NEWS
FEDERAL COMMUNICATIONS COMMISSION
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WASHINGTON, D.C. 20554

News media information 202 / 254-7674
Recorded listing of releases and texts
202 / 632-0002



March 27, 1991

# FCC RELEASES FIBER DEPLOYMENT ANALYSIS

The FCC has released a report entitled "Fiber Deployment Update - End of Year 1990."

This report presents fiber deployment data and associated information on interexchange carriers, regional Bell holding companies, urban fiber systems, and non-Bell local operating companies. The report includes limited data and a discussion of deployment of fiber by electric power companies and CATV firms. In addition, the report reviews the technology and innovative approaches for fiber deployment in the local loop and in the long haul environment.

Current estimates indicate that interexchange carriers increased their deployed fiber by about 12.5% during 1990. The local Bell operating companies' deployed fiber grew by about 31.7% during 1990 and stood at approximately 2.7 million fiber miles at the end the year. This compares with a growth rate of about 28.3% in 1989. Total fiber reported by all local operating companies exceeded 3 million fiber miles in 1990. Fifteen urban fiber carriers included in the study this year have deployed about 55,000 fiber miles of fiber as of the end of 1990. This compares with a total of somewhat over 33,000 fiber miles documented as of the end of 1989.

Included in the study are data on fiber rings, fiber-to-the-curb systems, fiber trials and investment, as well as a reference list for individuals wishing to pursue aspects of fiber deployment or technology in further depth.

This report is available for reference in room 537, Industry Analysis Division, Common Carrier Bureau, 1919 M Street, N. W. Copies may be purchased by calling Downtown Copy Center at (202) 452-1422.

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# FIBER DEPLOYMENT UPDATE
End of Year 1990

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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. 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. Next it discusses important issues and developments associated with each of the main categories of entities deploying fiber. Tables that illustrate some key fiber trends and developments are included with the text of the report.

The scope of this report, which originally consisted of data on the interexchange carriers and the regional Bell holding companies, has been expanded to include urban fiber systems and non-Bell local operating companies. Supplementary information on other entities deploying fiber briefly reviews the electric power industry's application of fiber to telecommunications and focuses again this year on the southeastern part of the country where much of this fiber has been deployed. A brief discussion of the application of fiber in cable TV systems is also included. Finally, the report 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. (Information on international fiber deployments is not included in this year's report; however, a summary of such planned deployments can be found in reference 92.)

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 route expansion and greater utilization of the existing deployed fiber, either by using technologies with higher bit rates or throughputs, or by equipping previously "dark" fibers. It should be noted that some fiber overbuilds have become necessary in certain routes where terminal and repeater technology has not kept pace with increased circuit requirements.

Local operating companies have increased their fiber in plant by about 32 percent and report the use of redundant fiber systems (sometimes called "rings"), fiber-to-the-curb systems, and a number of fiber-to-the-home trials. There is presently indication that significant levels 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.[1] It is also noted that growth rates of deployed fiber for these companies generally appear to have increased this year. There has generally been increasing interest in fiber architectures 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 gaining support within 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, the innovative spirit of these companies has 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.

Other entities such as electric utilities and cable TV companies have also been deploying fiber in an innovative or cost-effective manner. Agreements for joint use or deployment by power utilities and interexchange carriers were discussed in last year's report 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.

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1 See reference 27.

2 See reference 51

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.

While carriers were contacted by telephone, this year any carrier desiring a written description of the requested data items was forwarded one. 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, more than tripled the capacity of earlier systems. The impact of application of this technology could be predicted without needing new data from prior years. 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 DS-3 mileage was requested. This provides a measure of current fiber utilization. The 1.76 gigabit systems currently in use can handle about 36 DS-3's or about 25,000 circuits as compared to 28 DS-3's or 18,816 circuits in the 1.2 gigabit systems. 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.

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. Unfortunately some of the carriers were unable to provide this data.

Finally, 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 were revised to remove leased fiber, which had erroneously been included in prior data submissions. 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.

For the local telephone companies data was additionally requested this year for the first time on fiber systems used solely for internal company business and operating on an interlata basis or by a specific exemption from the Modification of Final Judgment (MFJ), which divested the Bell Operating Companies from AT&T. In addition, 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 were first identified last year and appear to compete with metropolitan or urban fiber systems. Finally, statistics on fibers to customers or buildings not associated with fiber trials were included.

For metropolitan fiber carriers, information on the number of DS-1 and DS-3 links serving customers and the number of customers or buildings served was requested for the first time this year. Information on buildings served was provided by nearly all entities and is reported in Table 13 and the text of this report.

Source Methods and Data Limitations

This report 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 year, this approach was supplemented with a written description of the survey items which was made available to each participating carrier. The items of data collected are described with the tables. It was hoped that this would make the reported data somewhat more uniform.

This report primarily focuses on domestic common carrier use of fiber. However, several selected power companies and cable TV companies were contacted in this survey to better assess overall fiber use and application of the technology by these entities, in view of the joint use of fiber by interexchange carriers and electric power utilities reported last year and the common interests of local telephone companies, cable TV companies, and electric utilities.

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 utilites, the National Cable Television Association and the Association for Local Telecommunications Services (ALTS) representing urban fiber carriers have been also contacted and have been very cooperative and helpful. The Bell Operating Companies were initially contacted by letter. The report benefited 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. 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. This was identified as a possible problem in AT&T's data provided last year. 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 information on fiber technology trials and fiber-to-the-curb systems was requested of the Bell Operating Companies, as well as the amount of fiber to business customers not associated with fiber trials. Both urban carriers and local operating companies were asked to supply counts of buildings served by fiber, especially where data on numbers of customers served by fiber was unavailable. This actually may provide a more realistic measure of fiber penetration in metropolitan areas than customers served by fiber. Finally, some clarification on required investment data was provided, particularly for the interexchange carriers who were asked to separate backbone investment from the investment associated with DS-3 additions.

