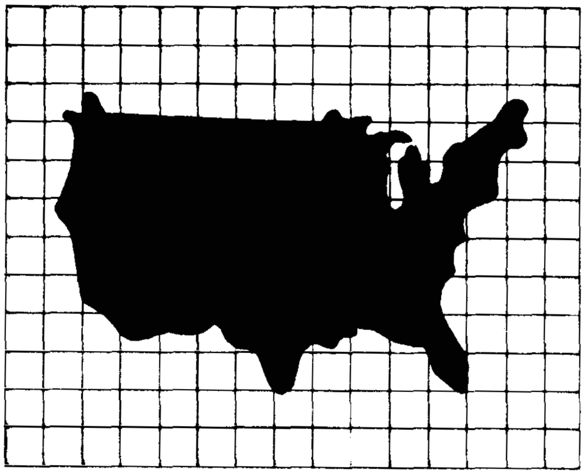
U.S. LONG DISTANCE FIBER OPTIC NETWORKS: TECHNOLOGY, EVOLUTION AND ADVANCED CONCEPTS



FINAL REPORT

VOLUME I
Executive Summary

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IGI Consulting, Inc.
214 Harvard Avenue, Suite 200
Boston, MA 02134 USA
617/738-8088

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VOLUME I
Executive Summary

Harvey Blustain, Project Director
Richard Guenther
John Lawlor
Paul Polishuk

IGI Consulting, Inc.

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VOLUME I:

EXECUTIVE SUMMARY

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U.S. LONG DISTANCE FIBER OPTIC NETWORKS:

TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

Summary

Over the past two decades, fiber optics has emerged as a highly practical and cost-efficient communications technology. Its competitiveness vis-a-vis other transmission media, especially satellite, has become a critical question.

This report studies the likely evolution and application of fiber optic networks in the United States to the end of the century. The outlook for the technology of fiber systems is assessed and forecast, scenarios of the evolution of fiber optic network development are constructed, and costs to provide service are determined and examined parametrically as a function of network size and traffic carried.

Volume I consists of the Executive Summary.

Volume II focuses on fiber optic technology and long distance fiber optic networks. Among the volume's conclusions are: fiber optic technology is still a young technology, with improvements yet to be realized in performance and cost; fiber optics is the preferred medium for many long distance applications; many companies have been investing heavily in long distance fiber optic networks, raising fears of a capacity glut.

Volume III develops a traffic and financial model of a nationwide long distance transmission network. A LATA-to-LATA traffic matrix is established and then applied to four long distance backbone network configurations with 11, 15, 17, and 23 nodes. The model is then extended to include transmission from the inter-exchange backbone network to the points-of-presence in individual LATAs. Cost calculations are done for first and annual costs for all four network configurations and for projected traffic from 1985 to 2000. Cost drivers are identified for various levels of the total network.

Among the study's most important conclusions are: revenue requirements per circuit for LATA-to-LATA fiber optic links are less than one cent per call minute; multiplex equipment, which is likely to be required in any competing system, is the largest contributor to circuit costs; the potential capacity of fiber optic cable is very large and as yet undefined; and fiber optic transmission combined with other network optimization schemes can lead to even lower costs than those identified in this study.

U.S. LONG DISTANCE FIBER OPTIC NETWORKS:

TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

INTRODUCTION

Background

Over the past two decades, fiber optics has emerged as a highly practical and cost-efficient communications technology. With potentially unlimited bandwidth, low attenuation, small size and weight, immunity from interference, and other advantages, fiber optics has competed with, and often displaced, other communications media in a number of applications. Long distance telecommunications networks are one area in which fiber optics has proven to be especially competitive.

Proper guidance of NASA's advanced communication satellite technology program requires an understanding and assessment of competing transmission systems such as fiber optics. Only through a comprehensive assessment of these technological alternatives can the most productive direction for satellite technology development be determined.

To assist them in their evaluation, NASA Lewis Research Center contracted with IGI Consulting to study the likely evolution and application of fiber optic networks in the United States to the end of the century. According to the scope of work,

> The outlook for the technology of fiber systems will be assessed and forecast, scenarios of the evolution of fiber optic network development will be constructed, and costs to provide service will be determined and examined parametrically as a function of network size and traffic carried. This information will provide a quantitative data base for the Phase II study which will directly study the impact of fiber networks on communications satellite systems.

This report is the result of that 14-month study effort.

Organization of The Study

This study is presented in three volumes.

Volume I is the Executive Summary, which provides an overview of the methodology, results, and conclusions of the entire effort.

Volume II focuses on "Fiber Optic Technology and Long Distance Networks."

- Section 1 provides an overview of fiber optic technology. Its principal subsections present a description of fiber optic systems, the advantages of fiber optics for long haul transmission, the historical development of fiber optics, trends in fiber optic technology, and factors affecting the development of the technology.

- Section 2 discusses performance characteristics, research and development foci, costs, and technology assessments for each of the major components required for long distance fiber optics networks: fibers, cables, light sources, detectors, multiplexers, and switches.

- Section 3 introduces fiber optic long haul systems and provides the background necessary to understand the phenomenal growth of these networks over the past several years. Among the issues discussed are the impact of divestiture and deregulation, the use of fiber in long distance networks, and market trends such as consolidation, overcapacity, and rights-of-way.

- Section 4 presents descriptions, route maps, and technology and market assessments for 22 national and regional fiber optic long haul networks. The national systems presented are ALC Communications, AT&T Communications, Fibertrak, MCI, National Telecommunications Network, and U.S. Sprint. The regional networks are Bandwidth Technologies, Consolidated Network, Digi-Net, Electra Communications, Indiana Switch, ICC, LDX Net, Lightnet, LiTel, Microtel, Mutual Signal, NorLight, Rochester Communications, SouthernNet, Southland Fibernet, and Wiltel.

Volume III develops a financial model of a nationwide long distance transmission network between local access and transport areas (LATA). This network uses optical fibers as the transmission medium and is capable of carrying the total domestic inter-exchange (IX) traffic.

- Section 5 establishes the traffic model upon which the financial model is based. Based on both switched telephone traffic and private line services, the model creates a LATA-to-LATA traffic matrix for the total switched IX telephone traffic. The data from this matrix are then applied to four long distance backbone network configurations consisting of 11, 15, 17, and 23 nodes. The numbers of voice circuits needed on each link connecting the access nodes of the backbone networks are then calculated. The model is also extended to analyze the regional access networks associated with each access node in each of the four IX backbone networks, i.e., the model includes transmission from the inter-exchange backbone network to the carrier's point-of-presence (POP) in the individual LATA.

- Section 6 provides the financial model for the four networks established in Section 5. This model establishes the costs of material and equipment, engineering, installation and testing so that a system cost analysis can be conducted for any network configuration and for projected traffic from 1985 to 2000. Cost calculations are carried out for first costs and annual costs. The model is divided into two major segments -- the inter-nodal and the LATA access -- for each prototype network. Each model segment is evaluated and analyzed separately, and the results are combined, making it possible to identify the various cost drivers and to note their effect on various levels of the total network.

- Section 7 presents summary statements about the evolution and impact of fiber optic networks. Comparisons are made between fiber optics, microwave, and satellites. Conclusions are also drawn concerning the current and potential capabilities and costs of fiber optic long distance networks.

U.S. LONG DISTANCE FIBER OPTIC NETWORKS: TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

Executive Summary

The past decade has seen the emergence of two major trends in the long-distance telecommunications market. First, the divestiture of AT&T and the move toward deregulation have stimulated intense competition in the long-distance transmission market. New companies, providing national and/or regional service, have joined more established carriers in an attempt to capture a share of this market. Second, fiber optics has emerged as a highly reliable and cost-efficient medium for long-distance transmission.

These two trends have been responsible for a tremendous amount of volatility in the long-distance communications market over the past few years. Uncertainty over the profitability, and even viability, of particular networks has been compounded by confusion over the appropriate role and niche of the various transmission media -- fiber optics, satellite, and microwave.

To provide proper guidance for NASA's advanced communications satellite technology programs, NASA Lewis Research Center contracted with IGI Consulting (NAS3-24682) to explore the application and evolution of fiber optic networks within the United States to the end of the century. This report is the result of that 14-month study effort.

The two volumes following the Executive Summary are divided into seven sections:

- Section 1 provides an overview of fiber optics technology, with particular emphasis on its advantages and on the major technological trends.

- Section 2 explores in greater detail the operation and capabilities of the fiber optics components that are critical for long-distance networks. Among the topics covered are the present state of the technology, R&D efforts, component costs, and forecasts of component development to the end of the century.

- Section 3 introduces the long-distance communications market with a discussion of the political and economic forces that are shaping the market.

- Section 4 presents detailed descriptions of the six national and sixteen regional long-distance carriers that are deploying fiber optics within their networks.

