Broadband Capable Network: Voice, Data, Video, and Graphics —

Architecture and Modeling Assumptions

Presentation at the July 27, 1992
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Alternative Costing Methods Project

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State Regulators	NARUC
Regional Holding Companies	Ameritech Bell Atlantic BellSouth NYNEX Pacific Telesis Southwestern Bell US West
Large Independents	Centel GTE Southern New England Telephone Sprint Local Telecom Division
Small Telephone Representative	NTCA
Interexchange Carrier	AT&T
Switch Manufacturers	Northern Telecom Philips Kommunikations
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Assisting with *public* data:

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- National Security Agency
- U.S. General Accounting Office
- United States Postal Rate Commission

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List of Acronyms

A\DM	Add\Drop Multiplexer
AP	Alternative Service Provider
ARMIS	Automated Reporting Management Information System
ATM	Asynchronous Transfer Mode
CATV	Cable Television
CAP	Competitive Access Provider
CO	Central Office
CPE	Customer Premises Equipment
DAT	Data Analysis Tool
DENT	Data Entry Form
DS-1	Data Service 1
DS-2	Data Service 2
DS-3	Data Service 3
FCC	Federal Communications Commission
IN	Intelligent Network
ISDN	Integrated Services Digital Network
IXC	Interexchange Carrier
LEC	Local Exchange Carrier
Mbps	Megabits per Second
MCI	MCI Telecommunications Inc.
MTS	Message Telecommunications Services
NNX	NNX codes, Part of the North American Numbering Plan
OC-n	Optical Carrier - n, where "n" Equals a Positive Integer
ONU	Optical Network Unit
PCN	Personal Communications Network
PSN	Public Switched Network
PON	Passive Optical Network
SCP	Service Control Point
SMS	Service Management System
SS7	Signaling System Seven
STP	Signal Transfer Point
SONET	Synchronous Optical Network
TO	Tandem Office
WATS	Wide Area Telecommunications Services

I. Objectives and Value of Broadband Model

Objectives and Value of Modeling Broadband Deployment

The objective for modeling broadband deployment is to identify and quantify the associated issues — regulatory, technical, financial, and service demand — that will assist policy makers in their decisions concerning competition and new technology deployment. The value of the model is that it's an interactive tool linking new technology costs and the current financial cost accounting structure of the local exchange carriers (LECs).

The modeling process also identifies key elements associated with broadband deployment and analyzes the result of changing these key elements. The interactive nature of the tool makes it valuable to regulators, LECs, and other industry members to analyze various deployment options.

Introduction

The telecommunications industry in the United States is in the midst of transformation due to the rapid pace of technological change and the introduction of competitors: alternative service providers (APs) — which include cable television (CATV) companies and competitive access providers (CAPs) — and non-traditional telecommunications competitors, such as computer networks, publishing companies, and other information service providers and carriers.

In this changing environment, there is debate over who should provide services, what these services might be, and what network structures might be required in the future. Participants in the Alternative Costing Methods Project are modeling various issues associated with this environment.[1] This paper focuses on the issues surrounding deployment of a broadband capable network able to carry voice, data, video, and graphics.[2]

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[1] For initial analysis of competitive and support mechanism issues by participants in the Alternative Costing Methods Project, see Carol Weinhaus, Mark Jamison, et al., *New Wine and Old Wineskins: Modeling Effects of Competition and Expanded Interconnection in the Local Exchange,* Program on Information Resources Policy, Harvard University, Cambridge, MA, July 27, 1992; and see Carol Weinhaus, Sandra Makeeff, et. al., *Support Mechanisms: Issues and an Example of Potential Problems in the Future,* Program on Information Resources Policy, Harvard University, Cambridge, MA, July 27, 1992.

[2] In the computer industry, this combination of voice, data, full-motion video, and graphics is called "multimedia".

This paper begins with a discussion of the current network environment and identifies some current misconceptions concerning broadband deployment. The next section defines features, functions, and components associated with broadband services and architectures. This paper then continues with an analysis of assumptions (including service definitions, demand parameters, and network cost components) needed to model the impact of deploying a broadband capable network. The last section is a status report on the project, followed by appendices which provide detailed definitions and descriptions of the technologies discussed in this paper.

Potential Future Environment — Network of Networks

The current environment for assessing broadband deployment is not just one network or the traditional telecommunications industry network: it is a network of networks. Starting in the 1960s, the introduction of competition in long distance and terminal equipment markets created an infrastructure with more than one network.[3]

Figure 1 is a representative diagram of some possible options a customer has in making an interstate call over the public switched network (PSN). This figure indicates the result of regulatory decisions made in the 1960s and 1970s. Note that each of the interexchange carriers (IXCs) in **Figure 1** has its own facilities — land-line, microwave, or satellite. The multiple networks in this diagram, IXC or local, are all interconnected producing a *network of networks*. Customers of individual carriers can receive incoming calls from other carriers as well as from their own carrier.