With continuing merger and acquisition activity as well as an increasing number of 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 this year, 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 in the past 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 has thus revised its previously submitted data to account for this. Williams Telecommunications has indicated that this year's reported data is 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 has therefore been adjusted downward by the author to account for the estimated impact of these factors. Also, AT&T this year reportedly has eliminated a practice of rounding or estimating components of its totals before arriving at an aggregate. Based upon information provided by the company, last year's fiber mileage was thus adjusted downward 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.

Interexchange Carriers

Data for the interexchange carriers is shown in Tables 1 through 4 which reflects a number of revisions to historical data. This year, growth in fiber mileage deployed by interexchange carriers was between 12 and 13 percent. Last year's overall fiber mileage growth calculated from data in last year's report was between 15 and 16 percent, but has been revised downward to between 10 and 11 percent to account for adjustments in historical data reported by the carriers or made by the author. AT&T's 11.6% increase in fiber mileage in 1990 includes 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. Total fiber mileage deployed by the interexchange carriers is estimated at over 2.1 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.

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 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 6.5 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 and other factors and appears to range between about $275 and $600 per DS-3 mile, with a weighted average of $310, as shown in Table 4.

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 been focusing attention on agreements facilitating joint deployment of fiber and associated shared use of rights of way with electric power utilities. At least two of the major carriers are actively extending their routes in conjunction 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 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 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.

Another factor affecting this sector of the industry has been mergers and acquisitions. Four major entities have emerged: US Sprint, the NTN companies, MCI and AT&T. The most recent major acquisition was MCI's acquisition of Telecom*USA during 1990. Data for Telecom*USA, however, is still reflected separately in this report. Historical data for other merged entities shown separately in prior fiber deployment reports has been combined in the tables this year for simplicity. Previously, the largest acquisition had been Williams Telecommunications Group's acquisition of Lightnet which had reported a fiber network of about 5,300 route miles.

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. [3] 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 the present economic slowdown continues. It is important to note, however, that current trends in fiber deployment activity in the long-haul environment

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3 See reference 35.

probably have less to do with current economic activity than the development of the technology, prior expectations of current economic activity and market share, and competitive effects discussed above. Capital construction programs for certain fiber backbone facilities of large carriers require significant lead times and thus tend to lag behind changing perceptions of market share and economic activity. This, perhaps, is partially evidenced by the fact that AT&T's fiber deployments have not generally mirrored its change in market share, which has slipped from 80-90% just after divestiture to somewhat over 60% today, as determined from NECA minutes-of-use data.

## Table 1: Route Miles and Sheath Miles -- Interexchange Carriers *

| | Route-Miles | | | | | | Sheath Miles |
|---|---|---|---|---|---|---|---|
| Calendar Year: | *1985* | *1986* | *1987* | *1988* | *1989* | *1990* | *1990* |
| AT&T | *5,677* | *10,893* | *18,000* | *23,324* | *28,900* | *32,398* | *35,600* |
| 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 without Telecom*USA | *2,560* | *5,580* | *8,775* | *10,975* | *11,900* | *15,658* | *NA* |
| Telecom U. S. A. | *465* | *1,172* | *1,492* | *1,492* | *1,939* | *1,942* | *1,942* |
| MCI (total) | *3,025* | *6,752* | *10,267* | *12,467* | *13,839* | *17,600* | *NA* |
| Norlight | *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* | *1,210* |
| RCI | *580* | *580* | *796* | *413* | *414* | *417* | *417* |
| Williams Telecom. | *3,084* | *7,936* | *8,202* | *9,135* | *9,725* | *9,893* | *NA* |
| NTN (total ) | *5,655* | *10,726* | *11,527* | *12,237* | *12,864* | *13,035* | *NA* |
| US Sprint | *5,300* | *11,915* | *17,476* | *21,938* | *22,002* | *22,586* | *22,586* |
| Valley Net | *NA* | *NA* | *NA* | *NA* | *520* | *570* | *630* |
| Total Reported: | *20,039* | *40,668* | *58,743* | *71,529* | *79,862* | *88,037* | *NA* |

* 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 Route Cross Section | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calendar Year: | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
| AT&T | 136,248 | 261,432 | 432,000 | 704,731 | 838,392 | 935,713 | 24.0 | 24.0 | 24.0 | 30.2 | 29.0 | 28.9 |
| Electra | 9,960 | 9,960 | 9,960 | 9,960 | 9,960 | 9,960 | 26.1 | 26.1 | 26.1 | 26.1 | NA | 20.2 |
| Mutual Signal Corp. | NA | NA | 4,021 | 4,021 | 4,021 | 4,210 | NA | NA | 9.6 | 9.6 | NA | 10.0 |
| CTI (Electra + Mutual) | 9,960 | 9,960 | 13,981 | 13,981 | 13,981 | 14,170 | 26.1 | 26.1 | 17.4 | 17.4 | 17.4 | 15.5 |
| Diginet | NA | NA | NA | 2,890 | 2,890 | 2,890 | NA | NA | NA | 32.1 | 32.1 | 32.0 |
| MCI without Telecom*USA | 79,200 | 167,400 | 245,700 | 264,680 | 285,700 | 405,430 | 30.9 | 30.0 | 28.0 | 24.1 | 24.0 | 25.9 |
| Telecom U. S. A. | 4,650 | 11,720 | 13,640 | 14,120 | 18,481 | 18,570 | 10.0 | 10.0 | 9.1 | 9.5 | 9.5 | 9.6 |
| MCI (total) | 83,850 | 179,120 | 259,340 | 278,800 | 304,181 | 424,000 | 27.7 | 26.5 | 25.3 | 22.4 | 22.0 | 24.1 |
| Norlight | NA | NA | 8,040 | 8,040 | 10,132 | 10,132 | NA | NA | 12.0 | 12.0 | 12.0 | 12.0 |
| ATC | 8,000 | 9,500 | 9,670 | 17,158 | 18,145 | 18,297 | 10.0 | 10.0 | 10.0 | 15.2 | 15.6 | 15.7 |
| Consolidated Network | 3,504 | 3,504 | 3,864 | 3,952 | 3,952 | 3,952 | 11.3 | 11.3 | 11.0 | 11.2 | 11.2 | 11.2 |
| Litel | 13,720 | 17,274 | 22,280 | 22,280 | 22,280 | 22,280 | 15.6 | 18.2 | 18.4 | 18.4 | 18.4 | 18.4 |
| RCI | 6,960 | 6,960 | 7,202 | 2,618 | 2,654 | 2,689 | 12.0 | 12.0 | 9.0 | 6.3 | 6.4 | 6.4 |
| Williams Telecommun. | 71,020 | 181,276 | 202,226 | 229,168 | 235,720 | 244,671 | 23.0 | 22.8 | 24.7 | 25.1 | 24.2 | 24.7 |
| NTN (total) | 103,204 | 218,514 | 245,242 | 275,176 | 282,751 | 291,889 | 18.3 | 20.4 | 21.3 | 22.5 | 22.0 | 22.4 |
| US Sprint | 122,400 | 249,337 | 343,173 | 449,490 | 450,846 | 463,256 | NA | 20.9 | 19.6 | 20.5 | 20.5 | 20.5 |
| Valley Net | NA | NA | NA | NA | 6,120 | 6,840 | NA | NA | NA | NA | 11.8 | 12.0 |
| Total Reported: | 455,662 | 918,363 | 1,301,776 | 1,733,108 | 1,909,293 | 2,148,890 | 22.7 | 22.6 | 22.2 | 24.2 | 23.9 | 24.4 |