- Section 5 provides the methodology by which the long-distance traffic model was constructed. Quantitative results from the application of the traffic model to four networks are also presented.

- Section 6 applies a financial model to the four networks constructed in Section 5. Cost data are combined with multiple scenarios of technology development to identify the economics of long-distance transmission over fiber optics.

- Section 7 concludes the report with observations on the likely evolution of long-distance fiber optic networks.

The numbers in paragraphs throughout this summary indicate the relevant sections in the full report.

1.0 <u>OVERVIEW OF FIBER OPTICS TECHNOLOGY</u>

Fiber optics involves transmission of light through a glass filament. The <u>basic elements of an optical system</u> (1.1) are:

- conversion and modulation electronics and a light source;

- a transmission medium, consisting of an optical cable with one or more fibers;

- repeater sites to regenerate the lightwave signals;

- a light detector and receiving electronics;

- methods of connecting optical fiber cables to the electronics; and

- splicing.

Among the <u>advantages of fiber optic transmission</u> (1.2) for long-distance communications are:

- high bandwidth;
- low attenuation;
- small size and low weight;
- immunity from electromagnetic interference;
- security;
- compatibility with digital technology;
- high reliability;
- modular design; and
- ease of installation.

Fiber optics has evolved through three discernible generations of technology (1.3) over the past 20 years. The first generation operated at "first window" wavelengths of 850 nanometers (nm) through step-index fibers. The second generation entailed a shift to multi-mode graded-index fibers and transmission at 1300 nm. The present generation consists of single-mode fibers operating at wavelengths of up to 1550 nm.

The evolution of fiber optics has involved improvements in at least three performance indicators (1.4).

First, bit rates have tended to double every year. Commercially available systems currently transmit at 810 Mbps, and AT&T has stated its intention to produce a 1.7 Gbps system next year. Although transmission speeds will continue to rise, the rate of increase will slow. Our traffic and financial models are based on the following estimates of bit rate over the next fifteen years:

- 405 Mbps/565 Mbps in 1985
- 810 Mbps/1.7 Gbps by 1990
- 1.7 Gbps/4.0 Gbps by 1995
- 4.0 Gbps/8.0 Gbps by 2000

The second trend has been an increase in unrepeatered transmission distances. Although the use of long-wavelength fibers could potentially result in transcontinental unrepeatered transmission, we believe that development to be unlikely before the end of the century. Instead, we project commercial transmission distances of up to 100 kilometers in 1990, 200 kilometers in 1995, and 320 kilometers in 2000.

Finally, there has been a trend toward operation at longer wavelengths. Again, despite intense work on fibers that transmit in the far infrared, it is unlikely that long-distance carriers will abandon their existing investment in favor of these new fibers. We anticipate, therefore, that operating wavelengths will remain in the "third window" of 1550 nm.

2.0 FIBER OPTIC COMPONENTS FOR LONG HAUL SYSTEMS

Components that are critical to the operation of a long-distance fiber optic network include: optical fibers, cables, light sources, detectors, multiplexers, and switches.

Optical fibers (2.1) consist of two concentric layers: the core and the cladding. Light travels down the core of a fiber through total internal reflection. Single-mode step index fibers are the kind used in long-distance transmission because they minimize signal dispersion and increase bandwidth.

Research and development on fibers (2.2.5) is focusing on three areas. First, with the attenuation of silica fibers having reached their theoretical limit, researchers are developing new fiber materials that can transmit at longer wavelengths (1.6 to 10 microns). Prime candidates are a class of fibers made of heavy-metal fluorides. Second, with the quality of silica fibers reaching very high levels, work is being conducted on increasing production efficiencies, i.e. deposition rates, drawing speeds, and yields. Third, dispersion-shifted and dispersion-flattened fibers are being developed that allow for better performance at longer wavelengths.

We anticipate that fiber prices will continue to fall, reaching close to 12 cents per cabled fiber meter by 1995. At the same time, bandwidth of fibers will increase, approaching 1000 GHz-km in 1995 (compared with approximately 100 GHz-km today).

The technology of cables (2.3) is relatively mature, but developments are occurring in two areas that could have an impact on long-distance networks. First, longer cable lengths are being produced, which could reduce the time and costs associated with construction. Also, new ribbon designs are making splicing easier, again with a positive impact on construction time and costs.

Light sources (2.4) for long-distance networks are primarily laser diodes, which offer advantages over light-emitting diodes in terms of bandwidth, operating wavelength, spectral linewidth, launching power, and beam shape.

Research and development on lasers (2.4.3) is being done in a number of areas. Distributed feedback lasers narrow the spectral linewidth of a laser and emit light stably at a single frequency wavelength when modulated at high speeds. New production processes, such as metallorganic chemical vapor deposition, promise lower-cost devices and an increase in manufacturing yields. Work is also proceeding on the use of light-emitting diodes with single-mode fibers. Finally, higher power output is being achieved, while required drive current is being reduced.

One of the least glamorous of fiber optic components, detectors (2.5) are also receiving attention from component designers and engineers. Research is underway to develop new materials (especially InGaAsP) that have a greater spectral response at longer wavelengths. Coherent detection systems are being investigated as a means of increasing receiver sensitivity and selectivity. Analogous to frequency modulation in radio, coherent detection could result in a potential 15 to 20 dB improvement in sensitivity.

Wavelength division multiplexing (WDM) (2.6) offers a means of increasing information capacity by combining optical beams of different wavelengths on the same fiber. Originally used by AT&T on its Northeast Corridor route, WDM has not been used since by AT&T or any other carrier. The primary reason for this disfavor is the fact that the present rate of increase in transmission speeds will more than match the demand for bandwidth. Compared to other means of increasing bandwidth, WDM is cost-ineffective.

Although work is proceeding on optical switching (2.7), it is unlikely that it will be developed or implemented before the turn of the century.

Whatever the specific outcomes of R&D efforts on individual components, its is clear that the overall result of technology development will be higher bit rate systems at lower cost. The most realistic projection of technology development would entail:

- Bit rates of 810 Mbps/1.7 Gbps by 1990, 2.4/4.0 Gbps by 1995, and 4.0/8.0 Gbps by 2000.
- Introduction of coherent detection and narrow linewidth lasers by 1990.
- Repeater distances of up to 100 kilometers by 1990, 200 kilometers by 1995, and 320 kilometers by 2000.

3.0 FIBER OPTIC LONG DISTANCE SYSTEMS

The long-distance service market, defined as inter-LATA communication traffic, is growing approximately 7.8 percent annually. It is projected that revenues will climb from $57.6 billion in 1985 to $78 billion in 1989.

To service this traffic, a number of long haul fiber optic networks are being implemented. If constructed as planned, these fiber optic networks will cover over 60,000 route miles. Over one-third of these route miles have been cutover. If construction schedules are maintained, this percentage will climb to over 75 percent by the end of 1986.

A major impetus for this competitive situation was the divestiture of AT&T and deregulation (3.2). Over the past few years, 5 national and 16 regional companies have initiated or expanded their networks (Exhibit 1). One strategy being used by all of the carriers in their attempts to gain a competitive edge is the deployment of fiber optics in their networks (3.3).

EXHIBIT 1

NETWORK	ANNOUNCED* LENGTH (MI)	MAJOR OWNERS	SUPPLIERS	FIBER COUNT	BIT RATE	ESTIMATED COST	LATEST ESTIMATE OF TOTAL CUTOVER MILES
NATIONWIDE:							
AT&T	10,200	AT&T	AT&T Technologies, Philips, R-C**, Telco Systems, NEC	24	40, 405, 417, 565	several $100 million	5,200
MCI	7,000	MCI	Siecor, Northern Telecom, R-C, Fujitsu	6, 22, 44***	405	$600-700 million	2,500
NTN:							
Consolidated Net	730	Consolidated Communications	Northern Telecom, R-C	12	565	NA	300
LDX Net	2,200	LDX Group	Ericsson, AT&T Tech., Pirelli, Siecor, Fujitsu	24	565	$110 million	600
LiTel	1,600	Several Private Investors****	Pirelli, Northern Telecom, SAT	18	140-565	$77-85 million	675
Microtel	1,300	Microtel	Ericsson, NEC, ITT	10	405	$60 million	731
SouthernNet	1,500	E.F. Hutton and Independent Telcos	Siecor, AT&T, Ericsson, NEC	10	405	$70 million	331
Southland Fibernet	330	Southland Communications	Ericsson, NEC	10	405	NA	272
Wiltel	3,500	Williams Co./TS&S	Siecor, NEC	10	405	$100 million	214
U.S. Sprint	23,000	GTE/U.S. Telecom	Ericsson, General Cable, Siecor, Fujitsu, Stromberg Carlson	6-32***	565	$2-4 billion	6,200
REGIONAL:							
Bandwidth Technologies	300	Optinet, Inc.	Northern Telecom	18	565	$21 million	100
Digi-Net	900	Private	AT&T Tech., Northern Telecom	32	405	$65 million	550
Electra	550	Cable & Wireless/MKT Railroad	Fujitsu, Telco Systems, AT&T Tech.	16-24***	405	$50 million	550
Indiana Switch	733	27 Independent Telcos/ U.S. Switch	Not Announced	6-22 (est)	560	$23 million	0
ICC	109	ICC	Not Announced	25-47***	140	$19.9 million	0
Lightnet	5,000	Southern NE Telephone/ESX Corp.	AT&T Tech.	38-48***	90-417	NA	700
Mutual Signal	404	Walker Telecommunications	Siecor, NEC	10	565	$30 million	0
Norlight	550	Five Midwest Utilities ****	Alcoa/Fujikura, Philips, Ericsson	12	130-565	$33 million	0
RCI	580	Rochester Telephone Corp.	AT&T Tech., Fujitsu	24	405	$90 million	580
TOTALS:	60,486					~$4,902.9 million	20,503

