NTIA Report 85-185

Military Access Area Characterization

R.F. Linfield
M. Nesenbergs

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

Rodney L. Joyce, Acting Assistant Secretary
for Communications and Information

November 1985

The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official U.S. Army Information Systems Management Activity policy or decision, unless designated by other official documentation.

Preface

The U.S. Army's Information Systems Management Activity in Ft. Monmouth, NJ, has directed the Institute for Telecommunication Sciences to conduct an access area characterization study, to provide Experimental Integrated Switched Network experiment design guidance, and to give other types of engineering support. This report covers Phase A of the access area characterization study. Recommendations are included for the development of a characterization model in Phase B.

Administration and technical monitoring of this study phase was performed by Mr. R. Annett of the U.S. Army's Information Systems Management Activity.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont'd)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF ACRONYMS

AA	Access Area
ACP	Action Control Point
AFSC	Air Force Specialty Code
AIS	Automated Intercept System
AISC	Army Information Systems Command
ANS	American National Standard
ANSI	American National Standards Institute
AO&M	Administration, Operations, and Maintenance
ATD	Average Tree-Direct
ATRS	Automated Trouble Reporting System
AT&T	American Telephone and Telegraph
AT&T-C	American Telephone and Telegraph Communications
BER	Bit Error Rate
BH	Busy Hour
BHC	Busy Hour Call
BLS	Bureau of Labor Statistics
BOC	Bell Operating Company
BSTJ	Bell System Technical Journal
CAROT	Centralized Automatic Reporting On Trunks
CCIS	Common Channel Interoffice Signaling
CCITT	International Consultative Committee for Telegraph and Telephone
CCS	Common Channel Signaling
C-E	Communications-Electronics
CO	Central Office
COM	Center of Mass
COMAS	Computerized Maintenance and Administrative Support System

CONC	Concentrator
CONUS	Continental United States
CPE	Customer Premise Equipment
CPU	Central Processing Unit
CSATS	Consolidated Service Administrative Telephone System
CSC	Civil Service Commission
DACS	Digital Access and Cross-connect Systems
DAX	See DACS
DCA	Defense Communications Agency
DCO	Dial Central Office
DCS	Defense Communications System
DCTN	Defense Commercial Telecommunications Network
D&D	Deregulation and Divestiture
DDN	Defense Digital Network
DDS	Dataphone Digital Service
DEB	Digital European Backbone
DMATS	Defense Metropolitan Area Telephone System
DNHR	Dynamic, Nonhierarchal Routing
DOD	Department of Defense
DRA	Dynamic Resource Allocation
DSCS	Defense Satellite Communications System
DSDC	Direct Service Dialing Capability
DSN	Defense Switched Network
E	Erlang
EADAS	Engineering and Administration Data Acquisition System
EISN	Experimental Integrated Switched Network
EMP	Electromagnetic Pulse

EO	End Office
FCC	Federal Communications Commission
FDM	Frequency Division Multiplex
FEMA	Federal Emergency Management Agency
FM	Frequency Modulation
FTS	Federal Telecommunications System
GOS	Grade of Service
GS	General Schedule
GSA	General Services Administration
HEMP	High-altitude Electromagnetic Pulse
IC	Interstate Carrier
IP	Intermediate Point
ISDN	Integrated Services Digital Network
ITC	Independent Telephone Company
ITS	Institute for Telecommunication Sciences
LAN	Local Area Network
LCR	Least Cost Routing
LMOS	Loop Maintenance Operation System
MCD	Minimum Cost Design
MCI	Microwave Communications Incorporated
MFJ	Modified Final Judgement
MILDEP	Military Department
MLPP	Multilevel Priority and Preemption
MOU	Memorandum of Understanding
MUX	Multiplexer
NATO	North Atlantic Treaty Organization
NCC	Network Control Center

LIST OF ACRONYMS (cont'd)

NCP	Network Control Point
NM	Network Management
NSA	National Security Agency
OC	Operations Center
OCC	Other Common Carrier
OCCS	Other Common Carrier System
O&M	Operations and Maintenance
PABX	Private Automatic Branch Exchange
PANS	Peculiar and Novel Service
PBX	Private Branch Exchange
PC	Primary Center
PCM	Pulse Code Modulation
PIN	Personal Identification Number
PLN	Private Line Network
POTS	Plain Old Telephone Service
PP	Primary Point
PSTN	Public Switched Telephone Network
PTT	Post, Telephone, and Telegraph
QOS	Quality of Service
RC	Regional Center
RHC	Regional Holding Company
RLU	Remote Line Unit
RP	Regional Point
RSS	Remote Switching System
RSU	Remote Switching Unit
SAS	System Analysis Section
SC	Sectional Center

LIST OF ACRONYMS (cont'd)

SCCS	Switching Control Center System
SDC	Switched Digital Capability
SLC	Subscriber Loop Carrier
SP	Sectional Point
SPC	Stored Program Control
SPCN	Stored Program Control Network
STP	Signal Transfer Point
TASC	Telecommunications Alarm Surveillance and Control System
TC	Toll Center
TCAS	T-Carrier Administration System
TDAS	Traffic Data Administration System
TDCS	Traffic Data Collection System
TNDS	Total Network Data System
TP	Toll Point
TSPS	Traffic Service Position System
USA	United States Army
USAF	United States Air Force
USAIC	United States Army Information Command
VLSI	Very Large Scale Integration
WWDSA	Worldwide Digital System Architecture

EXECUTIVE SUMMARY

The purpose of this study is to develop methods for characterizing military telecommunications entities known as "access areas" in the Western Hemisphere. In the past, the access areas were typically viewed as communities of users under Military Department (MILDEP) control who share local switching and transmission facilities and have common access to the long-haul networks like AUTOVON and AUTODIN. In the future, this simplified viewpoint may no longer apply because the local networks and the Defense Switched Network (DSN) are evolving into a much more complex structure of multiple networks based on digital technologies and because deregulation and competition are having an impact on the postdivestiture environment in ever changing ways.

The current deregulation and postdivestiture situation can be viewed in either of two ways--as a complex disarray or as an opportunity. We take the latter view. Deregulated services and customer premises equipment can and should lead to diversity of services, end-user options, and terminals with greater survivability. The competing vendors of the industry are bound to come up with innovative systems at potentially reduced cost. New technologies will lead to greater hardware and software reliability and, finally, novel features and functions will provide increased staff productivity.

At the same time, new issues abound. Procurement policies and regulations require the Department of Defense (DOD) to acquire services on a competitive basis. The multivendor equipment and automated systems environment complicates the Administration, Operations, and Maintenance (AO&M) problems. The separation of access area network and the long-haul network responsibility between the MILDEPS and Defense Communications Agency (DCA) introduces network management, control, and restoration problems similar to those in the postdivestiture commercial sector. There is no single end-to-end responsibility for the network, nor any centralized system for overall management and control. In the present environment, it is difficult to implement a technically sound system concept that provides for integration of voice, data, and other services. This separation also complicates the allocation of the total performance budget across the local and long-haul portions of the network.

These dynamic changes, both realized and contemplated, raise questions about the access area concept. Does any access area concept make sense or benefit the military? Do we need access areas? How many? How are they to be configured? Operated? Managed? What affects their size? Survivability? Security? Cost? What are the staffing requirements?

This report addresses certain of these questions directly, while recommending procedures for answering others. We must stress that this study does not recommend any single definition for all access areas. In fact, we have concluded that there is no fixed structure or universal formalism. Rather, each collection of posts, camps, stations, air bases, or shipyards has its own unique characteristics based on mission and telecommunications needs. These needs can be perceived as a combination of three foremost features seen by the users: overall performance, survivability, and often the most important item--low cost!

One's ultimate objective may be to develop goal architectures for all access areas. These architectures provide the framework for defining standards to access the long-haul networks, for routing intra- and interarea traffic, and for developing end-to-end procedures or protocols for data recovery, security, and error control. A substantial simplification would occur if a single architecture could satisfy the needs of all locations. For the end user, such a goal architecture would ideally 1) meet mission requirements including security requirements, 2) meet both local and long-haul performance objectives, 3) provide survivable/endurable service, and 4) be cost effective. For the network planner, this goal architecture would 1) identify locations and types of nodes, and terminals, and specify traffic intensity with allowance for its growth, 2) assign transmission links including media types, connectivity, and their capacity, 3) specify control signaling for switch control, routing, network management, and 4) define interfaces for inter-access area trunking.

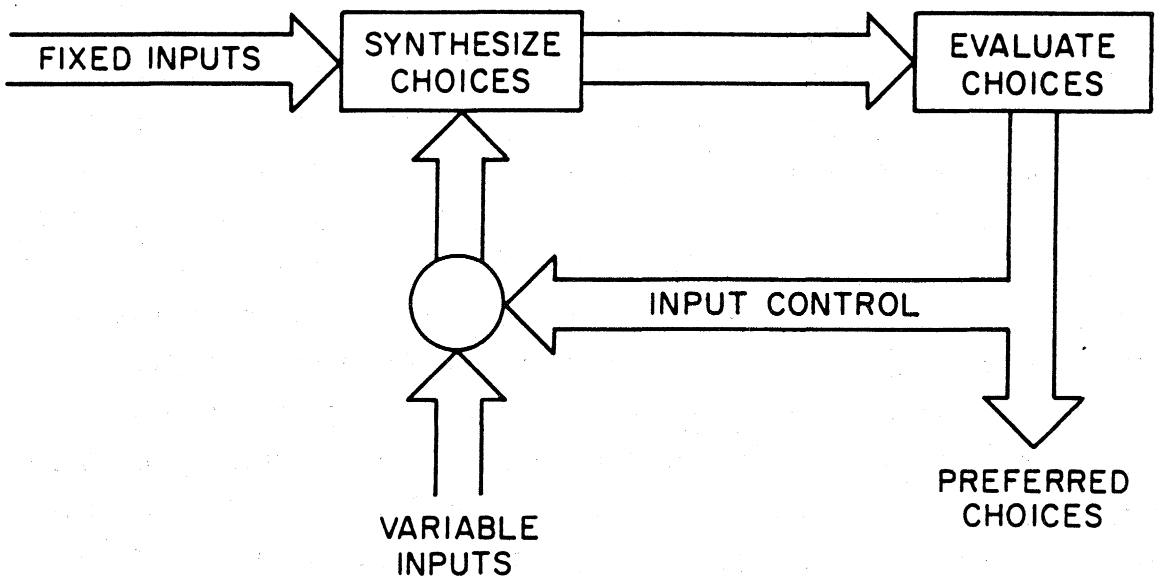
But while quite formidable in complexity, the definition of architectures is merely the first step in the process. Given the goal architecture, additional tasks must develop the management plan, the transition plan, and finally the implementation plan.

When one considers the mission requirements and their effect on telecommunication features (e.g., on electronic mail) and the functions to be performed by the network (e.g., preemption), it appears prudent to permit each base to be quite different from every other base. And even if the feature and function lists were identical, the performance requirement numbers, traffic levels, and destination statistics would differ. It is concluded that there can be no single set of parametric requirements defining every access area.

This report recognizes two broad classes of parameters that pertain to the access area definition: technical and nontechnical. The nontechnical parameters have their roots in the national chain of command, the legal--economic, commercial, political, and regulatory arenas. Nontechnical items such as the postderegulation and postdivestiture environment are covered in Sections 1 through 3.

Technical system parameters include the size, topology, switching, concentration, administration, operation, and maintenance. They are discussed in Sections 4 through 6.

Our approach to characterizing an access area is best explained with the diagram below.



Given a set of fixed inputs (e.g., subscriber numbers and locations) and a set of variable inputs (e.g., candidate hub capacities and locations), one can conceive a large number of architectural choices for a region. Each choice is evaluated based on critical factors, such as cost and survivability. New choices are made by changing some or all of the input variables until an apparent optimum choice is synthesized. The values of all the input parameters then define the goal architecture.

The above is a fairly standard process for selecting optimum alternatives in any study. The problem is the extremely large number of access area related inputs, both fixed and variable, which prohibits a comprehensive manual assessment. We recommend that the process be implemented with a fast, automated computer model. We have explored the possibility of developing such a computer model and, in the process, have discovered an already existing model that approximates the access area needs. This, the so called Consolidated Service Administrative Telephone Systems (CSATS) model, is described in Sections 7 and 8.

To make any model realistic, certain requirements must be satisfied or basic assumptions made. Consider the long-haul DSN network, which most local areas must access. The assumed DSN architecture has important consequences on the access area characterization. For example, if one assumes that all interaccess traffic must flow through a single gateway to the backbone network, then each subscriber location (post, camp, or station) must be tree or star connected to the gateway node, and the problem is reduced to defining the number of nodes, their locations, and their trunking capacity. If, on the other hand, one assumes a mixed-media architecture that allows each subscriber location to take maximum advantage of all available facilities, then optimization of the access area topology and trunking becomes far more complex.

In the past, new architectural concepts have focused on economy because the cost of leased AUTOVON service has continued to rise. One answer to the cost increases has been to concentrate traffic at selected locations and to transmit by satellite to other similar locations. The reason for this is the recognized fact that long distances and large traffic intensities make transmission via satellite cost effective. This has resulted in the Defense Commercial Telecommunications Network (DCTN) currently being developed for use in the Continental United States (CONUS). The problems with DCTN are three-fold: one is a security problem (due to the vulnerability of satellite transmissions to eavesdropping), the second is the communications sensitivity to active interference or jamming, and the third is a survivability problem (due to the physical vulnerability of the satellite itself).

We have also assumed that the base commanders must have the choice to control all of the resources under their commands. This includes all area communications facilities, the people who operate and control these facilities, the features and functions they provide, and the direct responsibility of how well they perform.

In the remainder of this summary we present a number of issues and answers addressed in this study.

<u>Is there a need or an advantage for the access area concept?</u>

- o The individual local areas constitute a diversified group. Their roles vary widely, thus justifying their individual identity.
- o To execute their missions, area commanders must have unrestricted control over their military and telecommunications resources.

- A major portion (typically 80%) of the traffic is local. It is characterized by a particular community of interest and unique communications requirements.
- While some support functions are regional, the majority are performed locally. These are technical and nontechnical, manual and automated functions needed to support the quality of service in a cost-efficient manner.

How can the access area be defined?

- As demonstrated, there is a large set of potential parameters that can be used in defining access areas. A small, workable subset should be selected from the above.
- Among the parameters seen, cost and other nontechnical support parameters (e.g., military command, multivendor liaison) appear to have extreme importance.
- The traditional technical parameters of network size, topology, switching hub, Private Branch Exchange (PBX), concentrator, and transmission plant layouts are still major defining tools.
- A new and evergrowing entity is automation. It is seen to enter into the AO&M, as well as into the Network Management (NM), activities. Automated functions supplant manual functions, require new personnel skills, and will constitute a key defining parameter in the future.

What are considered the most important military network requirements?

- This report emphasizes users' needs based on military commanders' missions as the principal requirement.
- The users generate various kinds of traffic. The present and future statistics of the offered loads represent a critical factor in network design.
- System performance is seen from the user's standpoint. It must be considered in terms of standard performance parameters.
- Network performance under stress can result in both focused and general overload conditions. Performance under stress is an essential requirement.

Where should the separation between the MILDEPS and DCA occur and what are their respective responsibilities?

- o No set demarcation point can be defined at this time. The basic separation is long-haul versus local area traffic. The major or dominant traffic type in a switch may determine who has AO&M responsibility for that switch.

How can the conflicting military concerns for survivability and cost be resolved?

- o A structured configuration is recommended. Faced with facility outage, such a configuration provides graceful performance degradation in terms of grade of service.
- o This configuration is less costly than a polygrid network but more costly than an ordinary loop or star network.
- o The method can be applied to both long-haul private line networks and to local access area networks.

As digital systems proliferate and automation for AO&M functions becomes feasible, where should they reside and how would they affect cost?

- o The centralized-versus-distributed question bears on survivability. Centralized functions, however, can be passed to lower levels in a distributed hierarchy if higher levels become disabled.
- o Automation is expected to result in net cost savings, largely due to reduction in personnel.
- o In the automated world of the future, cost-effective leasing of AO&M may be available.

What are the major networks, existing or contemplated, that affect access area characterization?

- o Commercial networks include the Public Switched Telephone Networks (PSTN), all Common Carriers, the Stored Program Control Network (SPCN), and the Integrated Services Digital Network (ISDN).
- o Military networks include the DSN, the DCTN, the Experimental Integrated Switched Network (EISN), and others to be implemented as per the Worldwide Digital System Architecture (WWDSA).
- o For the future, consideration and preparation must be started to anticipate the impact that ISDN's will have on the access areas, as well as on the telecommunications world in general.

How do the advanced digital networks differ from the older analog networks?

- o Network management and control differs considerably in analog and digital networks. Digital switches are controlled remotely with separate control networks that perform common channel signaling. These Common Channel Signaling (CCS) networks also provide to the user the AO&M and network management functions, as well as many new features.
- o As digital networks evolve, the integration of voice and data and possibly video services becomes feasible. The resultant ISDN is currently being standardized by international standards organizations.
- o Customer control of network services and feature packages becomes feasible with digital switches having stored program control and common channel signaling.
- o Integration of digital transmission and digital switching provides a potential for new and effective signal encryption systems.

Is there a need for access hubs (toll-type switches) or multifunction switches in every access area?

- o We believe that the computer modeling results will show that this is not always the case.
- o Some areas may require no hubs, others one or more.
- o Separation distances should be large enough to ensure survival of at least one hub or accessing switch.
- o Multifunction switches serving the dual role of long-haul access, tandem, and local area switching may be cost effective only in certain areas. We recommend a computer model to determine which areas need multifunction switches.
- o Multifunction switching requirements may change from area to area, due to traffic loads and the local features and functions needed to perform the unique military missions.

What architectural concepts are assumed for the long-haul network that area networks must access?

- o Each group of posts, camps, and stations would access via all locally available means (satellite, terrestrial, commercial, and private) and not necessarily through a single hub.

- Ultimately the International Consultative Committee for Telegraph and Telephone (CCITT) No. 7 signaling system would provide overall network management and control.
- Data communications could also be provided over an associated CCITT No. 7.

<u>What is the impact of divestiture, the Computer II Inquiry, and deregulation on military networks?</u>

- New features and functions should be optimally used to enhance productivity.
- The potential for greater survivability, lower cost, and more services should be utilized.
- Competitive procurements are now required.
- Deregulation leads to a multivendor environment with the resultant problems of system integration, procurement, and maintenance.
- Unless one engages a dedicated broker, there is no single entity with end-to-end responsibility for the network.
- There is no centralized means for allocating performance budgets (i.e., S/N, BER, GOS).

<u>What are the final recommendations of this study?</u>

- We recommend modification and use of an existing computer model to optimize local networks.
- With proper inputs, this model will provide goal architectures for the access area networks. It will show locations of hubs, remote switches, Private Automatic Branch Exchange (PABX's), concentrators, and interconnection gateways to long-haul networks.
- Each region in the United States should be individually assessed, so that commanders obtain a clearly defined long-term plan, a management plan, a transition plan, and an implementation plan for achieving the goal architecture.
- The estimated time to complete the computer model improvements and to demonstrate its access area capability is 2 years.

MILITARY ACCESS AREA CHARACTERIZATION

R. F. Linfield and M. Nesenbergs*

This report addresses the concepts, the justification, and the eventual configuration of military access areas. Many factors enter into this access area characterization effort. The key factors emphasized here are: the current telecommunications environment in the United States and abroad, the military (in particular, the U.S. Army) telecommunications requirements, pertinent architectures of present and future networks, and the associated major cost elements for access areas. An attempt is made to define the term "access area" in a quantitative and unambiguous way. To that end, many defining parameters appear needed to specify both the facilities and the functional elements of significance.

The report does not culminate in a particular recommended definition of access areas. Instead, the report recommends that automated means (computers and algorithms) be developed and used for network optimization. The reasons for this conclusion are elaborated in detail. However, the main features have to do with the ever-changing complexity, both in the costs, the end-user requirements, and in the technological world of communications. Dramatic changes take place repeatedly and create new circumstances for access area network designers. To take full advantage of this dynamic environment, the adequacy of skills and speeds of the best human experts can be disputed. Furthermore, the methods should be logically delineated and with repeatable results. To that end, a network optimization model such as the Consolidated Service Administrative Telephone System or CSATS, may be considered for modification and enhancement.

Key words: access area; cost; military communications; network architecture; performance; switches; traffic

*The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303.

1. INTRODUCTION

These are tumultuous times for telecommunications. Dynamic changes are occurring as the entire industry adjusts to recent regulatory actions and judicial proceedings. At the same time, to add more turmoil, the forces of change are affecting the underlying technologies as well. A whole new field of information services that combines office automation, voice/date communications, voice processing, data processing, and information management, is becoming available to the user.

Some examples of these forces of change are listed below.

- The Modified Final Judgment (MFJ) approved by Judge Green resulted in the divestiture of American Telephone and Telegraph Co. (AT&T) from the Bell Operating Companies (BOC's) on January 1, 1984.

- The final decision of the Computer II Inquiry has resulted in a distinction between basic and enhanced services and their regulatory status.

- Recent decisions by the Federal Communications Commission (FCC) have placed channel termination equipment on the customer premises side of the network.

- Microelectronics and large scale integrated circuitry continue to lead the general trend toward digitization of the network including computer controlled switches, digital transmission links, cellular radio, and common channel signaling.

- High capacity transmission facilities use fiber optics, microwaves, and satellite systems.

- Integration of voice, data, and imagery on digital networks continue and are coupled with an industry-wide merging of computer processing and communications.

- Automated network management and control systems are growing.

These are the major factors causing the changing environment faced by users of telecommunications. The regulatory environment today for one major telecommunication industry component, the PSTN, is illustrated in Figure 1.

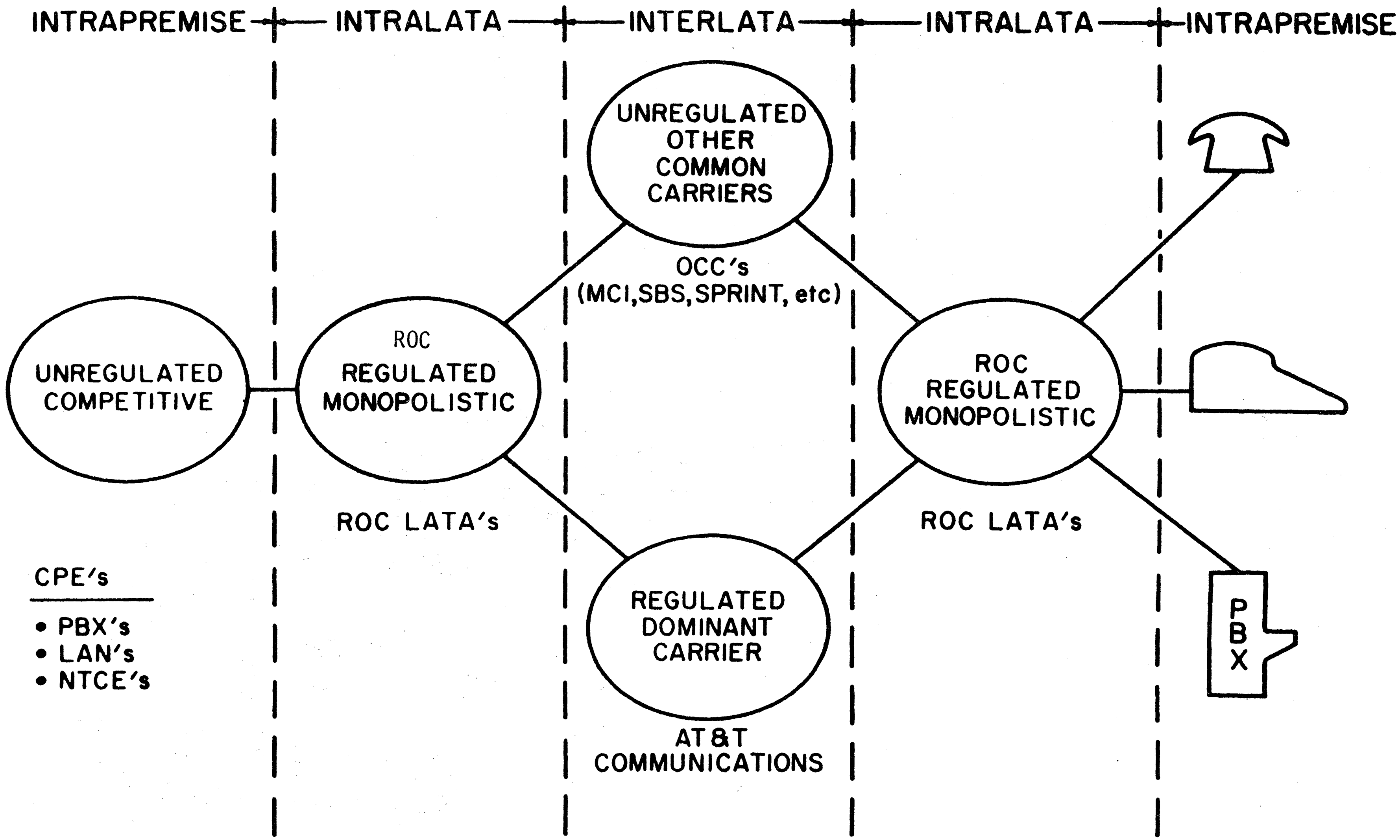


Figure 1-1. The telecommunications network environment, postdivestiture.

The repercussions from the divestiture of the BOC's from AT&T will be felt for a long time. Before divestiture took effect on January 1, 1984, ubiquitous service was desirable. This led to the regulated monopoly and subsidized prices for rural telephones. Today, due to Judge Green's Modified Final Judgment, local service remains a regulated monopoly. Except for the dominant carrier, all other telecommunications markets are competitive as shown in Figure 1.

As one of the largest telecommunications users, the military departments are faced with a dilemma--how to meet mission requirements in a multivendor environment with all the attendant costs of operating and maintaining the massive network.

While new digital technologies are merging the fields of switching, transmission, and data processing, they are also providing the necessary automation and integration of network maintenance to make such mergers practical. In fact, as noted by Joel (1982a), the greatest savings from the application of stored program controlled electronic switching have, to date, come as the result of the maintenance advantages realized by the use of modern data processing.

The purpose of the study reported here is to characterize the access area in this new competitive telecommunications environment. This includes considerations of multivendor switch procurements, increased traffic loads, various mixtures of satellite and terrestial transmission facilities, and the impact of automated management and control processors.

1.1 Approach to Access Area Characterization

There are, of course, many ways to define an access area. Some possibilities are listed below:

- political boundaries (e.g., state lines, counties, LATA's, etc.)
- natural boundaries (e.g., Hawaii)
- communities of interest (e.g., logistics, intelligence)
- regional collection hubs for long-haul concentration of traffic (e.g., to be carried on AUTOVON or DCTN)
- AO&M functional regions

- facilities ownership or responsibility (e.g., MILDEP'S or DCA)
- subscriber densities and distributions
- various combinations of the above.

In the past, an access area was usually identified with a geographic region that includes all posts, camps, and stations that home on an AUTOVON switch. The access lines for such an area are leased from a common carrier. The cost is determined by the number, type, and precedence level of lines. The administration of these lines is generally the responsibility of the base commanders. Some bases require multiple homing to several AUTOVON switches to ensure survivability. The AUTOVON network itself is a polygrid of transmission facilities connecting some 54 switch nodes in the CONUS. This "backbone" network is managed and controlled by the DCA. AUTOVON uses about 16,500 access lines between the 54 nodes and 972 subscriber locations. These subscribers generated about 5000 Erlangs of traffic during peak hours in 1983. Thus in 1983, on the average, there were approximately 20 subscriber locations per node, with 17 access lines per location carrying 0.3 Erlangs per line.

This greatly simplified, AUTOVON based, definition of an access area ignores many of the attributes listed above. The architecture of the long-haul portion is expected to change in the near future. The access area subscriber will undoubtedly be able to access a mixture of transmission media (satellite, terrestial, public, and private). Individual access choices will be made for economic reasons and for the appropriate function and service offerings. The connectivity in the access area itself may incorporate vastly different topologies to connect a variety of switch nodes to concentration points. Both single- and dual-function switches providing tandem routing functions and local service features may be used. Hubs may have dual homing and dual access lines for survivability. At the same time, the AO&M functions can be expected to change due to operational costs, automation, advanced control facilities, and reconstitution requirements.

Traffic intensity numbers can also be expected to change drastically in the future. This is because the technology is changing, the regulatory processes are changing, and the needs of the users are changing. These changes will impact the way networks and systems are engineered and implemented, and the particular services they offer. This in turn will affect the type and intensity of traffic carried. Some recent service examples include:

- video teleconferencing

- computer-based conferencing and electronic mail

- office automation including personal computers for data processing and word processing

- information services available through remote access

- teletext

- information management systems.

The impact of these new services within an access area and between access areas is bound to be substantial. Estimated increases of interarea traffic range from two to four times that currently carried by AUTOVON, i.e., 10,000 to 20,000 Erlangs. If these 10,000 to 20,000 Erlangs are offered to the DSN long-haul network, they must be handled by the tandem switches as well as by the long-haul trunks of the private line, common public, or other common-carrier networks.

The current U.S. policy encouraging deregulation of the industry and the recent judicial proceedings resulting in the divestiture of 21 BOC's from AT&T have raised a number of issues that must also be considered when characterizing access areas. Some pertinent issues are listed below:

- There is no longer a central network manager providing end-to-end service of overall network management or control.

- Government system acquisition practices must follow the competitive procurement processes.

- It is difficult to acquire a technically sound, traffic engineering justified, totally integrated system in this environment.

How does one assess and account for all of these factors to characterize the access area? There have been a number of studies attempted, but the changing environment has made them obsolete in a short time. The ideal approach would permit the inclusion of these changes as they occur and so that the characterization is continually updated. This leads to a computer modeling approach.

Our approach is illustrated in Figure 1-2. We begin by reviewing and assessing preceding work, including access area studies by GTE, AT&T, CSC, and Mitre Corporation. Based on these works and knowledge about the current state of regulatory and judicial actions, we must acknowledge certain limitations and constraints over which one has no control. We may also make certain basic assumptions. One critical assumption concerns the DSN architecture, which is presented and discussed in Section 4. With this initial background information we can define a number of the access area parameters that are unlikely to change, at least not rapidly. This includes items such as total number of subscribers, their location distributions, quality of service requirements, traffic projections, and cost estimates including tariffs. These items become fixed or predefined inputs to our initial access area characterization. At the same time, a set of variable inputs is developed. The variable parameters include items like concentration hub candidate locations, coverage area, stress level prerequisites, AO&M, and capacity of transmission facilities. These are the parameters that ultimately characterize the technical access area. A given set of values for each variable characterizes an alternative that can be evaluated using criteria such as cost, risk, performance, and transition ability. Based on this evaluation, the variable parameters are changed so that the relative merits of several access area alternatives can be assessed and an optimum alternative selected. This procedure is represented in Figure 1-2 by the selection feedback loop.

It became apparent as the work progressed that the structural approach illustrated by Figure 1-2 rapidly becomes too complex. However, there is a possibility that it could be modeled using a computer. While exploring this approach we discovered that similar modeling work has already been done at Ft. Huachuca for a somewhat different purpose--namely, for the CSATS model. This model was developed for the purpose of optimizing networks that are to be consolidated under a single management structure. The consolidation is to take place in limited geographic areas with high traffic density such as in metropolitan environments. The mathematical problem is very similar to access area consolidation but on a smaller scale. Our approach, then, was to examine this CSATS

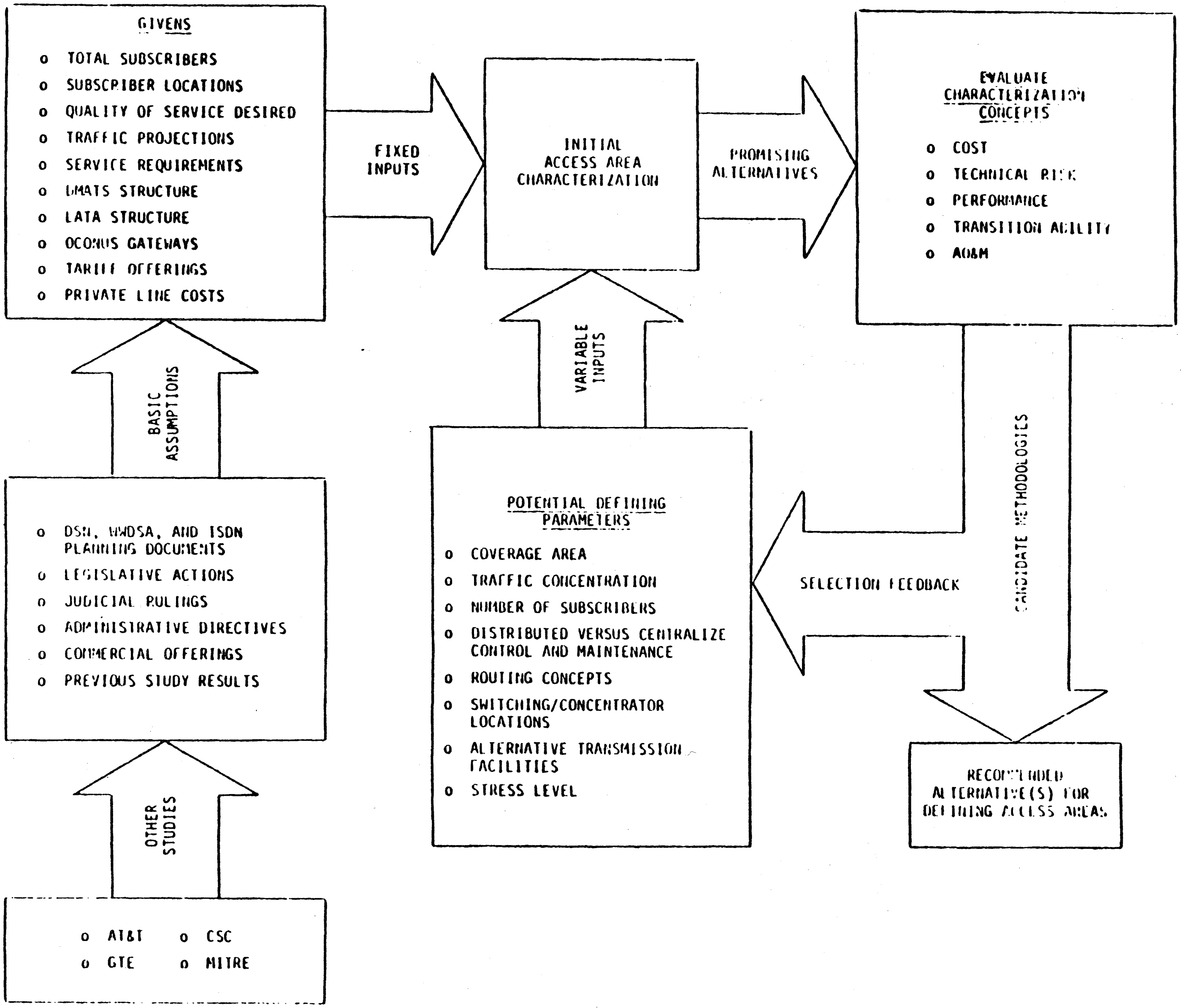


Figure 1-2. **ITS approach for developing a method for characterizing access areas.**

model in detail and to recommend what and how modifications should be made so that this model could be applied to access area modeling.