* 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 | 1987 | 1988 | 1989 | 1990 |
| AT&T | 26.5% | 41.6% | 45.5% | 49.6% | NA | 1,294,129 | 3,024,902 | 3,656,642 |
| Electra | 50.0% | 71.0% | NA | 61.7% | NA | NA | NA | 17,822 |
| Mutual Signal Corp. | 60.0% | 60.0% | NA | 43.4% | NA | 10,080 | NA | 5,944 |
| CTI (Electra + Mutual) | 52.9% | 67.8% | 55.1% | 56.3% | NA | NA | NA | 23,766 |
| Diginet | NA | NA | 56.0% | 50.0% | NA | NA | 5,400 | NA |
| MCI without Telecom*USA | 30.0% | 40.0% | 51.8% | 63.3% | 425,000 | 875,000 | 1,016,460 | 1,158,686 |
| Telecom U. S. A. | 70.0% | 80.0% | 81.0% | 86.4% | 24,829 | 32,802 | 44,683 | 44 772 |
| MCI (total) | 33.7% | 44.1% | 56.7% | 64.3% | 449,829 | 907,802 | 1,061,143 | 1,203 458 |
| Norlight | 33.3% | 50.0% | 41.7% | 65.0% | NA | 8,040 | 25,350 | NA |
| ATC | 80.0% | 69.0% | 75.0% | 90.0% | NA | 171,580 | NA | NA |
| Consolidated Network | 33.0% | 33.0% | 50.0% | 53.4% | NA | 4,224 | 7,026 | 12 672 |
| Litel | 54.2% | 54.9% | 55.9% | 60.6% | NA | 52,293 | 55,869 | 43,874 |
| RCI | 34.9% | 57.4% | 56.7% | 56.5% | 7,164 | 5,206 | 10,446 | 12 045 |
| Williams Telecommun. | 42.5% | 37.2% | 49.0% | 61.6% | 201,665 | 245,869 | NA | NA |
| NTN (total) | 45.5% | 45.2% | 62.8% | 68.7% | | | | |
| US Sprint | 30.0% | 31.0% | 50.4% | 54.4% | 865,000 | 987,000 | 1,431,985 | NA |
| Valley Net | NA | NA | 37.3% | 50.7% | NA | NA | 12,250 | NA |
| Total Reported: | 31.9% | 38.7% | 48.5% | 54.7% | | | | |

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

## 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 $) | Previously Identified Leasing of Fiber | | |
|---|---|---|---|---|---|---|
| | | | | DS-3 Mi. | Route Mi. | Fiber Mi. |
| AT&T | *2,022* | *275* | *62* | *11,281* | *NA* | *12,742* |
| CTI | *93* | *NA* | *102* | *NA* | *NA* | *NA* |
| Diginet | *7* | *NA* | *75* | *NA* | *NA* | *NA* |
| MCI without Telecom*USA | *1,133* | *353* | *72* | *NA* | *NA* | *NA* |
| Telecom*USA | *61* | *501* | *32* | *96,347* | *732* | *5,261* |
| MCI (total) | *1,194* | *360* | *68* | *215,000* | *5,500* | *NA* |
| Norlight | *63* | *NA* | *75* | *NA* | *155* | *NA* |
| ATC | *90* | *NA* | *77* | *NA* | *280* | *2,460* |
| Consolidated Network | *16* | *276* | *45* | *208* | *180* | *6,962* |
| Litel | *98* | *NA* | *81* | *2,400* | *90* | *1,734* |
| RCI | *9* | *624* | *21* | *5,613* | *130* | *558* |
| Williams Telecommun. | *442* | *NA* | *45* | *NA* | *275* | *1,100* |
| NTN (total) | *655* | *NA* | *50* | *8,221* | *955* | *12,814* |
| US Sprint | *1,694* | *350* | *75* | *NA* | *NA* | *500* |
| Valley Net | *10* | *NA* | *19* | *NA* | *NA* | *NA* |
| Total Reported: | *5,739* | *310* | *65* | *234,502* | *6,610* | *26,056* |

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

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

1. 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.

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

3. AT&T's 1989 fiber mileage has been adjusted downward to account for rounding errors in the components making up the total. AT&T's route mileage for 1989 has also been 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.

4. 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 last year's submission which is not reflected in the tables. Investment data for CTI reflects data which was previously provided.