NA = Not Announced
* rounded
** R-C = Rockwell-Collins
*** varies from different segments
**** detailed in profile, too numerous to list

As networks become operational, carriers are faced with the challenge of gaining customers to utilize their services. One network has already fallen by the wayside. Others have merged, and still others have agreed to share capacity rather than build their own overlapping links. As the shake-out continues, a number of forces and factors will shape the entire industry.

One trend is toward consolidation (3.4.1). For example, U.S. Telecom and GTE Sprint, the third and fourth largest alternative carriers, have merged to become U.S. Sprint. The National Telecommunications Network is a consortium of seven regional long haul carriers that have agreed to interconnect their networks. Exhibit 2 shows the trend toward consolidation.

With so many networks competing for customers, an important element in a company's success will be the first-in-ground (3.4.2) factor. Many analysts and carriers believe that the first operational network in a given area will have an unbeatable headstart in gaining customers. One reason for Fibertrak's demise was its late construction start.

The end of the decade should witness at least a five or six fold increase in long distance communications capacity (3.4.3) in the U.S., perhaps even topping 10 billion circuit miles. The question now arising is whether there is in fact a need for all of this capacity, especially given the rise in transmission speeds. Proponents of the new networks argue that the increase in capacity will lower costs and stimulate increased demand.

Rights-of-way (3.4.4) have proven to be a valuable commodity in the market as they provide the operator legal access to a cable route. Some railroads have taken advantage of their rights-of-way by establishing joint ventures with communications companies.

Some companies are establishing their niche in the market by exploiting secondary markets. Many of the regional networks, for example, see an opportunity in the delivery of fiber optic serivces to smaller cities that are ignored by the larger carriers.

After a year of frenzy, the fiber optic long distance market is showing signs of slowing down. In 1984 and 1985, 24 companies had announced plans to initiate or expand their national and regional networks. By the end of 1985, consolidation and shake-out had begun. The most likely scenario (3.5) calls for the continuation of present trends -- mergers, sharing of capacity, and the targeting of opportunities by smaller regional networks. Expansion will be incremental, with fiber otic spurs and connections being made as demand warrants. Although the industry will likely never reach a steady state, it will not be as explosive as it has been over the past two years.

EXHIBIT 2

CONSOLIDATION OF LONG HAUL FIBER OPTIC NETWORKS

1985 Announced Networks	1986 Announced Networks	Possible 1988 Scenario	Possible 1990 Scenario
Allnet	ALC Communications	ALC Communications	Possible Merger
AT&T	AT&T	AT&T	AT&T
Bandwidth Technologies	Bandwidth Technologies	*may have to merge with	
Digi-Net	Digi-Net	larger network to survive	
Electra	Indiana Switch	** U.S. Switch	U.S. Switch
Fibertrak	Institutional Communica-		
GTE Sprint	tions Company		
Indiana Switch	Lightnet	Lightnet	Lightnet
Institutional Communica-	MCI	MCI	MCI
tions Company	NorLight	*** Norlight	Norlight
Lexitel	U.S. Sprint	U.S. Sprint	
Lightnet	Electra	National Telecommunica-	National Telecommuni-
MCI	Mutual Signal	tions Network	cations Network
Mutual Signal	Rochester Communications		
NorLight			
Rochester Communications			
U.S. Telecom			
Consolidated Network	National Telecommunications		
LDX Net	Network		
LiTel			
Microtel			
SouthernNet			
Southland FiberNet			
Wiltel			

* may not have capital or marketing clout to survive alone

** now that FCC has approved Indiana Switch, company plans to try to expand concept to other states

*** pending FCC approval, approval could also stimulate networks of similar nature

4.0 FIBER OPTIC LONG HAUL NETWORKS

This section provides details on the development, configuration, services, suppliers, and strategies of all of the national and regional long-distance fiber optic networks.

The national networks (4.1) discussed are:

- ALC Communications Corporation
- American Telephone and Telegraph (AT&T)
- Fibertrak
- MCI
- National Telecommunications Network (NTN)
- U.S. Sprint

The regional networks (4.2) are:

- Bandwidth Technologies
- Consolidated Network, Inc.
- Digi-Net
- Electra Communications
- Indiana Switch
- Institutional Communications Company
- LDX Net
- Lightnet
- LiTel
- Microtel
- Mutual Signal
- NorLight
- Rochester Communications, Inc.
- SouthernNet
- Southland Fibernet
- Wiltel

5.0 ADVANCED FIBER OPTIC NETWORK CONCEPT DEFINITION

For the purpose of evaluating the cost effectivness of fiber optic long distance networks under present and projected traffic and technological conditions, an operational model of such networks was developed (5.1). The most important ingredient of this model is the traffic between nodes of the network.

In the post-divestiture environment, all the long-distance traffic is defined as interexchange, or inter-LATA, traffic. This is provided by the unregulated and competing inter-exchange, or IX, carriers. The concept of a LATA (Local Access and Transport Area) was defined during the divestiture proceedings as the franchised local service area(s) of the divested Bell and independent local telephone companies, generally referred to as the exchange carriers. Consequently, the basic traffic data needed for the long-distance network operational model have to be defined as to and from LATA-to-LATA traffic for the busy hour of the day.

Since nearly 90 percent of the long distance revenue is derived from switched voice grade traffic, the model is based primarily on that traffic, to which is added separately the best estimate for special services in the form of dedicated or private line services of all kinds.

The methodology for calculating the traffic originating in each LATA is based on LATA population, the number of user access lines in each LATA, and the average busy hour (BH) traffic (in hundred call seconds [CCS]) originating from each user access line. This methodology, therefore, first requires the determination of the LATA population from the Metropolitan Statistical Area (MSA) and non-MSA populated as reported by the 1983 census data and the geographical definition of each LATA.

The next step involved the determination of the number of user access lines in each LATA. This was accomplished by using 1984 U.S. Telephone Association (USTA) statistics on the number of user access lines in each state, and 1983 Census Bureau figures on state population. This ratio yielded the number of access lines for the state's population. The ratio was then multiplied by the previously calculated LATA population and represents the number of access lines in each LATA.

1983 local area traffic statistics indicate that about 40 percent of all traffic originating in a local exchange is addressed to destinations outside its own exchange area, and about 10 percent of all traffic is addressed to another LATA. Other statistics show that 80 percent of all toll calls are inter-LATA traffic. Using 1983 FCC statistics on toll calls, this would also indicate that 10 percent of all originating local traffic results in inter-LATA traffic. The average annual growth of the inter-LATA traffic is now about 11 percent, including population growth. Since the geographical distribution of the population changes little within a 10-year span, it is reasonable to assume a uniform growth of traffic nationwide. Compared with 1983, the inter-exchange traffic can be projected to have grown by a factor of 1.2 in 1985, will grow by a factor of 2.0 in 1990, by a factor of 3.4 in 1995, and by a factor of 5.7 by 2000.

From the total originating traffic in a LATA, the traffic to a particular destination was calculated from the total inter-LATA (IX) traffic multiplied by the fraction of the population in the receiving LATA in proportion to total U.S. population, i.e. from the ratio of destination LATA population to total population.

The basic population data and corresponding national long-distance telephone network data are summarized in three exhibits which represent the primary data base for the modeling process:

- The 1983 US Census data by MSA ranking with the related LATA numbers, NPA (area code), and inter-exchange (IX) access point definitions in terms of common language location indicator (CCLI) with its coordinates;

- The 1983 state and LATA population data derived from the preceeding table sorted by LATA number in geographical order, and the traffic related data derived according to the previously described methodology; and

- A summary of total 1990 projected LATA originating traffic (in CCS) and the inter-exchange (IX) traffic (in Erlang) together with access point information. Traffic for the years 1985, 1990, 1995 and 2000 are related to the each other by the traffic growth figures discussed earlier.