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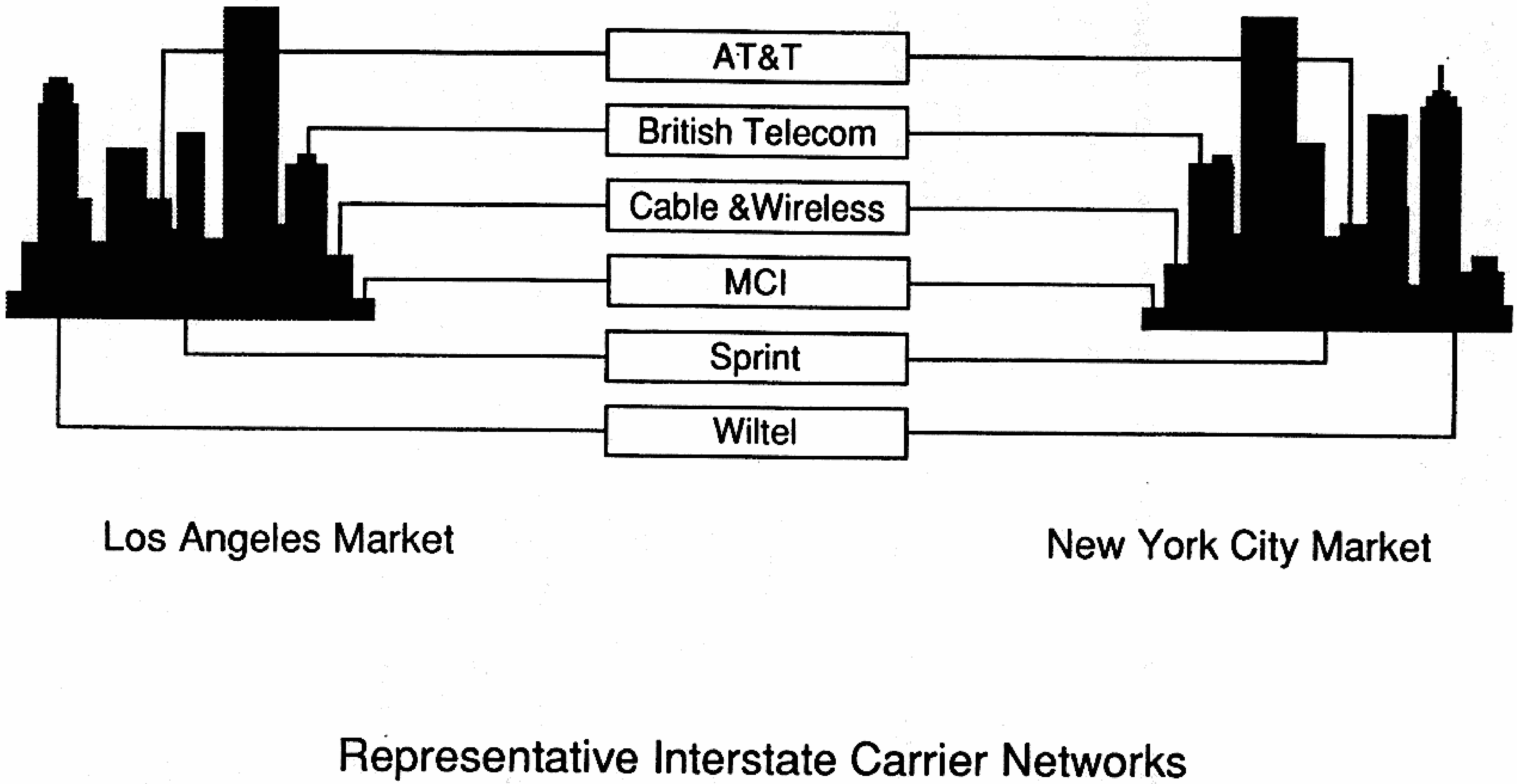
[3] The Federal Communications Commission's (FCC) *Above 890* decision opened the private-line microwave market. (*Allocation of Frequencies in the Bands Above 890 Mc.*, FCC Docket No. 11866, *Report and Order*, 27 FCC 359 (1959). Competition in the *Above 890* realm led to competition in the long-haul markets, starting with MCI in the early 1970s. The commission's *Hush-A-Phone* and *Carterfone* decisions opened the terminal equipment markets to competition. (*Hush-A-Phone Corp. v. AT&T et al.*, FCC Docket No. 9189, *Decision and Order on Remand*, 22 FCC 112 (1957); *In the Matter of Use of the Carterfone Device in Message Toll Telephone Service*, FCC Docket Nos. 16942, 17013, *Decision and Order*, 13 FCC 2d 240 (1968); *reconsideration denied, Memorandum Opinion and Order*, 14 FCC 2d 571 (1968).

Figure 1
Representative Public Switched Networks (PSNs) Transmission Paths



With competition firmly established in the interstate interexchange market, competition is currently expanding into local markets. **Figure 2** depicts one portion of today's environment. The traditional regulated network is illustrated by a representative LEC local network interconnected to the IXC point of presence (POP). This diagram also indicates other companies which currently provide telecommunications services or could do so in the future — CAPs, CATV companies, and personal communications networks (PCNs).[4]

In **Figure 2**, a LEC, a CAP, a CATV company, and a PCN all provide telecommunications services and all could be interconnected. Furthermore, a CAP or other competitor can place equipment in the same location as the LEC switch. In the metropolitan area, the CAP has a fiber ring equipped with add/drop multiplexers (A/DMs). In the suburban area, the CATV company has a fiber backbone coupled with coaxial distribution facilities.[5] The CAP and CATV networks are interconnected via the CAP's add/drop multiplexer. The LEC network has evolved to route diverse fiber rings in the metropolitan areas and dense business applications. In the residential suburban areas, the LEC has evolved to fiber passive optical networks.[6]

Regardless of ownership, the underlying technologies for these networks are similar. There are differences due to historical deployment patterns which have been influenced by regulation and legislation. Broadband capabilities are available to a certain extent in each of these companies; patterns vary by services and deployment.

Ideally, analyzing broadband deployment on a nationwide basis within the overall PSN would require examination of all networks. The current modeling process captures only LEC deployment of the nationwide PSN. Only the LECs file public data in a standardized nationwide format; no comparable data is available for other providers.

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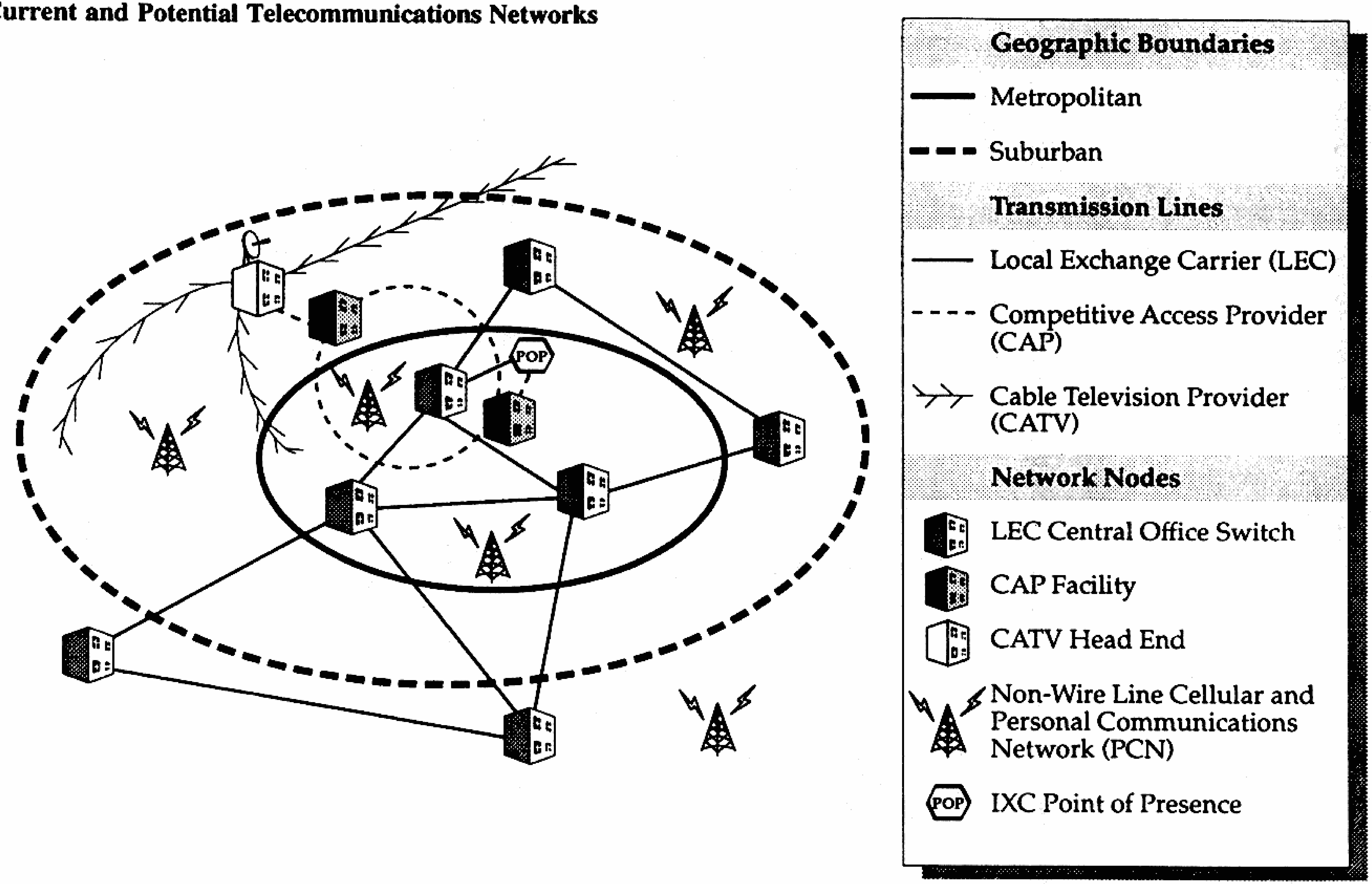
[4] This figure omits private networks and computer networks.