5. MCI data reflects the acquisition of Telecom*USA which had previously been formed by the merger of Southland Fibernet, SouthernNet and Teleconnect. Data for Telecom*USA, now part of MCI, is also shown separately. MCI historical DS-3 mileage has been adjusted to reflect fiber DS-3's only.

6. 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.

7. 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. The reader may also wish to refer to prior fiber deployment reports.

8. 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.

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

10. 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.

11. 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.

12. 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 associated with arrangements with electric utilities for long term use may be included in fiber reported as owned by some of the carriers.

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

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

2. 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.)

3. 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.)

4. 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 .

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

6. 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.

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

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

## 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 11. 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.

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 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, and provide a backdrop for other developments. [4]

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 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. Deployment of fiber in this portion of the plant has been the most

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4 See Reference 27.

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 had 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 had difficulty providing 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. US West, for example, 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 reported that it has used engineering estimates to separate interoffice and subscriber fiber and copper. Other companies either did not provide certain subscriber data or did not indicate whether estimation procedures were used. Subscriber data is displayed in Tables 8, 9, and 11.

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 9 through 11 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 7. Data was also requested on interLATA facilities used in connection with MFJ exemptions. Very few of the Bell Operating Companies reported statistics on facilities associated with exemptions.

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. In the future, 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 new 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:

| | |
|---|---|
| Pacific Telesis: | San Francisco, Los Angeles, El Segundo, Oakland, San Diego, San Jose, Santa Clara, Sunnyvale, California |
| BellSouth: | Birmingham, Mobile, Alabama; New Orleans, Shreveport, Louisiana; Jackson, Mississippi; Memphis, Nashville, Tennessee; Atlanta, Columbus, Georgia; Fort Lauderdale, Jacksonville, Miami, Orlando, Florida |
| US West: | Minneapolis, Minnesota; Denver, Colorado; Phoenix, Arizona |
| Ameritech: | Chicago, Illinois; Indianapolis, Indiana; Detroit, Grand Rapids, Michigan; Cleveland, Columbus, Ohio; Milwaukee, Wisconsin |
| Southwestern Bell: | Dallas, Houston, Fort Worth, Texas; Kansas City, Kansas; St. Louis, Missouri |
| NYNEX: | Boston, Massachusetts; New York City, New York |
| Bell Atlantic: | Philadelphia, Paoli, King of Prussia, Wayne, Conshocken, Pennsylvania; Cedar Knolls, New Jersey; Washington, D.C.; Norfolk, Virginia |

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 7. Bellcore supports the use of these systems on an interim basis, and it is likely that these systems will evolve as they proliferate further. [5]

Data on fiber technology trials is summarized in Table 7. 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, reports trials of its 2.4 gigabit interoffice synchronous optical network (SONET) as well as SONET 150 megabit loop trials. GTE reports an interesting high bandwidth trial for a research project called VISTANET involving a prototype network for interactive three dimensional medical imaging research. Pacific Bell reports a technology test of a loop optical carrier system and an associated software support system. To better enable assessment of the deployment cost per fiber, investment and fiber count data associated with fiber trials is also shown. 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.

Although fiber has been widely touted as the medium of choice for providing wide bandwidth services to residences, its attractiveness is sometimes overplayed to the extent that the medium becomes the focus rather than bandwidth. It may turn out that new fiber architectures involving some form of hybrid fiber-coaxial transmission and some form of sharing or cooperative venture comprised of entities interested in reaching customers will provide the most economical means for promoting wide bandwidth services and capabilities to subscribers into the next century.

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5 See Reference 51.

## Table 5: Fiber Deployment by Local Operating Companies Aggregated to Holding Company Level *

| | Sheath-Miles | | | | | | Fiber-Miles | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Company | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
| Ameritech | 3,200 | 5,200 | 6,700 | 8,700 | 10,800 | 12,100 | 77,700 | 111,100 | 147,100 | 177,500 | 228,400 | 285,500 |
| Bell Atlantic | 1,240 | 4,374 | 6,730 | 9,239 | 11,943 | 16,038 | 83,085 | 150,847 | 227,507 | 311,022 | 373,398 | 501,428 |
| BellSouth | 3,830 | 8,694 | 11,727 | 15,643 | 19,781 | 24,181 | 50,807 | 170,092 | 218,489 | 319,248 | 445,452 | 591,938 |
| NYNEX | 1,606 | 3,209 | 4,956 | 7,413 | 9,221 | 12,008 | 83,384 | 129,743 | 207,077 | 290,600 | 357,766 | 482,326 |
| Pacific Telesis | 2,318 | 2,779 | 2,964 | 3,480 | 3,767 | 4,790 | 84,310 | 97,800 | 101,090 | 110,273 | 126,944 | 168,782 |
| Southwestern Bell | 1,913 | 4,374 | 5,970 | 7,349 | 9,100 | 11,700 | 70,490 | 151,043 | 182,911 | 214,948 | 270,300 | 352,300 |
| US West | 3,527 | 5,017 | 6,937 | 10,030 | 13,425 | 16,082 | 47,341 | 70,082 | 107,782 | 163,968 | 234,851 | 300,442 |
| Regional Bell Totals: | 17,634 | 33,647 | 45,984 | 61,854 | 78,037 | 96,899 | 497,117 | 880,707 | 1,191,956 | 1,587,559 | 2,037,111 | 2,682,716 |
| Contel Companies | | | | 1,100 | 9,000 | 14,570 | | | | | | 109,788 |
| GTE Companies | | | | 8,999 | 11,855 | 15,123 | | | | 134,677 | 163,396 | 201,420 |
| United Companies | | | | 2,907 | 5,002 | 6,360 | | | | 32,287 | 54,569 | 77,940 |
| Rural Companies | | 500 | 2,584 | 4,651 | 6,369 | 8,689 | | 2,000 | 14,236 | 28,705 | 42,260 | 68,237 |
| Total Reported: | 17,634 | 34,147 | 48,568 | 79,511 | 110,263 | 141,641 | 497,117 | 882,707 | 1,206,192 | 1,783,228 | 2,297,336 | 3,140,101 |