1.2 Report Synopsis

Section 2, beginning with pertinent U.S. policy objectives, describes the telecommunications environment that exists in this country today. Commercial and other nonmilitary networks are described including the planned ISDN that is being standardized for and by the international community. Next, a sequence of existing and planned military networks is presented along with the expected schedule of their evolution. This same section covers the current structure of the divested BOC's and describes how the common-carrier services differ from the local-carrier services.

Section 3 addresses the military requirements for telecommunications with emphasis on telephone service. Features seen by the user and functions performed by the network range from Plain Old Telephone Service (POTS) to Peculiar And Novel Services (PANS), like multilevel precedence and preemption. Any military network must be capable of surviving certain stress conditions. These stress levels and their potential impact on network configuration are discussed.

We noted previously that an access area characterization study must make certain basic assumptions. In section 4 we describe the architectural concepts in use today and introduce a structured configuration, which is an architectural network concept with enhanced survivability.

Section 5 is concerned with the access area itself, including its facilities, the functions performed, and a description of the major cost elements.

Section 6 describes in detail the parameters that can serve to define an access area. The list includes size considerations, topology, AO&M, and switching. These are parameters that can be altered in many ways. In order to assess optimum access area concepts we explore in Section 7 an already existing computer modeling concept. The finally recommended plan to modify this concept is given in Section 8.

Appendices are included to explore certain topics in more depth. They include:

A. Skill Levels and Labor Costs

B. Traffic at a Local Circuit Switch

C. Proposed Memorandum of Understanding

D. Survivability and Capacity Assignments in the Structured Configuration

2. THE CURRENT TELECOMMUNICATIONS ENVIRONMENT

Before describing the network environment that exists today, it is useful to first ascertain objectives or goals that underlie all telecommunications policy making in the United States. Perhaps the most fundamental principle is the First Amendment of the Constitution and its interpretations. For example, in 1969 the U.S. Supreme Court noted that "It is the purpose of the First Amendment to preserve an uninhibited marketplace of ideas in which truth will ultimately prevail."

This inherently implies public exposure to diverse sources of information using multiple forms of communication media, i.e., radio, TV, telephone, etc. The public need to expand and to protect the diversity of information flow was recognized by the Congress when it passed the Communications Act of 1934, enabling the FCC to oversee its progress. A primary objective of this Act was to provide "a rapid, efficient nation-wide and world-wide wire and radio communication service, with adequate facilities" made available "to all of the people of the United States at reasonable charges."

There have been different views on how this so-called universal, affordable, service could be obtained. In 1934 a primary goal was to expand POTS to more and more users. The provisions of communication service were regulated by the FCC on the assumption that telephone service would best serve the public as a monopoly. In this way, savings accrued from combining and controlling the large-scale facilities by a single entity. In addition to the advantage of these so-called "economies of scale," the concept of universal, affordable telephone service led to a principle for rate averaging. The more profitable high-traffic portions of the network would subsidize the low-traffic portions and thereby make service available to almost everyone at a price all could afford. By the mid-1960's, POTS was generally so available and new goals were established--namely to add new features and functions, thereby permitting an even greater diversity of message content, transmission services, and terminals.

Beginning with the now famous Carterfone Decision in 1968 and culminating with an equipment registration program that allows consumers to connect their own equipment to the network, if that equipment conforms to certain technical standards, the FCC has consciously followed a policy of promoting competition in the terminal equipment market. The terminal equipment market's competitive potential is reflected today by the fact that there are hundreds of manufacturers and suppliers of all kinds of devices to connect to the network.

The growth of the specialized common carrier industry began in 1963 when Microwave Communications Incorporated (MCI) first filed for permission to construct a long-distance microwave system from St. Louis to Chicago. Six years later, a landmark decision by the FCC permitted MCI to begin construction and this was followed a short time later by many other applicants.

At about this same time (mid-1960's), the computer industry was developing the technology that would permit computer time-sharing and remote access via telecommunications. This required more efficient communications facilities and different terminal equipment. The FCC initiated what became known as the First Computer Inquiry to explore the issues and to assess the regulatory impact of interfacing computers with communications and of allowing common carriers to offer data processing services. It concluded that the transmission of data and the processing of data were separable and that data processing should not be regulated. However, by the mid-1970's the distinction between processing and communications became blurred as these two information industries converged. Electronic digital switches with stored-program control became common and so did widely distributed computer networks. It was apparent that regulation based on a dichotomy between processing and communication was no longer feasible.

In the final decision following a Second Computer Inquiry in 1980, the FCC adopted a regulatory distinction based on two types of service, basic and enhanced, rather than the type of technology involved. Basic services furnished by the dominant carrier, AT&T, were to be regulated, enhanced services would be unregulated. Basic services were defined by the Commission as follows:

> A basic transmission service is one that is limited to the common carrier offering of transmission capacity for the movement of information. In offering the capacity, a communications path is provided for the analog or digital transmission of voice, data, video, etc., information. Different types of basic services are offered by carriers depending on a) the bandwidth desired, b) the analog and/or digital capabilities of the transmission medium, c) the fidelity, distortion, or other conditioning parameters of the communications channel to achieve a specified transmission quality, and d) the amount of transmission delay acceptable to the user. Under these criteria a subscriber is afforded the transmission capacity to suit its particular communicaton needs.

The Commission defined an "enhanced service" as follows:

> The term "enhanced service" shall refer to services, offered over common carrier transmission facilities used in interstate communications, which employ computer processing applications that act on the format, content,

code, protocol, or similar aspects of the subscriber's transmitted information; provide the subscriber additional, different or restructured information; or involve subscriber interaction with stored information.

The Commission permitted AT&T to offer enhanced services and Customer Premises Equipment (CPE) on a nontariffed, competitive basis provided they did so through a fully separate subsidiary to ensure that there is no cross-subsidy between the regulated and unregulated business. This separate subsidiary today is known as AT&T Information Systems.

Another conclusion of Computer II was that all CPE's should be detariffed and separated from a carrier's basic transmission service. The Commission arrived at this conclusion because they "repeatedly found that competition in the equipment market has stimulated innovation on affording the public a wider range of terminal choices at lower costs."

For two decades the concept of enhancing competition to provide marketplace regulation by reducing Government involvement has been the philosophy of the FCC, the Congress, and the Justice Department. This was further demonstrated in 1982 when Congress introduced two bills (S898 and HR5158) to rewrite the Communications Act of 1934, and by the Justice Department's settlement of their antitrust suit against AT&T. Although the rewrite bills did not pass, they probably influenced the settlement of the antitrust suit, which resulted in a major restructuring of the industry under the terms of a modified final judgment by Judge Greene (1982). AT&T was directed to divest itself from its 19 BOC's by January 1984. The BOC's would provide local telephone exchange service but not long-distance service. They can market and sell terminal equipment but cannot manufacture such equipment. They must provide "equal access" to all long-distance carriers. AT&T, in addition to providing long-distance service, can also enter the data-processing field. This latter service had been denied previously by a 1956 Consent Decree that prohibited AT&T from entering the unregulated telecommunications business. AT&T cannot, however, enter the electronic publishing business (e.g., information such as news, weather, or sports disseminated through electronic means like videotex). This latter restriction will be reviewed in 7 years to assess its competitive status.
The restructuring of the dominant carrier in this way is intended to have major consequences on the industry by reducing many of the entry barriers to new competitors.

Based on this background some general principles underlying U.S. communications policy can now be given. The basic premise is that information, ideas, and their means of dissemination should be available to the American people from as many sources as possible. Emphasis is to promote a competitive marketplace for greater diversity and economic efficiency. To enhance the freedom of choice the public policy should:

- Use market forces wherever possible to displace regulatory control.
- Ensure equal access protection to information service providers, in particular, to afford reasonable opportunity for conflicting viewpoints to be heard.
- Maintain corporate separation between information providers and information carriers.
- Promote effective competition by eliminating barriers to those seeking to enter the market.

The old objective of universal, affordable service is not abandoned. However, new objectives are added, namely: efficiency, innovation, and diversity, all based on a competitive environment where customers' needs are expressed in the marketplace and where price is more directly related to cost.

With these objectives in mind, one is now in a position to review the telecommunication network environment as it exists in the United States today.

2.1 Commercial Networks and Other Nonmilitary Networks

The commercial networks in the United States include both voice and data networks commonly known as the Public Switched Networks. The dominant carrier in the United States has been the AT&T's PSTN. These networks are discussed in more detail in the following paragraphs. The PSTN (including the Independents) is of particular interest because it is so vast and encompasses most of the populated regions of the country. Because of its ubiquitous nature, the PSTN is considered a key support element for the DSN.

The Public Switched Telephone Networks

The PSTN is largely owned and operated by the AT&T and the BOC's. With roughly $150 billion in total assets and over a million employees, AT&T and the BOC's serve 150 million of the 187 million telephone subscribers or about 80% of all the subscriber lines. The other 20% are served by about 1500 independent telephone companies of which the four largest (General Telephone, United Telephone, Continental Telephone, and Central Telephone & Utilities) each boast over one million subscribers.

Since the divestiture of AT&T, the remaining former 19 BOC's have been associated into 7 Regional Holding Companies (RHC's) as shown in Figure 2-1.

AT&T itself has been reorganized into two major entities: AT&T Communications (AT&T-C) for the regulated side of the business, and AT&T Technologies for the unregulated side.

The long-distance or toll traffic in the United States is carried by AT&T Communications and around a dozen Other Common Carriers (OCC). While the coverage of the AT&T-C is nearly nationwide, the OCC's tend to serve selected locations. The same observation pertains to offered services. While AT&T offers the longest list of services, the offerings of the OCC's are more selective. The situation is summarized in Table 2-1. There is a great variety of services buried in such a table, especially under the heading Other, where such services as Facsimile, Video, Electronic Mail, Telemetry, and so forth are found. What the table neglects to clearly emphasize is the dominant size of AT&T Communications.

According to available data from May 1977, the OCC's share in the U.S. toll network amounts to 5% of all wire miles, 3% of all coaxial cable miles, 10% of all microwave relay miles, and roughly 1% of all 4 kHz or 64 kb/s carrier channel miles. In the intervening years the OCC percentages have grown somewhat, but in all likelihood they have not doubled.

Another fact that Table 2-1 fails to illustrate is the massive role of telephone voice traffic by itself and the provisioning of voice grade connectivity for various subscriber selected uses, such as quasi-data services. Over the past decade the percentage of nontelephony subscribers has gradually increased and may be approaching 10%. In other words, 90% or so of all subscriber terminals are for voice.

In summary, the main bulk of telecommunications services in the United States is POTS. It is provided (owned, operated, administered, installed, engineered, and researched) by what used to be one large company. The long haul traffic needs are largely served by AT&T Communications, the dominant carrier regulated by the FCC. Access to the dominant carrier and to other common carriers is via seven RHC's that cover the continental United States.

These RHC's are, in turn, divided into over 180 local access and transport areas of LATA's. There may be anywhere from 1 to 15 LATA's per state. LATA boundaries are insensitive to area codes and state lines. Each LATA is a

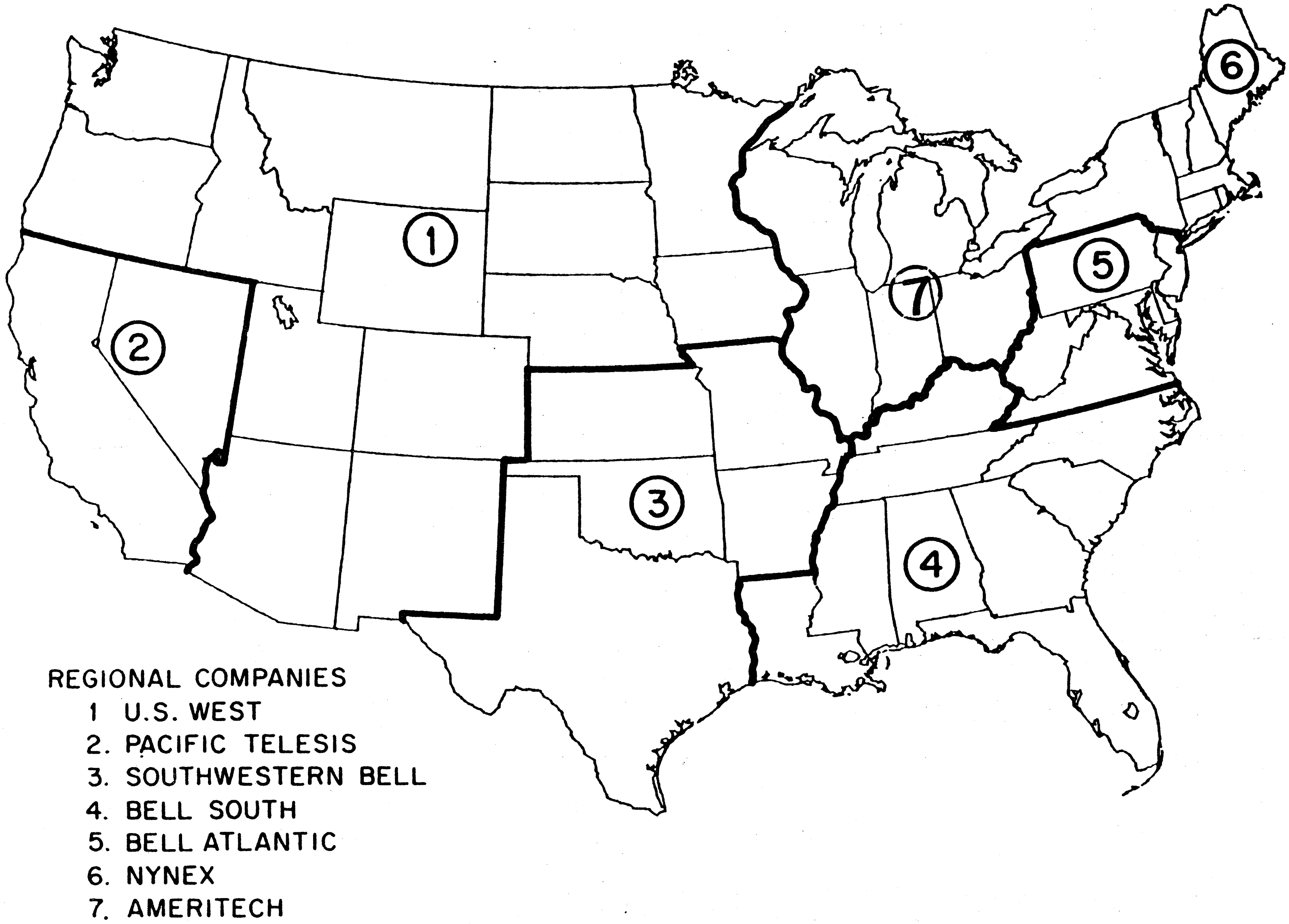


Figure 2-1. The seven Regional Holding Companies

Table 2-1. Common Carriers and Their Offered Services

Interstate Common Carrier	Private Line			Measured Use		
	Voice	Data	Other	Voice	Data	Other
American Satellite Company	X	X	X			
AT&T Communications	X	X	X	X	X	X
GTE Telenet					X	X
Graphnet						X
MCI Communications	X	X	X	X		X
RCA American Communications	X	X	X	X		
Satellite Business Systems	X	X				
Southern Pacific Communications	X	X	X	X		X
TYMNET					X	X
United States Transmission Systems (ITT)	X	X		X		X
Western Telecommunications Incorporated			X			X
Western Union Telegraph Company	X	X	X	X	X	

geographically defined area of service responsibility. Intra-LATA traffic is handled by a BOC. Inter-LATA traffic must be handled by competing interstate carriers (IC's) on an equal-opportunity basis. Since intra-LATA and inter-LATA traffic often uses the same switch on a shared basis, the dominant user is assigned ownership and responsibility for that switch. The boundaries of the four LATA's of New Jersey are shown in Figure 2-2.

In each LATA there can be many exchange areas or zones. Each zone has one or more wire centers that contain one or more central switches. One wire center in each zone has been designated as the primary routing point or rate center. These rate centers are assigned vertical and horizontal coordinates for use in determining the mileage-dependent interexchange costs.

Competing carriers in a given area will have a number of switches that interconnect to the BOC end offices. Today these access circuits for the OCC's commonly terminate as lines on the end-office switch as illustrated in Figure 2-3. Using multifrequency, dual-tone dialing, AT&T access terminates as the customer dials seven digits for the desired OCC, waits for a second dial tone, and then dials a personal identification number. This OCC procedure is definitely inferior to that of AT&T customers who merely dial a 7- or 10-digit number.

At present time the BOC's are required to provide equal access to all competing carriers, partially by September 1, 1984, one-third by September 1, 1985, and everywhere (except for the mechanical switching arrangements) by 1986. Under this equal-access arrangement the OCC's will be connected to the trunk side of the end-office switch as illustrated in Figure 2-4. With so provided equal access, customers can have all inter-LATA calls handled by the carrier they choose. In all cases they merely dial a 7- or 10-digit number. Since connections are on the trunk side of the switch, the Personal Identification Number (PIN) is automatically known and answer supervision is provided. Customers may also override their regular carrier choice by dialing a 10XXX access code of another carrier, where XXX designates one of up to 999 carriers.

The Stored Program Controlled Network

The AT&T telephone long-haul network is rapidly evolving into what is known as a Stored Program Control (SPC) network. This SPC network is based on special-purpose processors controlling the switching of the long-haul trunk circuits.

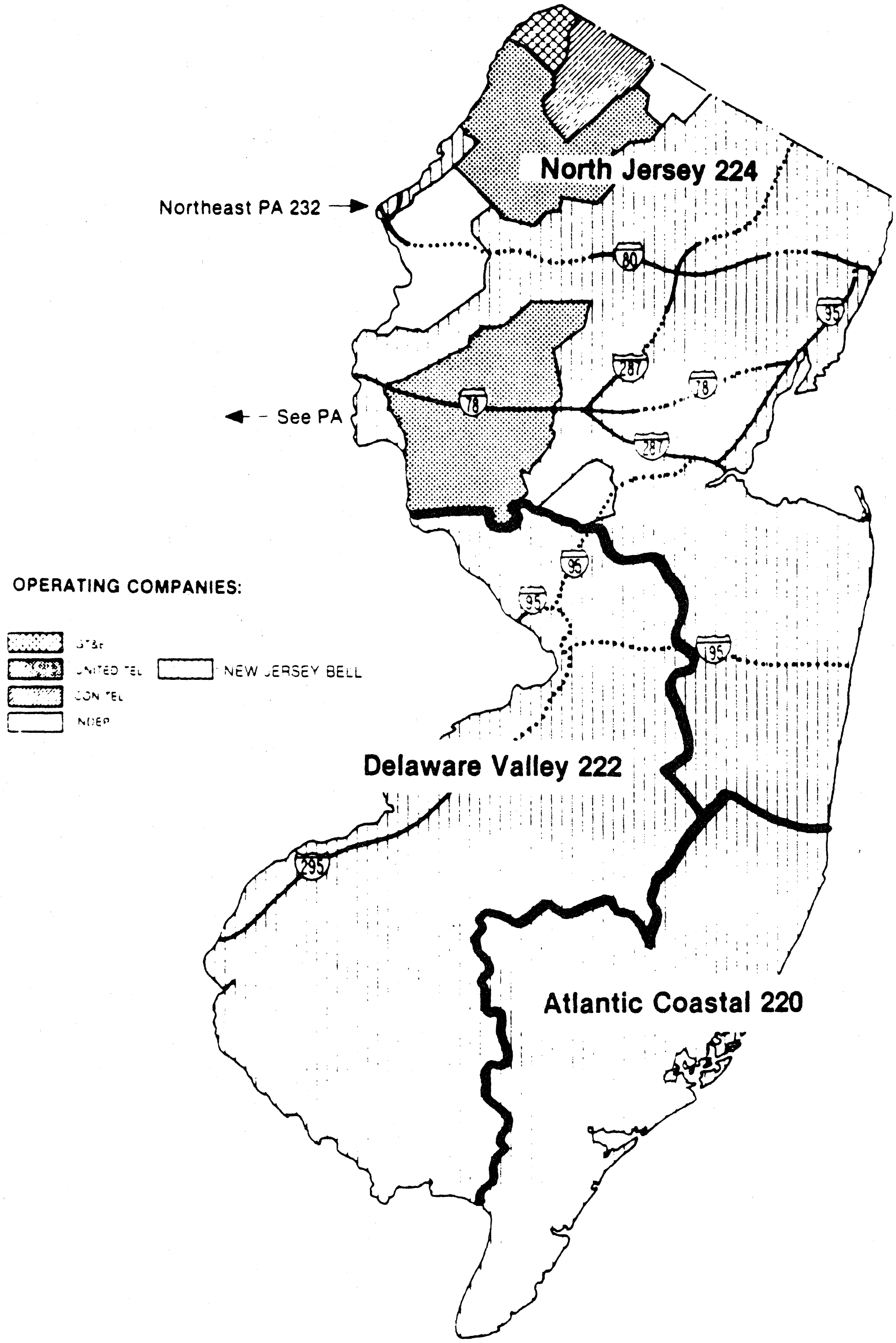


Figure 2-2. LATA structures and oDeratinq comDanies in New Jersey.

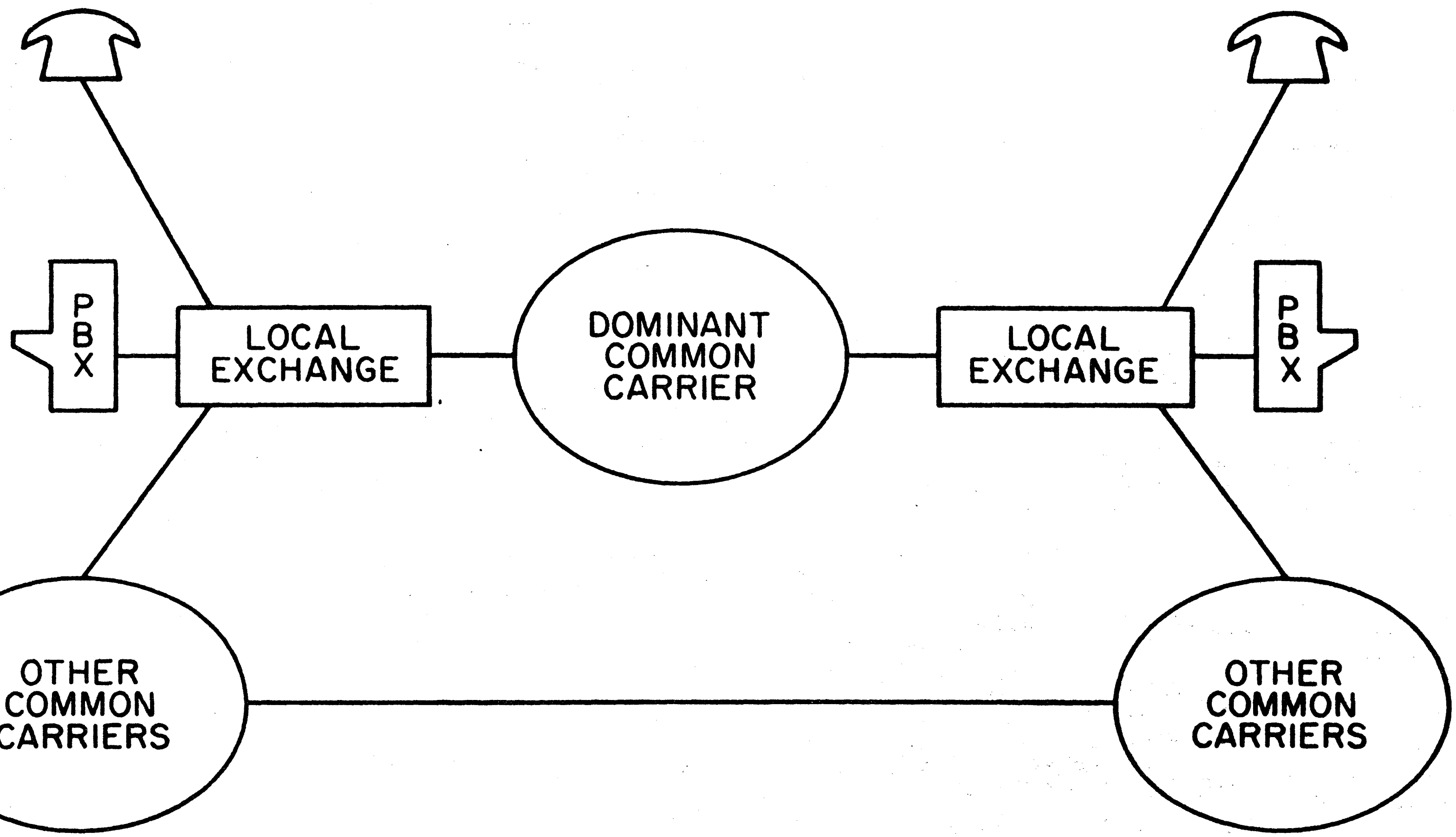


Figure 2-3. The Public Switched Telephone Network, predivestiture.

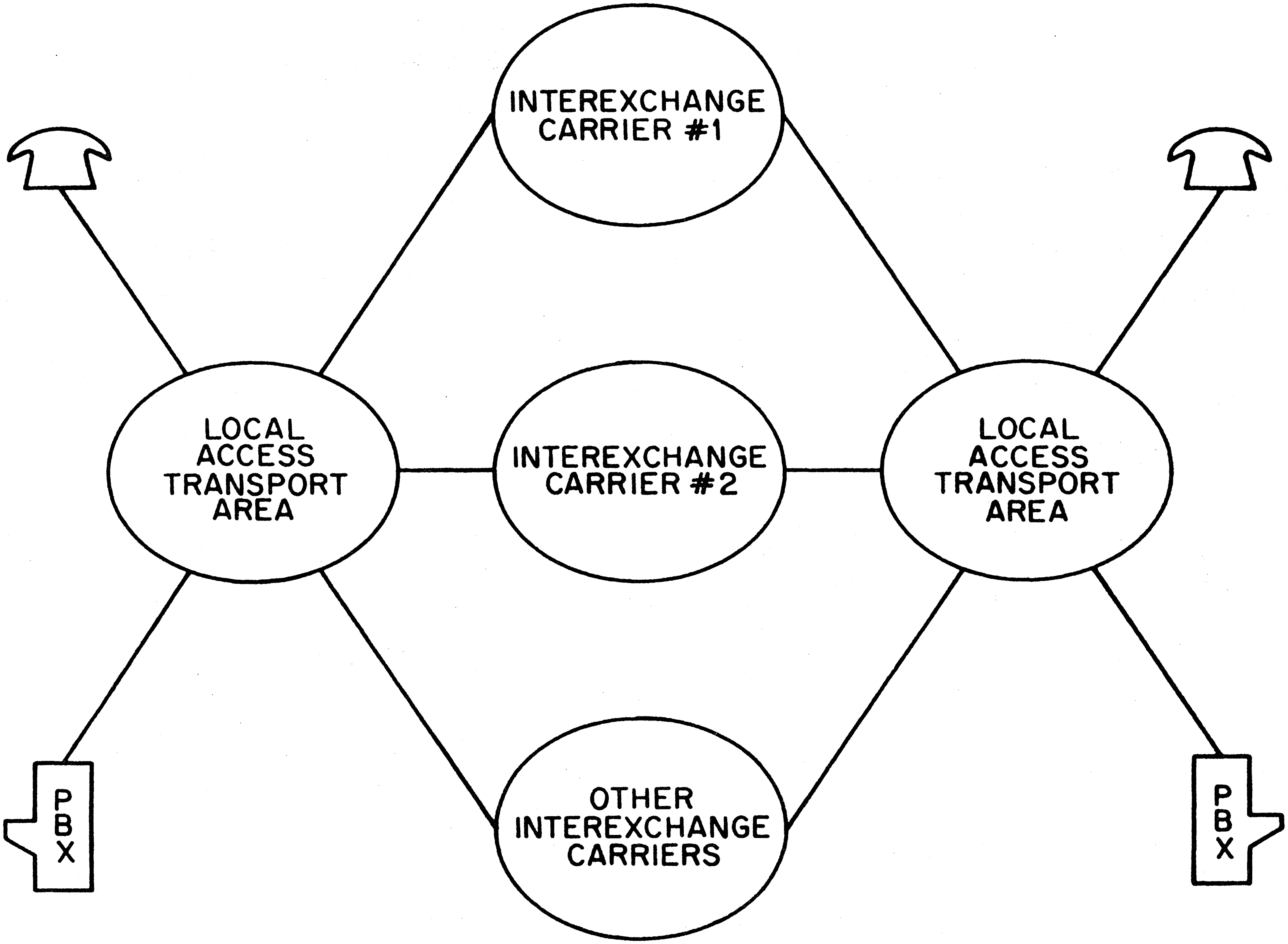


Figure 2-4. The Public Switched Telephone Network, postdivestiture.

These processors are interconnected by a separate packet-switched network known as the Common Channel Interoffice Signaling (CCIS) network. Thus, the SPC network is a nationwide network of switching nodes with the combined intelligence of many digital computers. See Figure 2-5. Using shared data bases, these switching nodes, called Action Control Points (ACP's), are capable of supporting numerous customized service packages for user groups of all kinds. See Bohacek (1982).

Since an underlying principle of the SPC network is digitization, it can also provide end-to-end digital service at 56 kb/s with relatively minor equipment modifications. This so-called Switched Digital Capability (SDC) resembles, in many respects, the DATAPHONE Digital Service (DDS) on leased lines. A user accessing SDC must alternate with voice service over the existing local loop plant. These SDC connections potentially support bulk data transfers, high-speed terminal access, computer graphics, facsimile, teleconferencing, electronic mail, secure voice, and combined voice-data services.

Figure 2-6 illustrates the elements involved in a long-distance call over the stored-program controlled network. In the future the SPC networks services are expected to be under customer control. This control is provided using a set of software-defined capabilities called Direct Service Dialing Capabilities (DSDC). The DSDC can access the support system shown in Figure 2-6 and change its data base for updated service definition. This service management concept allows the network to offer a specific set of services to specific groups of users under the users' control. Details of the concept are described by Raack et al. (1984).

The advent of SPC switching, CCIS control, and SDC services all are essential preludes to a future network concept known as the ISDN. The ISDN concept described below and envisioned by international standards organizations is probably one decade in the future. The SPC network, on the other hand, will be largely in place by the end of 1985. The rules and statutes that currently exist in the area of telecommunications will ultimately determine what features and functions can be offered to the public by regulated and unregulated service providers. The price of the feature options offered to user groups is yet to be determined. Offering will, of course, depend on demand and cost.

The Integrated Services Digital Network

The original concept of ISDN stems from the increased use of digital techniques in worldwide public telephone networks--and the consequent realization

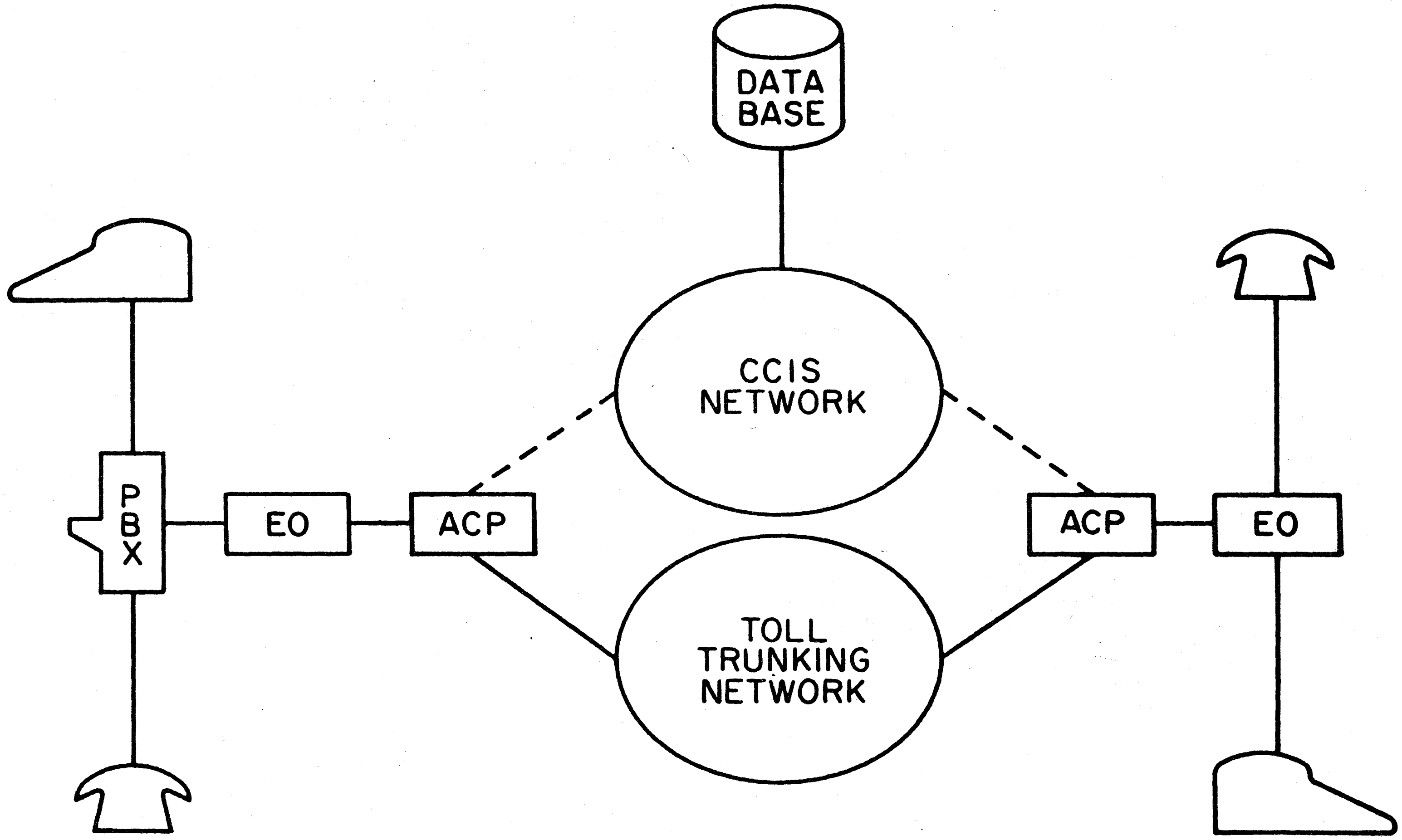


Figure 2-5. The stored-program control network.