Using the primary data base and applying the methodology described before, the results of the LATA-to-LATA traffic calculations are summarized in two tables:

- A table summarizing the distances in miles between any two of the 188 LATAs. (N.B. This exhibit [5.4] is printed in three parts to include all 188 x 188 [or 35,344] data points.)

- A table summarizing the projected 1990 LATA-to-LATA traffic matrix calculations containing the" from" (horizontal-to-vertical) and "to" (vertical-from-horizontal) traffic data in Erlang (Exhibit 5.5, also printed in three parts).

Data provided in the main text provide the necessary and sufficient data base for applying the traffic model to cost calculations of any network configuration consisting of any number of selected nodes. This exhibit also includes the access point identifications and location coordinates allowing all network configuration calculations to be performed from that data base.

Before the traffic model can be applied to a particular network, it is necessary to define its configuration in terms of access nodes and their connectivity. Network design is customarily based on placing nodes nearest the heaviest traffic centers, with some considerations for the primary future growth regions and reasonable routing possibilities.

After selecting the nodes, it is then necessary to decide on the connectivity. Demographic considerations will have the highest priority since access lines, and consequently traffic, follow population patterns very strongly. Therefore, there have to be north/south routes on both coasts and, for redundancy, at least two east/west routes with cross-connecting routes between them, also dictated by demographics.

Four networks -- consisting of 11, 15, 17, and 23 nodes -- were constructed. The first (Exhibit 3), an <u>11-node network</u>, included:

- New York
- Philadelphia
- Washington, D.C.
- Atlanta
- Dallas
- Phoenix
- Los Angeles
- San Francisco
- Denver
- Chicago
- St. Louis

To calculate the traffic from each node to any of the other nodes, the LATA-to-LATA traffic matrix is used in conjunction with the list of LATAs served by each node in a from/to summation of traffic between any two nodes, thereby defining a link in the network. Total traffic figures represent that part of the total inter-LATA traffic that is carried by the network, in this case, 2,530,757 Erlang during the busy hour. Roughly 19 percent is not included, representing the intra-regional traffic mentioned before.

Calculations for the <u>15-node network</u> (Exhibit 4) follow exactly the same procedure as for the 11-node network. Eleven nodes are identical with the ones in the previous network. Miami and Boston are such heavy traffic centers that they were made separate nodes. Similarly, Chicago turned out to be a heavy traffic center and was split off from Minneapolis. Seattle was added as a node to open up a northerly east/west route. As before, the intra-nodal (regional) traffic is excluded in the total busy hour figures. In this network, 85.34 percent of busy hour traffic -- 2,668,828 Erlang -- is included.

Following the same procedure, a <u>23-node network</u> (Exhibit 5) was selected. Florida and Texas were given two nodes each, Oklahoma City and Kansas City were added to the middle part of the country, and Detroit, Cleveland, Pittsburgh, and Buffalo were added in the northeast. Because of the larger number of nodes, the traffic is somewhat more distributed, at the price of more and shorter links. Not surprisingly, the resulting total originating busy-hour inter-exchange traffic carried by the network -- 2,914,262 -- is up to over 93 percent of the total.