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

## Table 6: Average Fiber Cable Cross Section *

| Company | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|---|
| Ameritech | 24.28 | 21.37 | 21.96 | 20.40 | 21.15 | 23.60 |
| Bell Atlantic | 67.00 | 34.49 | 33.80 | 33.66 | 31.27 | 31.26 |
| BellSouth | 13.27 | 19.56 | 18.63 | 20.41 | 22.52 | 24.48 |
| NYNEX | 51.92 | 40.43 | 41.78 | 39.20 | 38.80 | 40.17 |
| Pacific Telesis | 36.37 | 35.19 | 34.11 | 31.69 | 33.70 | 35.24 |
| Southwestern Bell | 36.85 | 34.53 | 30.64 | 29.25 | 29.70 | 30.11 |
| US West | 13.42 | 13.97 | 15.54 | 16.35 | 17.49 | 18.68 |
| Average -- Bell Companies: | 28.19 | 26.17 | 25.92 | 25.67 | 26.10 | 27.69 |
| Contel Companies | | | | | | 7.54 |
| GTE Companies | | | | 14.97 | 13.78 | 13.32 |
| United Companies | | | | 11.11 | 10.91 | 12.25 |
| Rural Companies | | 4.00 | 5.51 | 6.17 | 6.64 | 7.85 |
| Average -- All Companies: | 28.19 | 25.85 | 24.84 | 22.43 | 20.84 | 22.17 |

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

## Table 7: Other Fiber Data for Local Operating Companies *

| | Fiber Trial Data | | | | Other Fiber Systems | | | | | | Aggregate Fiber Investment (Million $) | | InterLata Fiber for Internal Co. Business | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Lit Fiber | No. Systems | Fibers | Investment Million $ | Fiber-to-Curb System | Fiber-to-Curb Fibers | Fiber Rings-Cities | Customers Served by Fiber | Fibers to Customer | Bldgs. Served | Sub-scriber | Total | Route Mi. | Fiber Mi. |
| Ameritech | 57.8% | 0 | 0 | 0.00 | 1 | 48 | 8 | NA | NA | 654 | NA | 386.7 | 900 | 4,800 |
| Bell Atlantic | NA | 2 | 132 | 0.80 | 1 | 5 | 9 | NA | NA | NA | NA | 483.1 | NA | 4,258 |
| BellSouth | 50.9% | 12 | 3,006 | 9.44 | 2 | 110 | 13 | 877 | 5,450 | NA | NA | 771.4 | 561 | 6,713 |
| NYNEX | NA | 1 | 130 | 0.25 | 1 | 130 | 2 | NA | NA | 797 | 182.4 | 571.6 | 154 | 2,872 |
| Pacific Telesis | 43.9% | NA | NA | NA | 0 | 0 | 8 | 163 | 4,941 | NA | 68.6 | 213.9 | 981 | 10,981 |
| Southwestern Bell | 45.9% | 1 | 576 | 1.70 | 3 | 325 | 3 | 600 | 8,140 | NA | NA | 411.8 | 1,429 | 7,178 |
| US West | 34.8% | 3 | 270 | 1.34 | 1 | 72 | 3 | NA | 1,878 | NA | 155.1 | 380.6 | NA | NA |
| Contel Companies | 54.7% | 2 | 417 | 2.40 | 1 | 183 | 9 | 13 | 92 | NA | NA | 95.7 | 2,622 | 14,968 |
| GTE Companies | NA | 1 | 2,316 | 11.83 | 0 | 0 | 1 | NA | NA | NA | NA | 255.0 | 8 | 67 |
| United Companies | 42.4% | 0 | 0 | 0.00 | 0 | 0 | 0 | 33 | 244 | NA | NA | 134.0 | 212 | 1,359 |
| Rural Companies | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 59.2 | NA | NA |
| Total Reported: | 47.7% | 22 | 6,847 | 27.75 | 10 | 873 | 56 | 1,686 | 20,745 | 1,451 | 406 | 3,763 | 6,867 | 53,196 |

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

## Table 8

### Fiber Subscriber Plant of Bell Operating Companies *

| | Sheath-Miles | | | Fiber-Miles | | | |
|---|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1990 |
| Ameritech | 2,800 | 2,600 | 3,000 | NA | 56,600 | 69,200 | 84,600 |
| Bell Atlantic | NA | 4,872 | 6,543 | 79,434 | 116,873 | 152,334 | 226,008 |
| BellSouth | NA | NA | NA | 136,807 | 185,795 | 267,271 | 355,163 |
| NYNEX | 1,935 | 2,656 | 4,045 | 45,938 | 66,823 | 90,027 | 134,981 |
| Pacific Telesis | 537 | 722 | 1,251 | 15,911 | 22,104 | 30,353 | 54,831 |
| Southwestern Bell | NA | 2,500 | 3,300 | NA | NA | 95,400 | 130,600 |
| US West | 2,816 | 3,484 | 3,512 | 61,616 | 84,824 | 112,373 | 113,795 |
| Total Reported: | 8,088 | 16,834 | 21,651 | 339,706 | 533,019 | 816,958 | 1,099,978 |

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

## Table 9

### Copper Subscriber Plant of Bell Operating Companies *

| | Sheath-Miles | | | Wire-Miles | | |
|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1988 | 1989 | 1990 |
| Ameritech | 242,700 | 245,200 | 244,600 | 139,588,000 | 140,419,900 | 142,001,500 |
| Bell Atlantic | 280,347 | 290,755 | 291,608 | 187,439,376 | 191,674,222 | 192,353,848 |
| BellSouth | 559,993 | 564,236 | 566,080 | 238,775,565 | 241,225,031 | 242,250,194 |
| NYNEX | 225,547 | 229,508 | 233,162 | 130,892,737 | 134,247,385 | 138,041,857 |
| Pacific Telesis | 170,267 | 167,522 | 169,564 | 128,766,710 | 127,455,716 | 129,643,873 |
| Southwestern | NA | 338,100 | 340,700 | NA | 156,900,000 | 158,300,000 |
| US West | 384,261 | 389,379 | 393,796 | 154,245,455 | 156,228,598 | 158,228,788 |
| Total Reported: | 1,863,115 | 2,224,700 | 2,239,510 | 979,707,843 | 1,148,150,852 | 1,160,820,060 |