[5] Technology already exists allowing CATV providers to take advantage of the efficiencies of combining voice, data, video, and graphics over a single broadband network.

[6] See **Section II** for a description of fiber-based architectures.

Figure 2
Current and Potential Telecommunications Networks



I. Objectives and Value of Broadband Model, cont.

Extent of Deployment

Currently there is debate over the deployment of fiber and other broadband technologies. One view is that deployment of narrowband ISDN would meet a vast majority of market needs at a fraction of the cost of full broadband deployment. On the other end of the spectrum, there is the view that broadband deployment must be ubiquitous to meet market needs. The essential differences between these views are the speed and the extent of the deployment of broadband. The modelling process in this project provides quantification and analysis for examining these views.

The next sections of this paper provide a description of one view of a broadband network architecture, followed by a discussion of modeling assumptions and the modeling process adopted by project participants.

II. Broadband Architecture and Service Definitions

Network Functions and Features

In order to model the deployment of a national broadband capable network, the participants of the Alternative Costing Methods Project reached a consensus on desired generic functions and features for such a network and a terminology to describe the derivation of broadband services.

The requirement for functionality was a flexible fiber-based platform, where services could be personalized to the individual subscriber. The word "platform" is used to represent the basic underlying capability upon which services can be configured by adding more software and/or hardware.

For example, if this concept were applied to the computer, the platform would be the microprocessor itself (e.g. 486) and the associated wiring, cabinet, and power unit. Adjuncts added to provide specific services would be the monitor, keyboard, mouse, and software. In the case of local access, "platform" refers to cable facilities, passive devices, powering equipment and cabling, initial switching and interoffice transport capability, enhancements to operation support systems for normal operations, administration and maintenance, and personnel training.

Current limitations on transmission capacity for a single-mode fiber system[7] are not found in the cable itself but in the associated optoelectronic equipment. Therefore, it makes sense to consider point-to-multipoint fiber-optic architectural platforms which reduce the amount of fiber deployed while still providing interconnection. Each network end point derives only that portion of the total information payload desired at that end point. The platform is "sized" to account for an average service delivery. Ideally, flexibility in service offering would only be limited by the maximum platform capacity.

In general, patterns of acceptance of new technology by customers creates network planning problems. Unlike consumer product manufacturers, who can adjust to the changes in demand by altering manufacturing schedules, telecommunications companies must install

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[7] The single-mode fiber system is the technology of choice for LEC networks.

networks initially with sufficient capacity to handle current as well as future demand. Failure to install sufficient initial capacity creates expensive re-engineering.

Recognizing these issues, the participants "sized" the fiber-optic platforms for business and residential customers for the following average service deliveries:

- **Residential platform:** Should support an average of one switched wideband signal (up to 1.544 Mbps) per current residential access line and one broadcast video signal per person per household. In addition, this platform also provides current residential narrowband service.

- **Business platform:** Should support two switched wideband signals per current business access line, as well as all current business services. Additionally, a business with a mix of wideband and broadband services should be able to reconfigure its own access to the PSN up to the information capacity of services purchased.[8]

A single "broadband" service is defined as one offered at data rates of 45 Mbps or greater. It is worthy of note that the majority of broadband services derived off these platforms arise from residential broadcast video or from multiplexed narrowband and wideband signals to business buildings.

Additional network features include electronic interfaces at customer and network interconnection points; network power sources and power back-up customized to customer density; and integration of narrowband, wideband, and broadband services on the same fiber.

Broadband Architecture: Components

In order to model the transition to a broadband capable network, it was necessary to consider national trends. These trends cover features and functions (discussed above) and

[8] The residential and business platforms are designed differently. The business platform carries only wideband and broadband services. Narrowband services are handled by the existing network.

network components. For example, current national trends include the following transitions in network technologies:

- Analog to digital.
- Narrowband to broadband (including wideband).
- Asychronous to synchronous transport.
- Unintelligent to intelligent customer premises equipment (CPE) and networking features.
- Circuit-switched and packet-switch to cell-based.

Figures 3 and 4 illustrate the network architecture that satisfies the modeling objectives selected for the project.[9] The broadband network components are as follows:

- Passive Optical Networks (PONs).
- Synchronous Optical Network (SONET).
- Digital switches capable of Integrated Services Digital Network (ISDN) services for the near term.
- Cell-based switching adjuncts (Asynchronous Transfer Mode, or ATM).[10]
- Advanced Intelligent Network (IN).
- Integration of operational support systems.

The integrated deployment of these key components provides a variable bandwidth and broadband-capable infrastructure for large business access line subscribers. This network evolution intentionally includes the deployment of improved communications capabilities to the small business and residential access line subscribers.

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[9] For a description of PONs architecture, see **Appendix A**; for a description of SONET architecture, see **Appendix B**. For descriptions of ISDN, ATM, and IN, see **Appendices C and D**.

[10] "All three carriers [AT&T, MCI, and Sprint] are building ATM networks...that initially will support the DS-3 speed of 45 megabits per second, and eventually support snychronous optical network [SONET] speeds." *Communications Week*, June 29, 1992, page 3.

