems exist. Urban fiber systems may have motivated local telephone companies to price special access closer to cost, and in some cases these systems have impacted local operating company efficiency in serving the larger customers through the use of redundant facilities and fiber rings. Nevertheless, it is still unclear whether and to what extent these alternative suppliers of special access services will promote greater overall long term economic and technical efficiencies and improved service within the local telephone companies.

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6 See reference 29.

Table 10 Urban Fiber Systems

	Route Miles			Fiber Miles				Percent Lit			
	1987	1988	1989	1987	1988	1989		1987	1988	1989	Cities Served
Diginet	*	*	5.4	*	*	684		*	*	*	Chicago, (Chicago– Milwaukee link not included)
Eastern Telelogic	*	*	68.0	*	*	2,184		*	*	41%	Philadelphia, Delaware Valley
I. C. C.	88.5	108.4	134.7	3,059	5,462	5,877		*	40%	62%	Washington, D. C.
Indiana Digital Access	*	7.0	34.5	*	238	444		*	12%	31%	Indianapolis
Inter–Media Communications	*	5.9	47.0	*	211	792.9	[1]	*	8%	*	Orlando, Tampa
IOR Telecom (Iowa Resources)	*	*	60.0	*	*	1,284		*	*	*	Des Moines
Metropolitan Fiber System, Inc.	*	9.5	81.7	*	399	7,497		*	69%	34%	Chicago, Boston, Baltimore, Minneapolis, Philadelphia
Philadelphia Fiber Optic [3]	*	*	3.8	*	*	274		*	*	28%	Philadelphia
Public Service of Oklahoma	*	*	120.0	*	*	2,500		*	*	*	Tulsa
Teleport Communications	44.5	57.7	227.2	4,711	5,433	12,346		38%	39%	*	New York City, Boston
Total of Reported Amounts	133.0	188.5	782.2	7,770.0	11,743.3	33,882.1					

NOTES: * Data not available.

[1] Includes 149.6 leased fiber miles.

[2] The facilities of some of the entities in this table may include non–fiber, such as microwave transmission. Information on fiber only was requested.

[3] Last year's report showed expected 1988 system comprising 7 route miles and 506 fiber miles. Part of planned system was not completed.

International Developments

Although this report is primarily intended to review domestic data and developments, a brief look at international developments helps to provide some useful perspective. The pace of transoceanic deployments appears to be accelerating as many sources of international capital, mostly from nontelecommunications, sources are being directed toward these deployments. In the future, new developments now in the research stage, such as very low loss repeaterless cable, will allow systems to be built which can be upgraded without laying new cable. Current investment in transoceanic fiber ventures is estimated at over $ 1.5 Billion with an estimated 50% increase expected in 1990 alone. By 1996 some estimates suggest that over $ 6 Billion will be invested. [7] Other domestic developments, such as the joint deployments of ground wire fiber by telecommunications carriers and electric utilities, are occurring overseas as well. [8]

Presently operating systems include TAT-8 (Trans-Atlantic Number 8) and PTAT (Private Trans-Atlantic Telecommunications) across the Atlantic Ocean and Pacific Link (TPC-3/HAW-4) across the Pacific Ocean, as well as a Guam-Philippines-Taiwan link (G-P-T). Another cable across the North Pacific (NPC) and a cable linking Hong Kong, Japan and Korea (H-K-J) are scheduled for deployment this year. Other transatlantic and transpacific links are planned through the decade.

The increase in international telecommunications capacity will further link the world into a single global economy and as mentioned in earlier fiber reports will increase demand for transiting U. S. fiber capacity.

Source Methods and Data Limitations

This report is based on survey work conducted since the fall of 1985 and is primarily based on telephone contacts with key representatives of the larger carriers. Also presented is a bibliography of public references which provide useful insights into the promotion and development of fiber by the industry. Data for the interexchange carriers is summarized in Tables 1, 2 and 3, data for the local telephone holding companies is summarized in Tables 4 through 9, and data for a selected group of urban fiber systems is shown in Table 10. This year a number of electric utilities were contacted to better assess the extent and availability of fiber-capacity for telecommunications use. Due to the very large number of power utilities in the U.S., the survey primarily concentrated on the larger utilities in the Southeast where use of power line rights of way and joint construction arrangements appears to be the greatest.