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

## Table 10: Fiber and Copper in Total Plant in Relation to Access Lines -- End of Year 1989 *

| Company Name | Access Lines | Total Plant: Strand Miles | | Total Plant: 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 | 16,050,334 | 187,226,600 | 228,400 | 326,900 | 10,800 | 11,665 | 14.2 | 20.4 | 0.7 | 3.2% | 0.12% |
| Bell Atlantic | 17,427,773 | 191,674,222 | 373,398 | 290,755 | 11,943 | 10,998 | 21.4 | 16.7 | 0.7 | 3.9% | 0.19% |
| BellSouth | 17,005,219 | 241,225,031 | 445,452 | 564,236 | 19,781 | 14,185 | 26.2 | 33.2 | 1.2 | 3.4% | 0.18% |
| NYNEX | 15,214,493 | 165,475,956 | 357,766 | 262,027 | 9,221 | 10,876 | 23.5 | 17.2 | 0.6 | 3.4% | 0.22% |
| Pacific Telesis | 14,208,174 | 147,513,115 | 126,944 | 185,760 | 3,767 | 10,382 | 8.9 | 13.1 | 0.3 | 2.0% | 0.09% |
| Southwestern Bell | 11,444,061 | 168,400,000 | 270,300 | 375,000 | 9,100 | 14,715 | 23.6 | 32.8 | 0.8 | 2.4% | 0.16% |
| U S West | 12,306,536 | 160,073,485 | 234,851 | 419,268 | 13,425 | 13,007 | 19.1 | 34.1 | 1.1 | 3.1% | 0.15% |
| Total reported: | 103,656,590 | 1,261,588,409 | 2,037,111 | 2,423,946 | 78,037 | 12,171 | 19.7 | 23.4 | 0.8 | 3.1% | 0.16% |

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

## Table 11: Fiber and Copper in Subscriber Plant in Relation to Access Lines -- End of Year 1989 *

| | Subscriber Plant | | | | | Per Thousand Access Lines | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Access Lines | Strand Miles | | Sheath Miles | | Miles Copper Wire | Miles Fiber Strand | Miles Copper Cable | Miles Fiber Cable | % Fiber Sheath Miles |
| | | Copper | Fiber | Copper | Fiber | | | | | |
| Ameritech | *16,050,334* | *140,419,900* | *69,200* | *245,200* | *2,600* | *8,749* | *4.3* | *15.3* | *0.16* | *1.0%* |
| Bell Atlantic | *17,427,773* | *NA* | *152,334* | *NA* | *4,872* | *NA* | *8.7* | *NA* | *0.28* | *NA* |
| BellSouth | *17,005,219* | *NA* | *267,271* | *NA* | *NA* | *NA* | *15.7* | *NA* | *NA* | *NA* |
| NYNEX | *15,214,493* | *134,247,385* | *90,027* | *229,508* | *2,656* | *8,824* | *5.9* | *15.1* | *0.17* | *1.1%* |
| Pacific Telesis | *14,208,174* | *127,455,716* | *30,353* | *167,522* | *722* | *8,971* | *2.1* | *11.8* | *0.05* | *0.4%* |
| Southwestern Bell | *11,444,061* | *156,900,000* | *95,400* | *338,100* | *2,500* | *13,710* | *8.3* | *29.5* | *0.22* | *0.7%* |
| US West | *12,306,536* | *156,228,598* | *112,373* | *389,379* | *3,484* | *12,695* | *9.1* | *31.6* | *0.28* | *0.9%* |
| Total reported: | *103,656,590* | *715,251,599* | *816,958* | *1,369,709* | *16,834* | *10,332* | *7.9* | *19.8* | *0.19* | *1.2%* |

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

Notes to Tables 5-11: (NA indicates data was not available)

1. Ameritech reports subscriber data based on engineering judgment.

2. Bell Atlantic and BellSouth data on subscriber copper is not available. (Table 9 shows total copper for these companies.) Bell Atlantic has had a total of 3 trials, one of which is ongoing. The data shown in Table 7 is for the earlier 2 trials.

3. BellSouth subscriber fiber mileage for 1989 and 1990 as shown in table 8 was estimated as 60% of the total fiber mileage based upon data provided by the company for 1987 and 1988. Fiber to customers and fiber used for internal company business shown in Table 7 applies to Southern Bell only.

4. NYNEX fiber-to-the-curb system is also shown as a fiber trial.

5. Southwestern Bell which had previously separated fiber and copper into interexchange and toll subcategories has provided data this year covering 1990 and 1989 in the loop and interoffice subcategories which were originally requested. Southwestern Bell has had 3 fiber trials to date. Data for the most recent fiber trial is shown in Table 7.

6. US West provided exchange and toll subcategories rather than subscriber and interoffice. This would tend to overestimate subscriber copper and fiber. US West data for the number of fibers in fiber trials shown in Table 7 is actually the number of customers. US West reported one additional fiber trial for which further data was not provided.

7. Total access line counts were taken from annual Form M submissions of the carriers. Tables 10 and 11 are presented for 1989, the latest year in which Form M access line data has been compiled. Table 7 reflects data as of the end of 1990.

8. Fiber rings refer to any form of redundant fiber facilities.

9. End of year 1990 data may be estimated.

10. Composite fiber cross section is the total fiber mileage divided by the total sheath mileage. This parameter may be useful in assessing data validity.

Definitions and descriptions of the items in Tables 5-11:

1. 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.

2. 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 .