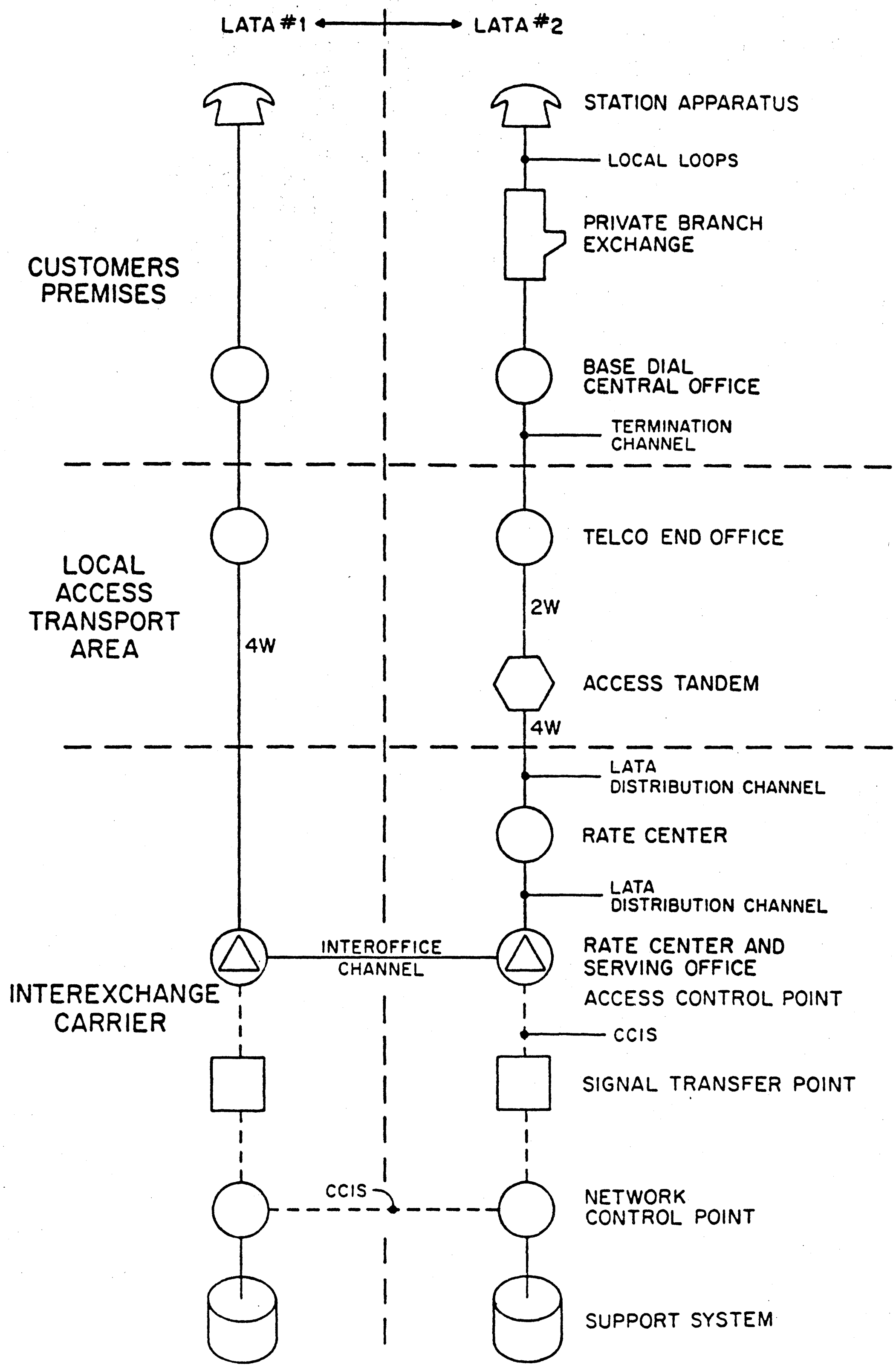


Figure 2-6. Long distance call on the stored-program controlled network.

that in a total digitally implemented telephone network the network itself might no longer be concerned with or be conscious of the actual nature of the information being passed--whether this information in its original form represents speech, facsimile, bulk data, etc., or is arbitrarily encoded. As a consequence of this argument, and because of the fact that the public telephone networks are the only networks providing essentially universal subscriber connectivity, the CCITT (1980) stated that ISDN will be based on and will evolve from the public telephone network. For many people this line of thought has implied that the term ISDN network inherently defines a physically complete and defined real network. In certain national environments, (e.g., the United States), this in turn, has led to the concept of "multiple ISDN's" and to discussions relating to interconnection of multiple (national) ISDN's.

As the study of ISDN and the development of CCITT Draft Recommendations progressed, there has been growing recognition that this concept may be overly simplified. By now it is recognized that in the real world the network cannot ignore the nature of the information to be passed (e.g., for speech communications certain network facilities may have to be invoked that are incompatible with the requirements for transparency associated with many data applications). Thus, Draft Recommendation I.310 of the CCITT introduces the ISDN concept as a network to which users connect through a limited set of multipurpose ISDN user/network interfaces. The new emphasis is thus placed on the user/network interface characteristics. From this it would be only a small step to qualify "an ISDN" in terms of a conglomerate of networks, not necessarily all having the same characteristics, maybe not mutually fully interconnected, but which as a group are accessed via standardized ISDN interfaces. While this concept has not yet permeated through all Draft Recommendations it is gaining increased recognition.

In the U.S. competitive environment, the ISDN is viewed differently than in most other countries. For example, in the United States the information transport functions are distinguished from processing and storage functions because of regulatory restrictions. This means that in the United States the processing/storage functions of ISDN must be external to the network while in most other countries all functions tend to be combined. A functional model of ISDN is illustrated in Figure 2-7.

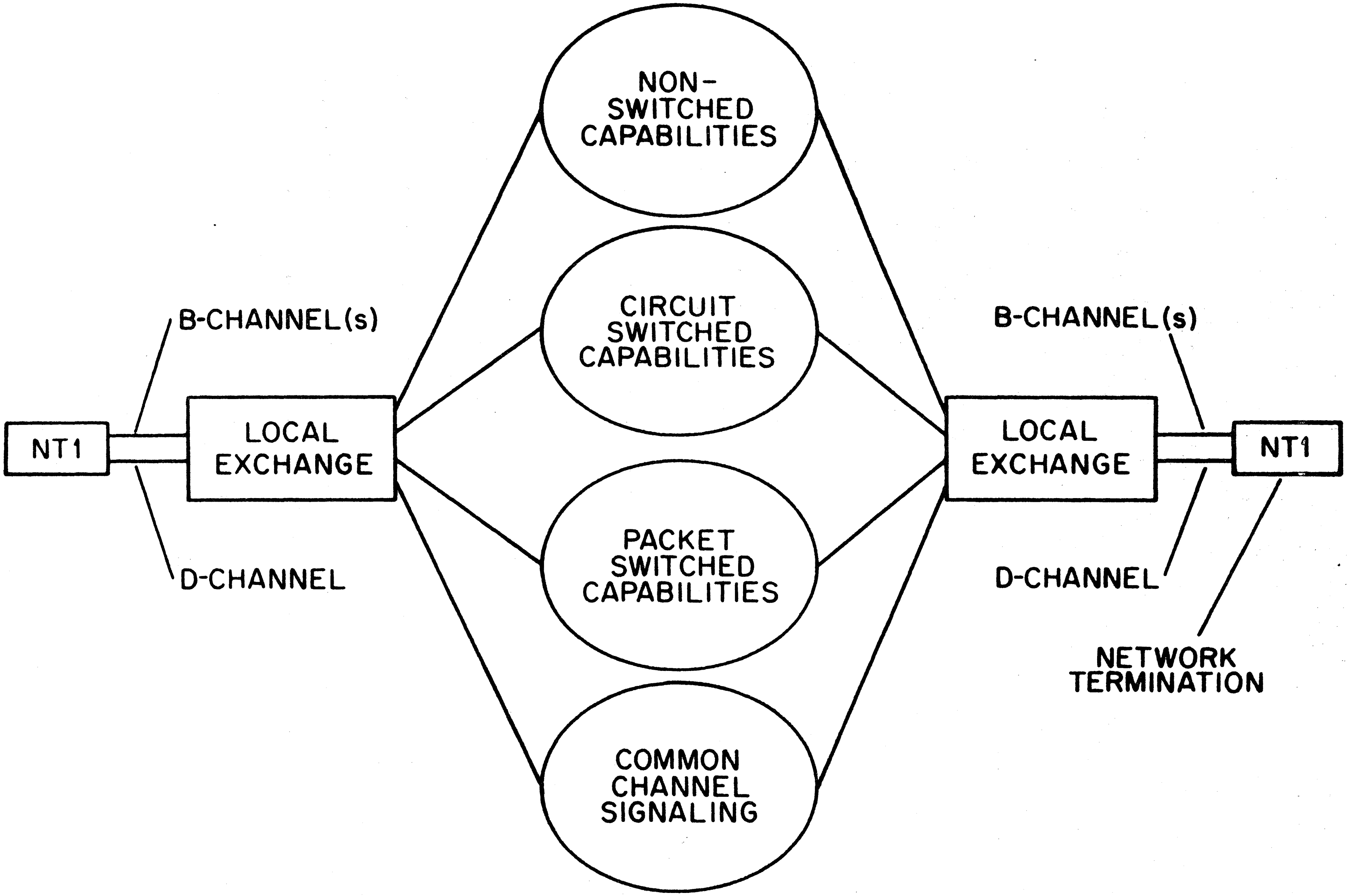


Figure 2-7. The Integrated Services Digital Network.

A fundamental principle underlying ISDN service integration is that the interfaces between the user and network will be defined and kept to a minimum. Currently, there are many interfaces between customer terminals and networks. Most would be eliminated as the ISDN interfaces become defined and implemented. An interface such as the standard data interface RS-232-C could operate in an ISDN environment but would need an adaptor. Such an interim solution would eventually be phased out. Another key principle is that facility varieties, such as circuit- or packet-switched channel options provided by a carrier, be limited. The premise is that the communications carriers would provide the user with a minimum number of standard channel services over circuit- and packet-switched facilities. The basic user-network interface will have two 64-kb/s channels for information transfer and a 16 kb/s channel for signaling and low-speed data. This is known as the 2B + D basic channel structure. Standard multiples and submultiples of these data rates are currently being determined by the CCITT. Except for some questions on bit sequence integrity, high-volume users could have available a 23B + D configuration at their user/network interface. It is the planned primary data rate channel structure for PABX and local area network (LAN) connections to the ISDN. Expected ISDN attributes include:

- special nodes with gateway functions and interfaces for interworking with other dedicated networks
- intelligence and data bases for service features, maintenance, and network management
- operation and maintenance centers
- combined voice and nonvoice communication
- a common channel signaling network to interconnect all nodes of the network
- encryption-compatible digital voice and data terminals used throughout the network
- no need for new special service networks, as new services can be tried and abandoned at little cost or risk as customer demand dictates
- stored-program controlled switch adaptability
- customer access arrangements and interfaces to connect various terminals, systems, and networks to the ISDN
- high-speed digital capability of ISDN connections.

Thus the real impetus behind ISDN is the desire for a common user interface for integrated services--not a single transmission facility. The ultimate system would have a user port into which anyone could plug almost any piece of terminal equipment (voice, data, or video) in a manner just like we use an electrical outlet today. This ISDN concept is not wholly unlike the WWDSA structure described later in this section.

The Federal Telecommunications System

The Federal Telecommunications System (FTS) is a private, Government-owned and operated network that ensures communications between civil agencies. Created under the auspices of the General Services Administration (GSA) in 1963, the FTS today consists mainly of electromechanical switches and analog transmission facilities. Currently there are 11 million miles of transmission circuits, 52 major switching centers, 35,000 access lines, 1.3 million phones, and more than 1500 PBX and Centrex switching arrangements. FTS is found in all 50 states. It connects various Government agencies including some military installations. Over 300 million calls, including 15% as data calls carrying $2(10^{14})$ bits, were handled by the FTS in 1983.

The GSA plans to upgrade the system with digital stored-program controlled switches and digital transmission facilities over the next 3 to 4 years.

On-net access to FTS is achieved by dialing 8 followed by a 7- or 10-digit number. FTS office codes differ from the PSTN. Figure 2-8 illustrates how most Government telephones can access either FTS or the PSTN using an 8 or 9 dialing prefix respectively.

2.2 Military Network Environment

Military networks include the present Defense Communication System (DCS). Beginning in 1985 it is expected to evolve into the DSN and will include the Defense Digital Network (DDN) and the Defense Satellite Communication System (DSCS). The DSN is actually an interim step toward a WWDSA, which calls for a global survivable system with separate but interoperable voice and data networks. Another transition approach to the WWDSA is the DCTN, formerly called the COMSATCOM system. Ultimately, the WWDSA could even be integrated into some military version of an ISDN.

The DCTN is a leased system designed to concentrate routine traffic sources in CONUS and reduce long-haul costs by taking advantage of diverse media including commercial satellites.

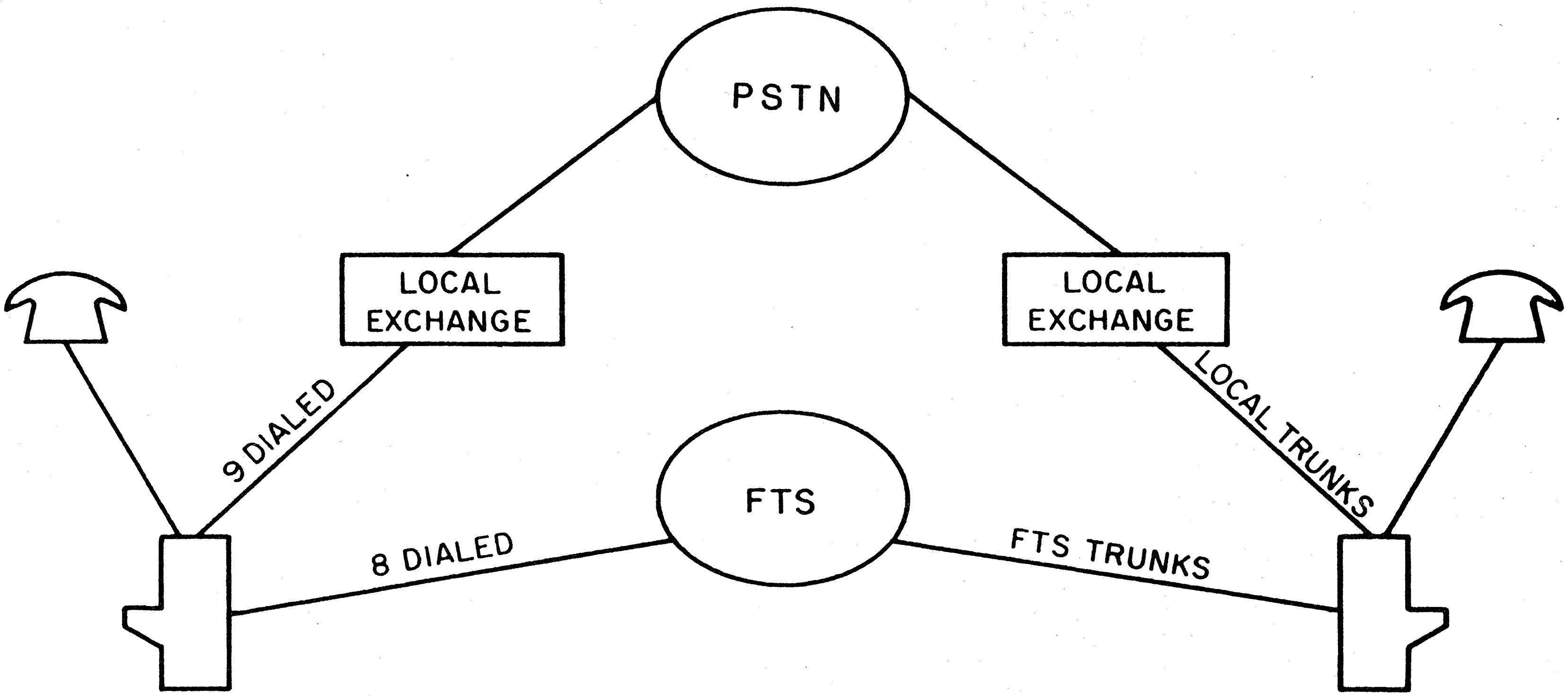


Figure 2-8. The Federal Telecommunications System access.

Closely related to DSN is the EISN, which is a scaled down network version for testing and evaluating many of the DSN features and functions.

The DCS, DSN, WWDSA, DCTN, and EISN are discussed in more detail in the following paragraphs. ISDN was covered in the previous section. A summary of their attributes and their schedule of evolution completes this subsection.

The Defense Communication System

The current DCS architecture is illustrated in Figure 2-9. Dial Central Offices (DCO's) on each base are star-connected to backbone switches of the DCS including AUTOVON and AUTODIN. AUTOVON is a leased military telephone service. The AUTOVON network has a polygrid topology for survivability. There are usually at least two 2-way paths connecting any two switching nodes. The switching nodes are located away from major target centers.

The busy hour traffic load currently offered to AUTOVON is about 5000 Erlangs. Approximately 150 Erlangs are priority calls. Access to the 54 AUTOVON switches is via some 16,500 access trunks from nearly 1000 subscriber locations in the CONUS. The blocking grade of service objective for routine calls on these trunks is $p = 0.10$ for access and $p = 0.05$ for egress. The backbone trunks are typically sized for $p = 0.03$ in the CONUS. Procedence calls, of course, have lower blocking probabilities depending on level of precedence. Flash level is essentially non-blocking.

The AUTODIN network is a message switched system that carries about 3×10^{11} bits per month. This system is being replaced with the DDN. The DDN is a packet switched network derived from the military portion of what was once commonly known as ARPANET, later as DARPANET.

The AUTOSEVOCOM portion of the DCS has a limited number of secure telephones at critical user sites. The total secure traffic has been estimated to be less than 1% of the total voice traffic on AUTOVON or about 50 Erlangs. This may increase considerably in the future.

The main DCS attributes as quoted by the Defense Communications Engineering Center (1982) are:

A. Endurability--
includes availability, survivability, restoration, reconstitution, self-sufficiency, electronic counter-counter measures, and responsiveness.

B. Distributed Communications--
includes processor intelligence near subscribers, mix of media, interoperability, and distributed control.

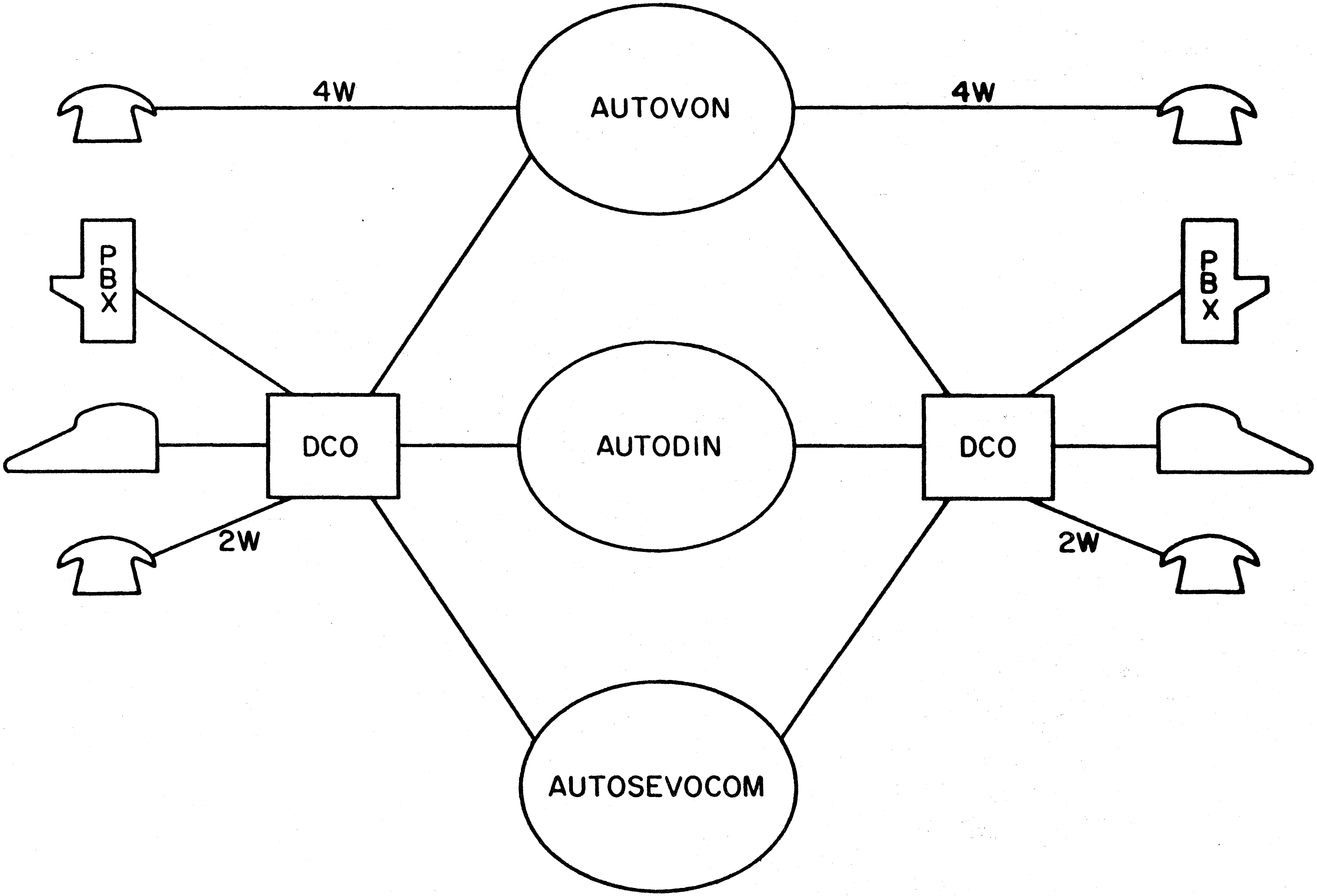


Figure 2-9. The Defense Communication System.

C. Responsiveness--

includes surge capacity, responsive system control, responsive AO&M, deployable transportable packages, and timeliness of information transfer.

D. Efficient Spectrum Utilization--

includes exploitation of higher electromagnetic frequencies, efficient use of transmission bandwidth, improved source coding, data and voice resource sharing, and diversification of common resources through interoperability/expanded resources.

E. Interoperability including Unified Signal Structure--

includes interfacing security, interfacing all voice terminals, interfacing all data terminals, interfacing control subsystems, flexible network structure, standardization (hardware, software, and protocols), and interoperability with other networks.

F. Security--

includes end-to-end encryption, link encryption, multilevel computer and switch security, secure remote programming/downline loading.

G. Economy and Affordability--

includes coordination of DOD strategic plant procurements (e.g., integration of special purpose networks and dedicated networks into the DCS), DOD software and protocol standardization, exploitation of commercial offerings, and effective management and control.

H. Evolutionary Capability--

includes operational philosophy, integration of services, integration of functions, capitalization on commercial systems, rationalization/-standardization/interoperability.

Upon examination, it is clear that the above system attributes are neither independent nor mutually exclusive of one another. They are designed for many diverse activities and functions that make up the DCS.

As illustrated in Figure 2-9, telephone connection to AUTOVON may be two-wire through the DCO (or via a private branch exchange, PBX) or four-wire direct to the AUTOVON switch.

The Defense Switched Network

The DSN is the interbase telecommunication system that provides end-to-end common user and dedicated telephone service for the DOD with a later capability of incorporating data and other traffic.

The initial DSN plan of 1982 called for a hybrid network consisting of an SPC network derived from the PSTN and a Private Line Network (PLN) with certain added features not available from the PSTN. This hybrid network provided a mix of transmission media for survivability. Access areas comprised of one or more contiguous military installations would access the long-haul portion via dual homing tandem switches located in the access area. These switches may, in some areas, provide the dual functions of access to the long-haul networks, tandem functions, and, at the same time, subscriber services or DCO functions for the local area.

One DSN concept called for 80 tandem switches in 40 CONUS access areas and around 1500 DCO's on military bases worldwide. An average sized tandem switch could handle 2000 trunks. The DCO's range in size from 500 to 20,000 subscriber access lines and 50 to 2000 trunks. The intertandem traffic was estimated to be 10,000 Erlangs of the entire busy-hour load attributed to military subscribers. That is, 10,000 Erlangs were offered to the DSN long-haul portion and had to be handled by one or more tandem switches as well as by the assets of the private line, PSTN, or other networks.

The PLN portion of the DSN would be expected to meet the same service objectives as AUTOVON. The PSTN portion is expected to contain certain Dynamic Resource Allocation (DRA) functions to critical users, so that even with no precedence procedures the callers would have essentially no blocking (i.e., p = 0.001) under all stress conditions with a guaranteed access delay of 10 seconds or less. The minimum required service features for the critical users on DSN, even under some damage conditions, are as follows:

A. end-to-end voice communication with DRA
B. access and egress preemption
C. originating call screening
D. authorization code
E. interconnection to private networks including AUTOVON
F. off-net to PSTN and vice versa access
G. off-hook service
H. teleconferencing.

Items A, B, E, and G are Government unique features. The other features are expected to be available commercially to the public sector on the PSTN. The basic architectural concept of the DSN is illustrated in Figure 2-10. A key advantage of the access to a range of transmission media is realized from least-cost routing algorithms in the switch hubs. At the same time this mix of media offers greater survivability.

The hubs shown in Figure 2-10 might be dual-function or stand-alone switches. Multiple switches and dual homing would provide enhanced survivability.

This general concept of an SPCN and a Private Line Network (PLN) hybrid outlined in the 1982 DSN plan recently has been questioned for a number of reasons, including:

- The access areas were not well defined in terms of AO&M and personnel requirements.
- Survivability was reduced due to vulnerability of on-base switches.
- The stored-program controlled network does not have multiple-level precedence/preemption features.
- The after-divestiture access to SPCN appears uncertain.
- Common channel signaling will not be available at class 5 office level after divestiture.
- The competitive procurement process may not be viable.
- There are cost uncertainties due to the fact that private line tariffs and access charges are unknown or unsettled.
- The new DCTN can provide service in 2 years and can meet many of the requirements for handling routine traffic at reduced cost.

Because of these concerns with the original plan, the Western Hemisphere DSN architecture is being reexamined. The communications requirements through various levels of stress and the capability of key programs (DSN, DDN, NETS, DCTN) to satisfy DOD requirements will provide the basis for developing implementation and investment stategies.

<u>The Worldwide Digital System Architecture</u>

The development of a WWDSA was undertaken in response to tasking from the Office of the Secretary of Defense. This tasking directed the DCA to propose a WWDSA in coordination with the military departments, the former TRI-TAC office, the National Security Agency (NSA), and other interested agencies and commands. The main purpose for the new architecture was to ensure that the many DOD command, control, and information processing systems be sufficiently interoperable to achieve

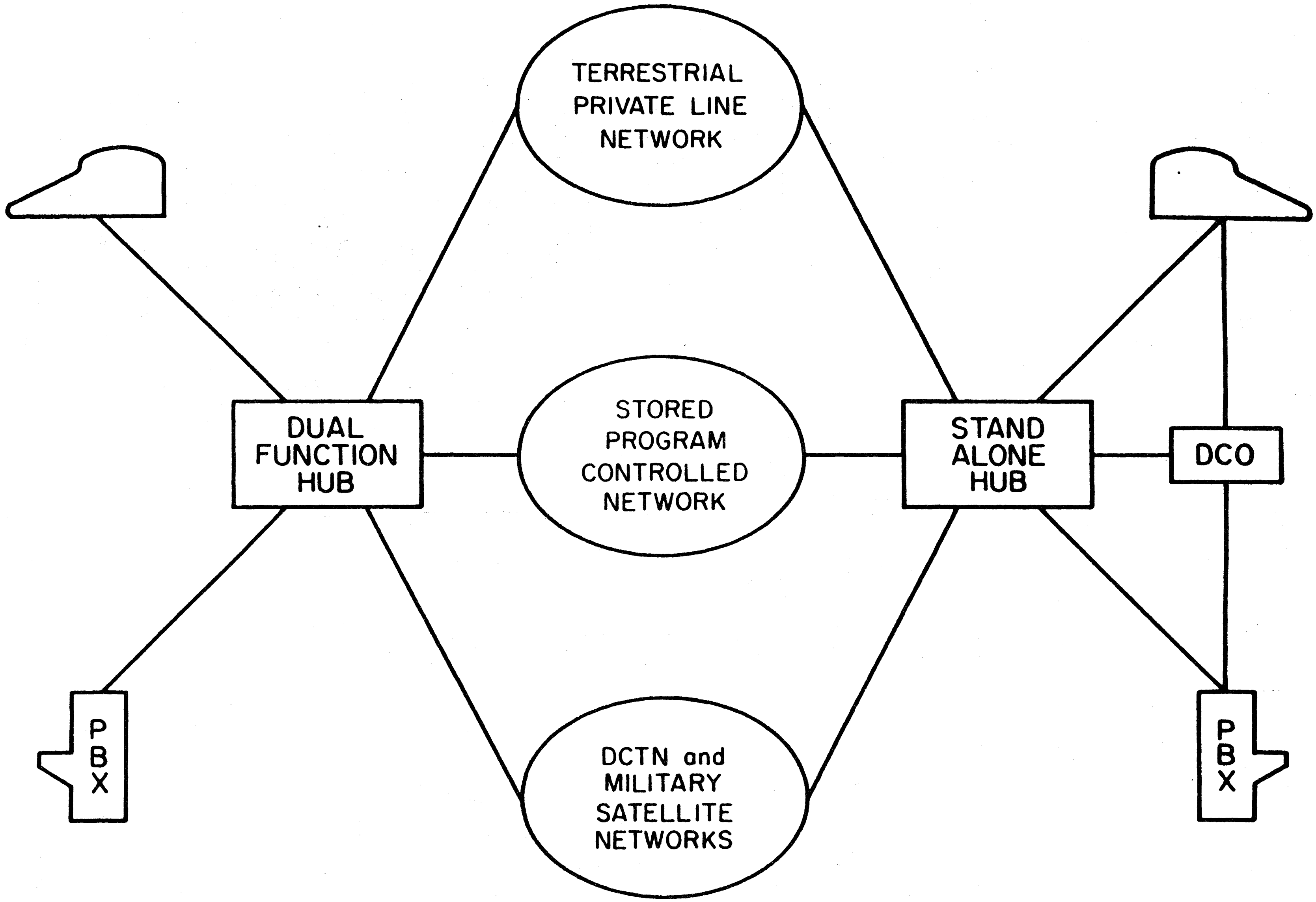


Figure 2-10. One concept for the Defense Switched Network.

needed survivability and endurability. The objective was to establish an overall DOD system architecture for the 1995 time frame. The goal is to define a secure, survivable, and interoperable command and control, communications and information processing system (Hatchwell et al., 1981). Figure 2-11 depicts the system concept for the WWDSA. The architecture consists of a two-level hierarchy consisting of a backbone level and an access level. The backbone contains a mix of media from commercial networks [i.e., common carriers and specialized carriers in the CONUS, foreign Post, Telegraph and Telephone (PTT's) outside the CONUS], as well as military owned and operated networks.

Although the architecture is hierarchal in nature, an increasing amount of intelligence is placed in the access nodes for the purposes of enhanced survivability, flexibility, and interoperability. The access nodes share or augment backbone functions such as switching and control. The access nodes have sufficient intelligence to perform the following functions:

- adaptive circuit routing
- selection of transmission media
- adaptation to contingency situations by reverting to lower rate secure voice.

Economic, performance, and survivability criteria are employed by the access nodes in selecting the transmission media and diverse routing. It is envisioned that eventually the backbone connectivity will be indistinguishable from the direct connectivity between access nodes, although not in the 1995 time frame (Hatchwell et al., 1981).

Another key feature of the WWDSA is that there will be many interconnects between the circuit-switched voice network and the packet-switched data network. The purpose of the interconnects is to increase the probability of survival for both voice and data services. The recommended architecture is a significant step toward achieving a fully integrated voice/data network. As envisioned by the WWDSA committee, this full integration into an ISDN will not take place by the year 1995.

One important feature of the WWDSA that is worthy of elaboration is the capability of the access nodes to revert to the lower digitization rate of 2.4 kb/s for secure voice subscribers. This feature may be needed when the numbers of interswitch trunks are reduced due to network damage. Several 2.4 kb/s channels can be multiplexed into a 16 kb/s basic rate and be switched via the multirate switch to their destination. Network conditions will dictate when the multiplex pattern is changed. The network situation and traffic intensity will also dictate when the multiplex pattern will revert back to the normal pattern. This reconfiguration strategy will be achieved either under automatic system control or by a human operator.

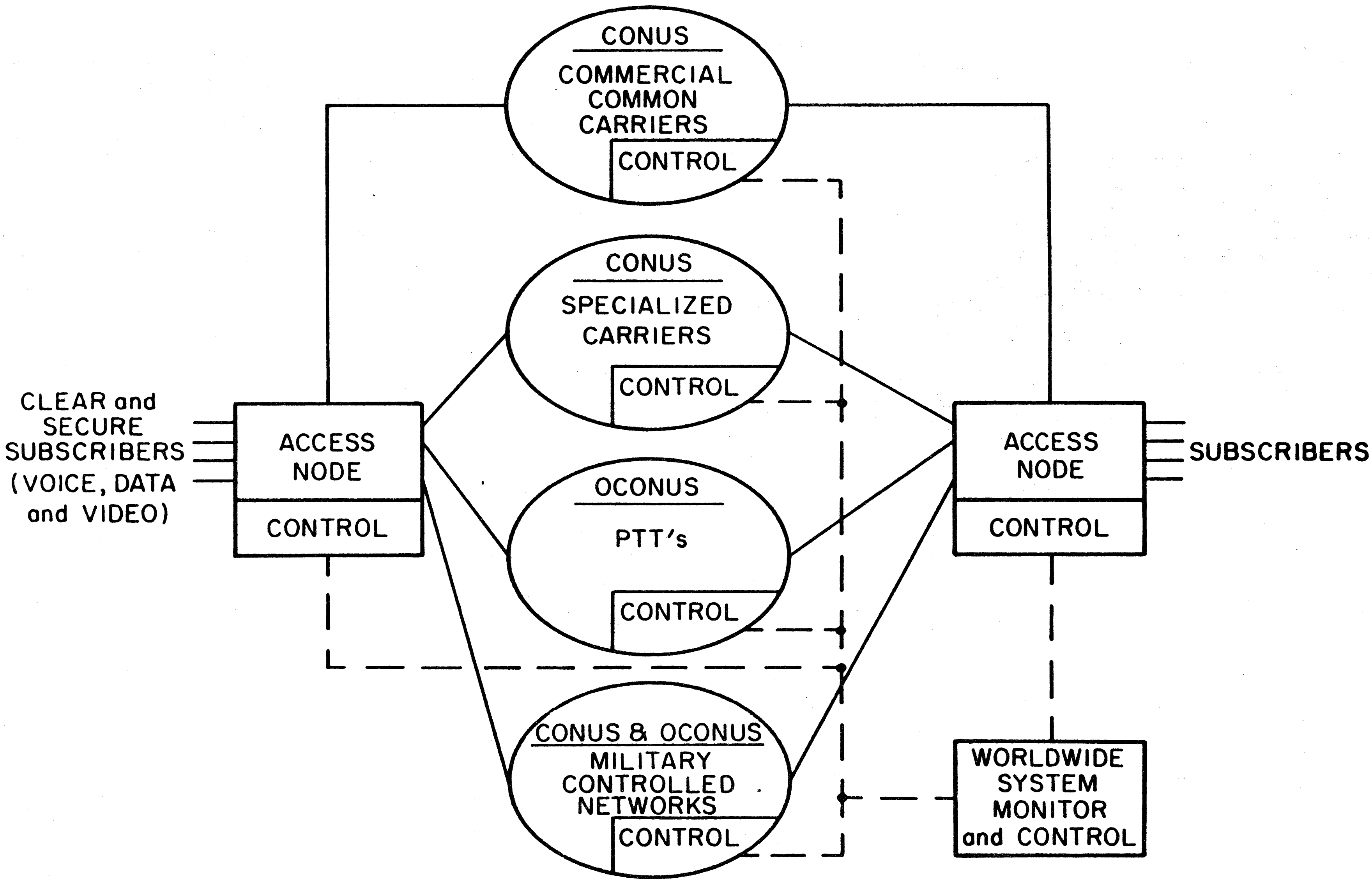


Figure 2-11. The worldwide digital system architecture.