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7 See reference 57.
8 See reference 36.

The process of data collection for this report was, for the most part, fairly informal. Telephone interviews were used as a means for conveying the statistical data required and inquiring about current developments. For the Bell Operating Companies the data was requested by letter. The report benefited from the approach used and the opportunity to talk directly with a wide variety of industry contacts. The author greatly appreciates the cooperation and interest of all those individuals who helped make this report possible. There are, of course, obvious limitations in this approach and inherent pitfalls associated with each of the data elements, despite the fact that followup contacts were made to examine possible data inconsistencies. Also, varying degrees of cooperation were encountered. As a check for data consistency, data for 1988 was requested again.

The interexchange carrier environment is dotted with a smorgasbord of internal agreements, including the joint power company ventures, facility and traffic sharing arrangements, and physical acqusitions and mergers. Some of these have been alluded to in fiber deployment reports of prior years. It is thus tricky to accurately portray the total amount of fiber deployed. This study which has been updated annually for several years and has the benefit of an historical time series has attempted to collect data based on a reasonably uniform set of procedures. Nonetheless, because the data is being provided on a voluntary basis and not all carriers collect data in exactly the same manner, there is an opportunity for erroneous reporting in some cases.

Stringent reporting requirements were not imposed, but a number of reporting guidelines were communicated to the carriers. The number of route miles and fiber miles that have been constructed in long term joint agreements between power companies and interexchange carriers were to be included. However, the carriers have been asked to exclude agreements with other telecommunications carriers which might result in double counting of telecommunications fiber, particularly where the right-to-use period is nonrenewable or relatively short, or where annual fees are paid for continuing facility use. They have also been asked to exclude standard leasing arrangements both for fiber and DS-3 capacity in the owned totals. Finally, the carriers have been encouraged to only include shared facilities for which they have physical ownership or a right-to-use approximating the expected life of the facility. Although in some cases there may be a chance for double counting of facilities due to the complexity and variety of sharing and leasing arrangements, the entities have been made aware of this concern.

With the increased number of joint ventures, capacity sharing agreements, leases and other arrangements, as well as continuing consolidation of the industry, it is difficult to be sure that no double counting of capacity has occurred. This is especially a problem for carriers that would like to report unowned facilites in a manner which would give an impression of more deployed fiber than actually exists. Also, it should be evident that the potential for double counting is greatest where several carriers report routes following similar paths.

Of special interest to this survey, as more agreements are being made with electric power utilities, is whether fiber so obtained is being categorized as leased or owned. This concern was conveyed to the major carriers. Those carriers known to be building fiber in conjunction with the electric power utilities have indicated that they are including this capacity as owned since there is typically a long term use agreement covering the life of the facility. Such arrangements may typically be characterized as enhanced right-of-way agreements. However, since the terms of these agreements are confidential and may vary widely, there is no way of being sure that all such agreements with the power companies were identified and handled in the same manner insofar as the statistics being collected on owned fiber are concerned.

The interexchange carriers were generally reluctant to discuss their involvement with the electric utilities in fiber deployment. Although this reticence may be associated with competitive concerns, the initial indication from this study is that while these activities represent a relatively small percentage of total fiber deployed, they appear to have been going on since about 1988, are now more widespread than originally believed, and may have benefits which cannot yet be fully assessed.

A problem identified for the urban fiber systems but also a potential problem for the larger interexchange carriers is the difference between route and sheath mileage. In at least one instance in the preparation of last year's report it was thought that one urban system had reported sheath mileage as route mileage. Although this apparently was not the case, this year each carrier was requested to provide both route and sheath mileage to be sure that there would be no misunderstanding in terms.

Where the urban fiber carriers have provided data to the press they have sometimes provided the number of fiber miles without the route mileage or reported sheath mileage rather than the number of route miles which gives the impression of greater size. Urban fiber deployments in each metropolitan area extend to lengths typically less than 10 miles and in many cases traverse just a few miles in each downtown area. However, they typically have very high density fiber cross sections often containing more than 100 fibers. Some of the larger operations may have deployed a combined total of more than 100 route miles of fiber as shown in Table 10.