3. 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.)

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

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

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

7. Fibers to customers other than for fiber trials --
   The number of customers and buildings served by fiber and the associated number of fibers including fiber to customers for special access services.

8. Cities served by fiber rings --
   Cities served by fiber rings or equivalent redundant structures

9. Investment in fiber backbone facilities --
   The total investment in fiber cable, deployment, and repeater sites (outside plant), not including electronic or optoelectronic equipment.

## 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. These entities access large business customers using a ring or loop of fiber through areas of high business concentration and appear to offer the customer very reliable service with competitive service and maintenance intervals. Table 12 lists the key companies known to be involved in such systems. It is not intended to be an all inclusive list. It excludes, for example, a number of companies that only operate microwave systems or that were constructing fiber plant that was not operational in 1990. Companies not shown include Bay Area Teleport in the San Francisco area, Teleport Denver and San Diego Linkatel. Some entities may be classified as common carriers and some as private carriers.

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 100 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 as 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. An operation in a single city typically involves a $2 million to $10 million investment and serves at least 20 buildings.

The companies presently 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. 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, and has been 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, Chicago, San Francisco, Houston, and Los Angeles; and it has been attempting to enter the Washington, D.C. market, a move that would put it in a total of seven major metropolitan areas. 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, Massachusetts in the Boston area. Teleport Communications Group operates in each city through wholly owned subsidiaries or through partnerships and indicates that it currently reaches about 290 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. While MFS is or will be operational in up to eleven major metropolitan areas by early 1991 and typically deploys several hundred fiber miles per city, the route mileage of each system is relatively small.

Metropolitan Fiber Systems presently operates in Chicago, Minneapolis, Boston, Pittsburgh, Philadelphia, Baltimore, Houston, Los Angeles and San Francisco and is expected to be operational in New York City and Dallas by early 1991. It presently serves about 270 office buildings nationwide roughly comprising about 150 million square feet. It has invested roughly $100 million to date.

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).[6] As of the end of 1990 its full system is estimated at about 145 route miles and it reports serving 230 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 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 59 miles. Finally, Intermedia Communications Co. of Florida which originally operated in Orlando and Tampa has expanded its service to include Jacksonville and Miami.

A large single city entity, Institutional Communications Company (I.C.C.), is based in Washington, D.C. and is using the subway tunnels as a right-of-way for much of its downtown fiber. This company has a number of small rings in areas of high business concentration and is serving about 168 buildings in Crystal City and Reston in Northern Virginia and New Carrollton in suburban Maryland. The company gathers traffic for its network by leasing DS-3 capacity to a number of distant cities and provides 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.

A number of entities which have recently begun to deploy fiber are identified this year for the first time. Available statistics for those companies which were identified as having operating fiber systems in 1990 are included in Tables 12 and 13. Metrex, for example, serves Atlanta and Birmingham. City Signal serves Grand Rapids and Detroit, Penn Access serves Pittsburgh, and New England Digital Distribution serves Boston and Cambridge. DFW/MetroLink, Inc. operates in Dallas. 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. Several other companies, either not having fiber systems in operation during 1990 or not providing data, were not included in the tables. These are Bay Area Teleport in San Francisco which is adding fiber to an all microwave system, Electric Lightwave which operates in Portland, Oregon, and Westmarc Communications which operates in Dallas and Chicago. Another company, Jones International, which already has a cable TV subsidiary called Jones Intercable, is now establishing a sister subsidiary to construct urban fiber systems. Construction for an Atlanta system is presently underway. Finally, Western Union ATS is operating urban fiber systems in a large number of

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6 See reference 91

cities. It was recently 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.

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 do not in their present form provide ubiquitous access, and as such they 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. Nevertheless, it will be important to continue to monitor the impact of these alternative suppliers of special access services on innovation, overall long-term economic and technical efficiencies, and improved service within the local telephone companies.

## Table 12 -- Urban Fiber Systems *

| Company Name | Route Miles | | | | Fiber Miles | | | |
|---|---|---|---|---|---|---|---|---|
| | 1987 | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1990 |
| City Signal | | | | 67.0 | | | | 5,628 |
| DFW/MetroLink, Inc. | | | | 25.0 | | | | 151 |
| Diginet | | | 5.4 | 24.0 | | | 684 | 1,147 |
| Eastern Telelogic | | | 68.0 | 145.0 | | | 2,184 | 3,666 |
| I. C. C. | 88.5 | 108.4 | 137.0 | 148.2 | 3,059 | 5,462 | 5,877 | 6,121 |
| Indiana Digital Access, Inc. | | 7.0 | 34.5 | 59.0 | | 238 | 295 | 469 |
| Inter-Media Communications | | 5.9 | 9.6 | 24.9 | | 211 | 643 | 972 |
| IOR Telecom (Iowa Resources) | | | 60.0 | 65.0 | | | 1,284 | 1,600 |
| Kansas City Fiber Net | | | | 83.5 | | | | 1,204 |
| Metrex Corporation | | | | 7.5 | | | | 342 |
| Metropolitan Fiber System, Inc. | | 9.5 | 62.6 | 84.1 | | 399 | 7,497 | 12,154 |
| New England Digital Distribution | | | | 10.0 | | | | 1,440 |
| Penn Access Corporation | | | | 31.0 | | | | 1,865 |
| Public Service of Oklahoma | | | 120.0 | 109.0 | | | 2,500 | 2,631 |
| Teleport Communications Group | 44.5 | 57.7 | 227.2 | 273.2 | 4,711 | 5,433 | 12,346 | 15,519 |
| Total Reported: | 133.0 | 188.5 | 724.3 | 1,156.4 | 7,770 | 11,743 | 33,310 | 54,909 |