As mentioned earlier, the WWDSA calls for the utilization of a mix of transmission media. Selection of the media is done at the access node under stored program control. The selection is based upon technical performance, economic, and survivability considerations. One key part of this media mix is the increased use of both commercial and military satellite links. The increased use of satellites will allow 10-30% of WWDSA traffic to be carried economically and efficiently over satellite links (Hatchwell et al., 1981). It will also provide a wide-band link for the provision of special services such as video conferencing. It should be emphasized, however, that critical users will still have the option of choosing either terrestrial or satellite links. This is required, of course, by survivability considerations.

The WWDSA is a plan that synergistically combines elements from the communication systems that support the U.S. military (including the tactical portion), civilian, and North Atlantic Treaty Organization (NATO) communities. Its endurable capability also achieves significant improvements in performance, interoperability, security, and provides new services to a wider community of users. The combined capabilities of many individual subnetworks are addressable to the subnetworks within the overall common architecture.

User requirements determine the overall characteristics of the WWDSA. The defined architecture embodies the following key features (Defense Communications Agency, 1982):

- access to many sources of connectivity
- ability to use many sources of connectivity intelligently
- modularly expandable switches
- interconnected voice and data networks
- improved intra-network system control
- tandem switching capability
- multirate capability among circuit switches
- enhanced 2.4 kb/ps secure voice for survivability
- high quality 16 kb/ps secure voice
- common proliferated key distribution system
- end-to-end encryption for classified data
- expanded and integrated use of satellite communications
- improved inter-network system control
- use of common standards.

The Defense Commercial Telecommunications Network

The DCTN combines satellite and terrestial digital transmisssion facilities to achieve cost savings in the long haul transmission of various kinds of traffic (i.e., voice, data, and video) from key concentration nodes. Access lengths (and costs) are reduced by locating the concentrating hubs close to major user concentrations. These hubs also provide the capability for the most economical routing by choosing between satellite and terrestial trunking, AUTOVON, DDD, WATS, FTS, and other common carriers. See Figure 2-12.

Although considered part of the DSN, the DCTN may also carry other non-DOD traffic. Services include near full motion video teleconferencing, wide-band data (including word processing), high-speed telemetry, facsimile, computer internetting, and bulk data transfer. Both switched and dedicated voice circuits can be furnished.

The contract for the leased DCTN communication services was awarded in 1984. Two levels of service are contemplated. Level I consists of a private line network connecting some 15 access area nodes that serve about 100 military locations. It is to be completed in 1986. Level II, scheduled for 1988, combines the private line facilities with stored program controlled portions of the PSTN, where economical, to increase coverage, add features, and reduce costs further. Service to another 100 bases is contemplated. This hybrid network provides the ubiquitous CONUS coverage and increased survivability over Level I.

Extensive automation of the administrative, operation, and maintenance systems will be used. A centralized Network Control Center (NCC) will be capable of reconfiguring the network to meet emergency conditions. Key military objectives of DCTN include:

- flexible allocation of transmission capacity
- diversity of transmission media for survivability
- bulk encryption on satellite paths
- optional transportable earth stations
- electromagnetic pulse (EMP) protection
- centralized network management and control facilities
- responsibility for AO&M is under the prime contractor.

The Experimental Integrated Switched Network

The network known as EISN contains five nodes located at Ft. Monmouth, NJ; Ft. Huachuca, AZ; Rome Air Development Center, NY; MIT Lincoln Laboratories, MA,

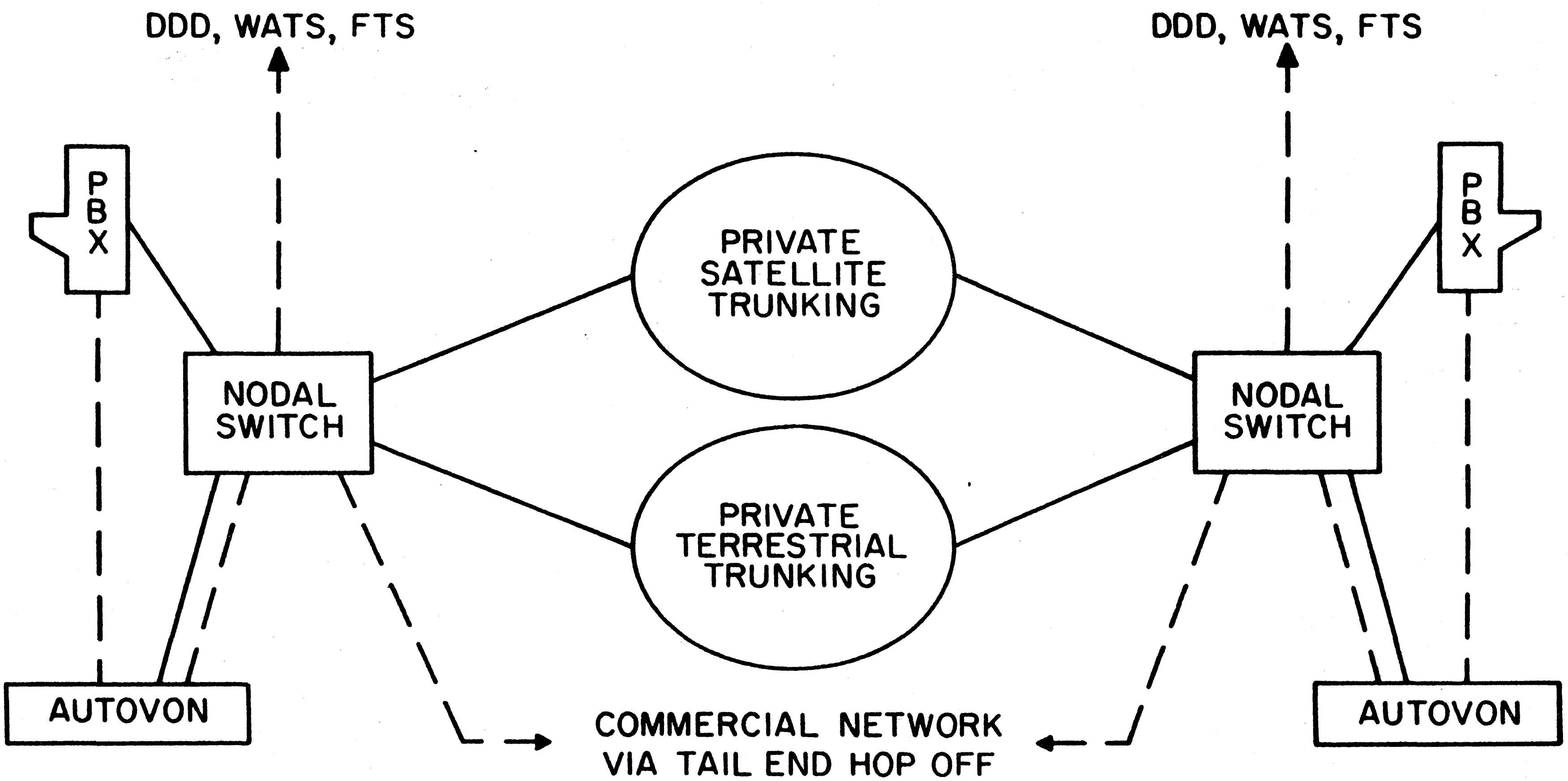


Figure 2-12. The Defense Commercial Telecommunications Network.

and the Defense Communication Engineering Center in Reston, VA. Each node contains a wide-band (3Mb/s) satellite Earth station and the associated wide-band equipment for packetizing voice and data over the satellite network. In addition, some of the sites are equipped with access lines to the commercial terrestrial circuits. Overall, the network serves as a scaled test bed for experimenting with new concepts (including routing algorithms, voice digitization techniques, packet switching, etc.), all of which may be useful in future military networks. Thus EISN, along with other transmission facilities shown in Figure 2-13, represents a concept validation facility for the DSN and for the WWDSA.

OCONUS Networks

Overseas networks are owned, operated, and managed by a number of different entities, e.g., the United States, NATO, allied nation military departments and host nation civilian departments. Major portions are, as in the United States, switched voice networks. Most facilities are concentrated in West Germany because most of the U.S. military forces are located there.

The main transmission system in Europe is the DCS wide-band network that extends from England, across the European backbone, to Turkey using redundant routes. This wide-band analog system is currently being upgraded and expanded to digital operation under the Digital European Backbone (DEB) program.

Another major transmission system involves satellites. The DSCS provides worldwide coverage via multiple DSCS II satellites in synchronous orbit.

Under DCA management and operated by the military departments, these backbone transmission networks tie together a number of switched networks (e.g., AUTOVON, ETS, AUTODIN, AUTOSEVOCOM).

In addition, the U.S. military departments operate a number of special-purpose networks of their own. NATO also has both voice and data networks, and each host nation has both military and commercial networks scattered across the continent. Some do interface with each other and others do not. Some overlap in coverage and others do not. Some carry voice, some data; others provide integrated services. Terminals range from conventional telephones, to sophisticated computer terminals, to transportable facsimile terminals.

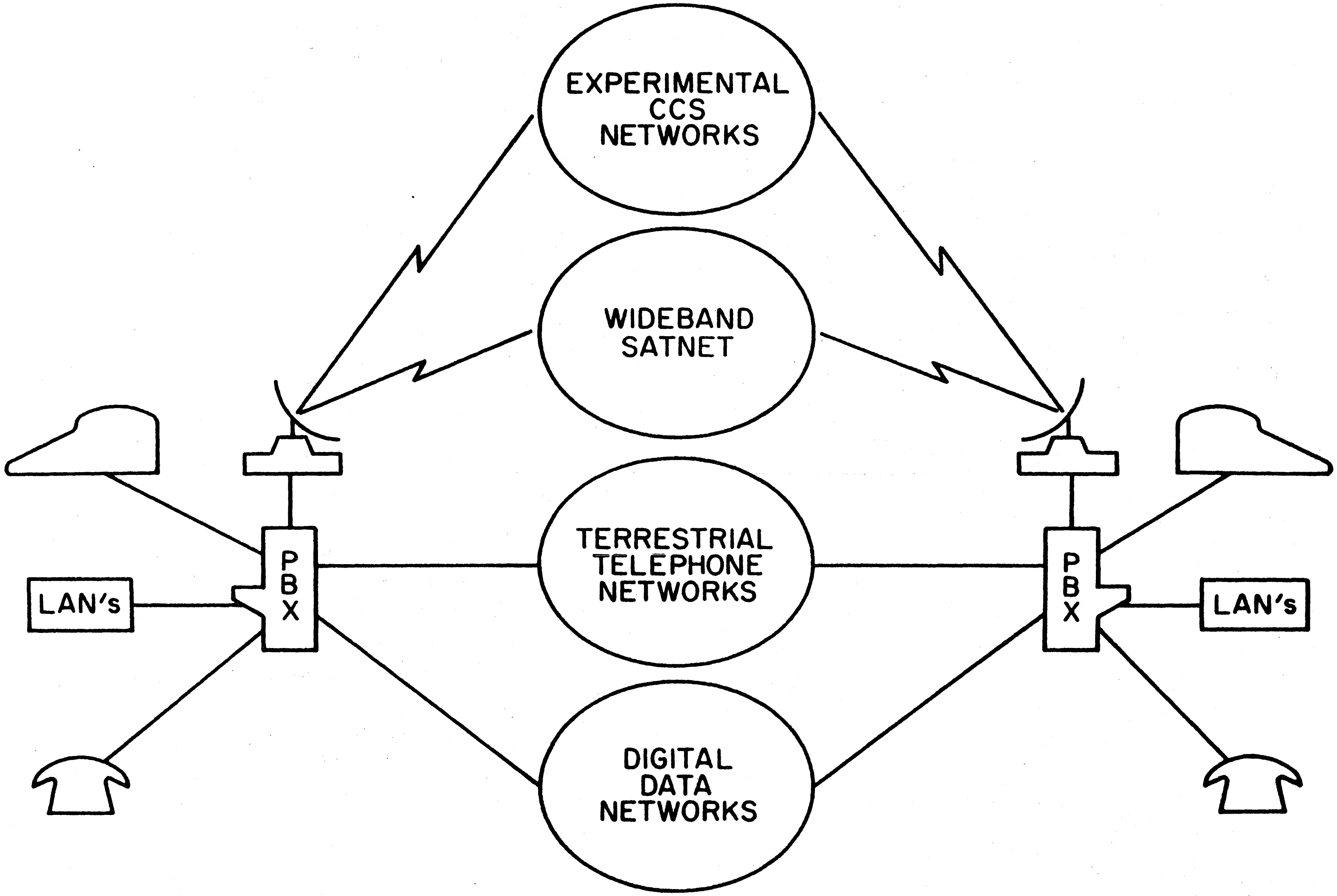


Figure 2-13. The Experimental Integrated Switched Network.

2.3 Schedule of Evolution

The expected schedule for the evolution of the military networks from the DCS today to DSN and WWDSA of tomorrow is presented in Figure 2-14. The ultimate evolution to a military version of the ISDN is certainly questionable at this time. The figure does not show the possible addition of new wide-band and super wide-band networks for video and computer connections.

No one can really foresee just how far into the future the WWDSA with separate voice and data networks will exist. Some have projected such networks to the year 2020. Separate dedicated networks require separate AO&M facilities and personnel to support them. There are obvious benefits in integrating all services into a single ISDN. Mabius (1984) insists that it is time to migrate away from functionally separated networks and services toward the ISDN to reduce our resource obligations.

The original ISDN concept was based on the premise that a digital public telephone network should be transparent to the type of information being transmitted, whether voice, facsimile, or bulk data. The concept assumed that the ISDN would evolve economically from the existing telephone plant. This concept reflected the view of European administrations where the communication networks are generally owned and operated by the PTT's. In the United States, it is now believed that the ISDN could be a conglomerate of mutually interconnecting networks, not necessarily with the same characteristics, but with the subscriber access based on the standard ISDN interface. That is not unlike the WWDSA concept.

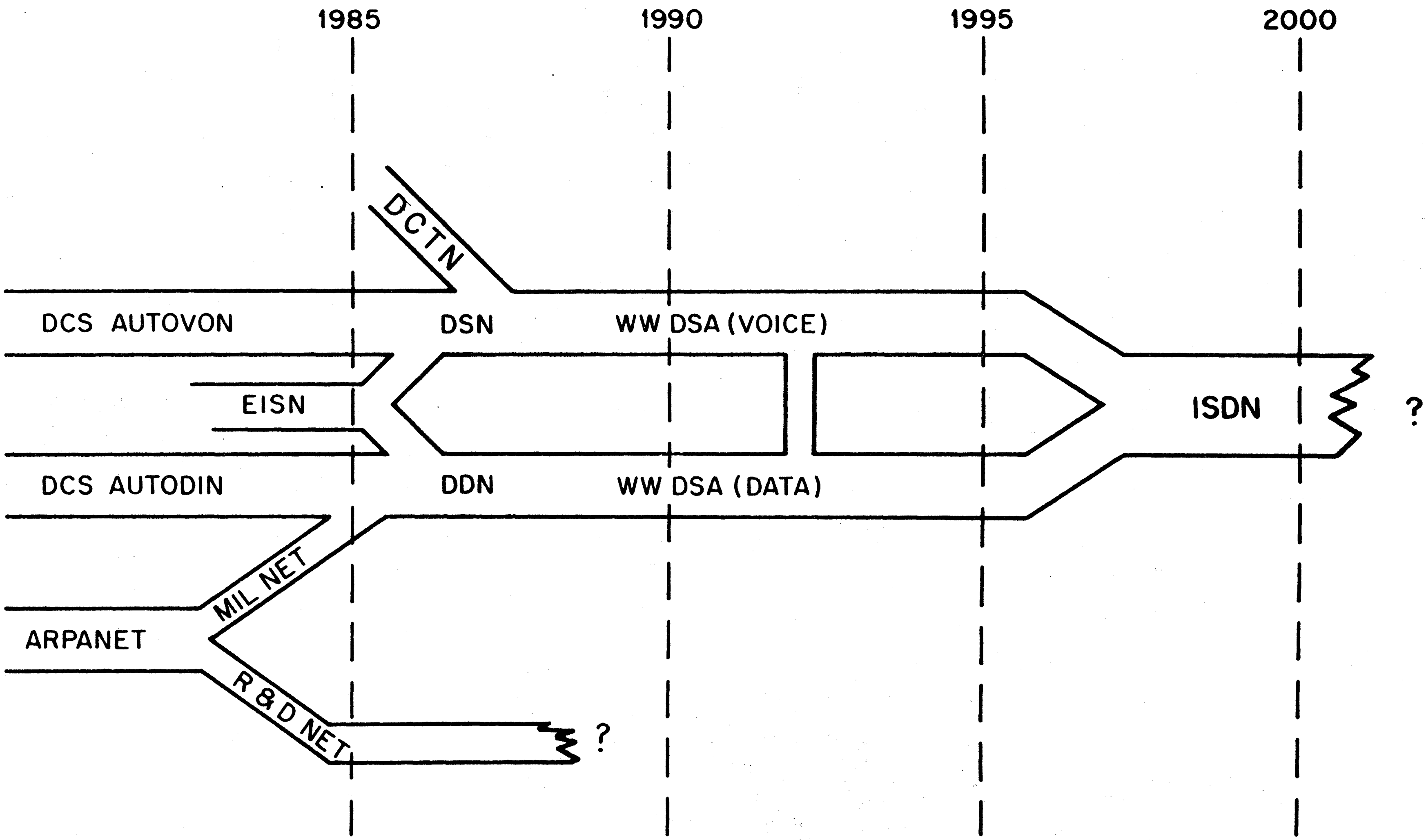


Figure 2-14. Schedule of evolution for military networks.

3. MILITARY REQUIREMENTS

Military requirements for telecommunications networks depend on a number of factors including missions to be performed; service features needed; the number, density, and location of users; kinds of traffic; traffic density profiles; and so forth. A complete listing of all of the requirements for all MILDEPS is beyond the scope of this study. Furthermore, requirements are perceived differently by different groups. This is illustrated in Table 3-1 where certain requirements are listed based on the viewpoint of the network user, network provider, network operator, etc.

In this section the emphasis is on the network operator and the end user. We are concerned with how many users there are, where are they located, what services they need, and the important criteria for performance assessment.

The user-oriented requirements are distinguishable from the operator's requirements. The latter includes short-term network management and control and long-term administrative and maintenance functions. To clarify the distinction between the user's view of the system (i.e., the service features) and the operator's view of the system, Figure 3-1 is presented. The user perceives the service, the service features, and the quality of performance of service from his/her side of the interface. The system provides this service by performing many functions. These functions, by our definition, take place on the system side of the interface and are typically not visible to the end user.

In case of military networks, the situation gets more involved when the military departments undertake some roles as network operators. The roles may include operation and maintenance (O&M), security, privacy, or multi-level priority preemption (MLPP). For such network operators another interface (see Figure 3-1) may be required. The key point is that system functions are again on the systems side, or inside of the interface. The operator features, like the user service features, are on the outside of the appropriate interface.

Finally, when new or modified services are provided, the system must possess sufficient capability to function as required. Similar needs for sufficient capacity arise when more end users, different operator controls, and various traffic surges are to be dealt with.

From our point of view, the preceding paragraphs provide basis for such terms as service features, system functions, and system capabilities. As a single-word synonym, the term "attribute" may then replace any or all of the above concepts. These so called system attributes are described below.

Table 3-1. Summary of Requirements Listings and Their Source

All the Things You Would Like to Know to Design a Communications Network and Where to Find Them

From the User

- o mission
- o service
- o performance
- o critical attributes

From the Supplier

- o availability of hardware/software
- o technical risks
- o economical risks
- o life cycle costs
- o tariffs

From the Operator

- o demographics
- o network control
- o interoperability requirements
- o maintenance
- o other attributes

From Other Sources

e.g., Host Nations, Other Agencies

- o stress scenarios
- o government policy
- o regulations
- o DOD directives

From the Traffic Engineer

- o traffic types and profiles
- o flow matrices
- o growth patterns
- o coverage

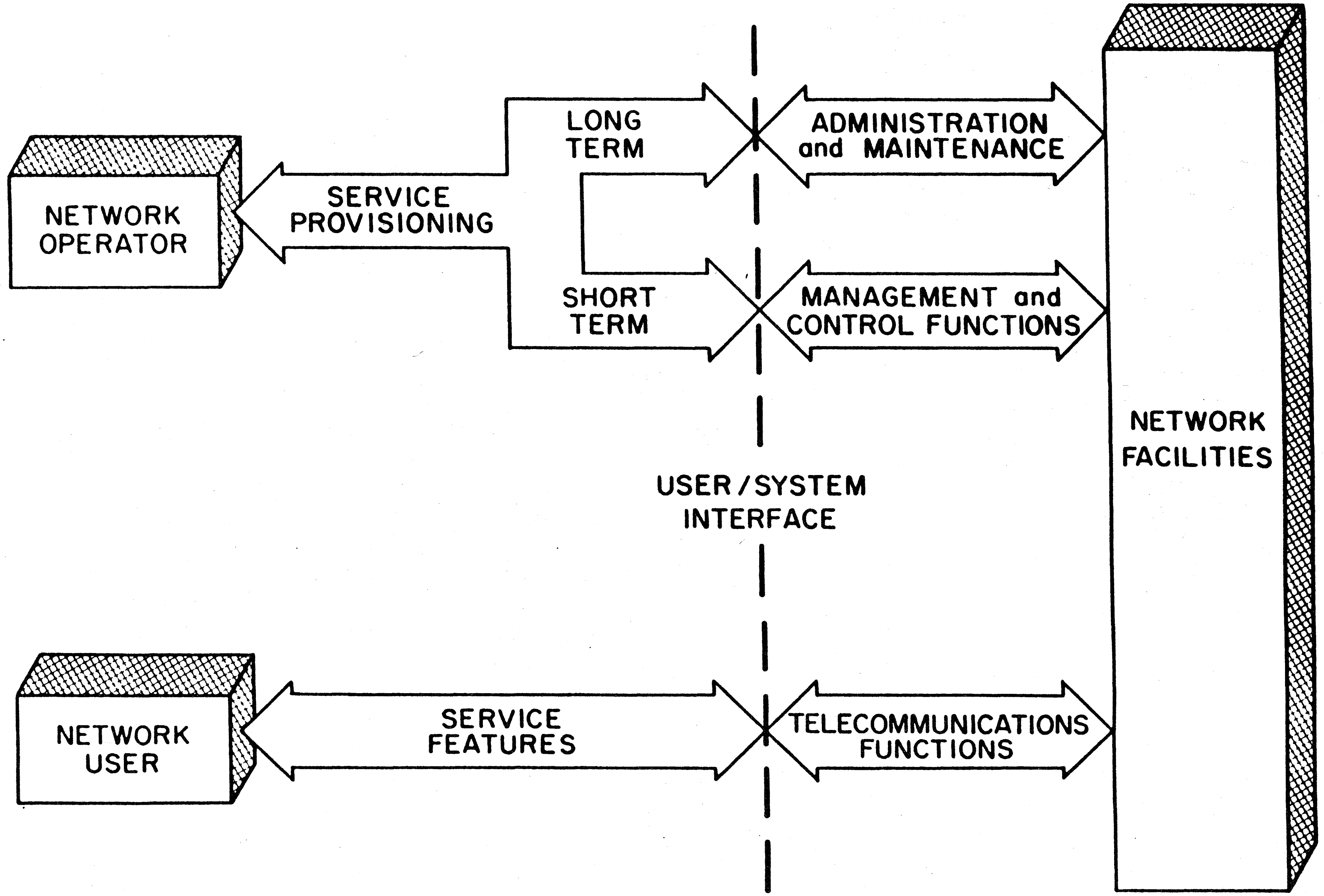


Figure 3-1. Basic system service concept.

3.1 System Attributes

The attributes of a network are the user features, network functions, and network capabilities discussed above. Table 3-2 is a list of attributes of communications networks that is divided into user service features and network functions. The user service features are divided into those required by critical users and those required by noncritical users. The network functions are divided into: 1) general network functions needed to meet user service requirements, and 2) administrative, operations, and maintenance network functions that are needed by the network operator to ensure that user service requirements are met on a day-to-day basis. This list of attributes was derived from a list compiled by Western Electric Company (1982). This list is submitted to illustrate the terms for features, functions, and AO&M attributes, as they are used in this report.

The line of demarcation between service features that are visible to the end user and network functional capabilities is not always easily defined. There is a certain amount of overlap between the user service features and the network functional capability. Consider the issue of survivability, for example. The user is concerned that his service be survivable despite damage to the network. In other words, the user requires that service be maintained between point A and point B and that the connection be of acceptable quality (acceptable blocking GOS, access time, bit-error rate, etc.). The user is not concerned about how the service is maintained after the network has been damaged, i.e., whether alternate routing is used, whether interconnects with other networks provide the tranmission path, or whether the damaged network is restored through the use of reconstitution packages. Alternate routing, network interconnects, and reconstitution are network functional capabilities that are primarily of importance to the network designer and operator, not the end user. Again, there is some overlap between the two points of view. For example, the time required to restore network services is obviously of interest to both the network designer and the end user.

As indicated previously, the attributes that define a network may be selected from different perspectives. Here we are concerned with the network user's viewpoint and the network operator's viewpoint. The users include DOD agencies and departments such as DCA, USAF, USA, USN, plus other Government users who

Table 3-2. Attributes of Communications Networks

<u>Critical User Service Features</u>

1. Authorization Code
2. Call Forwarding
3. Community of Interest Screening
4. Conferencing
5. Direct Outdialing
6. Hot Line
7. Least Cost Routing
8. Multi-Level Precedence Preemption (MLPP) or Equivalent
9. Secure Voice
10. Speed Calling (Minimum-Digit Dialing)
11. Station-to-Station Digital Capability

<u>Noncritical User Service Features</u>

1. Authorization Code
2. Call Forwarding
3. Conferencing
4. Direct Outdialing
5. Least Cost Routing
6. Speed Calling (Minimum-Digit Dialing)
7. Station-to-Station Digital Capability

<u>General Network Functions</u>

1. Authorization Code
2. Blocking Grade of Service
3. Call Forwarding
4. Call Screening
5. Call Set-Up Time
6. Circuit Provisioning for AUTOVON
7. Community of Interest Screening
8. Conferencing
9. Distinctive Ringing
10. Echo Control
11. Error Rate Grade of Service
12. Global Numbering Plan
13. Hot Line
14. Integrated Digital Structure
15. Intercept
16. Interoperability with Other Networks
17. Least Cost Routing

Table 3-2. (continued)

General Network Functions (cont.)

18. Loss-Noise-Echo Grade of Service
19. Multi-Level Precedence Preemption (MLPP) or Equivalent
20. Secure Voice
21. Speed Calling
22. Station-to-Station Digital Capability
23. Synchronization
24. Common Channel Signaling
25. Propagation Delay Control
26. Sliprate Grade of Service
27. Subrate Capability
28. Service Protection Against Transmission Failure

Administration, Operations, and Maintenance Network Functions

1. Battery Reserve Power
2. Centralized Maintenance
3. Centralized Operator/Attendant Positions
4. Interfacing Operations Systems
5. Network Administration, Operations, and Management Activity Centers
6. Network Management Capability
7. Network Reconfiguration Capability
8. Protection Switching
9. Repairability
10. Service Protection Against Transmission Failures
11. Small Reinitialization Interval
12. Traffic Data Gathering
13. Traffic Overload Control within a Switching System
14. Usage Sensitive Reports
15. User Numbering, Privileges, and Features Management

communicate with officials and contractors who are on the PSTN. This large DSN user group along with the network operator group includes individuals and organizations who have widely different views of their service and the networks attributes. This divergence of viewpoints gives rise to assorted listings of attributes that must be selectively sorted. To illustrate the magnitude of the problem, we present Table 3-3.

Table 3-3 expands on Table 3-2 and lists almost 50 service features and system functions that may be available at an access area PABX. This is only about half of the total features listed in a given sales brochure. After a brief description of its nature each feature of function is assessed as to whether it is a basic requirement, a desirable function, or just a useful enhanced feature. These assessments are subjective assuming a military user is making the selection.

3.2 Classification Viewpoints

There are many ways to categorize telecommunication networks. For example, networks can be classified by application, by architecture, by ownership, or by the features offered, and so forth. Here we are concerned with two classification perspectives: the users and the system operators. The user is interested in service offered and the performance of these services rather than the performance of equipments and facilities which supply these. Performance measures from the user's viewpoint depend on mission requirements. Thus, there is a need to classify user services and missions.

The system operator is concerned with the types of terminals, their geographic distribution, and the volume and kind of traffic they generate. Based on this information various network topologies and control procedures are implemented to ensure that the desired quality of service is achieved. The network is specified through node and link functions that meet the network design objectives. The system operator provides equipment facilities to meet the user requirements.

3.2.1 The User

It is possible to classify user services in various ways. Stavroulakis and Tjaden (1975), for example, specify a service in terms of the attributes of the switching, transmission, and terminal parts of the network. Others classify them in terms of the applications, e.g., fixed, mobile, broadcast, data, etc. The basis for defining service classes here is different. The objective is to group services

Table 3-3. Selected Functions and Features

#	Name	Description or Comment	System Function Needed	System Function Desirable	Service Feature Basic	Service Feature Enhanced
1	Attendant	At least one, and a single console	X		X	
2	BORSCHT	Battery, overload protection, ringing, signaling, clock, hybrid, testing-requirement	X			
3	Call Forward	All incoming calls to one of several designated stations			X	
4	Call Pickup	Answer calls in a given group only			X	
5	Call Transfer		X		X	
6	Call Waiting	Indicates that another call is waiting			X	
7	Camp-on	Reminds original caller when the other party has gone on-hook. Sets up call if so indicated by original caller			X	
8	Classes of Service	Restrictions on various groups of users, for toll calls, priority, security, etc.			X	
9	Conferencing Few	Conferencing for 3 or 4 parties			X	
10	Conferencing Many	Conferencing for larger groups, 5 or more				X
11	Diagnostics	Automatic, mainly for maintenance	X			
12	DID	Direct Inward Dial			X	
13	Digital Lines	64 kb/s PCM, 16 kb/s CVSD, A/D at sets	X		X	
14	Digital Repeaters	Inward and/or outward	X			
15	Digital Trunks	64 kb/s T1,T2,..., compatibility	X			
16	DOD	Direct Outward Dial			X	

Table 3-3. (continued)

#	Name	Description or Comment	System Function		Service Feature	
			Needed	Desirable	Basic	Enhanced
17	DTMF Conversion	Dialing compatibility	X			
18	Ext-to-Ext	Extension to extension dialing in PABX local area			X	
19	Extra Consoles	Backup consoles, more attendants		X		
20	Flexible Numbering	Sta. No's vs. Frame No.		X		X
21	Foreign Exchange	Translation and control for remoted operation	X			
22	Hold	For additional in-calls without aid			X	
23	Intercept	By attendant	X		X	
24	Line Lockout	If station is off-hook too long		X		
25	Line/Trunk Card Density	Assume 75% packing density on cards	X			
26	Line P=0.01	Assume probability of blocking for lines when 5 ccs/line	X		X	
27	Message Accounting	For billing, statistics		X		X
28	MODEM Compatibility	With a list of standard modems, their interfaces	X			
29	Modularity	For growth: distribution and concentration modules. For operation: line and trunk card interchange	X			
30	Multiple Listing	Main No., residence, extension(s)		X		X
31	Night Answer	When nobody at consoles, call preassigned station(s)		X	X	
32	Override	Ability to break into certain existing calls, with constraints				X
33	Privacy	Optional lockout of break-ins			X	
34	Private Lines	Dedicated lines through PABX to CO		X		X
35	Power Fail Transfer	Automatic routing of certain CO trunks to designated lines	X			

Table 3-3. (continued)

#	Name	Description or Comment	System Function Needed	System Function Desirable	Service Feature Basic	Service Feature Enhanced
36	Public Address	To broadcast input		X		
37	Secure Voice	A/D and encryption at certain stations. Protected facilities			X	
38	Speed Calling	Abbreviated dialing to frequently called stations				X
39	Standby CPU	Duplicated CPU for reliability, periodically exercised	X			
40	Standby Power	Standby power plant, periodically exercised	X			
41	Stored Program Control	Best CPU control with present technology	X			
42	Tandem	PABX to interconnect other PABX's, CO's		X		
43	TDM	Time-division switching	X			
44	Toll Restriction	On outgoing toll calls for certain station categories, perhaps all			X	
45	Tone Buzz	To alert station when phone is off-hook too long		X		X
46	Traffic Measurement	To gather statistics for upgrading or modification of PABX		X		
47	Trunk P=0.002	Assumed probability of blocking for trunks, when 5 ccs/line and 30% trunk traffic	X		X	
48	Trunk Types	Include the following trunks: 2W, pulse, indial and outdial; 2W, DTMF, indial and outdial; 2W, pulse, tie trunks; 2W, ringdown; 4W, pulse, tie trunks; 4W, AUTOVON; 4W, digital.	X			
49	Voice Recorders	Several recording channels to record urgent messages				X

so that each group has similar performance characteristics as perceived by the end user. This approach simplifies the development of user parameters and the assignment of values for specified services.

The service classifications are illustrated in Figure 3-2. Five major levels of division are shown. The levels are, beginning at the top of Figure 3-2:

1. The nature of the information signal perceived by the end user. At this level, the signals are either continuous (analog) or discrete (digital).