It has been the general intent of this survey to capture redundant network paths as separate routes. Route mileage is still being reported for interexchange carriers. However, as route cross sectional densities increase through overbuilds and mergers, the likelihood of misinterpretations about how to account for paralleling cable sections increase. For example, the route mileage for cable between Washington, D. C. and New York City and between Washington, D. C. and Baltimore (where Baltimore is an intermediate point on the Washington-New York route) may be determined differently by different carriers. Also, merging entities with common routes may produce a combined route mileage which is less than the sum of the component route mileages.

AT&T has indicated that it uses a set of consistent and well defined procedures to establish its route mileage. The Bell Operating Companies have only reported sheath mileage due to the deployment of more than one cable in portions of their networks and the problem of obtaining meaningful route mileage data. Potential discrepancies in comparing present route mileage with previous data from the merged or acquired entities were noted for Williams Telecommunications Group, Telecom U. S. A. and Communications Telecommunications Transmission, Inc. (CTI) which all have been involved in extensive merger and acquisition activities. Although the route mileage data reported generally appears reasonable and followup questions were conveyed to several of the carriers, caution is advised in interpreting the route mileage data, especially for the larger carriers.

In some instances significant discontinuities in data were noted from one year to the next. This may suggest a problem in the way data was assembled by the carriers or in the way the request was interpreted. It is expected that these discontinuities reflect the fact that some information provided was estimated by different individuals within a company rather than coming from actual internal company records. For example, corrections to data provided by MCI last year resulted in the average cross section for 1987 changing from over 35 to about 24. Similar corrections provided last year by U. S. Sprint resulted in a higher cross section for 1987 than previously reported. Both carriers' corrections appear to have been much larger than could have been explained on the basis of projects completed either before or after target dates near the end of the year. This year U. S. Sprint indicated that its data for fiber mileage and DS-3 mileage is based on multiplicative factors applied to route mileage but that it expects to have available an independent tabulation of fiber mileage and other requested parameters next year. When the multiplicative factors used changed so did the fiber mileage and other parameters dependent on them. In many other instances increases in the average fiber cross section resulted from fiber overbuilds on existing routes and from errors in estimating project completion dates near the end of the year. Obviously, average cross sections which appear excessive or parameters which change sigificantly from year to year are one means of establishing a possible problem in properly estimating the requested parameters.

While the average fiber cross section is of interest in its own right, its use as a validity check now appears more doubtful than it did initially, since some of the carriers now appear to have obtained the fiber mile figure by estimating their average cross section and multiplying it by the number of route miles. Generally fiber cross sections for local operating companies would be expected to decline as more feeder cables with lower average cross section are deployed. This appears to be the case for a few of the Bell Operating Companies.

Besides fiber mileage, some of the carriers reported data on DS-3 mileage and lit fiber mileage on the basis of internally generated factors based upon system route mileage rather than tabulating the actual data. This, of course, affects the accuracy of reported data and requires the user of this data to be cautious about drawing too many detailed conclusions from specific data provided unless, of course, some corroborating information is available. One should note, for example, that data on lit fiber this year has risen significantly over levels reported last year in a couple of instances. Nonetheless, much of the data appears to have been reported in a consistent manner and data on average fiber cross sections and lit fiber appears reasonable in most cases.

The number of lit fiber miles was collected, where protection fibers were assumed to be lit, in order to determine the percentage of fibers lit or equipped with electronics and repeaters. While information on lit fiber is useful to generally assess fiber utilization, such data may potentially be misleading. First, while it may be simple to calculate the lit fiber mile percentage in homogeneous systems with the same number of fibers throughout, carriers with complex networks may have taken shortcuts or used estimates in providing this information. In addition, complex protection schemes and the need for backhauling traffic in large networks to enhance system reliability may either artificially inflate the percent of lit fiber or lead to the conclusion that full exploitable capacity may not always be useable. Last year one large carrier noted that route redundancy and backhauling may cause an extra 10-15% of its capacity to be lit. (See the section in this report on system reliability.) It should also be noted that the number of lit fibers may have very little to do with the number of active circuits, since additional multiplexing gear is required to derive the individual circuits. In some cases, new construction and upgrading of existing capacity by using newer vintages of electronics may have actually caused the lit fiber percentage to decline. This year MCI declined to provide any data on lit fiber. In the case of other interexchange carriers, significant increases in lit fiber shown in Table 2 may suggest erroneous reporting, lags in the data collection process, increasing system redundancy, or an increasing reliance on existing dark fiber rather than new fiber builds.