EXHIBIT 3

Map of 11-Node Network Configuration

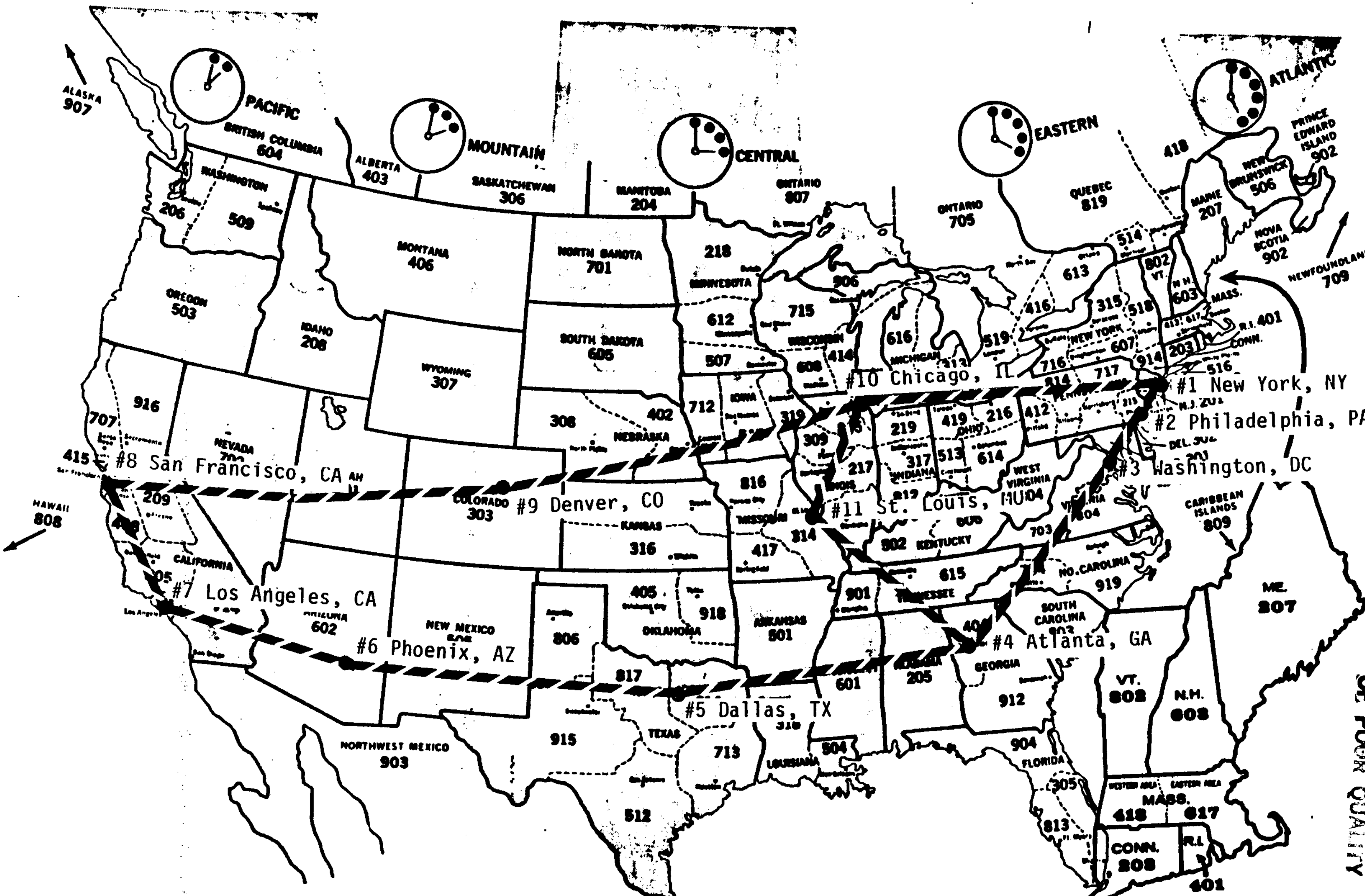


EXHIBIT 4

Map of 15-Node Network Configuration

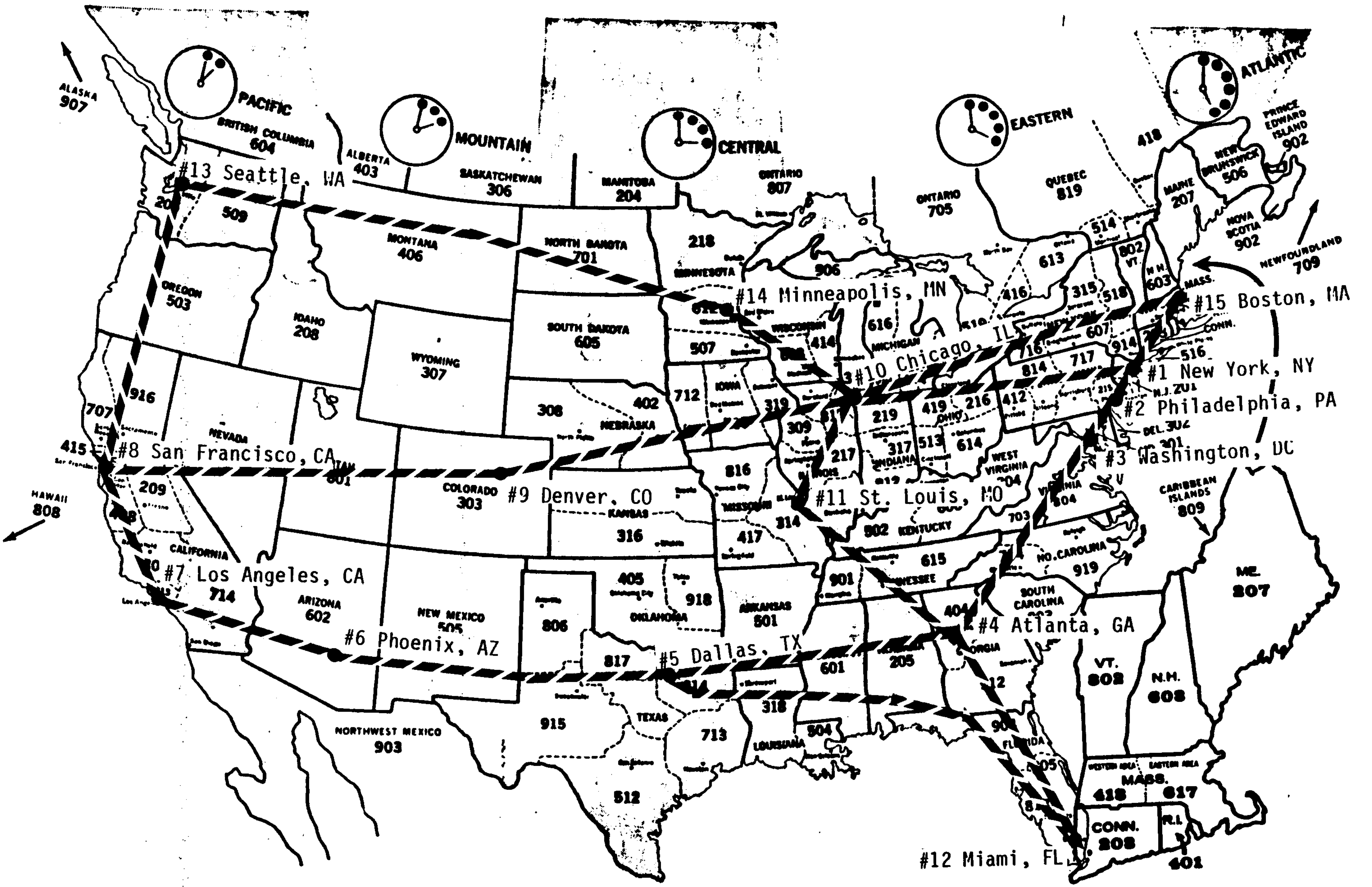


EXHIBIT 5

Map of 23-Node Network Configuration

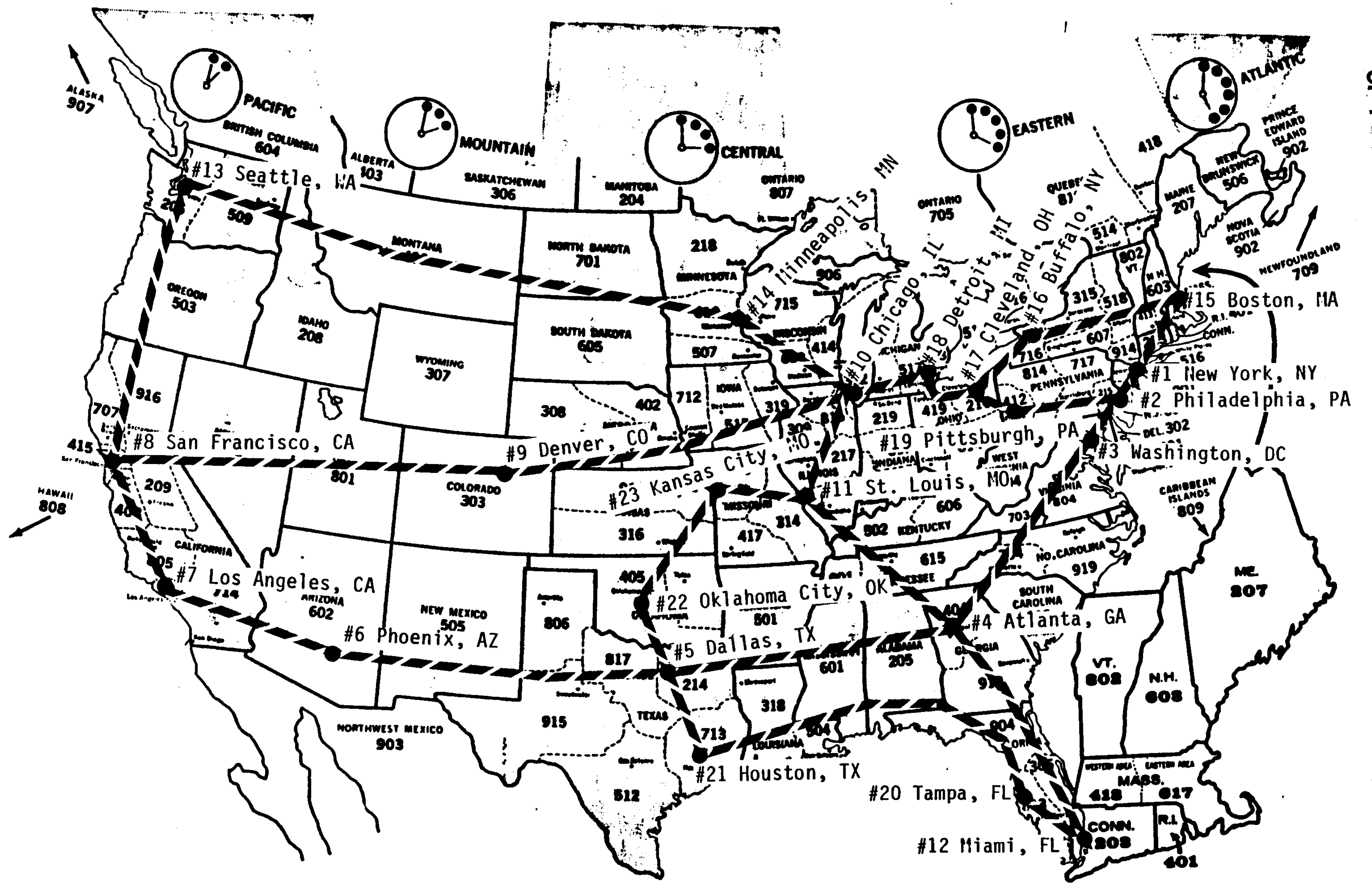
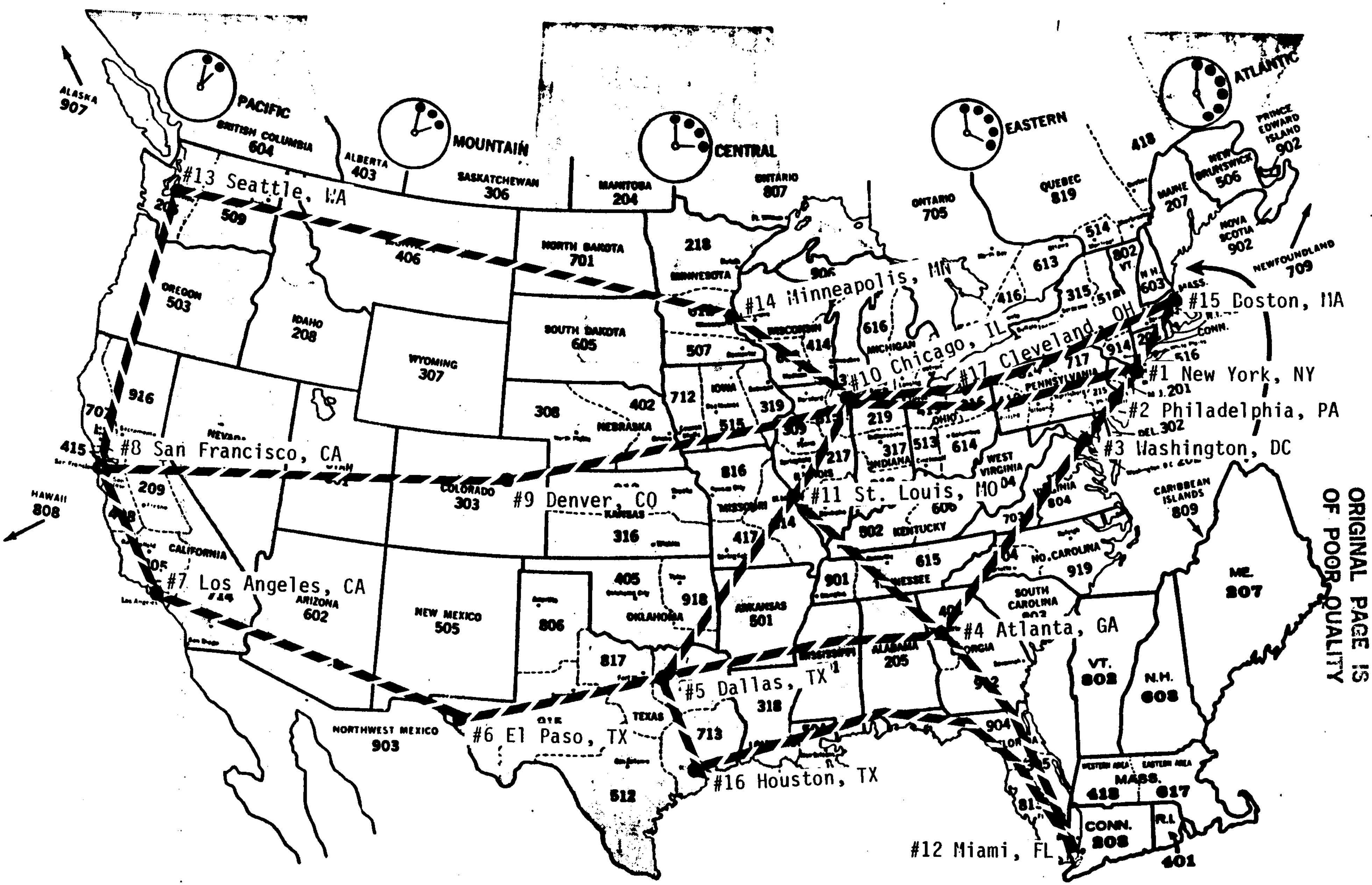