Figure 3
Passive Optical Network (PON)

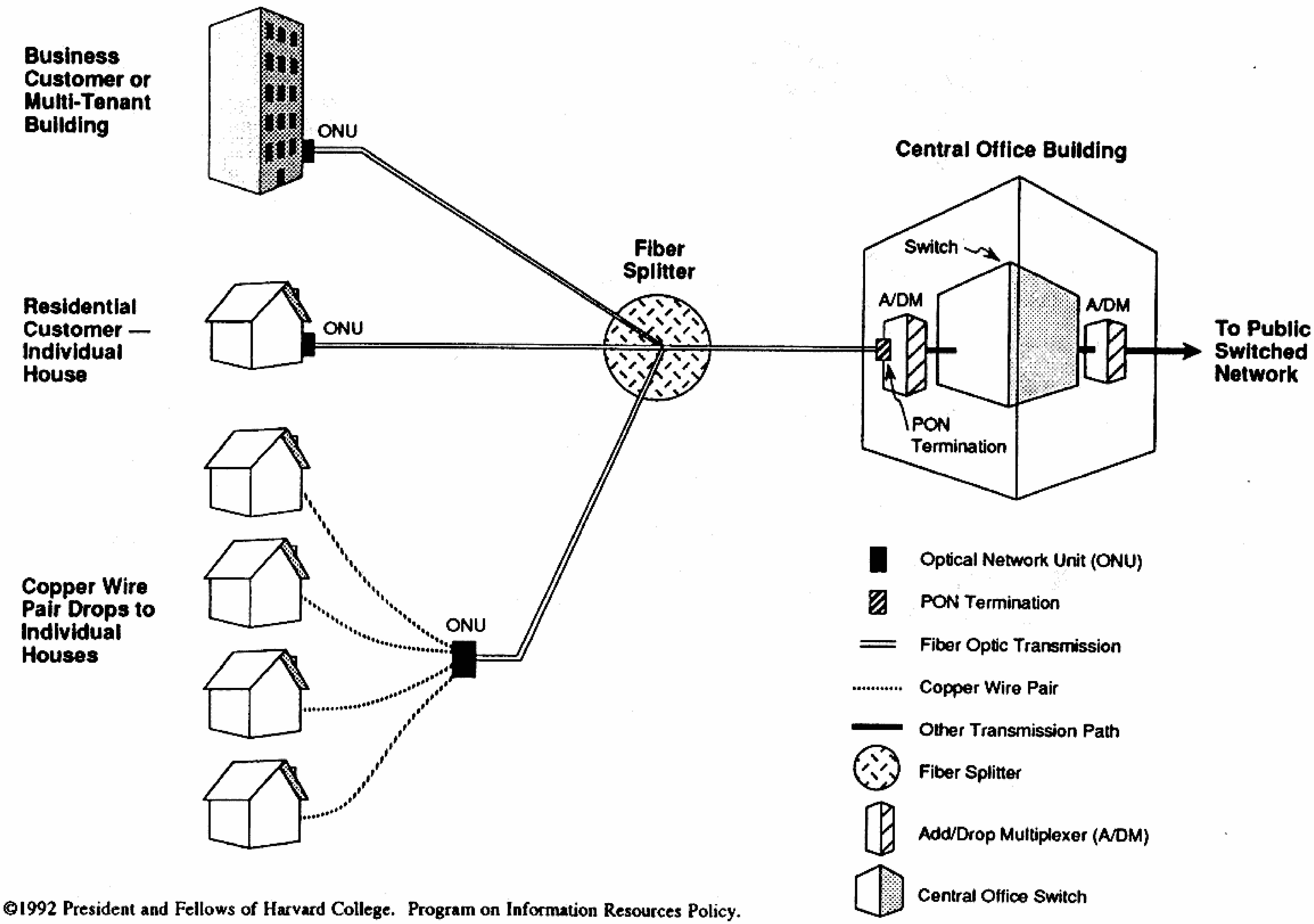


Figure 4
Intelligent Network (IN) Configuration with SONET and PONs

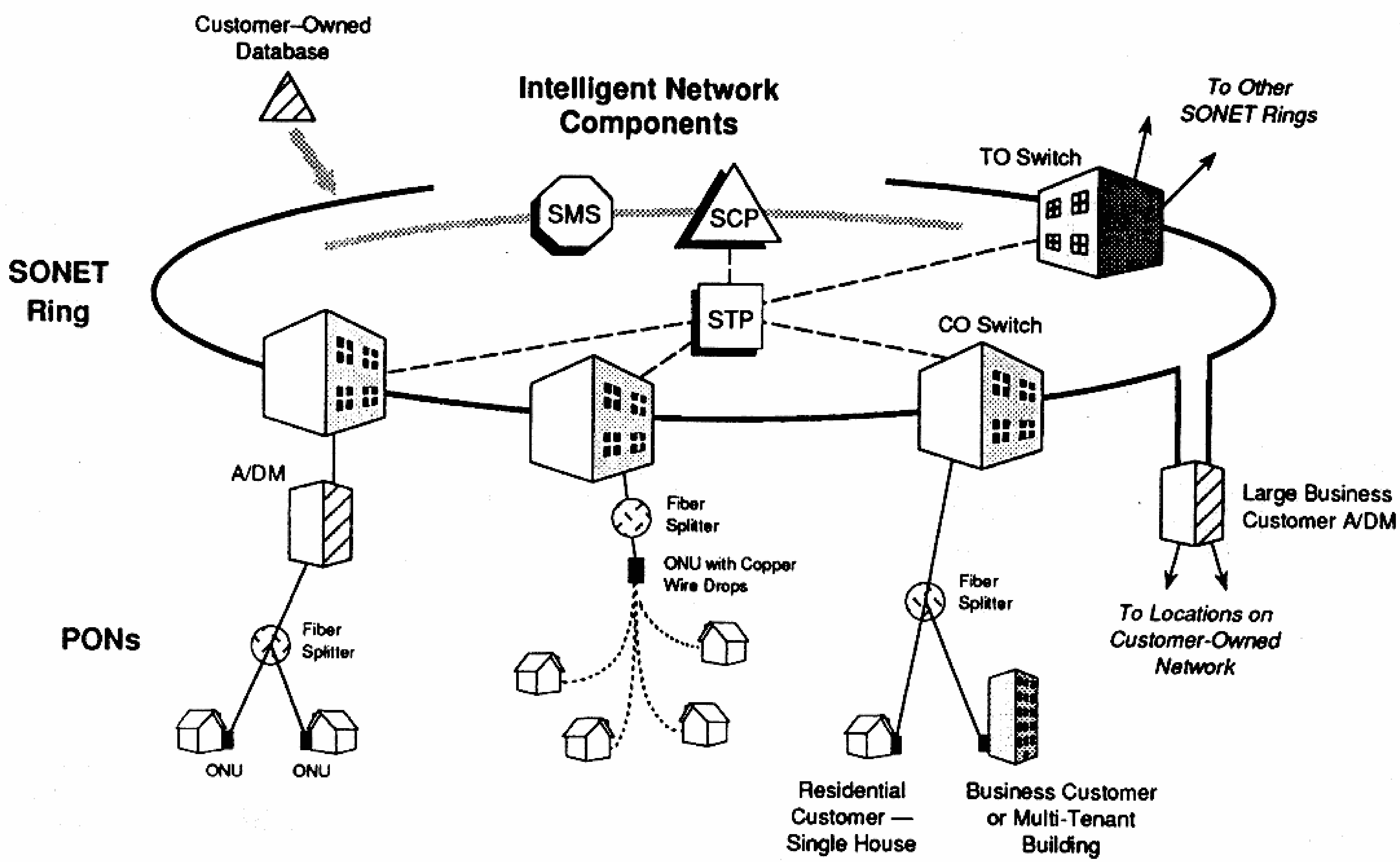


Figure 4
Legend

Intelligent Network Components:

- SCP — Service Control Point: Database with information on customers and their service requirements.
- SMS — Service Management System: Database for system operations and support.
- Links between IN databases.
- Customer-Owned Database

SONET and PONs Components:

- Central Office (CO) Switch
- Tandem Office (TO) Switch
- STP — Signal Transfer Point: A fast packet switch. Routes information between Central Office and SCPs.
- Add/Drop Multiplexer (A/DM)
- Fiber Splitter
- Optical Network Unit (ONU)
- Synchronous Optical Network (SONET) Transmission Links
- Signaling System 7 (SS7) Transmission Links
- Passive Optical Network (PON) Transmission Links
- Copper Wire Transmission Links

III. Modeling Assumptions

Modeling Assumptions

The broadband deployment modeling assumptions fall into three major categories: subscriber demographics, network geographics, and deployment timing schedules.

By design, the user of the tool (the DAT) is responsible for setting a scenario for deployment of the nationwide broadband infrastructure and for a penetration rate for the business and residential broadband services described above. For example, the user can specify the starting date for broadband deployment, the annual percentage of this network conversion (customized for business and/or residential platforms), and the annual service penetration rates.

However, subscriber demographics and network geography are presumed in the DAT. Subscribers are first partitioned by the size of their serving wire center:

- **Small or rural:** Less than 4,000 network access lines.
- **Medium or suburban:** From 4,000 up to 40,000 network access lines.
- **Large or urban:** Greater than 40,000 network access lines.

Within each of these three sizes of wire centers, subscribers can be grouped into one of six cost-distinctive service distribution area types:

- **Residential, single-family:** One parcel of property, one building foundation, living quarters for one family.
- **Residential, multi-family:** A set of buildings, each with living quarters for up to tens of household.
- **Residential, high-rise:** One multi-tenant building serving hundreds of households.
- **Business, rural:** Undeveloped geographical area with scattered farms or light industry.