2. The type of source or human/machine usage of the information. For analog services, there may be audible, visual, or other sensory sources. For digital services, the sources may be a human operator, device media, or computer applications program.

3. Networks are used for three general types of interaction: human access to a machine (such as a computer) and vice versa, machine interaction with one another, and interaction among humans.

4. The directivity of the access path. The information may be transferred in one direction only (simplex) or in both directions (duplex or half duplex).

5. The number of users, human or machine, that participate in a given dialogue can vary. This involves at least two or more end users on a one-to-one, one-to-many, many-to-one, or many-to-many basis.

The actual performance required for each service class depends on other factors. Some networks are designed to serve users from a single community of interest. Others may serve many communities of interest. The single-user networks are functionally specialized and optimized to the user's needs. The common-user networks are not specialized. They must be adaptive to many different user's needs. In some cases, however, the user's view of performance is highly dependent on what the user does, or the mission he or she performs. Military users of telecommunication networks can be divided into the three basic mission categories: strategic, tactical, and nontactical, as shown in Figure 3-3. In each category, various types of information may be transferred. We have divided this information into four basic types: intelligence, command and control, operations, and administrative.

Users of military networks must often contend with the limited resources available. When contention occurs, priorities are established using multiple precedence levels. For data messages in the old AUTODIN, the precedence levels used in CONUS were as follows:

Level	Precedence	Designator	Handling Time
I	Flash	Z	10 minutes
II	Immediate	O	30 minutes
III	Priority	P	3 hours
IV	Routine	R	6 hours

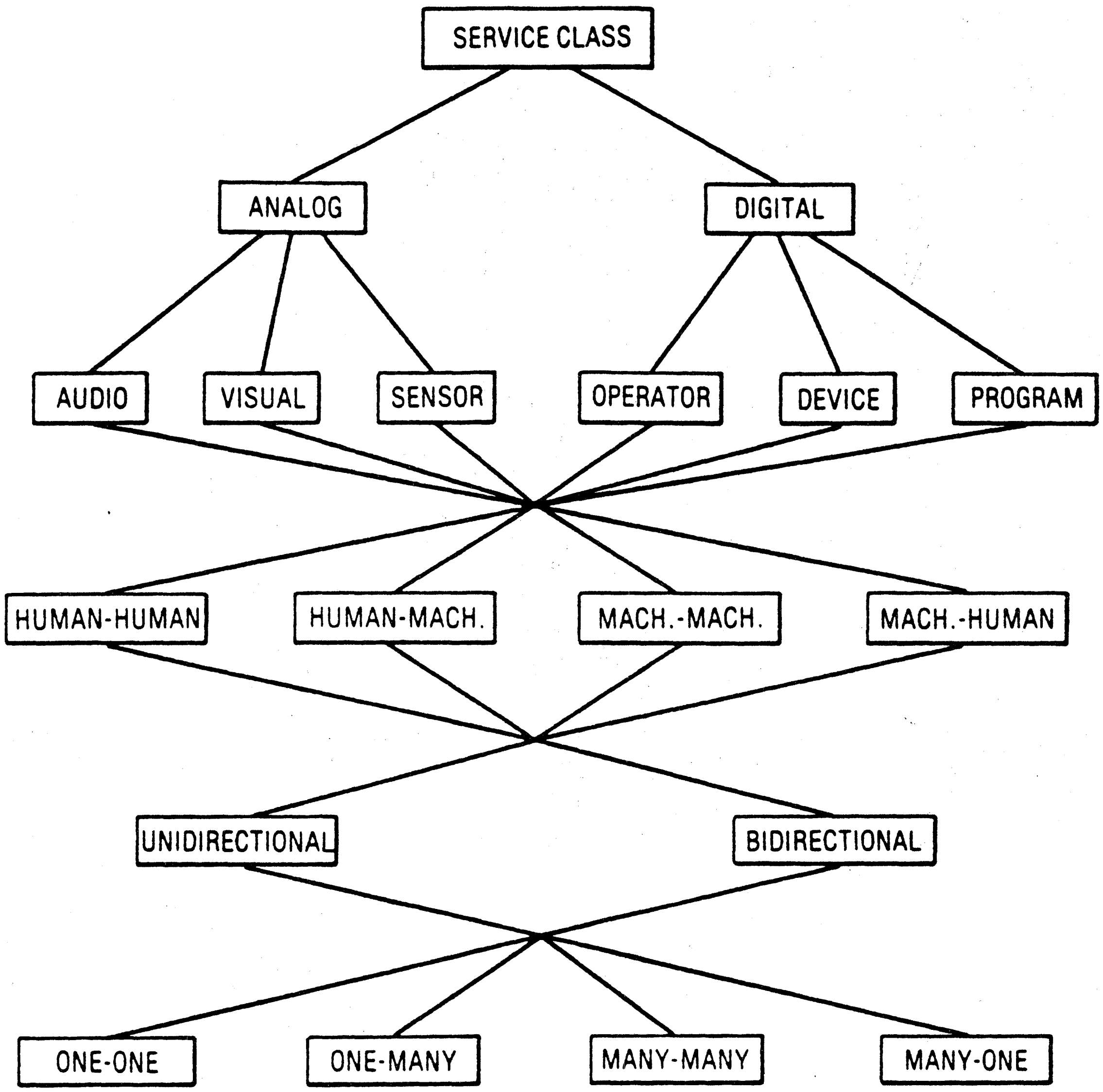


Figure 3-2. Service classifications.

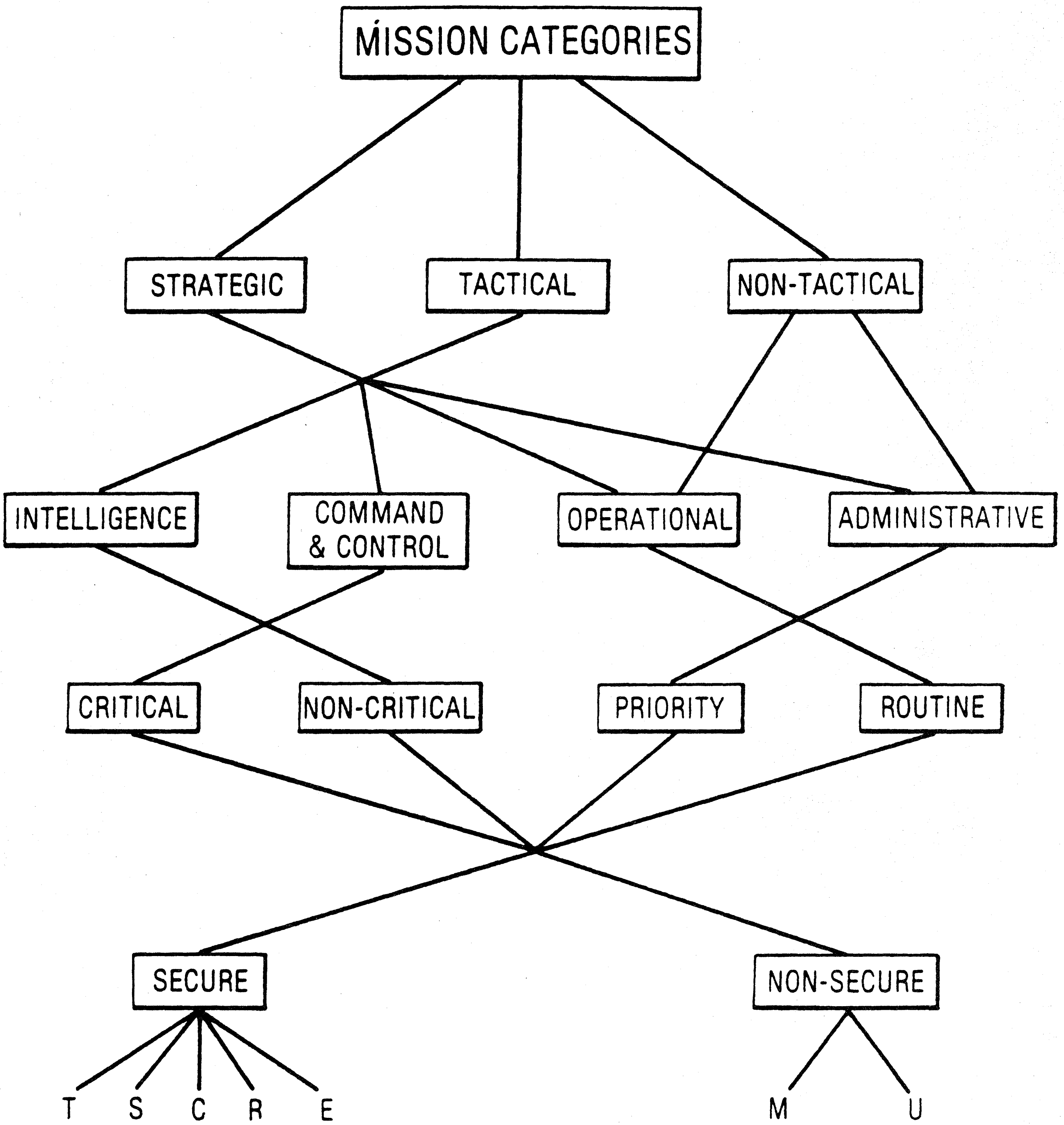


Figure 3-3. Mission categories.

The handling time given above is the speed of service from receipt at the origination node until delivery at the destination node. It has been estimated that 50% of the messages handled by AUTODIN I are routine messages and approximately 1% are flash messages. AUTOVON I employs a flash override precedence level in addition to the four levels used in AUTODIN I. When lines or trunks are busy, the AUTOVON switch can also preempt lower precedence calls in progress. Military networks also use multilevel security to prevent disclosure of classified information. These levels of security are tabulated below along with the designator used.

Level	Designation
Top Secret	T
Secret	S
Confidential	C
Restricted	R
Encrypted for Transmission Only	E
Classified (clear transmission)	M
Unclassified	U

The letter designators are used in message headers as part of the overhead control signals to identify the security level. When the designator is received at a node it is checked against the security classification of the destination terminal. A secure access path must be found to that terminal.

3.2.2 The Operator

The operator is concerned with user terminals, the traffic they generate, and the means for providing acceptable access paths between them.

The type terminals, their geographic distribution, the volume and kind of traffic generated by each terminal, as well as the required grade of service, are important factors in any network design.

There is no foreseeable limit to the types and variations of terminals. New types are continually being introduced. They range from the traditional voice terminals consisting of a telephone handset with rotary or pushbutton dial, to keyboard and printer terminals for teletypewriter and computer access, to visual display terminals with cathode-ray tube or other optical readout. Many terminals incorporate microprocessors and memory. Software programs add useful intelligence and processing power to such "smart" terminals. A program addition can change the character of the terminal to meet changing communications requirements or to adapt to new applications.

The telephone handset is the most common terminal in use today. Over 500,000 telephone terminals with about 1 million telephone instruments (including extension telephones) are projected to be in worldwide use by all U.S. military services in the mid 1980's. Data terminals are experiencing their own relatively rapid growth and could, over the same period, approach 50,000 terminals worldwide. Note that this still is only 10% of the telephone terminal population.

There are approximately 1500 military access areas worldwide. Based on the number of user terminals in each area, the areas range from small (<300 terminals), to medium (300 to 3000 terminals), to large (>3000 terminals). Although the majority of terminal types are telephones, they also include computer, teletypewriters, facsimile, and a myriad of other terminals. Terminal densities vary from less than 10 per km^2 to over 10,000 per km^2. The higher density cases offer a variety of line concentration alternatives.

The estimated number of advanced terminals of different types can be derived from numerous sources. For army bases worldwide, one recent estimate indicated 200,000 local automated offices, 10,000 management information systems, and 35,000 sensors and controls.

The volume, data rate, duration, and delivery delay for traffic generated by various types of terminals is indicated in Table 3-4. Only nominal values are shown in this table for most of the parameters. Actual values may depart considerably from these nominal values. To be used, data rates must conform to the DOD and general Federal Government standard rates for synchronous transmission. The standards, such as MIL STD 188-100, basically establish rates at increments of 75×2^k bit per second for $k = 1, 2, \ldots, 7$; or $800 \times k$ bits per second for $k = 1,2, 7$; plus several exceptions, such as 19.2 and 50 kb/s. Thus the data rate generated by any given terminal may vary over a fairly wide range. The voice digitization rate depends on the process employed. At higher rates the voice quality is generally higher for a given bit error rate over the channel.

The estimated characteristics for various access areas are given in Table 3-5 for areas with sizes ranging from very small (< 100 people) to very large (> 30,000 people) bases and including all of CONUS. Given the number of trunks, it is possible to parametrically determine the total traffic intensity in average busy- hour Erlangs per trunk. Results are shown in Table 3-6. A value of 0.5 E/trunk and a GOS of P = 0.01 seems to be a reasonable estimate for sizing the trunk groups.

Our projection for the total traffic in CONUS and to OCONUS in the 1990's is indicated in Figure 3-4. This projection is based on estimates from a number of sources. The traffic densities indicated include current levels of AUTOVON, FTS, and WATS traffic on the DSN as well as expected increases due to computer-based

Table 3-4. Characteristics of Traffic Generated by Various Types of Terminals

	Volume	Digital Rate (one-way)	Call Duration	Delivery Delay
Voice				
PCM	continuous bits	64 kb/s	minutes	<200 ms
CVSD	continuous bits	16 kb/s	minutes	<200 ms
LPC	continuous bits	2.4 kb/s	minutes	<200 ms
Data				
Data Base Update	10^2 b/message	2.4-16 kb/s	seconds	seconds to minutes
Interactive	10^3 b/message	150 b/s-56 kb/s	hours (Bursts in seconds)	seconds
Query/Response	10^4 bits/transaction	150 b/s-9.6 kb/s	seconds to minutes	<1 second
Bulk	10^5-10^8 bits/transaction	100 b/s	minutes to hours	minutes to hours
Narrative				
Alpha Coded Text	3×10^4 bits/page	75 b/s-9.6 kb/s	seconds to minutes	minutes to hours
Text Editing	10^3 bits/page	75 b/s-9.6 kb/s	seconds to minutes	seconds
Facsimile				
No Gray Scale	3×10^5 bits/page	4.8 kb/s	minutes	minutes to hours
Half Tone Photo	3×10^6 bits/page	9.6 kb/s	minutes	minutes to hours
Color	10^7 bits/page	1.5 Mb/s	minutes	minutes to hours
Video				
Picture Phone	continuous	6.3 Mb/s	minutes	<200 ms
Color TV	continuous	30 Mb/s	hours	seconds
Slow Scan TV	continuous	100 kb/s	minutes	minutes

Table 3-5. Estimated Characteristics of Access Areas

Access Size	Staffing	Main Line Terminations	Access Trunks
Very Small	100	35	2
Small	300	100	5
Medium	3,000	1,000	50
Large	10,000	3,000	150
Very Large	30,000	10,000	500
CONUS	1.5-2.0 M	500,000	27,000*

*1982 estimate derived by Western Electric Co. (1982) assuming 3% per annum AUTOVON growth and DDD/WATS/FX traffic migration estimates.

Table 3-6. 1985 Traffic Intensity Estimates

Access Size	Average BH Erlangs per Trunk			
	0.3	0.5	0.7	0.9
Very Small	0.6	1	1.4	1.8
Small	1.5	2.5	3.5	4.5
Medium	15	25	35	45
Large	75	75	105	135
Very Large	150	250	350	450
CONUS	8,100	13,500	18,900	24,300

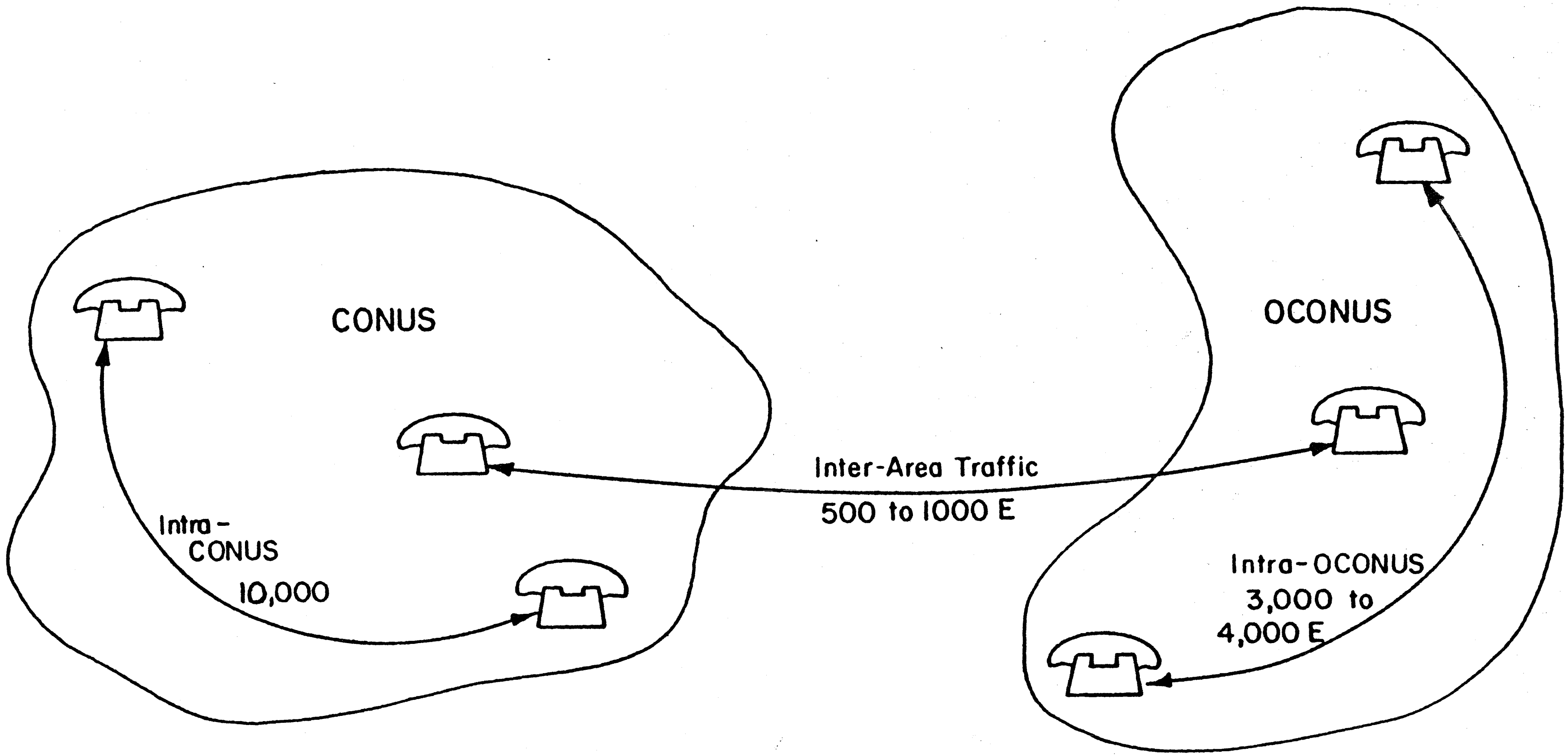


Figure 3-4. Inter- and intraarea traffic estimates for the DSN in 1990's era.

teleconferencing, data management, and data access systems. Such traffic estimates are needed to determine overall DSN network capacities required to carry future traffic loads with an acceptable grade of service. The accuracy of such projection is discussed in the next section.

3.3 Estimation Accuracy For Future Traffic

A network can be efficiently sized if the traffic it must carry is known. Traffic estimates in the future can only be based on present traffic data. Just how accurate the present data must be is the subject here. Traffic needs are by no means constant, but do change from year to year. Some of these changes are predictable and can be planned for. Other changes occur at hard-to-predict times and are apparently random in size. If that is so, an initial estimation error may or may not be significant when compared with other random traffic factors of military access area systems. As time goes on, the effects of the initial traffic estimation error can be expected almost certainly to become increasingly insignificant.

Being limited in time and scope, this short study is not based on specific DOD communications data. Instead, our chief source of trends and their variability has been the Bell System Technical Journal (BSTJ) Special Issue on Loop Plant (1978) and the U.S. Bureau of Census Statistical Abstract (1979). Using such statistics as a general ballpark guide, we present a parametric approach that demonstrates two things:

(1) Estimation accuracy with standard deviation of error less than or equal to 5% may be adequate for initial DSN access area design planning.

(2) Given more precise military communication growth data, the same logic and methodology could be used to improve on our initial 5% estimate.

A future traffic requirement, such as the offered busy-hour load for telephone service, is expected to vary from year to year. For a typical access area, let its mean yearly increment be μ and let the variance of the yearly increment be σ^2. After N = 1, 2, 3, ... years, the traffic requirement is subject to variability that grows as $N^2\mu^2 + N\sigma^2$ with time.

In estimating the present value of said parameter, let one commit an unknown, perhaps random, error. We denote the variance of this estimation error by σ_E^2. After a meaningful time period, one wants the natural variability to dominate the impact of the initial estimation error. We postulate that a suitable period is N = 5 years. After 5 years, one requires that σ_E^2 be no more than, say 10% of $N^2\mu^2 + N\sigma^2$. Such a condition puts an easily computable upper bound on σ_E as a function of μ and σ.

The resultant constraint is plotted in Figure 3-5 as individual curves for σ_E = .05, .10, .15, and ,20. Figure 3-5 also shows two shaded regions identified as A and D. Region A depicts typical annual growth for analog (i.e., voice, or regular telephone) service for the military departments. Region D refers to data or digital services. In our assessment, data has shown so large an annual variability that its planning can tolerate $\sigma_E \cong 20\%$ initial estimation error. On the other hand, the growth of telephone service has been more restricted, perhaps in line with nationwide population, economics, military modernization, and O&M trends. To satisfy the "10%-within-5-years" objective, the analog services reqire σ_E in the 5-10% range. The lowest value, namely $\sigma_E = 5\%$, seems like a safe bet and has been quoted earlier as our answer to the accuracy question.

A pertinent question concerns the validity of regions A and D in Figure 3-5. Our sources are those listed in the reference section. By concentrating on available data from the 1970's and what little year-to-year and region-to-region data there seems to be collected, we have constructed the statistical growth factors of Table 3-7. Since the relative accuracy of the (μ, σ) numbers are unknown, the table itself must be used with utmost care. Furthermore, there is no real established relationship that would express the dependence of the desired military traffic (μ, σ) on those (μ, σ)-s listed in Table 3-7. More scrutiny of growth statistics may be advisable.

From the U.S. Bureau of the Census (1979) Abstract, our main statistics were deduced from:

Table No. 46, Mobility of the Population by States: 1970 and 1976 (p. 39)

Table No. 47, Mobility Status of the Population, by Race and Spanish Origin: 1975 - 1978 (p. 40)

Table No. 603, Department of Defense Personnel and Payroll: 1950 to 1978 (p. 373)

Table No. 666, Labor Turnover Rates in Manufacturing: 1960 to 1978 (p. 402).

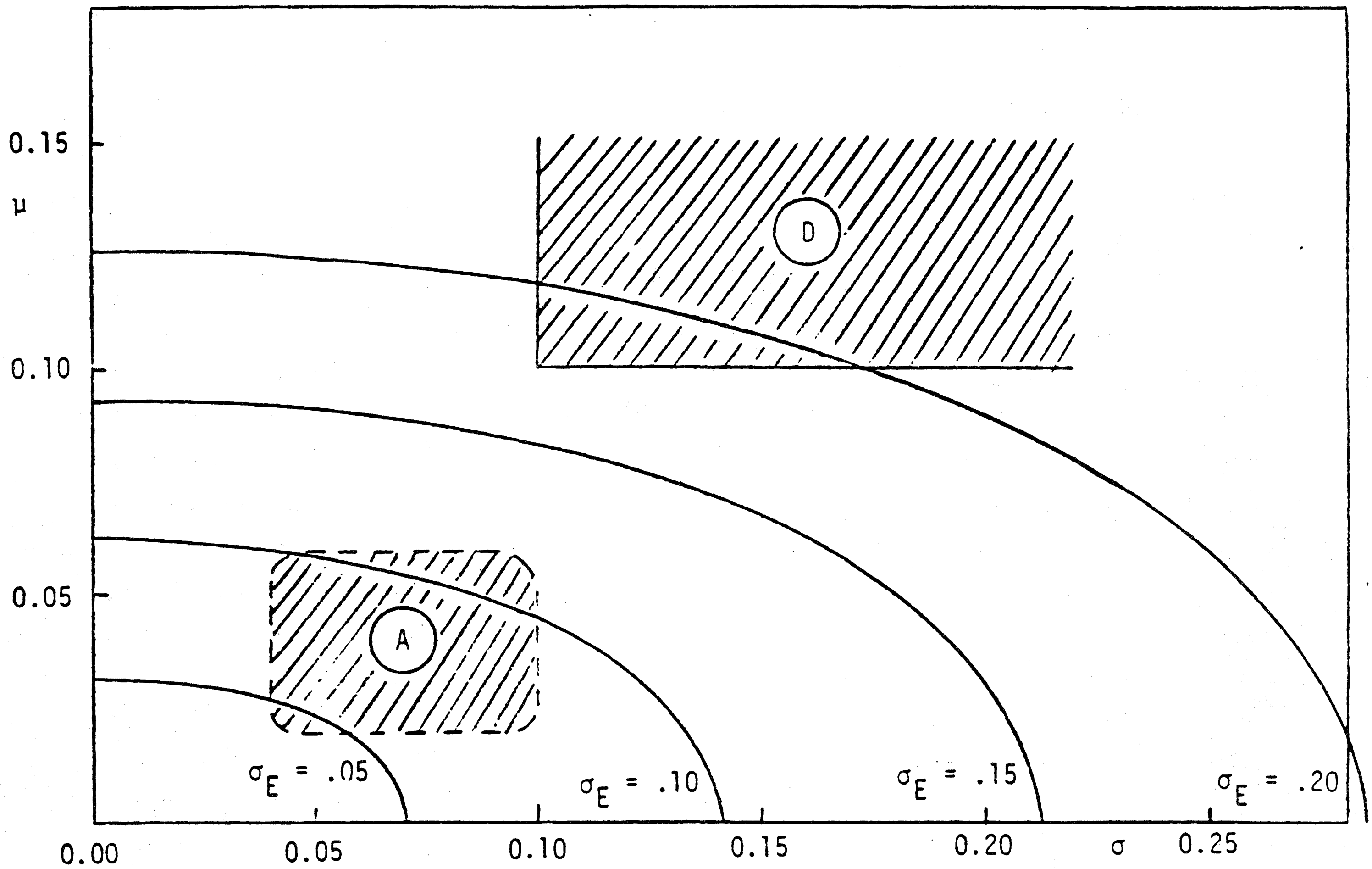


Figure 3-5. Largest σ_E values that meet the 10%-within-5-years objective versus typical annual growth ranges for A (analog) and D (digital) services.

Table 3-7. Approximate Mean and Standard Deviation Estimates for Several Related Growth Factors

Statistical Growth Factor	Estimate of	
	μ	σ
Mobility of U. S. Population	0.10	0.15
Growth of U. S. Population	0.08	0.04
Growth of U. S. Telephony	0.06	0.05
Growth of Military Telephony	0.04	0.06
Growth of DOD Personnel	-0.05	NA
Growth of DOD O&M Outlays	0.07	NA
Growth of U. S. Data Services	0.16	0.10
Growth of DOD Data Services	0.15	0.10

NA = Not Available

3.4 Performance Requirements

The performance of telecommunications services in terms of quality of service to the user is a key requirement. Performance can be described in many ways depending on the user's requirements and perception of the service. Generally, performance parameters are classified into two groups--system oriented (or engineering parameters) and user-oriented (or subscriber parameters). This classification is indicated in Figure 3-6 with further breakdowns noted on the figure.

Here our primary interest is on the user-oriented parameters since completion of the user's mission is paramount.

The rapid convergence of computer processing and communications coupled with the recent trend toward competition and deregulation in the U.S. telecommunications industry have created a need to specify and measure performance of telecommunicating systems as seen by the user in a uniform, consistent manner. The Federal Government and the American National Standards Institute (ANSI) have been working together to meet that need through the development of user-oriented, system independent, performance parameters and methods of measuring these parameters.

The initial emphasis has been on digital communication standards.

Two related data communication performance standards have been developed. The first specifies a set of user-oriented performance parameters. That standard was approved as Interim Federal Standard 1033 in 1979 and was subsequently adapted for proposal as an American National Standard (ANS) by a task group of the American National Standards Institute (ANSI Task Group X3S35). The proposed ANSI standard, designated X3.102, was formally approved by ANSI's Board of Standards Review in February of 1983 (ANSI, 1983). It is expected to replace Interim Federal Standard 1033, probably as a mandatory Federal Standard. During its trial period, Interim 1033 was applied successfully in several Federal procurements of public packet-switching services.

The second standard, proposed Federal Standard 1043, specifies uniform methods of measuring the standard performance parameters. An initial 1043 draft was completed in 1980 and an ANSI adaption, designated X3S35/135, is expected to be completed in 1985. It will follow a review and approval path similar to that of Interim 1033.

ANS X3.102 and its Federal counterpart are unique in providing a set of performance parameters that may be used to describe any digital communication service, irrespective of features such as topology, code, control protocol, or other design characterizations. Because the performance parameters are system-independent, they are useful in relating the performance needs of data communications

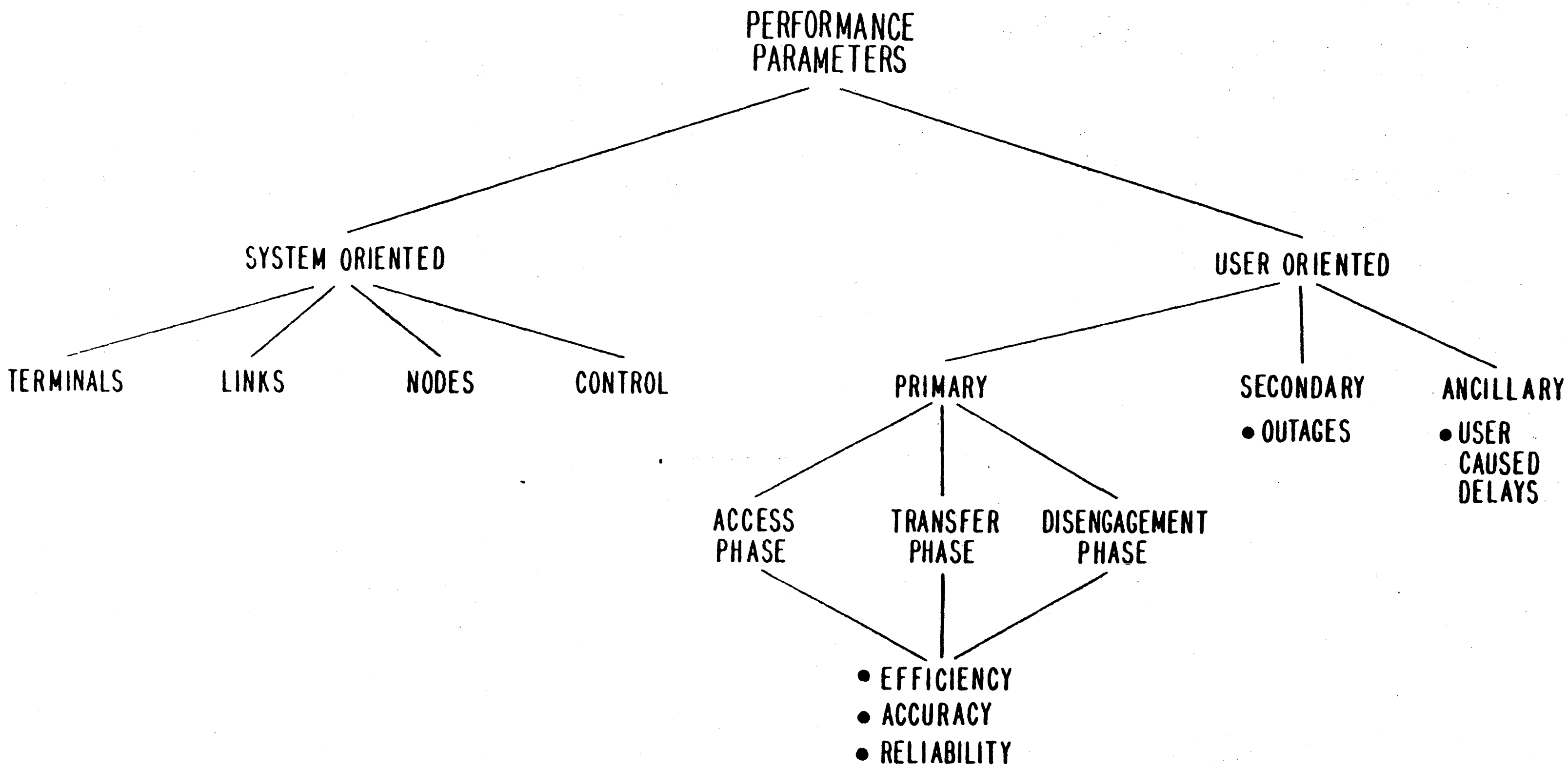


Figure 3-6. Performance parameter breakdown.

users to the offered services. The measurement standard will exploit this property by enabling users to compare performance among competing services.

Table 3-8a summarizes the 21 user-oriented performance parameters defined in ANS X3.102. The parameters express performance relative to three primary communication functions: access, user information transfer, and disengagement.

The parameters are of two basic types: primary parameters and ancillary parameters. The primary parameters describe performance with respect to speed, accuracy, and reliability. Thus they all fall within a matrix bounded by access, information, and transfer on one side and by speed, accuracy, and reliability on the other. The ancillary parameters describe the influence of user delays on the primary "speed" parameters. These functions correspond to connection, data transfer, and disconnection in connection-oriented services, but are also applicable to connectionless services (e.g., electronic mail). They divide a data communication session according to the user's perception of service and provide a structure for performance description.

In defining the parameters, each function was considered with respect to three categories of results: successful performance, incorrect performance, and nonperformance. These possible results correspond closely with the three performance criteria most frequently expressed by data communications users: speed, accuracy, and reliability.

One or more primary parameters were defined to express performance of each function-criterion pair. As an example, four primary parameters were defined for the access function: one access-speed parameter (Access Time), one access-accuracy parameter (Incorrect Access Probability), and two access-reliability parameters (Access Denial Probability and Access Outage Probability). Access failures attributable to the user (e.g., called user does not answer) were excluded.

The X3.102 parameters also include four ancillary parameters. Each ancillary parameter relates to a primary speed parameter and expresses the fraction of the performance time attributable to user delays. As an example, the primary parameter, Access Time, normally includes delays attributable to the users (e.g., dialing time, answer time, etc.) as well as delays attributable to the system (e.g., switching time). The ancillary parameter, User Fraction of Access Time, expresses the average fraction of total Access Time that is attributable to user delays. The ancillary parameters remove user influence on the primary speed parameters and allow the entity (user or system) responsible for nonperformance to be identified (e.g., access timeouts).

Table 3-8. Summary of ANS X3.102 Performance Parameters

a. Organization by function and performance criterion.