The total DS-3 mile capacity on lit fiber was requested but it appears that most carriers have simply provided the total number of DS-3 miles in service. If the capacity change from year-to-year could be correctly inferred from the data, one could assess the impact of new repeater and optoelectronic equipment on potential fiber capacity. However, due to the problems in obtaining the data in this form and the fact that a number of the responses may have been estimated, the DS-3 mileage should be used with caution, as it typically only represents the number of DS-3 miles actually in service.

System Reliability

While it is generally agreed that new technology offers maintenance and cost advantages over older technologies, a number of important reliability issues relating to a number of new technologies, including fiber, are affecting development of the industry. Some of these issues which relate to fiber are reviewed here. With many new technologies the frequency of failure tends to decrease as the potential impact of failure increases. In this context it is important to note that the failure modes of state of the art high reliability systems such as fiber transmission systems are often different from that of earlier systems and potentially more disasterous as the number of circuits per fiber pair is increased.

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

The interexchange carriers surveyed in this report were asked to provide statistics on the number of outages or cable breaks occurring per thousand route miles of system during a recent twelve month period. Although many of the carriers appeared very sensitive about this kind of data and the number of entities reporting this information was limited, more than six responses were received and it appears that typically carriers experienced fewer than four such incidents per thousand route miles per year. An experience of less than one outage per thousand route miles per year would be significantly better than the typical figure reported. Because of their acute awareness of this problem, a number of the carriers have developed extensive system redundancies to significantly reduce the risks to their customers associated with cable cuts. As a result most cable cuts have been virtually unnoticed by the public.

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

AT&T, in response to its own concerns about fiber outages is developing restoration plans which will involve switching of fibers at designated nodes. This will enable switching to be done from a centralized location and will facilitate automation and control by computer. U.S. Sprint also has restoration plans which appear to involve some backhauling of traffic. Some carriers, including MCI, appear to be relying on leased fiber to provide route redundancy on backbone routes. These situations would distort the measure of lit fiber reported, since spare fibers may have to be dedicated for restoration purposes and thus would not be available for traffic growth. Such factors and the need for system redundancy suggest that some fiber systems may presently be less under utilized than originally thought. Nonetheless, it should be remembered that future terminal and repeater technology advances are expected to increase the potential capacity of existing fiber far beyond what is presently possible.

To provide additional coverage on a regional basis and to deal with reliability issues, several carriers have placed some of their fiber on electric utility poles and on high voltage lines. Although overhead fiber is not vulnerable to fiber dig ups which have plagued the industry, there are other risks inherent in this mode of deployment, as discussed further elsewhere in this report. In general, however, these risks do not appear to be unreasonable and are probably lower than the risks associated with dug up fiber. In addition, the power line fiber may offer an attractive means for providing route redundancy.

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 DS-3. Before defining 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 contains up to 28 channels operating at the DS-1 rate of 1.544 Megabits per second.

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

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

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

The modulation of the light signal may take a number of forms. Traditionally, the highest capacity systems encoded transmitted information on pulses of light, since the lasers producing the light could easily be made to emit light pulses. The use of newer techniques of heterodyning, more analogous to information transfer of information on radio, enable even higher throughput data rates. In addition, wavelength division multiplexing using slightly different colors of light to enable simultaneous transmission of multiple signals, each in the Gigabit range, are being developed. Theoretically, maximum throughputs as high as 25,000 Gigabits or 25 Terabits (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 feasible based on known technology. Engineers are investigating new technologies which may eventually make throughputs in the Terabit range possible.

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. Research on more advanced systems, both using wavelength division multiplexing and higher bit rates using a single optical wavelength is continuing. AT&T, for example, has reportedly demonstrated 8 Gigabit per second transmission over a 68 kilometer link without any repeaters. In contrast, early multimode systems operated at 45 Megabits and handled a single DS-3 or up to 672 voice conversations. In the somewhat more distant future are systems with throughputs of between 16 and 27 Gigabits which are reportedly being developed or demonstrated in the laboratory by AT&T and Bellcore. These systems will use the wavelength division approach with a separate laser for each optical frequency (color) and will enable hundreds of thousands of telephone conversations to be simultaneously carried over a single fiber pair.

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

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

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