- **Business, park:** Area zoned for small to medium business enterprise(s) in single and in multi-story buildings.

- **Business, high-rise:** One large business building, either single-tenant or multi-tenant.

Detailed analysis on actual representative wire center serving areas was performed to determine how the distribution area types are positioned within each serving area and with what frequency.

IV. Modeling Process

Technology Deployment Costs

Based on the service definitions, network architecture assumptions, and demographics (**Sections II and III**), the next step for modeling technology deployment is to develop costs. Current work in progress focuses on the investment costs for this deployment. Later modifications will include similar calculations of changes in expense accounts, such as depreciation and maintenance.

The three factors that have the greatest effect on investment costs for fiber-optic system deployment are the number of lines deployed (volume), subscriber density, and broadband service type (business and residential).

The modeling process contained in the tool consists of a flow of calculations starting from a fundamental cost matrix. The fundamental investment cost matrix is built up from appropriate cost elements for the following:

- Tandem office switches.
- Central office digital switches and ATM adjuncts.
- Interexchange transport equipment.
- Interexchange fiber facilities.
- Loop outside plant fiber facilities.
- Optical network units.
- Access distribution equipment.

These cost elements are grouped into platform and line costs according to characteristics of the wire center and the service type. **Figure 5** indicates the incremental investment costs for various platforms and service types. The final step in the development of the matrix is the distribution of these incremental investment costs into regulatory financial accounts.

Figure 6 shows the overall process for calculation of the investment costs for broadband deployment. **Step 1** is the generation of fundamental cost matrix described above. **Step 2** combines the user input for deployment schedule with national network statistics. This results in the allocation of deployment across wire centers and access lines. From this allocation, volumes of technology units are accumulated and subtotaled by year (**Step 3**). As technology progresses and deployment increases, costs for equipment and facilities decrease. This pattern

Figure 5
Distribution of Technology Deployment Cost Elements into Financial Accounts