FUNCTION	PERFORMANCE CRITERION: SPEED	PERFORMANCE CRITERION: ACCURACY	PERFORMANCE CRITERION: RELIABILITY	PERFORMANCE TIME ALLOCATION
ACCESS	ACCESS TIME	INCORRECT ACCESS PROBABILITY	ACCESS DENIAL PROBABILITY ACCESS OUTAGE PROBABILITY	USER FRACTION OF ACCESS TIME
USER INFORMATION TRANSFER	BLOCK TRANSFER TIME	BIT ERROR PROBABILITY BIT MISDELIVERY PROBABILITY EXTRA BIT PROBABILITY BLOCK ERROR PROBABILITY BLOCK MISDELIVERY PROBABILITY EXTRA BLOCK PROBABILITY	BIT LOSS PROBABILITY BLOCK LOSS PROBABILITY	USER FRACTION OF BLOCK TRANSFER TIME
	USER INFORMATION BIT TRANSFER RATE	TRANSFER DENIAL PROBABILITY		USER FRACTION OF INPUT/OUTPUT TIME
DISENGAGEMENT	DISENGAGEMENT TIME	DISENGAGEMENT DENIAL PROBABILITY		USER FRACTION OF DISENGAGEMENT TIME

Legend: (open box) Primary Parameters; (hatched box) Ancillary Parameters

b. Organization by function and performance parameter type.

FUNCTION	PERFORMANCE PARAMETER TYPE: DELAY (IF COMPLETED)	PERFORMANCE PARAMETER TYPE: RATE (IF COMPLETED)	PERFORMANCE PARAMETER TYPE: FAILURE PROBABILITY
ACCESS	• ACCESS TIME • USER FRACTION OF ACCESS TIME		• INCORRECT ACCESS • ACCESS OUTAGE • ACCESS DENIAL
USER INFORMATION TRANSFER	• BLOCK TRANSFER TIME • USER FRACTION OF BLOCK TRANSFER TIME • USER FRACTION OF INPUT/OUTPUT TIME	• USER INFORMATION BIT TRANSFER RATE	• BIT ERROR • BIT MISDELIVERY • EXTRA BIT • BIT LOSS • BLOCK ERROR • BLOCK MISDELIVERY • EXTRA BLOCK • BLOCK LOSS • TRANSFER DENIAL
DISENGAGEMENT	• DISENGAGEMENT TIME • USER FRACTION OF DISENGAGEMENT TIME		• DISENGAGEMENT DENIAL

For statistical estimation, the X3.102 parameters are most naturally classified as: time delay, time rate, and failure probability parameters. This classification is shown in Table 3-8b. Note that the ancillary performance parameters are classified with the delays.

Figure 3-7 illustrates the structure of the proposed measurement standard, X3S35/135. The standard is divided into four parts. The first defines a procedure to design experiments to measure the ANS X3.102 parameters. The second specifies functional requirements for extraction of performance data. The third specifies functional requirements for reduction of the data. The fourth specifies methods of analyzing and reporting the ANS X3.102 performance data. See ANSI (1984) for details on the proposed measurement standard.

Miles (1984) describes the design and use of an interactive computer program that relates the measurement precision of the ANSI X3S35/135 parameters to sample size. This greatly simplifies the measurement process in terms of run length and test result reporting. Statistical theory is used to determine the minimum sample size necessary to achieve a desired precision based on knowledge of the dispersion and the dependence among sample values. This can result in substantial cost savings in testing. The sample is analyzed by calculating its mean value and determining the interval about this estimate within which a true mean can be expected to fall with a certain level of confidence.

3.4.1 Analog System Performance Parameters

In order to assess speech quality in a quantitative manner, it is important to determine how quality assessment measures are chosen. Both subjective and objective measures have been used. Flanagan, et al. (1979) related speech digitization rates and speech quality as follows:

Speech Quality	Digitization Rate
commentary	>64 kb/s
toll	12 kb/s to 64 kb/s
communications	6 kb/s to 12 kb/s
synthetic	<6 kb/s

Subjective measures based on opinion rating methods and articulation scores are described by Kitawaki, et al. (1984).

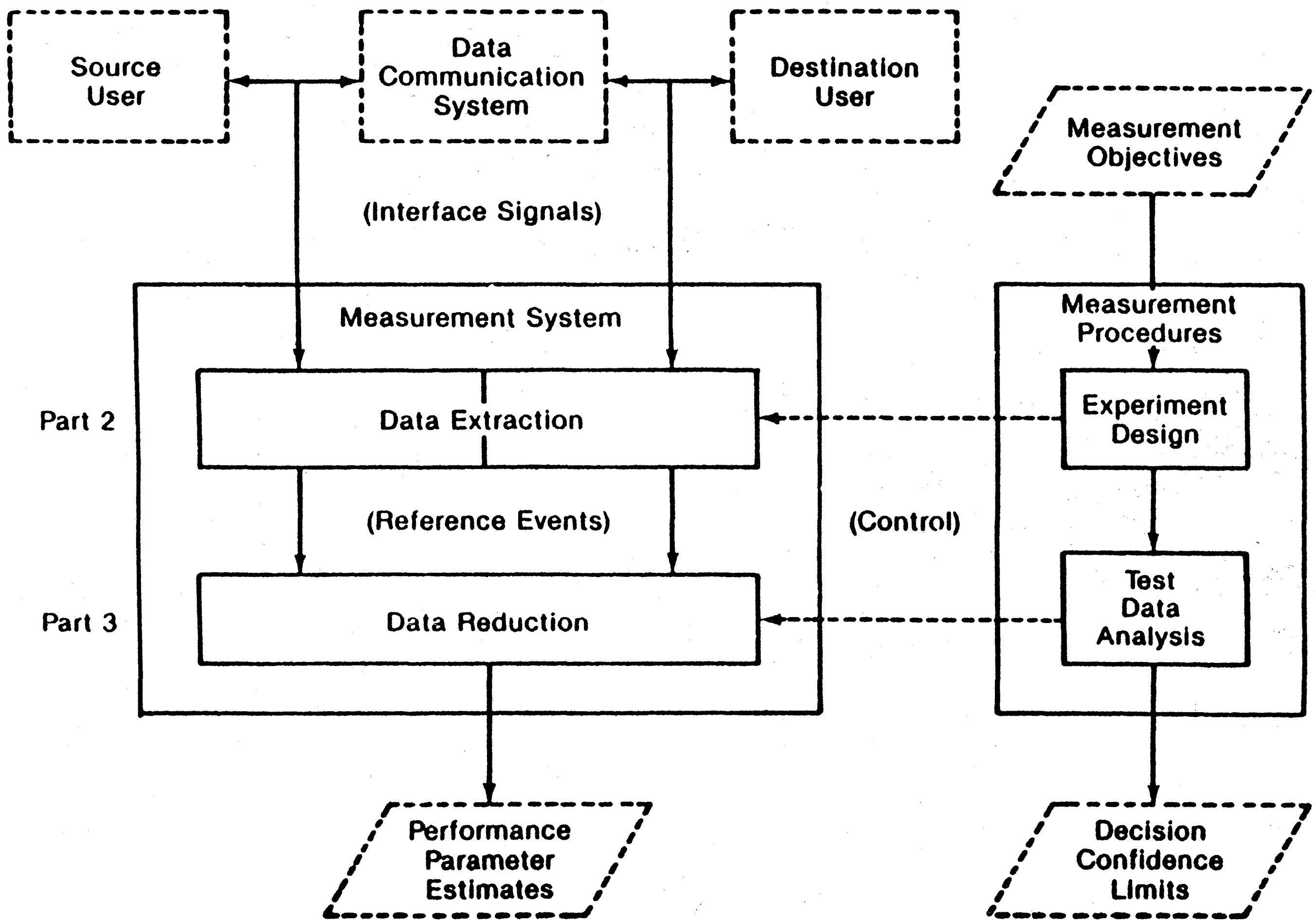


Figure 3-7. Structure of proposed measurement standard.

Most of the user-oriented parameters for data communications can also be applied to analog voice systems, except for the information transfer phase. Certainly, criteria like access time and access denial (or blocking grade of service) still pertain, but voice intelligibility, naturalness, and recognizability are subjective terms for which objective standards remain to be developed.

Some work is being done on subjective evaluations method standardization by the IEEE. It pertains to voice-band codecs. Also, CCITT Study Group XII has proposed a reference unit for speech correlated noise. A summary of this work is given in Kitawaki, et al. (1984). The problem with objective measurements is that none have been found to be both highly correlated with the results of human preference tests and at the same time are compactly computable.

W.J. Hartman addresses the question of selecting analog service parameters and their measurement methods in Nesenbergs, et al. (1981), chapter 6. He recommends four basic parameters for the transfer phase of voice systems, namely intelligibility, acceptability, speaker recognition, and delay.

Table 3-9 lists these parameters for the transfer phase. This table also includes the pertinent parameters listed previously for the access and disengagement phases.

3.4.2 Assignment of Values to Performance Parameters

The assignment of numerical values to the user-oriented performance parameters defined above should ideally be done by user groups in the MILDEPS. Based on these values, system engineering specifications for the network could then be developed.

This process of translating user-oriented parameter values to corresponding technical (engineering-oriented) system specifications has only been studied in part and much work remains to be done. See Nesenbergs, et al. (1981). In addition, neither the parameters themselves nor their values for analog information sources are well defined. In spite of these limitations, we have included Tables 3-10 and 3-11 to illustrate typical values for some of the parameters. Table 3-10 includes all of the primary performance parameters for one digital service mode used in AUTODIN, namely, the host computer program to high-speed terminal application.

Table 3-11 lists some of the values for an analog source, namely, voice (telephony) transfer. The values given apply to existing DCS systems. Many networks specify different blocking probabilities during the user's phase for denial

Table 3-9. Analog Service Performance Parameters

Part A - Primary Parameters

1. Access Time
2. Incorrect Access Probability
3. Access Denial Probability

4. Intelligibility

    (a) Normalized Energy
    (b) Log Area Ratios
    (c) Short-Term S/N
    (d) Band-weighted S/N

5. Acceptability

    (a) Normalized Energy
    (b) Log Area Ratios
    (c) Short-Term S/N
    (d) Band-weighted S/N

6. Speaker Recognition

    (e) Computer Speaker Recognition

7. Delay

    (f) Round Trip Delay

8. Disengagement Time
9. Disengagement Denial Probability

Part B - Secondary Parameters

10. Service Time Between Outages
11. Outage Duration
12. Outage Probability

Part C - Ancillary Parameters

13. User Access Time Fraction
14. User Delay Time Fraction
15. User Disengagement Time Fraction

Table 3-10. Tentative Values for a Digital Service

Function	Performance Criterion: Efficiency or Speed	Performance Criterion: Accuracy	Performance Criterion: Reliability
Access	1. Access Time 0.10 s (Mean) 0.15 s (0.9-Perc.)	2. Incorrect Access Probability 10^{-10}	3. Access Denial Probability 10^{-3} (at 0.3s)
Bit Transfer	4. Bit Transfer Time 0.5 s	5. Bit Error Prob. 10^{-10} 6. Bit Misdel. Prob. 10^{-11} 7. Extra Bit Prob. 10^{-11}	8. Bit Loss Probability 10^{-11}
Block Transfer	9. Block Transfer Time 0.5 s	10. Block Error Prob. 10^{-9} 11. Block Misdel. Prob. 10^{-9} 12. Extra Block Prob. 10^{-10}	13. Block Loss Probability $3 \cdot 10^{-11}$
Message Transfer	14. Bit Trans. Rate 8510 b/s 15. Block Trans. Rate 8510/n* blocks/s 16. Bit Rate Eff. 50% 17. Block Rate Eff. 50%	X	X
Disengagement	18. Diseng. Time 0.05 s (Mean) 0.10 s (0.9-Perc.)	19. Diseng. Denial Probability 10^{-3} (at 0.15 s)	

*n = number of bits per block.

Table 3-11. Typical Ranges of Values for Key Performance Parameters Analog Sources

	Lower Bound	Upper Bound
<u>Access Phase</u>		
Access Time		
o Flash Override	0	2s
o Flash	10s for 90% of calls	20s for 99% of calls
o Immediate	10s for 90% of calls	20s for 99% of calls
o Priority	10s for 90% of calls	20s for 99% of calls
o Routine	10s for 90% of calls	20s for 99% of calls
Access Denial		
≥ Flash	0	0.0001
< Flash	0.001	0.1
<u>Transfer Phase</u>		
Intelligibility	not specified	toll quality
Recognizability	not specified	
Acceptability	not specified	
Terrestrial Delay	2.5 ms	50 ms
Satellite Delay	N/A	300 ms
<u>Disengagement Phase</u>		
o Time	unknown	
o Denial Probability	unknown	
<u>Secondary Parameters</u>		
o End-to-End Availability	0.90	0.990

probability, i.e., the GOS. Typically, this may be P(0.1) for outward calls plus P(0.05) for inward calls on a telephone network. This difference results from the progressive control systems used. In such systems it is preferable to block calls early rather than near the end of the path, so circuits and facilities are not tied up. Common channel signaling eliminates this requirement since progressive control is not used.

Items left blank or marked unknown such as voice recognizability, voice acceptability, and disengagement denial probability are yet to be determined. As noted previously, the objective voice measures have not yet been developed and accepted by the standards-making community.

3.5 Performance Under Stress

The performance parameters defined in the previous section may not all be pertinent to every military user. Some missions may depend on one set and others on a different set. The values may also be different for different communities of interest or mission groups. In addition, the environments in which a group operates can change. Here we examine that environment from the military standpoint. Our discussion is based on the five stress levels defined by DCA.

The stress levels are listed below along with the priority for each and an explanation of the primary role of the DSN at that level.

	STRESS LEVEL	PRIMARY DSN ROLE	PRIORITY
1	Peacetime Readiness	Support Command and Control functions and intelligence traffic plus DOD administrative users	4
2	Crisis and Preattack and Theater Non-nuclear War	Above plus surge requirements, handled according to established precedence	1
3	Early Transattack (Few weapons, possibly HEMP)	Support critical C^2 traffic	2
4	Massive Nuclear Attack	No capability assured, provide support as able	5
5	Post Attack	Contribute to reconstitution of national networks	3

The DSN is expected to support critical traffic and routine traffic through stress levels 1 and 2. It should have sufficient capacity to withstand various surge requirements and overload conditions. This excess capacity can be obtained by alternate routing and rich connectivity to various transmission facilities. During stress level 3 (early transattack) the DSN should support critical user traffic. This requires high-altitude electromagnetic pulse (HEMP) hardening, as well as network diversity with reconfiguration capabilities for cases of minor damage. The DSN must also assist in reconstructing the National Communication System in stress level 5 (after a massive attack). This can be accomplished by interconnecting surviving fragments of many networks by various means.

Some performance objectives for the DSN under stress were developed by a technical working group of Government and industry representatives. Results are given in Western Electric Co. (1982) and are summarized here.

The DSN should provide assured service (i.e., essentially nonblocking service) for critical users when there is no damage (stress levels 1 & 2) and under all traffic load conditions. Endurable service (i.e., essentially nonblocking given connectivity) is to be provided when there is minor damage or system failures independent of traffic load conditions. Traffic may be congested over the entire network causing a general overload (as on Mothers Day) or it may be congested in only a portion of the network, causing a focused overload condition (as during the recent Los Angeles earthquake).

The performance objectives for critical users under assured and endurable service conditions are as follows:

Type of Service	End-to-End Blocking Probability	Access Time (End of dialing to ringing)
assured (level 1 & 2)	p = 0.001	< 10 seconds
endurable (level 3)	p = 0.001 (given connectivity)	< 20 seconds (given connectivity)

Required service features or functions for these critical users for both assured and endurable services included:

- end-to-end voice communication (toll quality POTS)
- precedence/preemption capability (essentially nonblocking for critical users)
- originating call screening
- authorization code
- interoperation between commercial and private nets
- interface to AUTOVON
- offnet to PSTN and PSTN to DSN
- off-hook service (no dialing to designated stations)
- teleconferencing
- facility selection (underground, digital).

We assume that the total engineered capacity of the DSN long-haul network is 10,000 Erlangs. This is twice the traffic load carried on AUTOVON in 1982 and allows for future growth and the access of certain nonmilitary critical users. It has been estimated that there are probably less than 5,000 critical users in CONUS, including military, Government and civilian personnel. Critical user traffic on AUTOVON during peacetime is about 3% of the total. If one includes other nonmilitary critical users this could increase by a factor of 2, to 6% of the total (i.e., 600E) during a normal busy hour. Under stress conditions the total traffic carried on the network can be no more than its total engineered capacity of 10,000 Erlangs. This "worst-case" situation is a conservative value that can be used for a general overload condition. For focused overloads, the average value assumed is twice the normal busy-hour load or 2 X 600 = 1,200E. These are twice the values given by Western Electric Co. (1981), to account for growth and nonmilitary users on the DSN. Results are summarized in Figure 3-8.

The traffic loads indicated on this figure are for the traffic the long-haul networks is expected to carry in the 1990 era. This traffic is offered by critical users- military, government and civilian -who are distributed nonuniformly throughout CONUS. It is the traffic that must be handled by the tandem switching nodes and the transmission and control assets of the DSN. Intra-access area traffic, which consists of local critical-user traffic on a military base, is not included.

The average traffic load per main-line telephone in the United States is about 0.08 Erlangs per main-line phone. For military bases one can assume above average use of 0.1 Erlangs, corresponding to an average of two 3-minute calls per phone. The 10,000 Erlangs of DSN traffic load would be generated by 100,000 telephone stations conversing long distance with 100,000 others. Since long distance calls are typically 20% of the total calls, the local traffic comprises the other 80%. This means that 400,000 telephone stations must be conversing with another 400,000 and the local lines are carrying around 40,000 Erlangs. The situation is depicted in Figure 3-9. The total number of main-line phones is one million and the total traffic load is 50,000 Erlangs of which 80% is local traffic. This local traffic must be handled by the PBX's, DCO's, and local lines on either the military bases or within access areas.

At a given post, camp, or station, the traffic situation looks like that illustrated by Figure 3-10. Here 80% of the traffic remains on site. The other 20% consists of 7% arriving from outside and terminating on the site, 8% originating on the site but with an outside destination, and 5% being relayed to other sites. This is just one of many possible traffic scenarios.

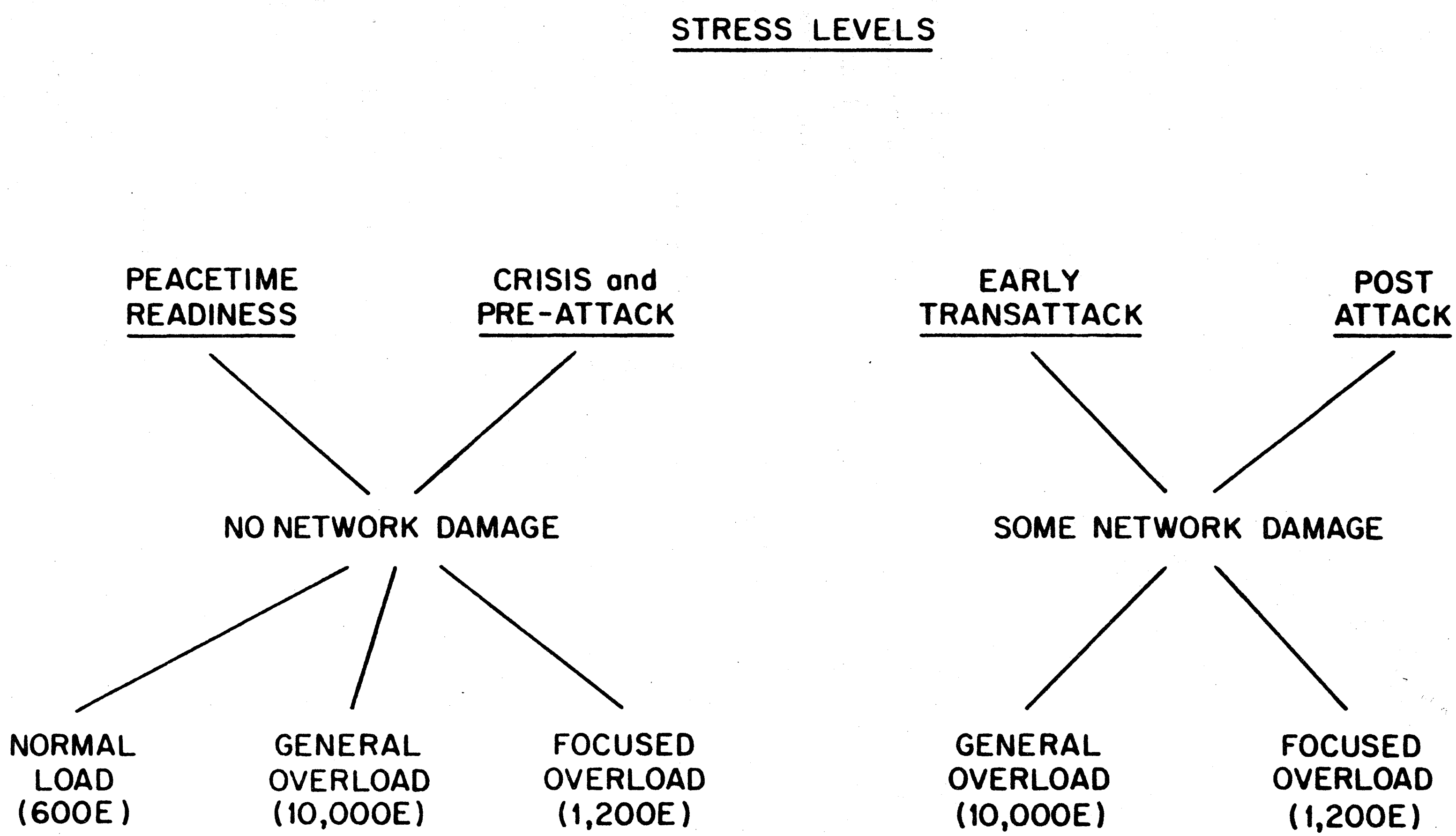


Figure 3-8. Stress levels and traffic loads for critical users under stress conditions.

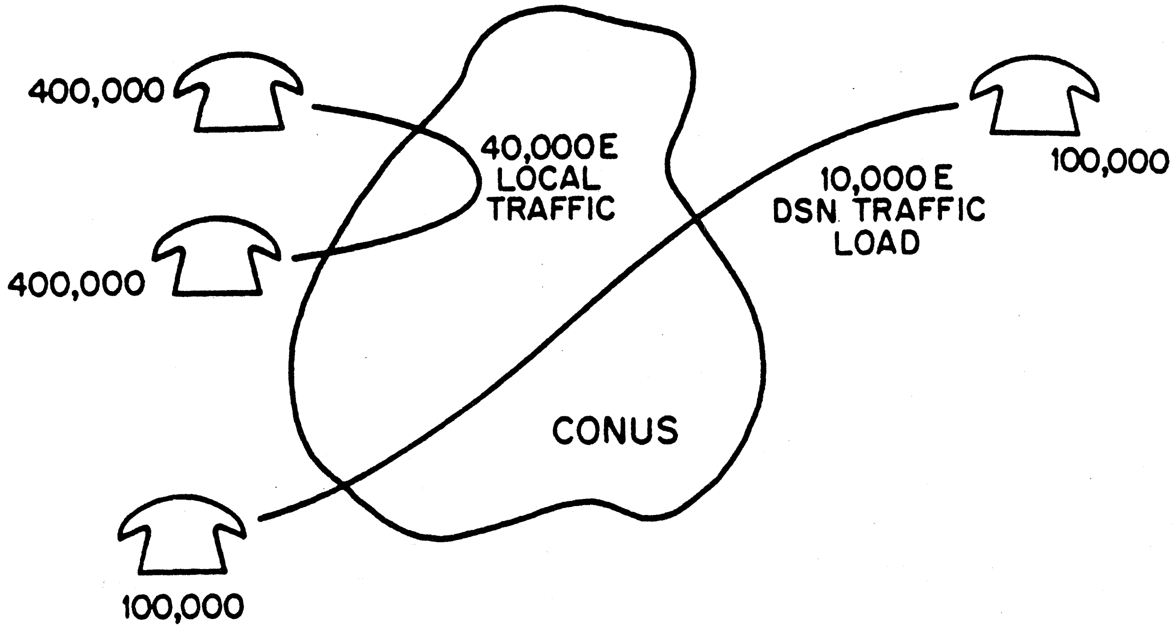


Figure 3-9. Estimated traffic in CONUS.

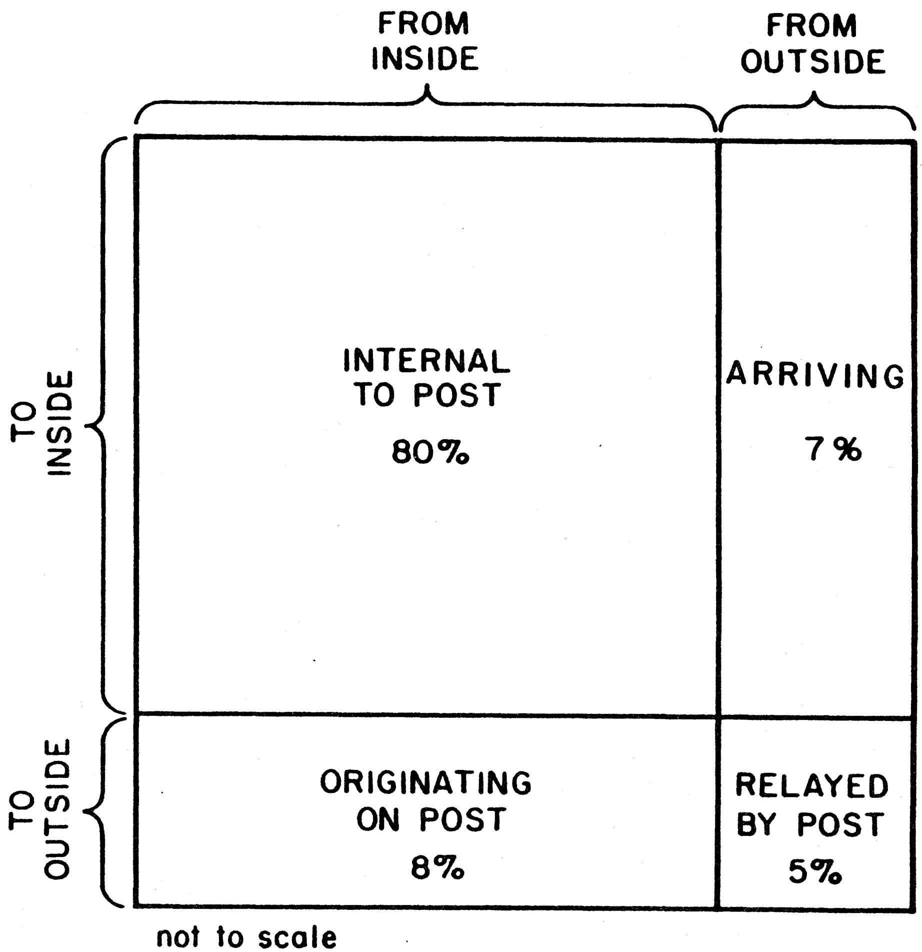


Figure 3-10. Example of one possible traffic scenario on a military post.

4. NETWORK ARCHITECTURAL CONCEPTS

A network's "architecture" defines the functions that the network components are to perform. The architecture provides the framework for routing traffic, end-to-end procedures for recovering data, message security, and protocols at all levels. Thus, the architecture is distinguished from a network's "implementation," which defines exactly what hardware and software is used. In this section we are concerned with the major network architectural concepts--namely the topology, switching hierarchy, and control signaling. First we define some architectures that are either in current use today or are planned for the near future. Later on we present a concept that merits consideration for the access area and for the DSN long-haul network because of its cost effectiveness under the unique military requirement of survivability.

4.1 Hierarchal Architectures

A network architecture normally used by the common carrier industry is a hierarchal structure typified by the diagram in Figure 4-1. The switching nodes at each level in this hierarchy perform separate and distinct functions. The first and lowest level consists of the user terminals. These terminals (e.g., telephone handsets) connect to the next level via station loops. The network functions at this level are the familiar telephone loop functions. The next level in this architecture involves the PABX, where the initial switching, processing and control functions take place. This is the level where service features seen by the users are generated. The PABX's are connected to the third switching level via local trunks. This third level involves central office switching and trunking to the long-haul networks. The long-haul switches are shown as level four. They serve as both toll and tandem switches.

An example of this type of hierarchal structure with even more levels is depicted in Figure 4-2. This is the familiar toll switching hierarchy of the public switched telephone network. Various circles, hexagons, triangles, and squares denote switching offices, centers, or points. The darkened offices are those serving either end subscribers or supporting lower level switching machines, such as PABX, RSU, and other customer owned terminal support or concentration facilities. The largest majority of subscribers are homed to these Class 5 End Offices. The EO's in turn can have trunks to just about every class of switching nodes, such as local tandem, EO plus local tandem, Class 4X Intermediate Point (IP), Class 4 Toll Center (TC), or Toll Point (TP), Class 3 Primary Center (PC) or Point (PP), Class 2 Sectional Center (SC) or Point (SP), and at the tip of the hierarchy, to the Class 1 Regional Center (RC) or Point (RP).

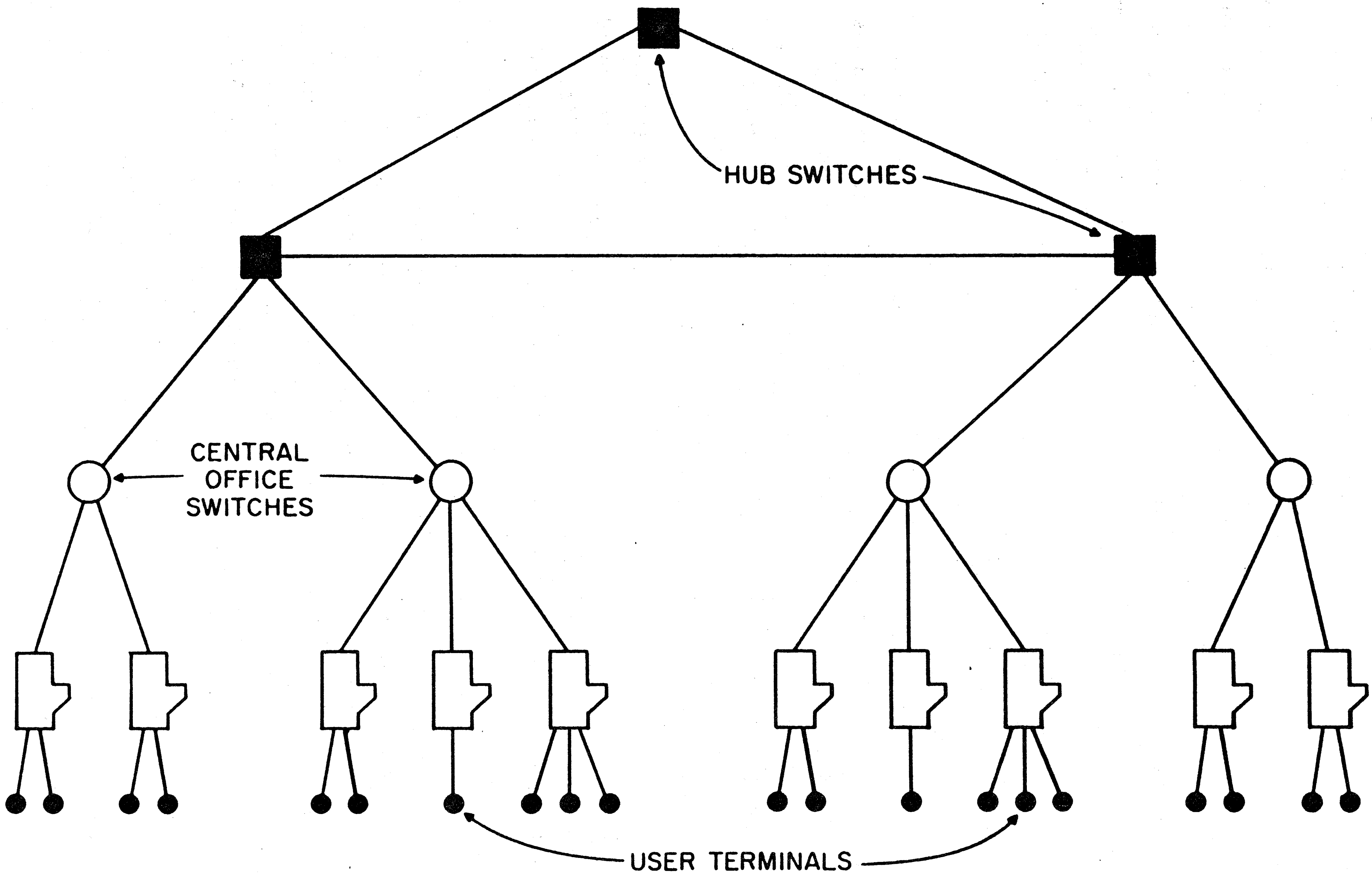


Figure 4-1. A hierarchal switching plan.

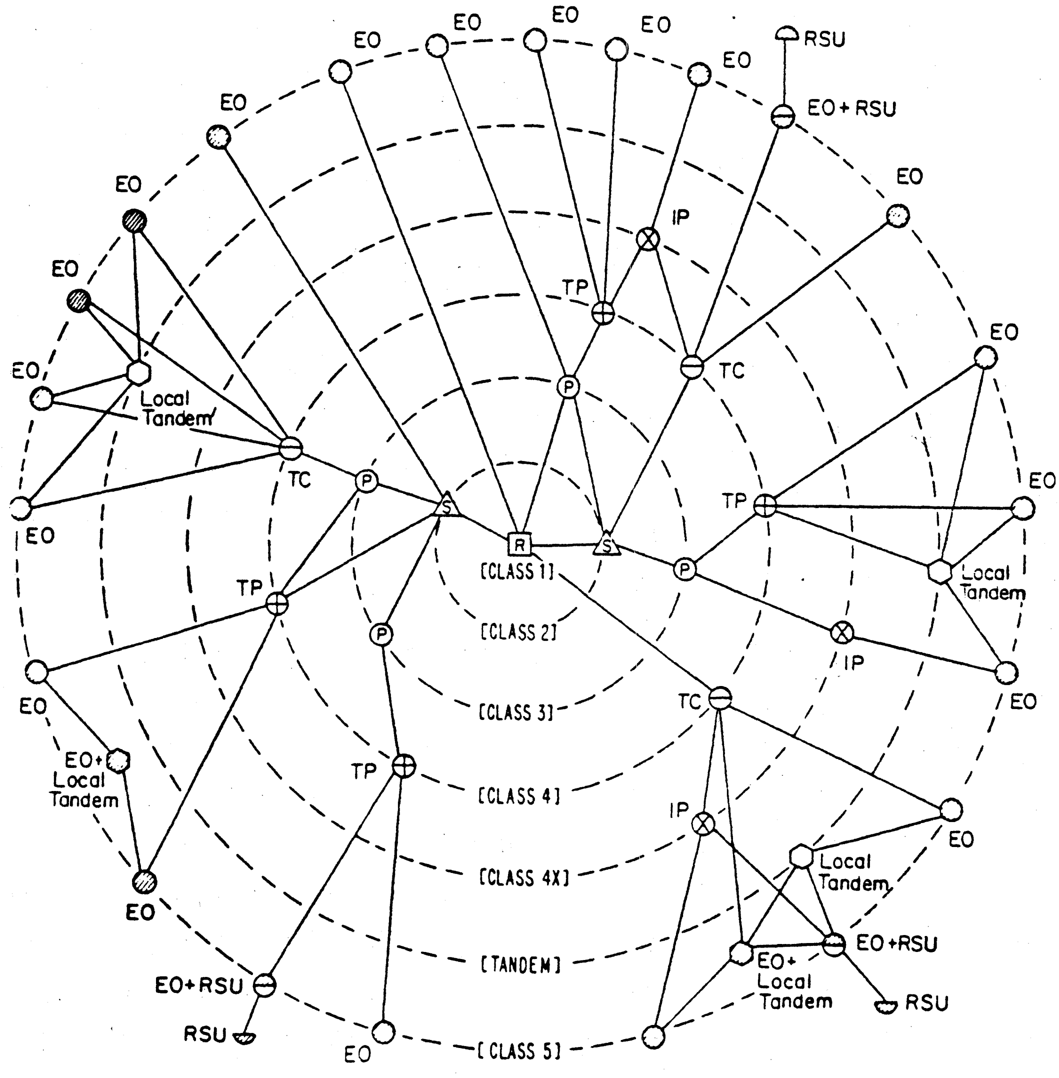


Figure 4-2. Intra- and interexchange network, predivestiture.