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

**Table 13 Urban Fiber Systems**
**Other Current Data -- 1990 ***

| Company Name | Sheath Miles | Investment Millions $ | Percent Fiber Lit | Buildings Served |
|---|---|---|---|---|
| City Signal | 67 | 5 | 27% | 52 |
| DFW/MetroLink, Inc. | 25 | NA | NA | 18 |
| Diginet | 24 | 11 | 32% | 38 |
| Eastern Telelogic | 149 | 13 | 31% | 230 |
| I. C. C. | 148 | 10 | 45% | 168 |
| Indiana Digital Access, Inc. | 59 | NA | 42% | 35 |
| Inter-Media Communications | 32 | 4 | 50% | 82 |
| IOR Telecom (Iowa Resources) | 65 | 3 | 60% | 45 |
| Kansas City Fiber Net | 88 | NA | NA | 21 |
| Metrex Corporation | 10 | 1 | 1% | NA |
| Metropolitan Fiber System, Inc. | 84 | 100 | 77% | 270 |
| New England Digital Distribution | 10 | 4 | NA | 22 |
| Penn Access Corp. | 32 | NA | NA | 32 |
| Public Service of Oklahoma | 127 | 3 | 73% | 45 |
| Teleport Communications Group | 308 | NA | 85% | 290 |
| Total Reported: | 1,228 | 151 | 63% | 1,348 |

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

Notes to Tables 12 and 13: (NA indicates data was not available)

1. Sheath mileage for Diginet and Metropolitan Fiber System, Inc. was assumed to be equal to route mileage.

2. Statistics shown are for backbone system.

3. Diginet fiber data shown in tables 12 and 13 does not include fiber connecting Milwaukee and Chicago.

Definitions and descriptions of items in tables 12 and 13:

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

2. 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.

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

4. 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 .

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

7. Buildings served --
   The total number of buildings accessed by fiber.

8. 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.

Last year's report 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 this 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. A revised current estimate 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 appears to be associated with interexchange carriers.

While no unexpected increases in ground-wire fiber in the Southeast have been noted over the last year, continuing construction plans of these utilities through the 1992-93 time frame include an additional 770 route miles and about 18,800 fiber miles associated with interexchange carriers to be constructed by three of the above entities during 1991. Besides long-haul ground-wire fiber, electric utilities are interested in reaching customer premises through communications facilities for meter reading and remote power control to facilitate conservation measures. It has been suggested that in the future these access requirements might be met by some kind of joint facility similar to the joint facility the interexchange carriers and electric utilities have constructed for their long-haul requirements. [7]

Besides the electric utilities, several cable TV companies have been fairly active during the past two 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. More than 25,000 fiber miles have been deployed by ATC and Jones 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.[8] 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.

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7 See references 80-82.

8 See References 17-19.

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.[9] 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.[10]

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 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 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. Excessive bit rates could not be transmitted because dispersion caused the pulses to spread out and make the transmitted signal unintelligible.

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9 See References 86 and 109.

10 See Reference 58.

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 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 unless further problems with dispersion are solved.

Technological Developments

Developments in fiber technology are occurring in several areas. Much of the ongoing research has a long-term horizon and will not have impact during the next few years. 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. British Telecom appears to be at the forefront of some of the advanced research currently going on and has recently demonstrated a 62-mile (100-kilometer) fiber transmission at effective data rates as high as 20 gigabits per second, more than 10 times the capacity of typical systems in current operation.[11] Earlier, AT&T had reportedly demonstrated 8 gigabit per second transmission over a 42-mile (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. Similar systems with throughputs of between 16 and 27 gigabits are also reportedly being developed or demonstrated in the laboratory by AT&T, Bellcore, 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 of 1988 the longest repeaterless laboratory system extended over 218 miles, but only operated at 2 megabits per second.[12] The longest operational unrepeatered link deployed as of this writing is believed to be a 112-mile link between Nova Scotia and Newfoundland operating at 560 megabits per second.[13] As should be evident, accomplishments of greater spacing

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11 See Reference 86.

12 See Reference 86.

13 See reference 9.

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.

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. This 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 requiring new repeaters that effectively require a new cable to be laid. [14]

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

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14 See Reference 71.

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 transmision". A soliton is a pulse that remains unchanged by dispersive fiber effects during its transmission. This phenomenon uses a nonlinear quantum effect known as stimulated Raman scattering, which occurs when background laser power levels are high enough. 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 propogating lower power pulsed optical signal.[15] It is expected that this nonlinear phenomenon when applied correctly can be used to both amplify the optical signal and to cancel the effects of dispersion. This would allow transmission at very high data rates without the need for repeaters which require conversion of optical to electronical 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. In the future, if remaining problems can be solved, unrepeatered transmission over 4,000 kilometers would be possible. Transmision up to 9,000 kilometers would then only depend on proper control of the jitter of pulses due to quantum effects. These developments demonstrate that many current fiber system technologies, as amazing as they seem, are still only in their infancy.

Soliton pulse transmission and related technologies will probably 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

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15 See Reference 98.

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 minimize the cost of fiber deployment in the loop plant. 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 particularly important when trying to reach end users with fiber in a more cost effective manner. For this reason, more attention is being placed on new approaches for configuring fiber and electronics in the local loop. [16]

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 of such approaches may eventually lead to new and more cost-effective ways of providing high bandwidth capabilities to residences.

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 bandwith is sometimes sacrificed by using a switched optical signal allowing the 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. [17] It is likely that other technologies, including data compression technologies, will also find application in video to the home systems.

The cable TV industry has only recently begun to use fiber (since about 1988); however, early developments suggest that it has developed cost

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16 See Reference 64.

17 See Reference 24.

effective methods of deploying fiber in video applications that provide wide bandwidth for one-way communications.[18] 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.

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.[19] 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. Shared use or development of such a facility by all utilities including electric utilities would allow the focus to shift towards development of advanced but more limited return bandwidth requirements. While these ideas may be inhibited by industry structure and there may be practical difficulties in implementing them, such approaches merit further investigation and highlight the need for careful and thorough planning prior to significant commitments of capital.[20]

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18 See References 17, 18 and 64.

19 See References 18 and 71.

20 See Reference 110.

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 7 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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