EXHIBIT 6

Map of 17-Node Network Configuration



Using basically the same method, a more traffic-balanced 17-node network (Exhibit 6) was defined. This meant a reassignment of LATAs to a limited number of nodes with resulting total originating traffic volume closer to the average per node. This configuration is closest to the 15-node network analyzed before with additional nodes in Cleveland (#17) and Houston (#16), and with an additional link from Dallas to St. Louis, and, of course, to the new nodes.

If compared with the other network configurations, it may be seen that the 17-node node-to-node traffic is also more evenly distributed. For example, in the 15-node network, the highest node traffic reaches almost 80,000 Erlang, and the lowest is just over 1000 Erlang. By contrast, the maximum link in the 17-node network is 30,000 Erlang, with the minimum having about 2000 Erlang. The 17-node network carries 90.51 percent -- approximately 2,830,397 -- of the total inter-exchange traffic.

The traffic model used to analyze these four long distance backbone networks is based on the busy hour (BH) traffic entering and leaving the nodes. However, the analysis does not account for the regional access traffic data between nodes and the individual LATAs served by each node. To add the necessary data for the regional access network around each node in the backbone network requires an extension to the individual LATA level. By using the definition of LATAs connected to each node, the traffic originating from and terminating in each LATA is derived together with mileage data for each access link constituting the regional access network, thus extending the model to the individual LATA level. Again, this procedure is applied to the four backbone network configurations.

Busy hour (BH), or peak hour, traffic data are needed for both the backbone and regional access network analysis since this is what determines the required number of circuits in the network used for cost calculations. However, for easier comparison with other transmission services, a conversion from BH traffic to call-minutes is introduced. This conversion is accomplished by analysis of the average diurnal variation of hourly calling rates and the corresponding daily average. The ratio of the prevailing BH traffic to daily average results in the desired conversion factor.

Finally, the average cost of local exchange links within a LATA was estimated from the operational reports of local exchange carriers on the yearly call-minutes of inter-exchange traffic and the total revenue collected for these services. The records of the seven regional former Bell Operating Companies indicate for these end links an average cost of $.115 to $.187 per call-minute. This cost, when added to the backbone and regional access network cost, represents the average end-to-end user cost per call-minute.

6.0 FIBER OPTICS SYSTEM FINANCIAL MODEL

Using information obtained from the communications common carrier industry, from equipment manufacturers, and from several specialized common carriers, representative first cost and continuing operating expense data have been developed for a nation-wide fiber optic communications system network. The inter-nodal circuit links are sized using the traffic estimates, and the cost estimates for the financial model are based on the traffic loading estimates.

The FO transmission system financial model is based on the prototype 11-node, 15-node, 17-node, and 23-node transmission networks developed in the network concept definition. The model has been divided into two major segments, the node network and the LATA access network, for each prototype network. Each model segment is evaluated and analyzed separately, and the results are combined, making it possible to identify the various cost drivers and to note their effect on various levels of the total network.

The following average cost data are used in the financial models:

		Annual Cost as % of First Cost	
	First Cost	Oper/ Maint	Ad Val. Taxes
24-fiber cable	$ 14280/mile	2.5%	2.25%
24-fiber cable splicing (5-km lengths)	$ 966/mile	2.5%	2.25%
48-fiber cable	$ 28560/mile	2.5%	2.25%
48-fiber cable splicing (5-km lengths)	$ 1932/mile	2.5%	2.25%
96-fiber cable	$ 54058/mile	2.5%	2.25%
96-fiber cable splicing (5-km lengths)	$ 3622/mile	2.5%	2.25%
Cable installation	$ 15840/mile	2.5%	2.25%
405 Mbps Trans/Rcvr	$ 18000	5.0%	2.30%
405 Mbps Line Repeater	$ 12000	5.0%	2.30%
Terminal/Repeater Bldg, Power	$150000	3.0%	2.10%
Controlled Environmental Vault, Power	$ 35000	3.0%	2.10%
M13 Multiplexer	$ 15000	5.0%	2.30%
T-1 Terminal (24 2-way Voice Channels)	$ 5880	5.0%	2.30%

To determine the total annual costs associated with each model, accelerated write-off is assumed for the fiber optic cable (10-year life) and the associated electronic equipment (5-year life). The financial structure assumes an objective return on investment (ROI) of 15 percent annually, a corporate debt ratio of 50 percent, and an average interest rate on debt capital of approximately 14.4 percent. Overall income tax rate is estimated at 50 percent.

A number of technological assumptions were made in developing and costing the various network models. These assumptions, listed below, are consistent with the technology forecasting presented in Sections 1.4 and 2.7.

1983 Technology

- 405 Mbps line transmission rate
- 40 kilometer (25 mile) line repeater spacing
- 48-fiber fiber cable

1985 Technology

- 405 Mbps and 565 Mbps line transmission rates
- 565 Mbps equipment cost = 1.1667 x 405 Mbps equipment cost
- 40 kilometer (25 mile) line repeater spacing
- 48-fiber and 96-fiber cables

1990 Technology

- 810 Mbps and 1.7 Gbps line transmission rates
- 810 Mbps equipment cost = 1.75 x 405 Mbps equipment cost
- 1.7 Gbps equipment cost = 3.5 x 405 Mbps equipment cost
- 85 kilometer (50 mile) line repeater spacing
- 48-fiber and 96-fiber cables
- ADPCM available to double voice channel capacity
- MX3 for ADPCM cost = 1.75 x basic MX3 cost

1995 Technology

- 1.7 Gbps and 4.05 Gbps line transmission rates
- 1.7 Gbps equipment cost = 3.5 x 405 Mbps equipment cost
- 4.05 Gbps equipment cost = 8.75 x 405 Mbps equipment cost
- 170 kilometer (100 mile) line repeater spacing
- 48-fiber and 96-fiber cables
- ADPCM available to double voice channel capacity

2000 Technology

- 4.05 Gbps and 8.1 Gbps line transmission rates
- 4.05 Gbps equipment cost = 8.75 x 405 Mbps equipment cost
- 8.1 Gbps equipment cost = 17.5 x 405 Mbps equipment cost
- 250 kilometer (150 mile) line repeater spacing
- 48-fiber and 96-fiber cables
- ADPCM available to double voice channel capacity
- MX3 for ADPCM cost = 1.75 x basic MX3 cost

Technological assumptions made in developing and costing the inter-LATA circuit network models are as follows:

Common Assumptions

- 405 Mbps (6048 voice circuits) line transmission rate (1983-2000)
- 24 fiber FO cable (1983-2000)

1983 and 1985 Technology

- 40 km (25 mile) line repeater spacing

1990, 1995, and 2000 Technology

- 85 km (50 mile) line repeater spacing
- ADPCM available to double 405 Mbps transmission voice channel capacity to 12,096 circuits
- MX3 for ADPCM cost = 1.75 x basic MX3 cost

Because mileage between nodes is calculated on a point-to-point basis using V and H coordinates, an additional mileage allowance is made to account for indirect fiber optic cable routes between nodes and between nodes and POPs. This is covered by the Mileage Factor, which allows for 15 percent additional mileage for inter-node circuits to account for indirect cable routing, and makes the assumption that the shorter LATA access circuits will be 35 percent longer than the point-to-point distance between nodes and POPs.