The general connectivity of the toll network is not far removed from a star topology. At the loosely defined center of the star, the final route is provided through the regional centers R. There are 10 regions and 10 regional centers. The numbers of other class facilities are given in Table 4-1. A call may proceed (i.e., be routed) through just about all the switch classes, as directed by CCIS and alternate routing arrangements. Alternate routing is sometimes associated with the Least Cost Routing (LCR) "for the user," but that phrase is somewhat misleading. Alternate routing can instead be viewed as a method of alleviating trunk group congestion, improving inter-switch blocking GOS, carrying more traffic through the trunk network, and thus producing more revenue for the Bell System, at the given investment in the overall facilities. It helps the end-to-end GOS of the subscribers as a secondary effect.

This multilevel hierarchal network is gradually being replaced by a network structure having two parts: a hierarchal part and a dynamic, nonhierarchal routing (DNHR) part. The basic structure is described by Ash and Mummert (1984) and is shown in Figure 4-3. The nonhierarchal nodes contain No 4 ESS switches and common channel signaling. All switches perform equal functions. Ultimately the DNHR network in the United States will contain 140 such switches. The routing in the DNHR network is considered dynamic because routing can change as a function of the time of day. Overall network efficiency is maintained as calling patterns change by rerouting calls through uncongested portions of the network.

4.2 AUTOVON Architecture

The basic architecture of the AUTOVON network is illustrated in Figure 4-4. This polygrid network consists of about 50 switch nodes in CONUS interconnected by at least two two-way paths between any two nodes. The network is a privately leased service for the military and performs military functions such as multi-level precedence and preemption. Access to the AUTOVON nodes is via a star connecting topology from subscriber locations. Special four-wire telephones are used for direct access in some instances. Figure 4-5 indicates the number of locations and number of access trunks per location homing on the AUTOVON switch at Cedar Brook, N.J. The total number of access lines at this switch is 505 from 22 subscriber locations. Distances range from less than 10 miles to several hundred miles.

Figure 4-6 indicates the number of backbone trunks or servers required to handle these 505 access trunks, as a function of blocking probability. The curves on this figure correspond to the average traffic intensity in Erlangs

Table 4-1. Bell System Toll Switching Centers

Class	Name	Number
1	Regional Center or Point	10
2	Sectional Center or Point	63
3	Primary Center or Point	204
4*	Toll Center or Point	approx. 900
5	EO Wire Centers	approx. 9,000
	EO plus Tandem Switches	approx. 10,000

*Class 4 includes the, so called, Class 4X or Intermediate Points (IP).

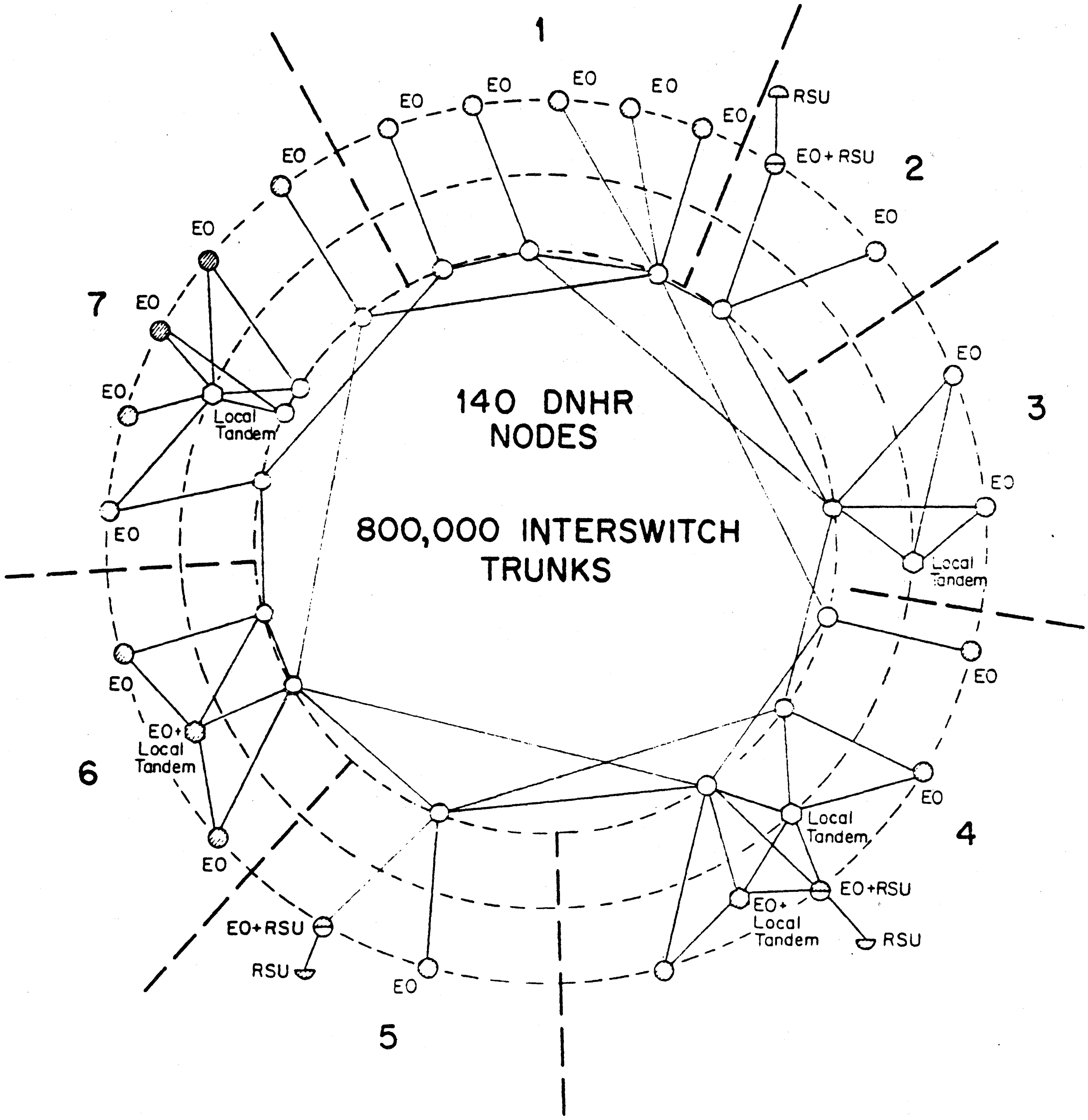


Figure 4-3. Intra- and interexchange network, postdivestiture.

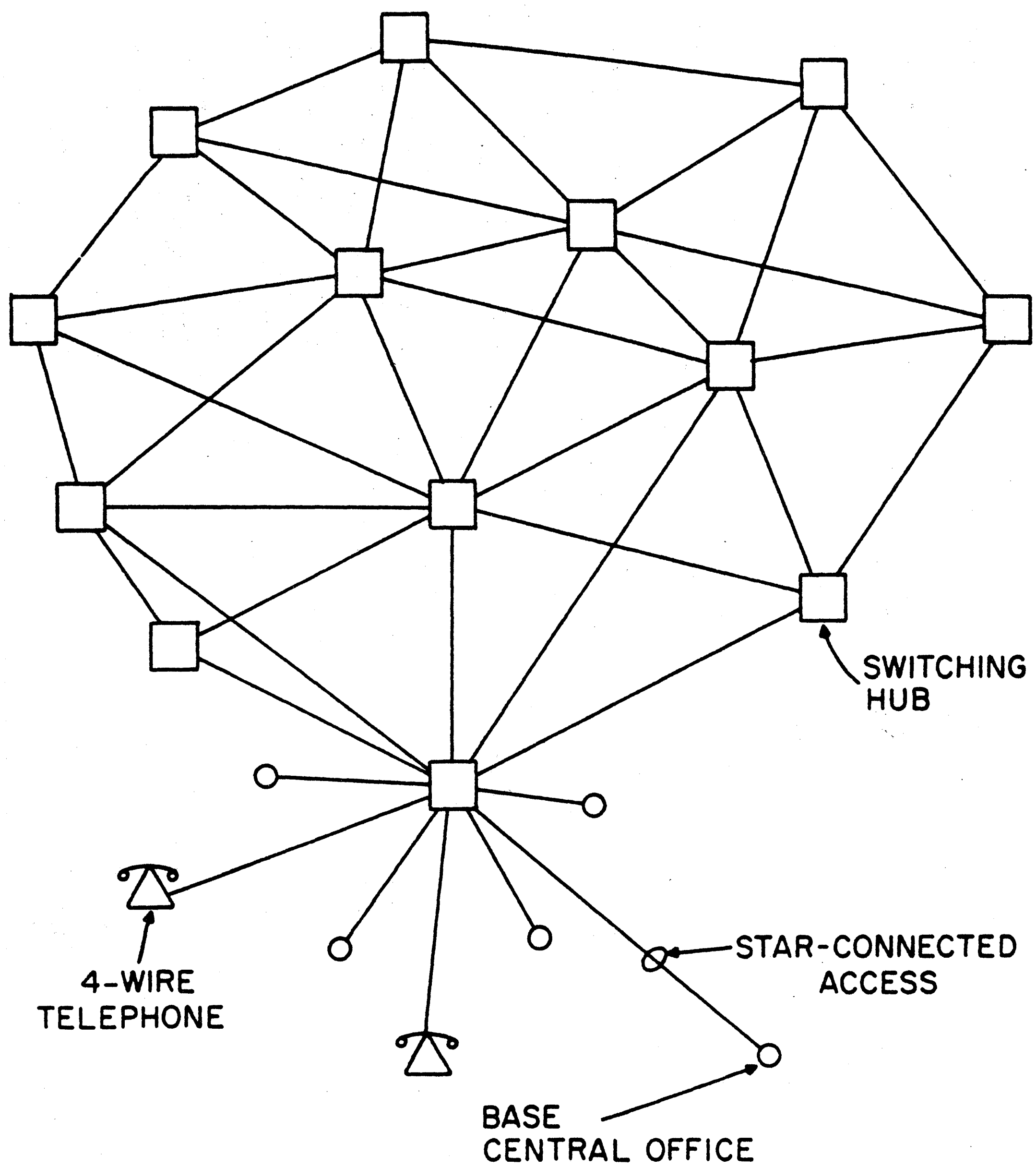


Figure 4-4. AUTOVON polygrid network with star-connected access.

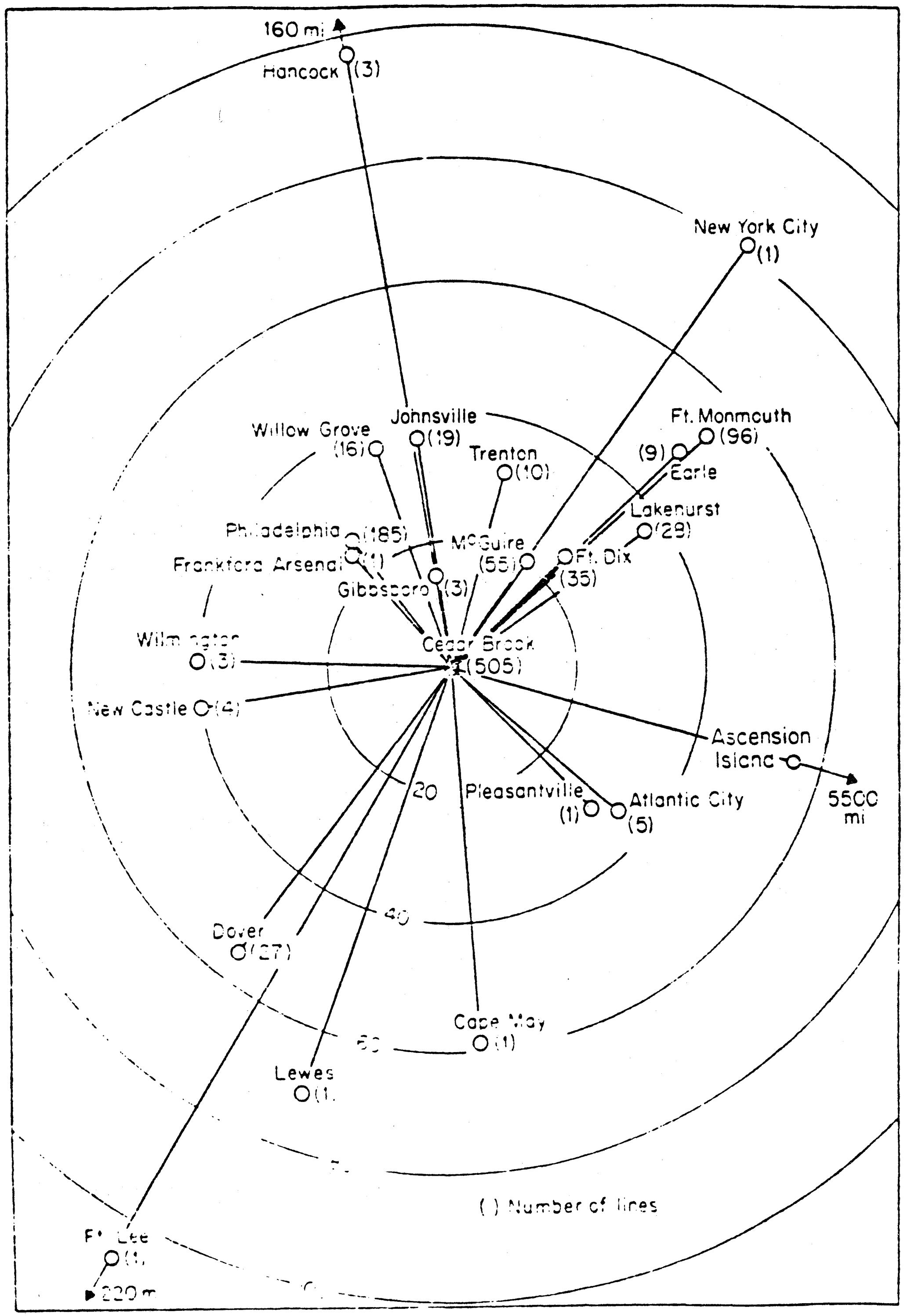


Figure 4-5. Star connections to AUTOVON switch at Cedar Brook, NJ.

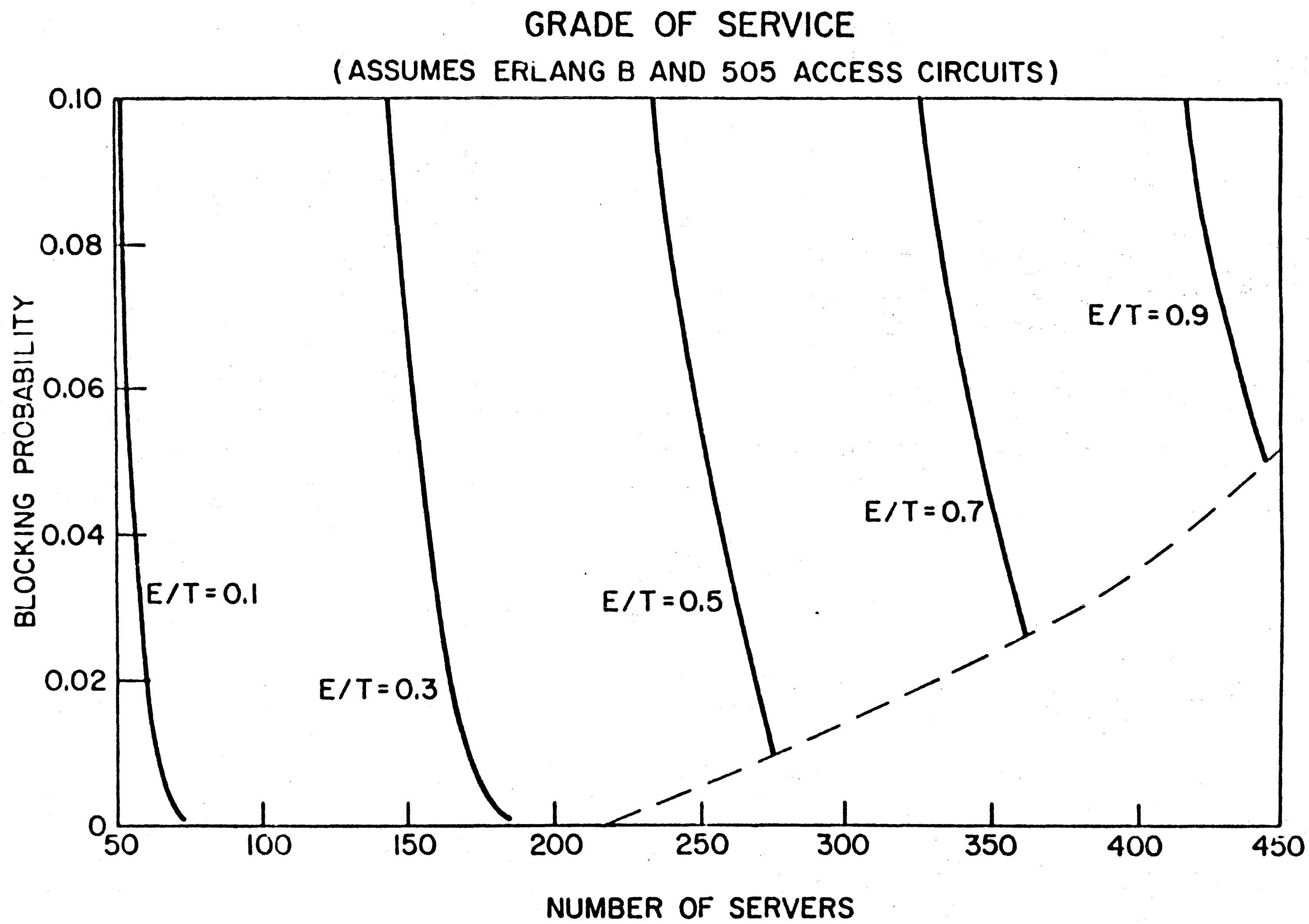


Figure 4-6. Grade of service estimates for Cedar Brook parametric in Erlangs per access trunk.

per access trunk, or E/T. Each curve is based on the Erlang B formula, which assumes that blocked calls are lost and that there are an infinite number of sources. The Erlang B formula does not apply when the number of servers approaches the number of sources times their offered load. This is indicated by the dashed line on Figure 4-6.

4.3 The Structured Configuration

In this section we present a different architecture than the hierarchal and nonhierarchal ones discussed previously. Here the switching hierarchy still exists but these switches are limited in a manner that provides redundant paths from user terminals. As link and node damage occurs, a graceful degradation in quality of service takes place. Telecommunications survivability is enhanced for the end users.

A fully connected network with many (> 100) distributed hub switches is expensive. A structured configuration appears to be a cost-effective compromise. This structured concept is shown in Figure 4-7 for an arbitrary number of N nodes. See Linfield, et al. (1980).

To start, the nodes are ordered in accordance with the number of terminals they serve. If T_n is the number of terminals for the n-th node, then the ordering is

$$T_1 \geq T_2 \geq T_3 \geq \cdots \geq T_N \quad .$$

Thus, in this sense, T_1 is the largest node. T_2 is the next largest node, and so on. Finally, T_N is the smallest.

For N = 2 or 3, connect the nodes fully to each other. These are the lowest networks in Figure 4-7. If $N \geq 4$, construct a pyramid structure as follows. Interconnect nodes n = 1 and n= 2. Connect nodes n = 3, 4, ..., N only to nodes 1 and 2. What results is a multiloop structure with 2N - 3 links for $N \geq 3$ nodes. For larger N, this number is nearly double that for a minimum spanning tree (such as the star network). But, it is noticeably less than for fully connected networks with the same number of nodes.

The notation for the structured configuration was introduced in Figure 4-7. The nodes or switches are identified by n = 1, 2, ..., N. The individual number of terminals at a node n are T_n, n = 1, 2, ..., N. The link capacities between nodes n and m are C_{nm}, $n \neq m = 1, 2, \ldots, N$. The key questions that must be answered are how the structured configuration link capacities C_{nm} should be

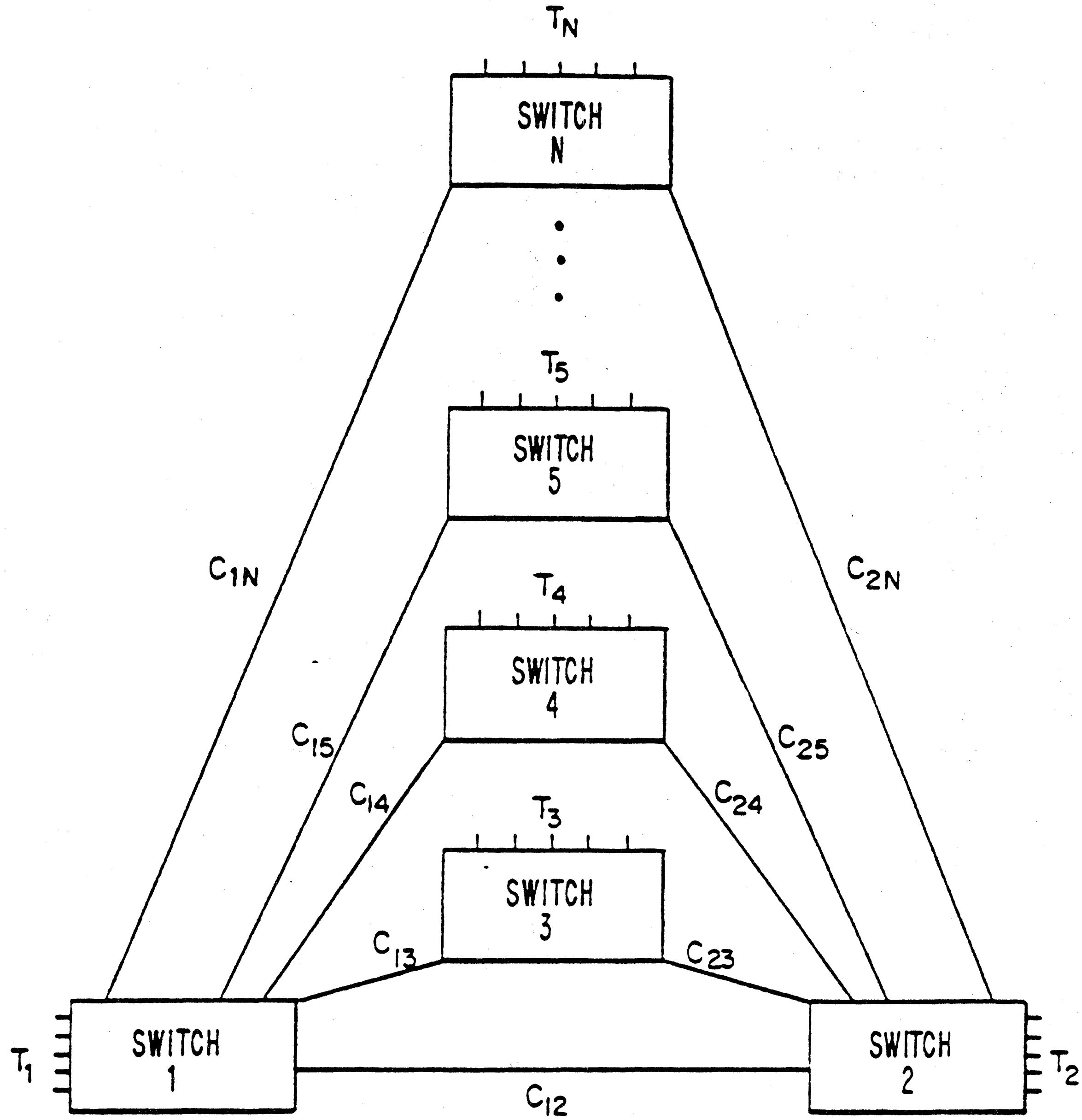


Figure 4-7. The general structured configuration.

assigned and where should one place gateways to outside networks. Effective capacity assignment must be a function of the user terminal set, telecommunications traffic requirements, and other general design objectives, such as survivability. Because of their multiple connectivity, the base switches (i.e., 1 and 2 in the figure) are primary gateway candidates. Appendix D addresses the capacity assignment problem.

The structured configuration may not be limited to only two switches at the base level or to a single pyramid structure as in Figure 4-7. Multiple structures for the DSN in the CONUS can be envisioned as illustrated in Figure 4-8. Here the major traffic centers provide the base structure to which all other access area hub switches are connected.

Figure 4-9 compares the number of links necessary to implement the more common network types. The structured configuration appears to offer reasonable survivability at the least cost.

4.4 Control Signaling, User Data, and Network Management

Control signaling systems permeate a network to remotely control the user terminals, the switching nodes, the transmission links, to update data bases, and to manage the overall network. Like a nervous system, the facilities that perform all of these network functions must sense the system and the user's needs and react accordingly.

Subscriber information (e.g., messages) and overhead information (e.g., control signals) proceed through the network in many ways. They can be distinguished easily when the overhead information is transferred on a separate channel that is dedicated to signaling. This type of control signaling is known as common channel signaling. When overhead information is transferred over the same channel as the user information, three methods are commonly used for signaling. They are: 1) using unique sequences of bits or characters that are recognizable only as control signals, 2) allocating certain time slots or periods for transmission of control signals, and 3) specifying fixed positons in a sequence of bits for the control signals. Various combinations of these and other signaling systems may be employed in military access areas and in the DSN backbone. Ultimately, the goal architecture is expected to use a common channel signaling format like CCITT Signaling System No. 7. See CCITT (1980). This system provides an internationally recognized, general-purpose signaling system. It appears ideally suited for DSN because:

- It is optimized for use in digital networks with stored program controlled switches.

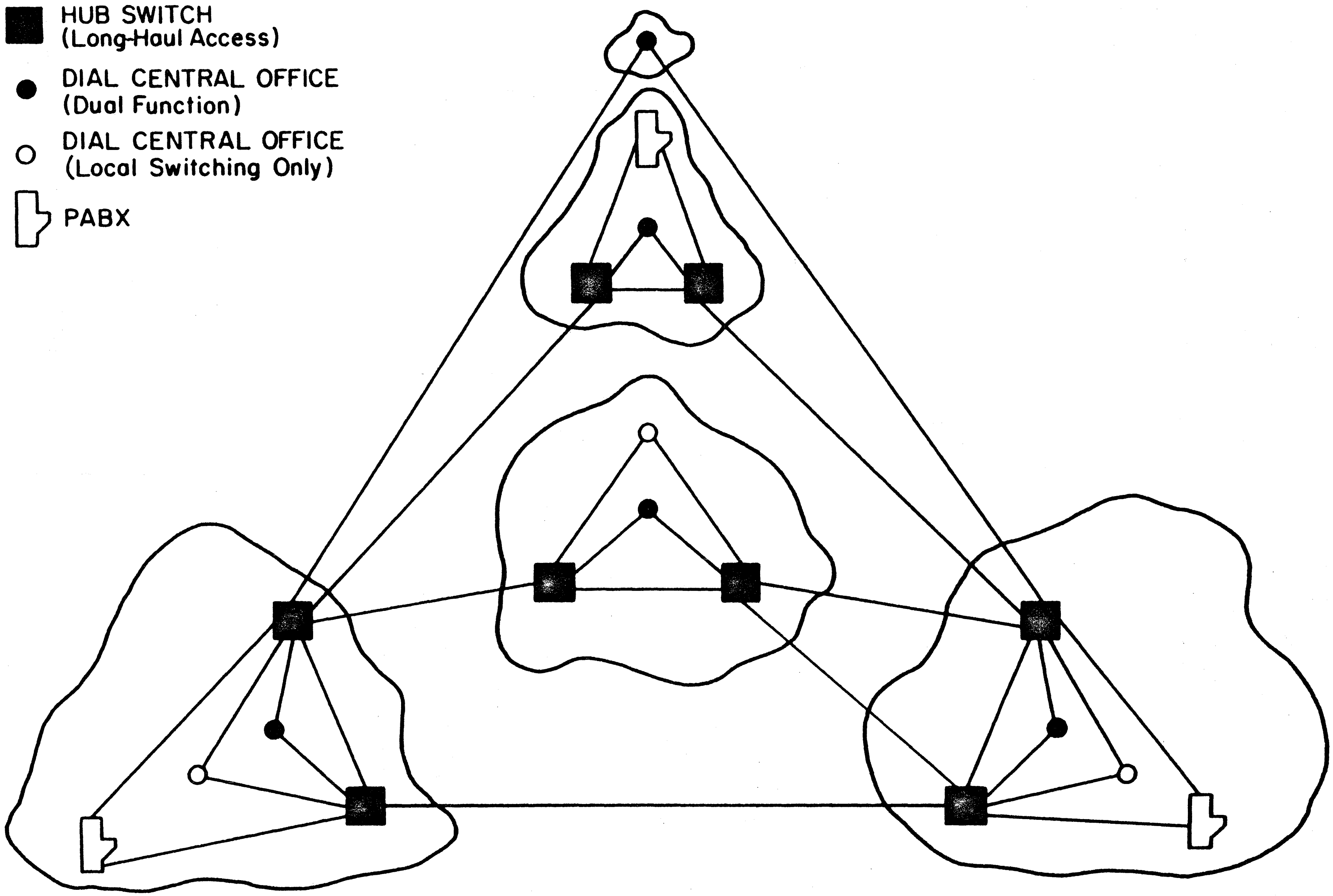


Figure 4-8. Structured configuration for DSN access and long-haul.

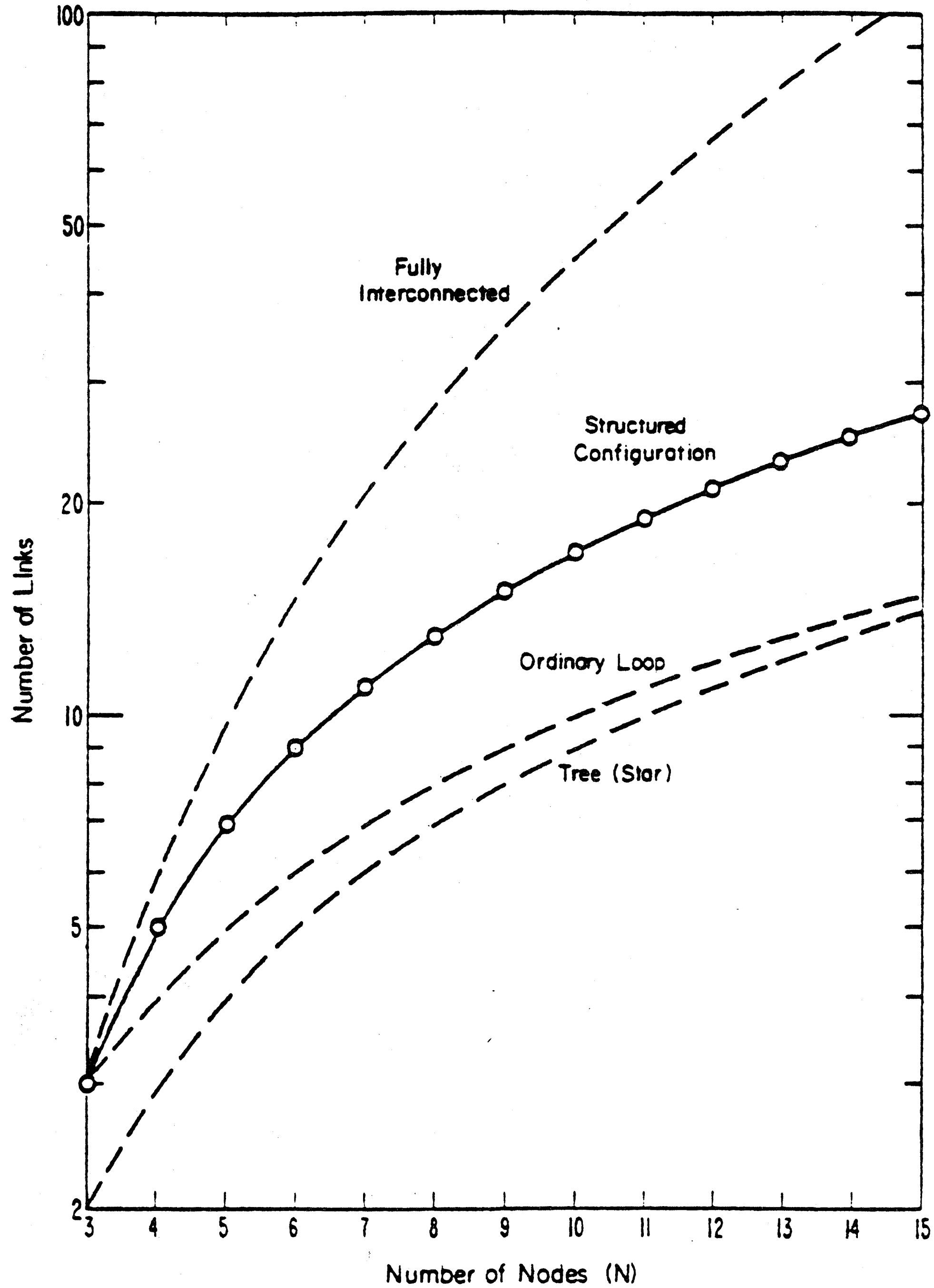


Figure 4-9. The number of links required by several common topologies.