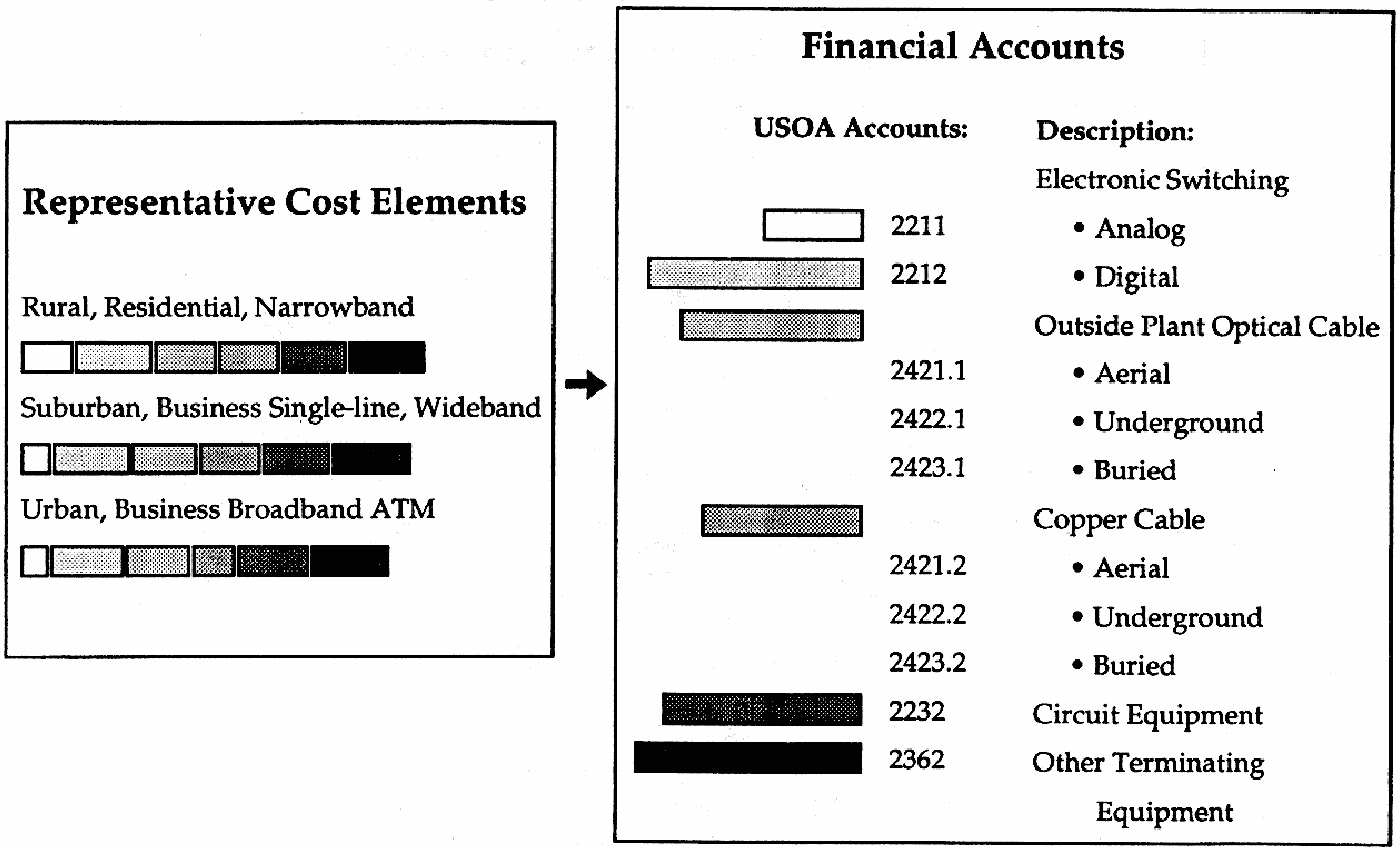
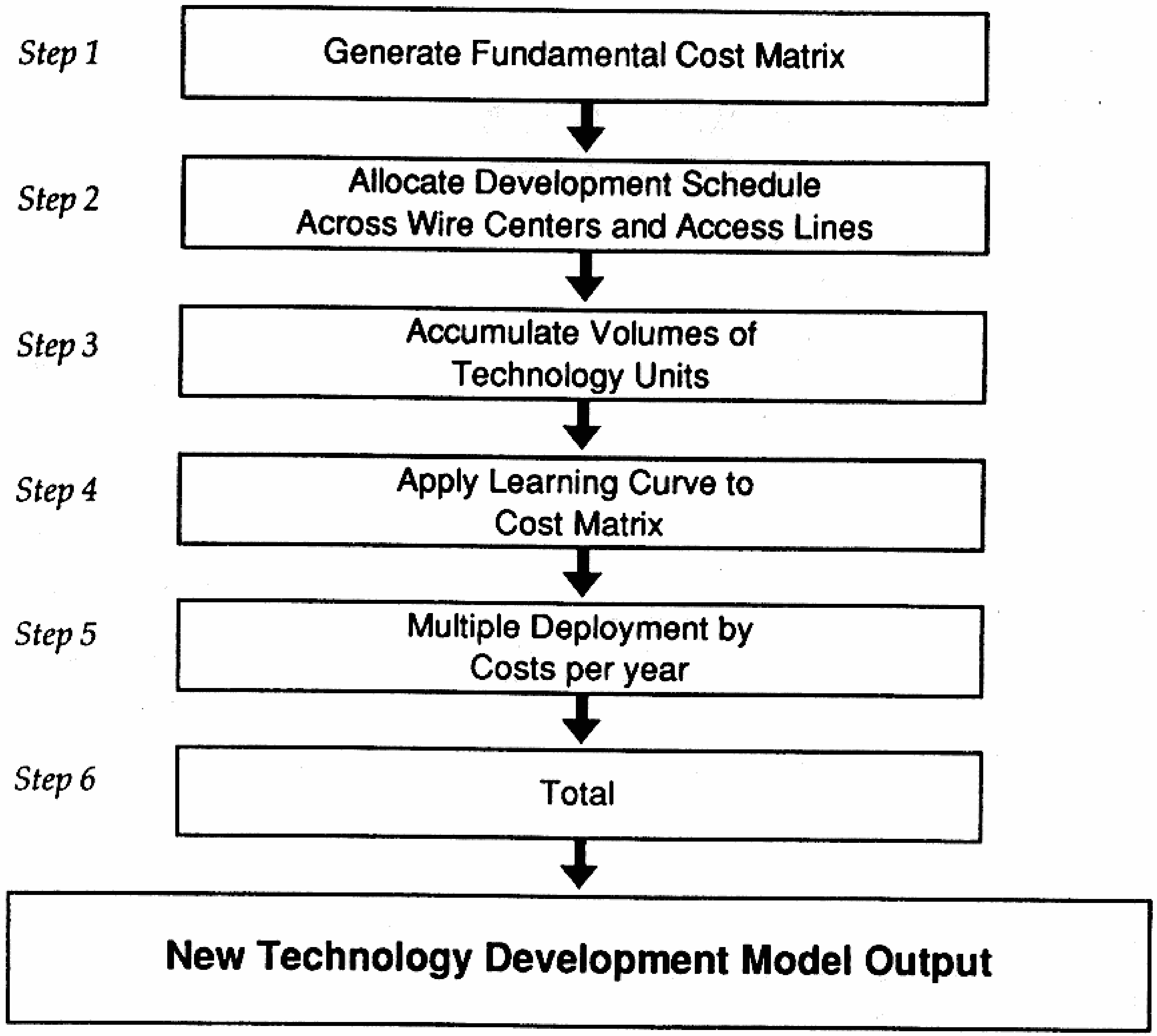


Figure 6
Calculation of Investment Costs for Broadband Deployment



can be calibrated by a graph called the learning curve. **Step 4** applies the appropriate learning curves to the cost matrix. **Step 5** multiples the counts of platforms and lines by the costs of these network structures by year. Finally, **Step 6** totals the investment over all years and produces input for the Depreciation Model.

One outcome noteworthy to equipment manufacturers and suppliers is the sizing of market for broadband transport equipment, switches, and fiber cable as a function of assumed deployment schedule.

V. Broadband Project Status Report

Modeling Tools: Status Report

To perform modeling of broadband deployment and other models associated with changing the LEC cost structures, the project is creating a set of computer software tools. Combined, these tools provide a unique model that links technology deployment with financial and cost accounting structures.