Also, traffic data have been calculated using 1990 estimates for AT&T inter-LATA voice traffic only. Adjustments for private line and other common carrier inter-LATA traffic and for total traffic variations in the different study years, using a uniform average annual voice traffic growth rate of approximately 11 percent, have been made as follows:

Year	Growth Factor	Private Line, OCC Factor	Traffic Factor
1983	.1	.135	.5675
1985	.12	.14	.684
1990	.2	.14	1.14
1995	.34	.15	1.955
1995 + 30%			2.5415
1995 - 30%			1.3685
2000	.57	.15	3.2775

where Traffic Factor = (1 + (PL, OCC Factor))(Growth Factor/1990 Growth Factor). For 1995, a parametric analysis was employed which assumed a variation in traffic of plus or minus 30 percent.

For each of the prototype networks studied, traffic data and cost data corresponding with the technological assumptions for each year have been applied.

In terms of comparative first cost, the cost of installed fiber optic cable is the greatest single item for the lower-speed digital fiber optic systems, with the effect of greater line repeater spacing and higher circuit-capacity electronic equipment increasing as it leads to a reduction in overall fiber optic cable cost.

In terms of annual cost, a similar situation prevails with a larger share of the annual cost being charged to the electronic equipment, mainly because of the shorter depreciation lives.

First cost and annual cost data for the internodal networks and for the LATA access networks are combined for each prototype network, broken down by basic circuit arrangement (i.e. line transmission rate and number of fibers in the FO cable).

The combined annual cost data have been converted into revenue requirements to assist in estimating the user charges necessary to operate each of the prototype networks profitably. In a practical operating situation, the objective is to generate sufficient revenue to pay capital and operating costs, and to realize an objective return on investment. This is the basis for the concept of "revenue requirements". Annual costs can be converted to revenue requirements; that is, the amount of revenue that must be realized from the investment in order to meet expenses and earn an after-tax return on the investment. Under these circumstances, the revenue requirements can be translated into the rates that must be charged to make the investment meet objectives.

Having estimated total annual revenue requirements, it is possible to estimate the average revenue requirement per call-minute of use. The traffic data used for designing the prototype network models is "busy-hour" traffic only. This is an estimate of the total traffic carried by the network during the busiest hour of the busiest day. Obviously, traffic is carried in varying amounts during the remaining hours of the day. Based on empirical data published by various telephone organizations, the average network circuit will be in use 642 minutes or 10.7 hours per average 24-hour day. Multiplying the usage per circuit by the total amount of traffic load (measured in Erlangs) provides the total call-minutes per day. From this, the average revenue requirement per call-minute is calculated.

It is noteworthy that the average revenue requirement per call-minute is less than one cent (ranges from $.004 to $.008) for any traffic load or configuration of the combined internodal and LATA access network models.

Two basic network components are under analysis, and each has somewhat different characteristics. The internodal network model consists of long and relatively large circuit groups interconnecting the nodes. The LATA access network model envisions smaller circuit groups, ranging in average length from short to relatively long, depending on the node, which interconnect the POP in each LATA with its "home" node.

In terms of both first cost and annual cost of the internodal network, the cost of installed fiber optic cable is the largest single item for the lower-speed digital FO systems used for the smaller traffic loads. As the traffic load increases, and as forecast technological advances are realized, the use of greater line repeater spacing and higher-speed, higher circuit-capacity electronic equipment are effective in leading to a decrease in overall FO cable cost.

The annual cost of the FO cable is reduced proportionally more than the annual cost being charged to the electronic equipment, mainly because of the shorter depreciation lives of the electronic equipment.

As the circuit capacity of the FO cable systems increases, the major cost driver changes from the FO cable to the M13 multiplexers, which change the digital line rate from the DS-1 level (1.544 Mbps) to the DS-3 level (44.736 Mbps). Further increases in the line transmission rate take place in the FO transmission terminal equipment. As the capacity of the FO systems increases, the first cost of the FO cable, FO transmission equipment, and associated structures falls to a low in the vicinity of 20 percent of total first cost and 15 percent of total annual cost.

The <u>LATA access network</u> uses lower speed FO systems throughout, with an increase in line repeater spacing being allowed as the traffic load increases (1990 onward). Because of the area served by each node in the various network configurations, no general comments can be made about cost drivers for the smaller traffic loads. In some instances, FO cable costs dominate; in others, multiplex (T1 and M13) costs dominate; and in some cases, they are about equal. The average circuit length affects the FO cable investment, while the number of voice circuits affects the multiplex investment.

As the traffic loads increase, however, the multiplex becomes the undisputed cost driver in the LATA access network, regardless of the node involved.

When the internodal network and the LATA access network models are combined, the cost driver situation does not change significantly. At lower traffic loads, the FO cable cost dominates. This changes as the traffic load increases, and the multiplex becomes the dominating cost element.

The major cost driver for the larger traffic loads, the T1 and M13 multiplexers, are equipment items that could also be required on competitive transmission systems.

Fiber optic cable is not likely to experience any dramatic price reduction in the next 15 years, and the costs of splicing and installation are likely to increase at a rate corresponding to the the Consumer Price Index (CPI). Fiber optic terminal and line equipment are likely to come down in cost in terms of the circuit-carrying capacity of a single fiber. This cost item is likely to decline with the cost per circuit dropping by 50 percent every five years and the circuit capacity per fiber doubling every five years.

A considerably less optimistic set of cost assumptions was used for the fiber optic terminal and line equipment in the financial models, but since the major cost driver becomes the M13 multiplexers as the system capacity increases, cost reductions in the M13 multiplexers will have a much greater effect that changes in the fiber optic line and terminal equipment costs.

Several possible <u>sensitivity analyses</u> are possible, in addition to the sensitivity range provide by variations in traffic load that is built into the detailed study covered in this report. Three basic areas are analyzed briefly: network costs without multiplex, network costs using only 1980s' technology, and network costs under regulated operating conditions.

In each of the network component studies and in the combined network study, the cost of multiplex is significant and dominates as the traffic load increases. Since multiplex equipment is likely to be required in any system design, it is possible that the multiplex could represent a common cost among competitive designs. Thus, the combined network study results are shown for each network configuration with multiplex costs eliminated, with first cost per circuit and revenue requirements per circuit ranging from roughly 20 percent to 70 percent of the corresponding normal cost. As might be expected, the FO cable represents the major cost driver in this situation, although the cost per mile and the cost per circuit is fairly flat over the range of traffic loads. This leads to the conclusion that installation of high-capacity FO links is the most cost-effective solution, starting with the one-time installation of large-size FO cables, and adding electronic equipment as the demand increases.

Eliminating multiplex from the financial considerations reduces the revenue requirement per circuit per minute from $.004 to $.008 per minute for the normal assumptions to $.001 to $.005 per minute.

A number of technological assumptions have been made for both the internodal network and the LATA access models. These assumptions are discarded and it is assumed that the following 1980's technology applies throughout:

<u>Internodal Network</u>

- 405 Mbps line transmission rate (9 DS-3 or 6048 voice circuits)
- 40 km (25 mile) line repeater spacing
- 48 fiber or 96 fiber FO cable

<u>LATA Access Network</u>

- 405 Mbps (6048 voice circuits) line transmission rate
- 24 fiber FO cable
- 40 km (25 mile) line repeater spacing

Results of these studies indicate that the effect of 1980s' technology on first cost and revenue requirements will be to increase them by up to 38%, depending on the year and the network configuration.

In terms of revenue requirements per circuit per minute of use, the 1980s' technology assumption maintains the range from $.005 to $.008, only slightly higher than with the normal assumptions.

In reviewing the results, another cost-affecting factor should be considered. This is the service life, debt ratio, and ROI assumptions made in the financial models, which are appropriate for the recently-founded specialized and unregulated communications common carriers. If a regulated common carrier is assumed, it is likely that the fiber optic cable will have a 20-year service life, the associated electronic equipment will have a 12-year service life, the objective ROI will be 12.2 percent, the debt ratio will be 40 percent, and the average interest rate on debt capital will be approximately 10 percent. With these figures, the revenue requirements associated with the financial models will be revised downward by 20 percent to 30 percent.

In terms of revenue requirements per circuit per minute of use, the regulated rates assumption reduces the range from $.004 to $.008 for the normal assumptions to $.003 to $.006 per minute.

The fiber optic cable transmission networks of <u>two companies</u> have been analyzed as a means of injecting a practical and realistic view of actual system experience with costs. Only first cost data are available, some of which have been used in the financial models described earlier in this report.