For example, if broadband deployment occurs in a given year, various financial accounts will be affected. **Figure 7** gives some indication of the starting point for measuring the impact of various deployment scenarios. For 1989 Tier 1 LECs, 67%, or $153 billion, of investment for total plant in service will be affected by new technology deployment. As **Figure 7** indicates, the potential impact on investment is considerable. In addition, expense accounts, such as depreciation and maintenance, are affected by new technology deployment.

The analysis tool (the DAT) mirrors the financial accounting and cost structures of the LECs. The software for this tool is in Lotus 1-2-3, Version 3.1 and the financial calculations are in a single spreadsheet.[11] Since the spreadsheet is a draft version, errors may exist. Project participants welcome comments on the spreadsheet to enable corrections to be made.

There is also a database in Paradox software which is associated with the DAT. The database contains financial accounting and cost data, usage measurements, and facilities statistics from various public data sources.[12]

The third component is a module for incorporating broadband deployment and depreciation assumptions and technology cost modeling (described in **Sections II through IV**). A set of user-friendly screens asks a series of questions, such as the percent of deployment per year and the percent of facilities equipped to provide broadband services. The answers to

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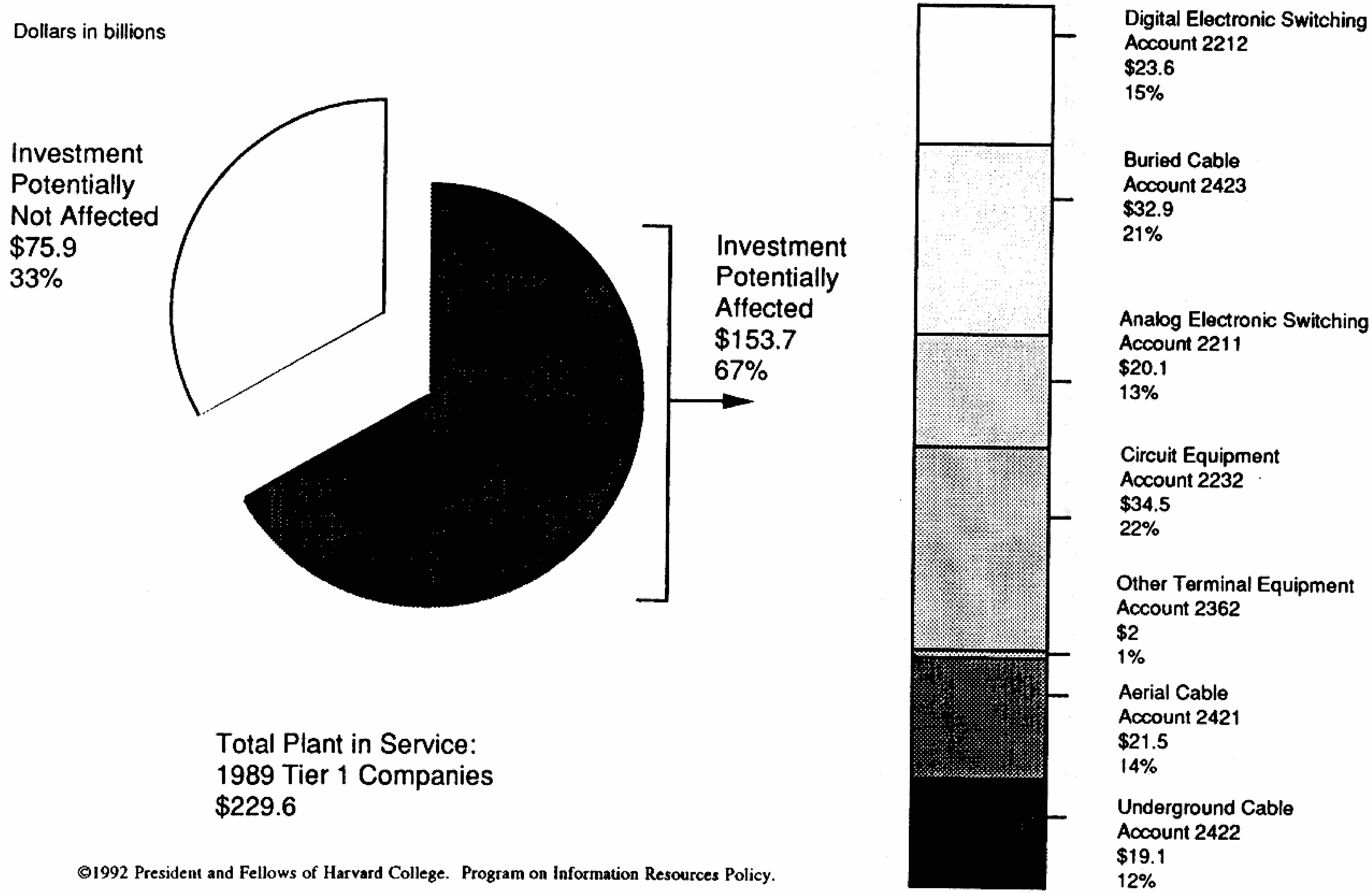
[11] For a description of the DAT, see *Data Analysis Tool, 1989 Nationwide Data Set, December 21, 1992*. The DAT requires approximately two megabytes of memory.

[12] These include Automated Reporting Management Information System (ARMIS) reports, other FCC reports, and NECA data. See the *DAT User Guide* for sources for the input data used in the DAT.

Figure 7
1989 Total Plant in Service



these questions feed into a component, transparent to the end user, which produces appropriate technology costs. These results, in turn, produce deployment data for each selected year.

A fourth component, the data entry form (DENT), allows entry of data not found in the Paradox database. For example, it is possible to create a new data set and enter the data in the appropriate areas of the DAT. Software development is in progress to link these components together. Proposed modifications include an interface transparent to the end user which links all components through user-friendly screens.

VI. Appendix A: Passive Optical Network Architecture

Appendix A: Passive Optical Network Architecture

One of the new technologies for this link is fiber optics. Already, optical fibers are the preferred technology for interoffice trunks, institutional local area networks (LANs), and point-to-point links to large business subscribers. **Figure 3, Section II,** shows the basic components of the fiber optic link — called passive optical networks, or PONs — for residential and business customers to the LEC central office.

Unlike copper wire technology which requires individual wires running the entire route from each customer to the central office, optical fibers may be split into multiple branches somewhere along the route. **Figure 3** indicates the PON termination in the central office. A splitter allows numerous customers to share a single feeder fiber. **Figure 3** shows fibers linked to three representative ONUs. In this figure, the optical network transforms the incoming optical signal (i.e., light pulses) into an electrical signal recognized by the customer's inside wiring. In other words, the splitter broadcasts a single multiplexed signal among a number of ONUs.

Figure 3 indicates three representative types of customer ONUs:

- **Business Customer or Multi-Tenant Building:** The ONU may be in the basement with copper wire serving as the inside wire technology or individual tenants may have their own fiber optic links.

- **Residential Customer, Individual House:** The ONU is typically on the outside of the house.

- **Copper Wire Pair Drops to Individual Houses:** A single ONU serves four sets of copper wire pairs. Upgrading this copper wire drop to fiber technology requires the addition of a smaller splitter at the ONU and a second ONU on the customer's premises.

As the requirements for greater bandwidth services exceed those for current narrowband services, optical amplifiers could be added to provide additional bandwidth. This means that the network can grow smoothly as customer needs dictate.

VII. Appendix B: Synchronous Optical Network (SONET) Architecture

Appendix B: Synchronous Optical Network (SONET) Architecture

SONET is an international standard interface which performs the following functions:

- Allows interconnection of equipment produced by multiple manufacturers.
- Provides increasingly faster transmission rates based on a basic SONET bit-rate (51.84 Mbps). Provides transmission rates greater than 45 Mbps, the DS-3 basic rate.
- Provides space for additional bandwidth within communications paths. This additional bandwidth may provide faster maintenance and may reduce the number of equipment conversions between electrical and optical signals.

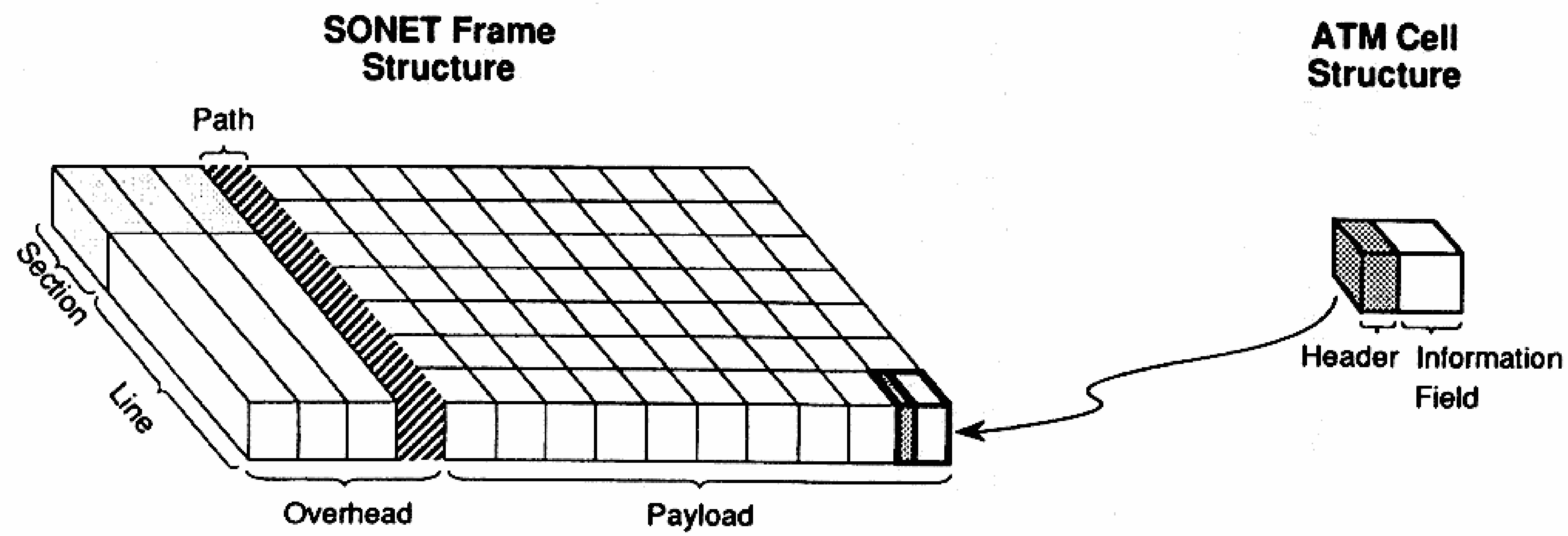
Also with SONET technology, the customer may be able to dynamically configure his allocated bandwidth into different services (i.e., private line, MTS, WATS, packet, or new services).

Figure 8 shows the components called the frame structure of the SONET signal. There are two major divisions:

- **Overhead**: Provides routing, maintenance, and other information processing associated with sending the attached payload through the optical transmission network.
- **Payload:** Contains digitized information. Payloads may vary by type of signaling technology and by type of service. For example, the payload in **Figure 8** consists entirely of ATM cells.

The overhead section of the SONET frame structure is subdivided into layers. As a SONET frame structure moves through a node, these layers allow access to only the required portions of the overhead and payload. This creates the ability to find any signal of any technology within a payload without demultiplexing the entire SONET signal.

Figure 8
SONET Frame and ATM Cell Structure



Components of Synchronous Optical Network Frame Structure:

Overhead:

- Maintenance
- Channel identification — identifies contents of payload
- Routing — based on contents of ATM headers inside the payload
- Allows user control of ATM cells in the payload
- Other information processing

Payload:

Type varies by signaling technology and by service
- ATM cells (shown above)
- Asynchronous DS1
- Asynchronous DS3
- DS1 circuits
- DS2 circuits
- 2.048 mbps signals
- etc.

Components of Asynchronous Transfer Mode (ATM) cell:

Header:

Routes ATM cell through nodes (switches, multiplexers) in the SONET network.

Information Field:

Digitally encoded data.

VIII. Appendix C: Integrated Services Digital Network (ISDN) and Asynchronous Transfer Mode (ATM)

Appendix C: Integrated Services Digital Network (ISDN) and Asynchronous Transfer Mode (ATM)

ISDN both merges and standardizes customer access to two different communications networks — analog and digital packet.[13]

ATM, or cell-based technology, enables the merging (or integration) of all possible service characteristics within any given network node. This technology separates customer information and system operations data from the switching fabric. ATM switches can flexibly support a wide variety of services with different information transfer rates.

[13] The older technology is analog, circuit-switched, voice-grade, or the traditional basic voice service. The relatively newer technology is digital, packet-switched protocol X.25 services.

IX. Appendix D: Intelligent Network (IN)

Appendix D: Intelligent Network (IN)

The term "Intelligent Network" denotes the use of database technology to provide flexible network communications configurations — routing, terminating, and intermediate call processing functions — that can be used for enhanced customer communications.

The initial application for Intelligent Network is the creation of enhanced network service capabilities. This allows multiple vendors to develop network services in less time and at less cost than can be accomplished today. The major themes of Intelligent Network are:

- Distributed databases for customer data.
- Network element location and interconnection.
- Operational support systems.

Figure 4, Section II, shows the topology of an Intelligent Network with integrated access and transport based on SONET.