The first company, Company A, is a relatively small operation having the following characteristics:

<u>COMPANY A</u>

Route-miles: 687 in service, total of 930 planned

Location: 2-state area

Initial construction: 405 Mbps system, 1 active, 1 standby

Average cable cross-section: 10 fibers

Average construction conditions: Easy

Financial: 100% equity capital, objective ROI = 15%

Specific first cost data:

- Fiber optic cable: $0.40/fiber meter; $6,437/mile
- Cable splicing: $700/splice; 3 splices/day; 10 fibers
- Underground conduit: $0.25/duct-foot; 6-way conduit @ $3/foot
- Controlled Environment Vault (CEV): $35,000 installed
- FO line repeater: $48,000 (redundant) plus $6000 for battery
- Drop/insert repeater: $180,000 redundant
- Fiber optic terminal: $120,000 (redundant)

The second company, Company B, is a sizeable company with a nationwide fiber optic cable network. Major characteristics are as follows:

COMPANY B

Route-miles: 2500 in service, total of 5500 planned

Location: Nationwide

Initial construction: 405 Mbps and 565 Mbps systems, planning 810 Mbps systems; 2 active, 1 standby

Average cable cross-section: Main routes: 22- and 44-fiber
Spur routes: 12- and 32-fiber

Average construction conditions: Moderate to difficult

Financial: 60% debt capital, objective ROI = 15%

Specific First Cost Data:

Fiber optic cable: $0.45/fiber meter
$15,933/mile for 22-fiber cable
$31,865/mile for 44-fiber cable
Cable installation: $2 to $3 per foot average, up to $50 per foot
Repeater housings: $150,000 per repeater site, all associated costs
FO line repeater: $9000 to $12,000, depending on OW/Alarm access
FO terminal: $2,000 per terminal per DS-3 port
$18,000 for 405 Mbps
$24,000 for 565 Mbps
M13 multiplexer: $8,000 to $15,000

Neither company has any reliable information concerning annual operating and maintenance costs, ad valorem tax rates, etc. that are necessary for the assembly of an Annual Cost study.

A representative cost analysis has been prepared for each company using their first cost data, typical system link lengths for each network, and industry averages for service lives, salvage values, operations and maintenace expense, and ad valorem taxes. In this way, estimates of overall first cost and annual cost, together with approximate system mileage costs, have been calculated.

In summary, the cost per link between the various nodes is dependent on two variables -- distance and number of circuits.

Long routes with high traffic volumes result in low cost transmission over backbone routes. The costs per circuit mile derived for the various networks, as low as they are, do not represent the optimal solution. By balancing the circuit load or changing the routing, even lower costs can be achieved. It is also important to note that cost assumptions for technology items were also on the conservative side; it is possible that lower prices for cable and electronic equipment could bring the costs down even further in the future.

7.0 IMPACT OF FIBER OPTIC SYSTEMS

Summary statements about the evolution and impact of fiber optic networks must consider a number of factors. These include comparison of fiber optics with other transmission media and the likely development of fiber optics technology.

Fiber optics, of course, is not the only transmission technology for long-distance communications. The other widely used media are microwave and satellites, each of which offers distinct advantages and disadvantages.

Microwave (as well as satellite) systems deploy radio waves which are open to interference, susceptible to interception by unauthorized persons, and subject to propagation fluctuations due to tropospheric variations. In addition, microwave is subject to the limited availability of the frequency spectrum. Microwave systems are already critically crowded, especially within metropolitan areas.

These disadvantages nothwithstanding, microwave is a very economical solution for transmission distances between 50 and 1500 miles and route cross sections of up to 1300 voice circuits or aggregate data rates of about 90 Mbps. For higher cross sections, the cost advantage extends to over 3000 miles.

Since microwave technology is already mature, it is not expected that its relative standing with the other two media will improve in the future; if anything, it will probably lose some ground. There are limited possibilities for new applications of very light-weight, small capacity, short-distance, point-to-point links in the local distribution area.

As an open-air medium, satellite communication is subject to many of the same problems as microwave: interference, interception, and propagation fluctuations. For geostationary satellites, the limited availability of frequency spectrum is characterized by a shortage of orbital slots above the continental United States, although the reduction of orbital slot assignments to 2 degrees should bring some alleviation.

Satellite communications are also subject to a round-trip propagation delay of about .25 seconds, not including any additional delay contributed by the equipment itself. This delay has no detrimental impact on TV and bulk data transmission, but it becomes highly objectionable in interactive communications such as data processing and telephony.

Although satellites are economically attractive for transmission over 1000 miles, the disadvantages imposed especially by propagation delay make it a poor choice for telephone common carriers. It is likely that satellites will find their niche in the transmission of TV signals for broadcasting stations or cable systems, and in the transmission of bulk data not requiring interactive responses.

The advantages of fiber optics have been discussed in Section 1.2. These advantages include:

- Potentially unlimited bandwidth;
- Low attenuation;
- Small size and weight;
- Immunity from interference;
- Security;
- Compatibility with digital technology;
- High reliability;
- Modular design; and
- Ease of installation.

The major advantages of fiber relative to microwave and satellite are that transmission over optical fibers is free from spectrum congestion and outside interference of any kind. Its potentially unlimited bandwidth and long repeaterless distances also make it the ideal medium for long haul transmission.

Like all terrestrial media, optical cables have the disadvantage of being locked into point-to-point connections of fixed routes with no mobility. Although this limits fiber's versatility somewhat, it still works admirably well for heavy backbone traffic in large long-distance networks.

Optical systems are economical against microwave systems for short distances, including the local telephone distribution plant. At the other end of the market, they are economical against satellite, particularly for route cross sections of 8000 voice circuits and over. Since fiber optic transmission systems have not yet reached their potential, we believe that further developments in optical technology will tilt the scales in favor of fiber optic at both ends of the market. By the criteria of quality of transmission, lack of interference, lack of delay, and low cost, fiber presents itself as a superior alternative to other media.

Fiber optics from its early beginnings has held the promise of being an exceptionally high quality medium. And for the reasons outline in the previous section, fiber optics is on its way to becoming a universal transmission medium. Technological developments over the past two decades have been phenomenal, and they show every sign of continuing for the indefinite future.

The recent rush to install fiber networks is one indication that fiber optics is the medium of choice for all of the domestic long distance communications carriers. While satellite and microwave will continue to occupy niches, these other transmission media are being replaced by fiber whenever and wherever economically feasible.

Revenue requirements per circuit for LATA-to-LATA links for each of the four model networks are less than one cent per call-minute ($.004 to $.008). This is much less than the end-user to end-user cost, which also includes charges for local distribution.

The relative ratios of the cost distribution for an average end-user to end-user connection are:

Backbone Inter-Nodal Network	1.0
Lata Access Network	2.1 to 4.0
Local Distribution Network	80.0 to 120.0

The long distance (inter-nodal) portion of the connection therefore represents a very small proportion of the total cost.

The average cost per circuit in the LATA-to-LATA network (inter-nodal plus LATA access networks) is relatively insensitive to technology changes. Restricting the network design to 1980s' technology throughout the study period (i.e. up to 2000) increases the revenue requirements per circuit by less than 10 percent. Even if the traffic and cost estimates prove to be greatly in error, doubling or tripling the revenue requirements per circuit still results in a relatively small cost per minute.

As the fiber optic utilization factor increases, multiplex equipment (both voice (T-1) and M13) is the largest contributor to circuit costs. Since multiplex equipment of this type is likely to be required in any competing system, it is interesting to note that the average revenue requirements per circuit without multiplex are less than one-half cent per minute ($.001 to $.005).

Fiber optic cable potential capacity is very large, and the capacity limit has not yet been defined, much less realized. It is possible that, because of the advances being made in higher line rate transmission systems, the larger cables may not be used to their maximum capacity during their installation lifetime (20 years).

Because fiber optic transmission systems are so cost-effective, they can be used lavishly, thus eliminating to a large degree the requirement for node switching in the backbone network. Network optimization schemes -- such as dynamic circuit routing using DACS equipment, or the use of routing algorithms to take advantage of time zone load differences -- can lead, if economically justifiable, to even greater network utilization and lower costs.

U.S. LONG DISTANCE FIBER OPTIC NETWORKS: TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

VOLUME I: FIBER OPTIC TECHNOLOGY AND LONG DISTANCE NETWORKS

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U.S. LONG DISTANCE FIBER OPTIC NETWORKS:

TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

VOLUME III:

ADVANCED NETWORKS AND ECONOMICS

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15. Supplementary Notes

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16. Abstract This study projects until 2000 the evolution of long distance fiber optic networks in the U.S. Volume I is the Executive Summary. Volume II focuses on fiber optic components and systems that are directly related to the operation of long-haul networks. Optimistic, pessimistic and most likely scenarios of technology development are presented. The activities of national and regional companies implementing fiber long haul networks are also highlighted, along with an analysis of the market and regulatory forces affecting network evolution. Volume III presents advanced fiber optic network concept definitions. Inter-LATA traffic is quantified and forms the basis for the construction of 11-, 15-, 17-, and 23-node networks. Using the technology projections from Volume II, a financial model identifies cost drivers and determines circuit mile costs between any two LATAs. A comparison of fiber optics with alternative transmission concludes the report.

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