- It meets requirements for call control, remote control management, and maintenance.
- System No. 7 provides reliable means for packetized information transfer without loss of sequence or duplication.
- It is suitable for operation over analog channels at low speeds (e.g., 4,800 b/s) and over digital channels up to 64 kb/s.
- It is suitable for use on point-to-point terrestrial and satellite links.

The CCITT Signaling System No. 7 provides the means to transport user data as well as control information. The size of the DSN and the signaling rate of 64 kb/s may allow sufficient capacity to carry a considerable amount of user data in addition to the required management and control information. Thus, it is entirely feasible to use this signaling system to carry user data traffic as well as control signals. Ultimately the packet-switched control signaling network would serve the combined role of managing the network (including administration, operation, and maintenance), controlling the network (including addressing, supervision, and routing), and data transfer (including narrative message, inquiry/response, and bulk traffic).

Although the goal architecture may ultimately use CCITT Signaling System No. 7, the DSN-AA network interfaces must be capable of handling and interfacing with other signaling systems currently in use.

Overall management of the DSN network, including the access area, involves all the administrative, operation, and maintenance functions. These functions could be performed by local (access area) management centers, plus a few (5-10) regional centers with possibly one national center. For survivability, any regional center would have to be able to assume the role of the national center and any local center could assume the role of regional center. The interface between access area centers and regional centers is shown in Figure 4-10. Note that the Dial Central Office (DCO) and access hub may be combined as a stored program controlled switching system that serves a dual function role.

4.5 Long-Haul Transmission Facilities

This far we have defined certain architectural concepts for nodes, such as structured switching levels and topologies, but not the actual transmission facilities. Within the limited size of an access area, most of the links between switch nodes would be terrestrial land lines, some microwave links, and some fiber optics. The majority, however, will continue to be conventional cable, primarily T-carrier. As distances and traffic intensities increase

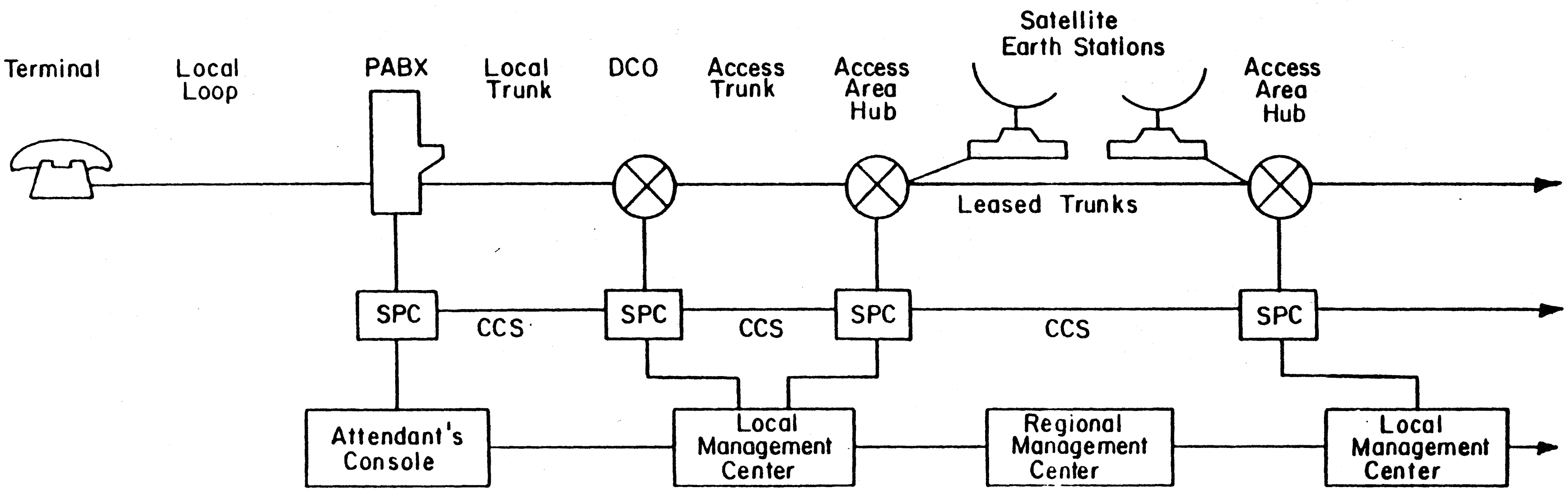


Figure 4-10. Local and regional connectivity.

for a given line or trunk, one finds that different modulation and coding techniques have different costs. A few years ago at distances less then about 5 miles, baseband voice frequency transmission appeared to be most economical. This technique is still used for most local loops. For long distances starting at about 30 miles, analog frequency division multiplex (FDM/FM) microwave carrier systems (e.g., TD systems at 4 GHz, TH systems at 6 GHz, and TJ or TL systems at 10 GHz to 12 GHz) are cost effective. Single-sideband microwave carriers are also competitive at these distances.

Between 5 and 30 miles, pulse code modulation (PCM), such as on the 24-channel, T-1 carrier, is commonly used in the intraexchange plant. This is why exchange areas that are typically no larger than 30 miles across are increasingly installing digital T-carrier, while analog carriers continue to prevail on the longer haul toll trunks. These relative transmission costs in terms of cost per circuit versus circuit length are illustrated in Figure 4-11.

Satellite links for the long-haul circuits come into play at much greater distances and at high traffic concentration levels. A typical commercial satellite circuit proves in at about 800 miles. This actual cost is flat as a function of distance for the satellite and increases with distance for terrestrial circuits. With the exception of the latest fiber optics and subject to traffic capacity, the cost crossover tends to occur around 800 miles.

Satellite links exhibit their cost advantage at much greater distances. Figure 4-12 indicates the relative circuit costs per month in 1984 dollars for three transmission facilities: geostationary satellite, point-to-point terrestrial microwave, and optical fiber. This figure depicts how costs increase with distance for these facilities and decrease with number of circuits. The results are based on average costs of typical facilities. Actual costs could vary widely. (See Telephony, 1984). It is interesting to anticipate more dramatic cost savings from the proposed 20,000 (plus) circuit fiber optic systems that are to be deployed around 1988 and thereafter.

The gateway function between carriers is depicted in the self-explanatory structured configuration of Figure 4-13.

4.6 Blocking Probabilities in the Access Area

In Section 3, end-user performance was listed as an important military network requirement. One of the most important performance parameters is access denial or blocking probability. We have considered the blocking probabilities at the local access-area switch or between the switch and the long-haul networks.

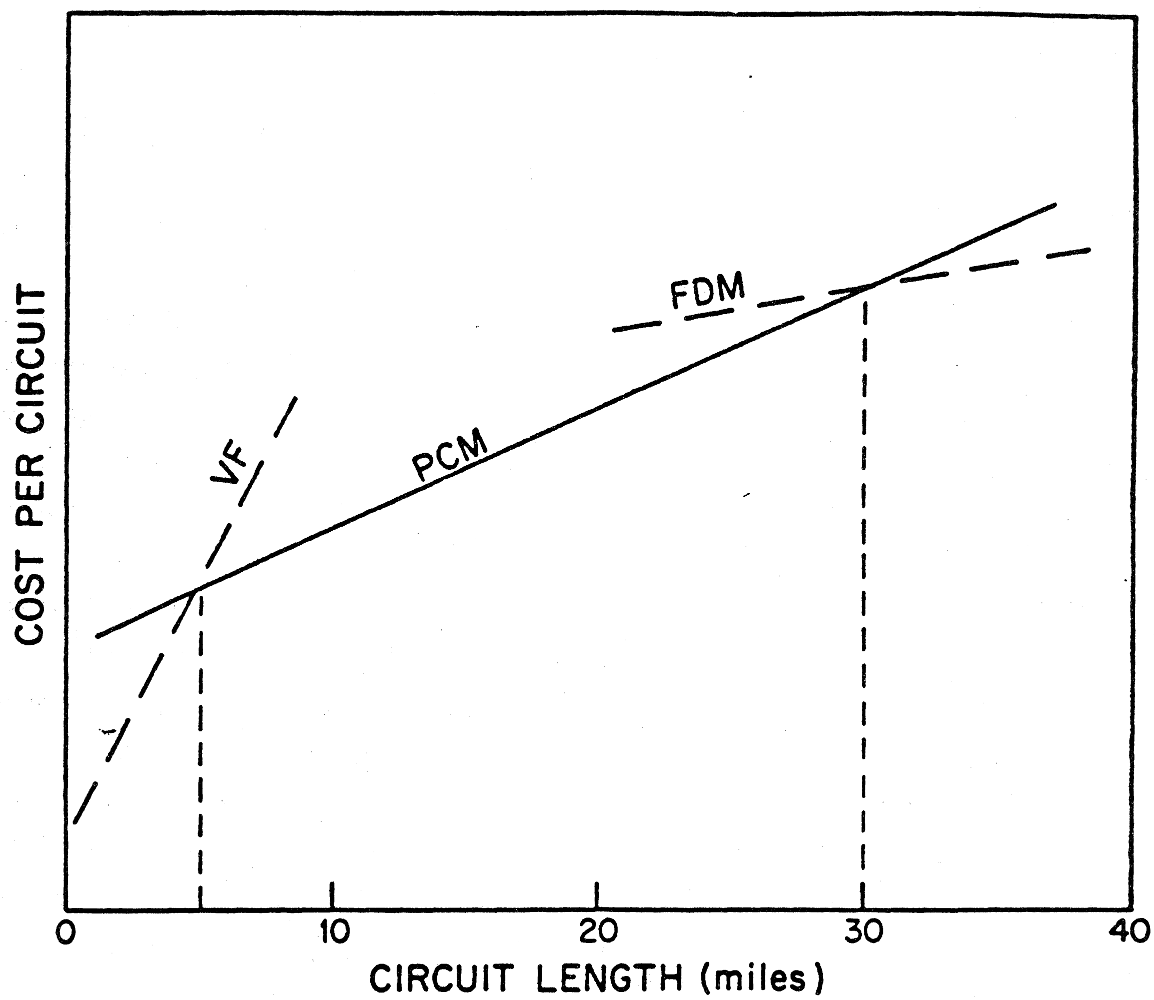


Figure 4-11. Relative transmission costs.

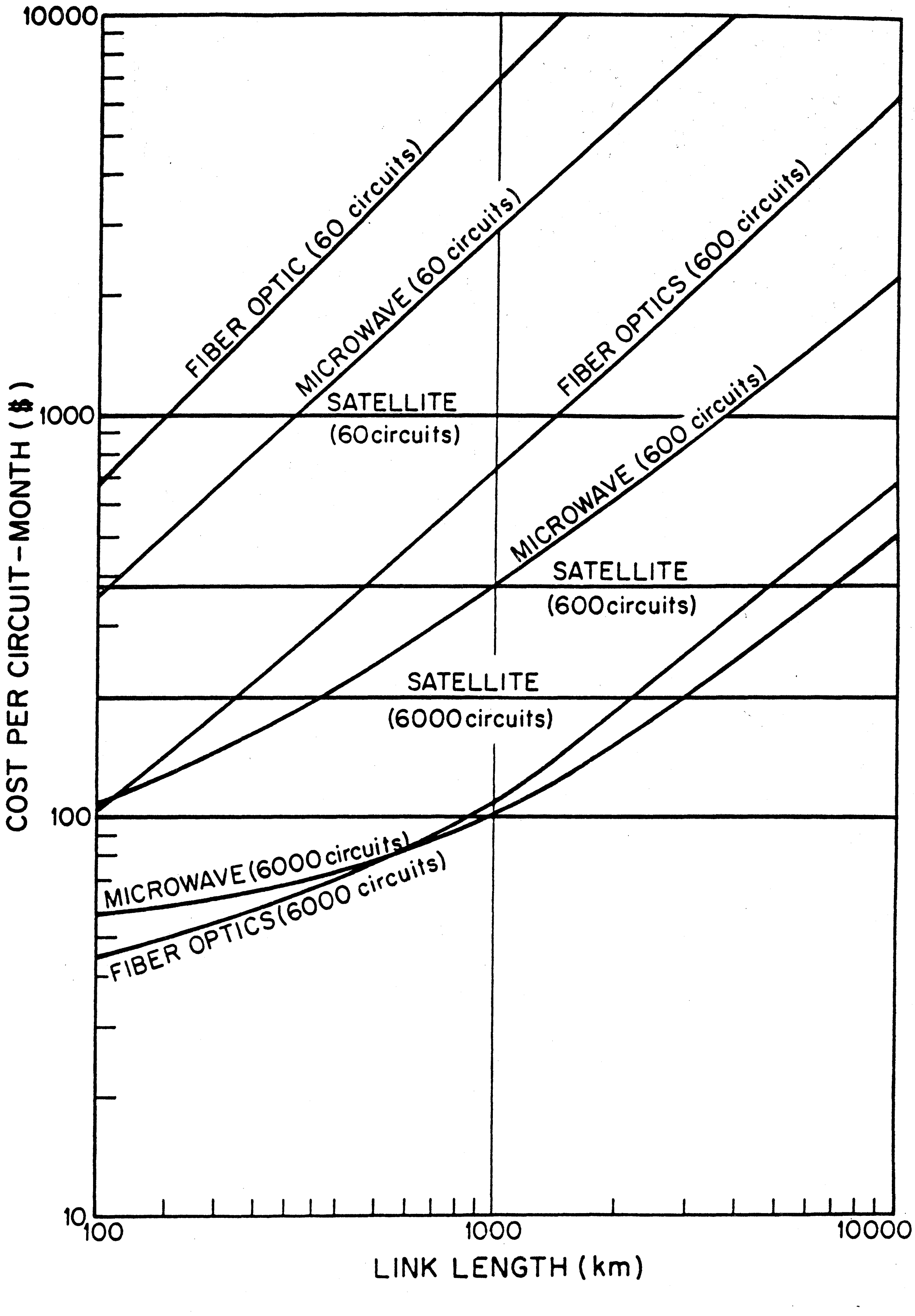


Figure 4-12. Circuit costs per month as a function of distance and parametric in transmission media.

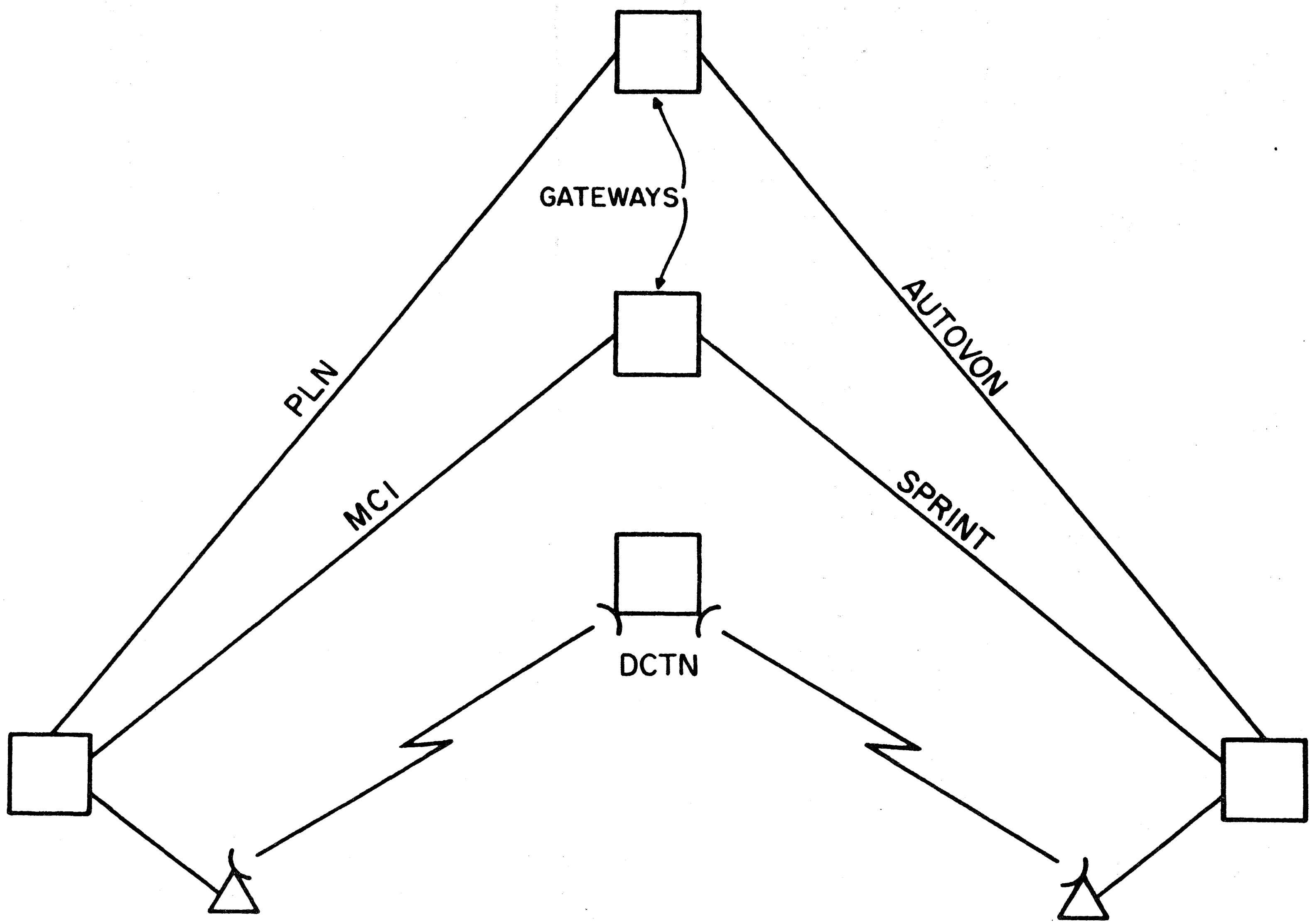


Figure 4-13. Access hubs functioning as carrier gateways.

Results of the study are given in Appendix B. Appendix B indicates that blocking between the access-area switch and the access point on PSTN, for example, is a function of many factors. Some of these factors are under the control of the administrator of the local area facilities (i.e., the MILDEP's) while others are not. For instance, the results show that critical users on a base desiring long-haul access with low blocking probability should be connected directly to the access point and not through any potentially blocking concentration points or PABX's. The optimum network topology from the standpoint of Grade of Service should always consider calling habits and needs of all users.

5. ACCESS AREA CHARACTERIZATION CONCEPTS

It appears inadequate to describe the access area (AA) as a local military network, or the boundaries of its domain, or to claim the obvious need for AA cost effectiveness, survivability, and grade of service. Every telecommunications network has practically the same concern. If AA's are to exist as useful concepts, one must look deeper for reasons for their existence. But then one needs means or definitions that provide characterizations necessary for comparison and distinguishing of arrangements.

Local areas, and in particular military areas, have unique missions and telecommunication needs. If no other areas in the CONUS have those same needs, it stands to reason that the nationwide nets, such as the DSN, should not be burdened by peculiar local requirements. Local service needs should be met locally and, hopefully, cost effectively. To do so, one may employ special technologies, e.g., custom cryptos, optical fibers, etc. Localities belong to one or a few civilian administrative regions (e.g., state, LATA), hence may have limited interest in CONUS-wide rules and regulations. The architectures of local networks correspond to local military site layouts. They have few nodes and relatively thin connectivity, especially when contrasted with the interstate networks. Local nodes typically employ a rather broad spectrum of switches, old and new, end offices, electromechanical, digital, assorted PBX's, etc., all coming from just about every imaginable switch manufacturer in this country. Likewise, the local loop plant varies from two-wire, four-wire, to others, and is subject to terminal station reconfiguration activities.

All this implies a considerable maintenance effort by local installers and repair persons. One wonders whether the local personnel needs in the 1980's for the MILDEPS are indeed comparable to those of the Bell System in the 1970's, where according to Long (1978): "...over 30 percent of the total telephone work force interacts with (the loop plant), to select network paths and to connect customers, to rearrange and repair the network, to monitor and analyze service and costs, and to design and construct network additions." There are other personnel intensive local activities, but the above should suffice to demonstrate the local characteristics of providing MILDEP's with assured or guaranteed end-user service.

A good first look at the AA may be to think of it as the service area of one or more hub switches. Such a concept is illustrated in Figure 5-1. In the center of this concept one finds the tandem hub switch, or hub for short. As shown, this hub is a multifunction switch. It provides connectivity to potentially

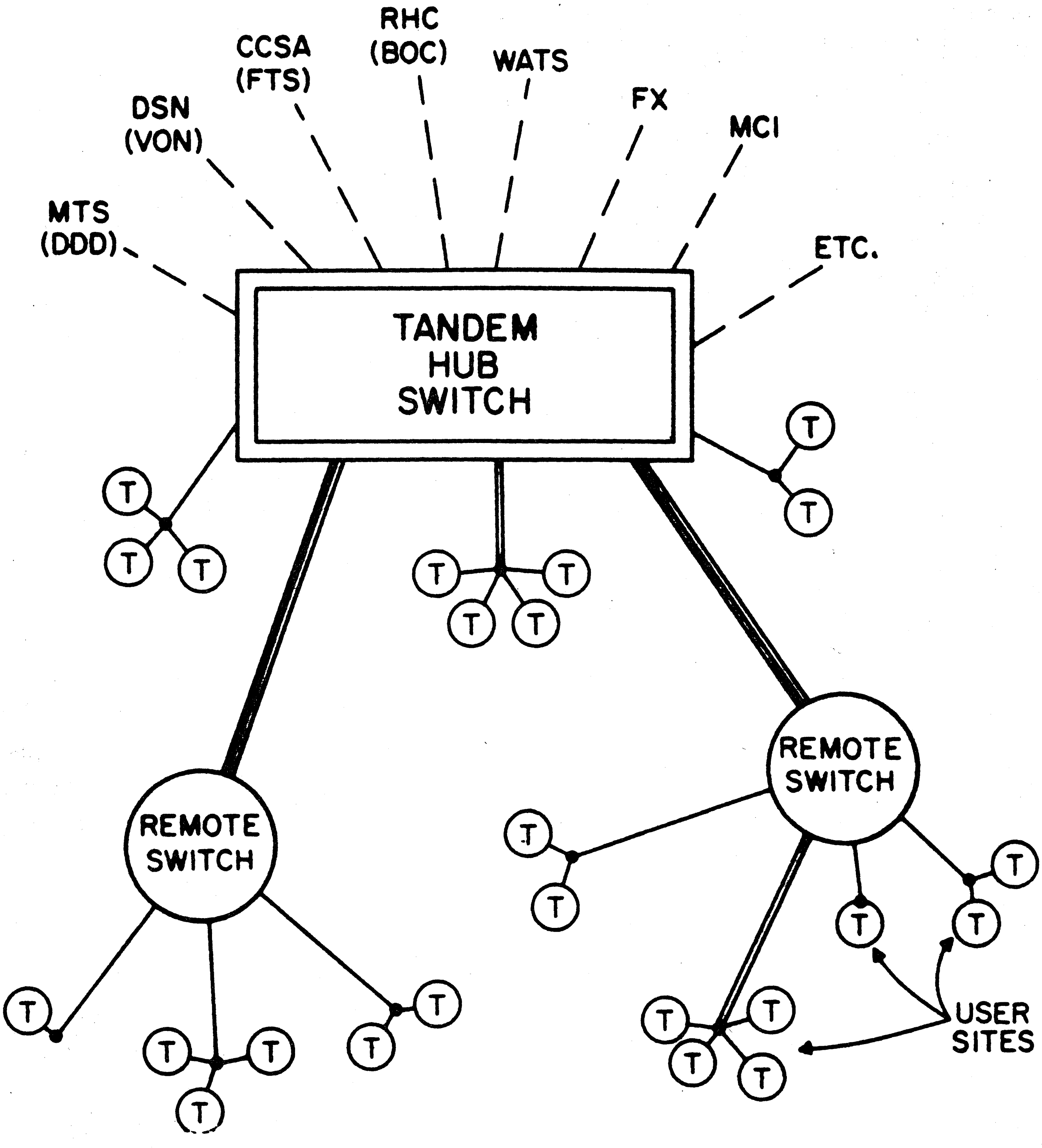


Figure 5-1. The service domain of a hub switch.

many long-distance carriers, as seen at the top of the figure. It acts as a tandem for its subordinate local remote switches. And it provides local end office terminations for subscriber loops. The latter is denoted by circled T's and may or may not be subject to line concentration.

The carriers or telephone companies at the top of Figure 5-1 can be reached via one, two, or more, gateways. Some carriers may not be available everywhere, or may be purposely disregarded for traffic or economic reasons. The utilization of several dispersed gateways becomes an important survivability and traffic distribution issue when the domain in question is served by several hubs. The number of subscribers must be consistent with the sizing of switches and other available nodal elements. But, of equal if not of more importance, is the offered traffic and the geographic distribution (e.g., clustering) of subscriber sites.

To decide whether the hub domain of Figure 5-1 should or should not be called an "access area," it may be advisable to establish the scope of accesses provided. The functional illustration is represented in Figure 5-2. Here the number of hubs does not appear as a decision quantity. Nor does it seem germane to establish the sizes of all AA's. More relevant is the conclusion that access areas must perform certain functions. Every network facility in Figure 5-2 may have to establish a switched local path to everybody else. There may be exceptions, such as absence of certain OCC or lack of satellite Earth stations. However, the main point is the requirement for economic, workable, survivable, and reliable access arrangements. Many technical functions are implied in the technology of the interconnecting network. Other less technical support functions--for example, repair, billing, etc., are also needed.

5.1 Functional Elements

It is traditional to view any network as a set of interconnected elements that individually and as a whole carry telecommunications traffic. In a local area, said traffic consists mostly of locally generated and/or locally terminated telephone calls. Three major classes of functions are performed by the network elements. They are the transmission, switching, and support (e.g., control, maintenance, and other) functions. Widely available references to these three overlapping areas are found in Bell Telephone Laboratories (1971), Joel (1982b), AT&T Bell Laboratories (1984), plus throughout the Bell System Technical Journal. In a modern network, especially at a local level, the switching and transmission functions are rather intermixed, as may be the case of digital carrier and remote

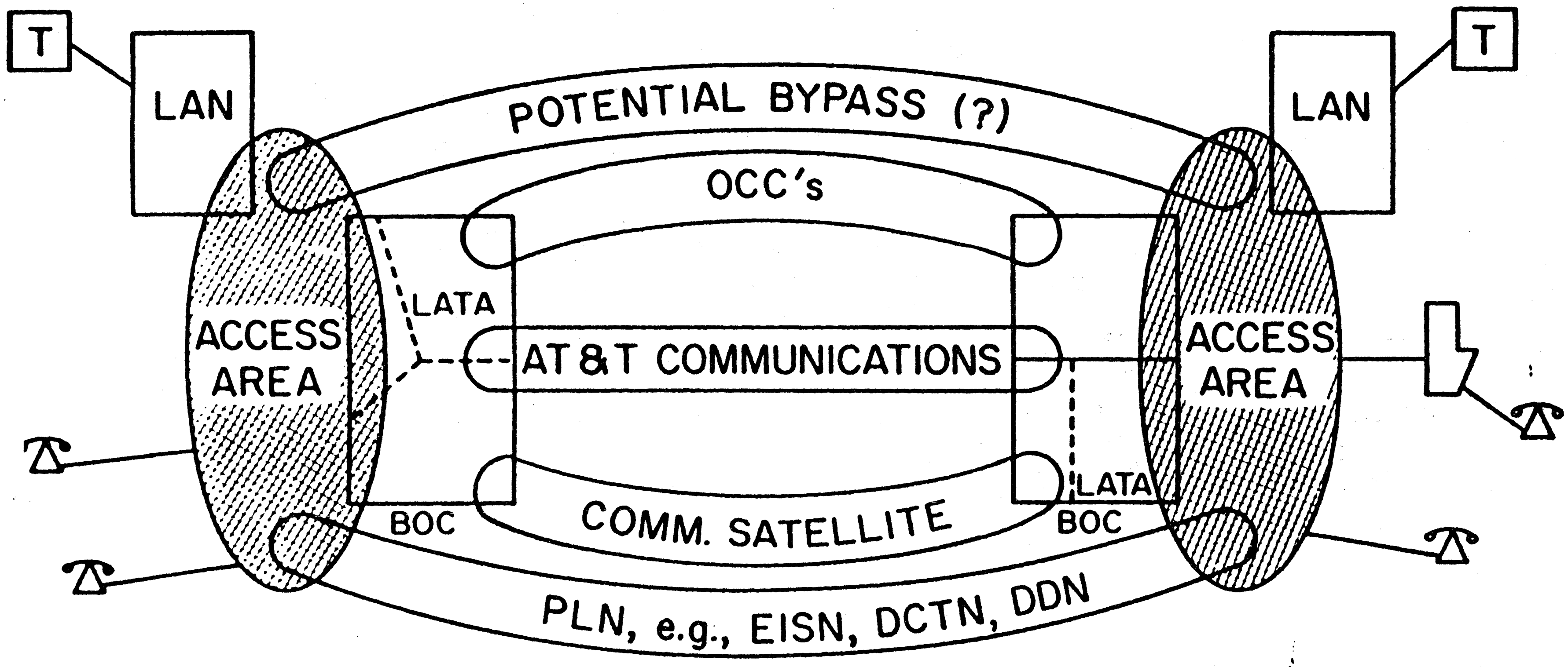


Figure 5-2. Variety of accesses through potential access areas.

concentrator trunks. Both switching and transmission are supported by partially automated and manual support systems. And all three together see to it that the network performs as planned, thus providing the required end-user services. For ease of visualization, this functional triad is illustrated in Figure 5-3.

Because they are common to the entire field of telephony and would not be substantially affected by where and how one defines an access area, the transmission and switching functions are not to be discussed here in any detail. Instead, emphasis is to be put on the support functions.

As noted, the support functions can be automated, manual, or some mixture of the two. They can be the responsibility of the MILDEPS, DCA, or one or more vendors under the applicable tariff or contract arrangements. Viewed as operations, the manual support is typically local or within the reach (i.e., reasonable travel radius) of the appropriately skilled people. This differs from automated operations that can be locally resident, but may be performed or affect performance over regions of various sizes. The software and hardware needed for such support can be implemented in either centralized or distributed ways. In fact, hierarchal and nonhierarchal architectures can be used to structure support deployments.

While more is to be said later, the suppport functions can be seen initially as assuring that the network services in Figure 5-3 follow specifications. To that purpose, the network--including its transmission and switching elements--must be conceived, designed, implemented, and monitored throughout its useful life. Need must be recognized for modification and enhancements. This calls for traffic engineering on a longer time scale and traffic control on short notice. Performance monitoring and assessment functions of all kinds can be used to diagnose problems. Both remote network management and local technical control have been found to be essential in management of telephone and data networks.

In reference to recently automated maintenance of the merged switching and transmission networks of the entire Bell System, Amos Joel (1982a) states : "...the greatest savings from the application of electronics to switching have to date come as a result of the maintenance advantages realized by the use of modern data processing."

While the local military user networks have many dissimilarities from the nationwide networks, the basic question nevertheless should be addressed. What advantages can the DOD realize from automation of local support functions, such as maintenance?

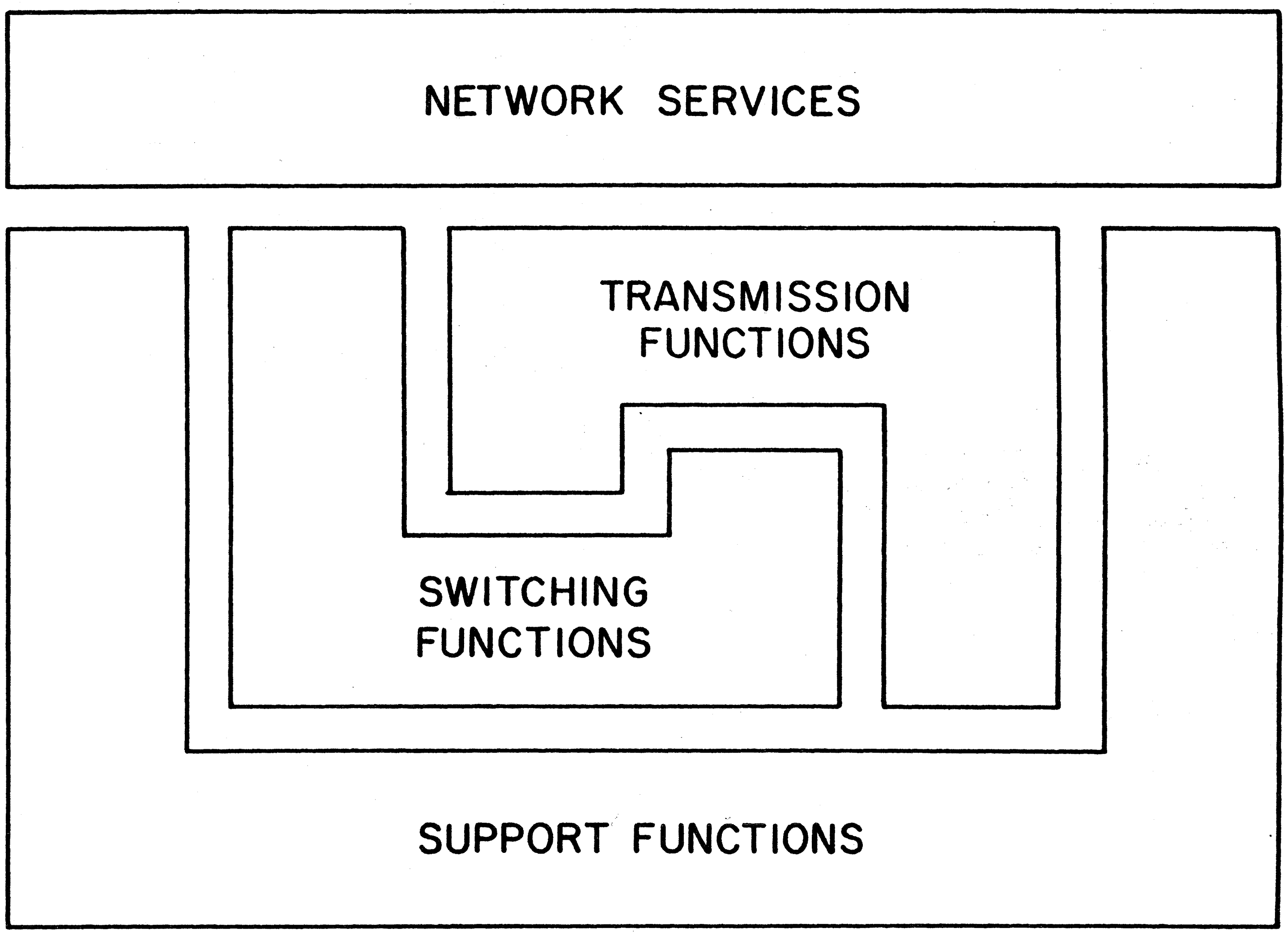


Figure 5-3. The triad of functions that are needed for a service network.

One way to look at this topic is to introduce the so-called AO&M. The acronym stands for Administration, Operations, and Maintenance and often, but not always, includes also the functions of NM. We prefer to view AO&M as a part of service provisioning, a caretaking process that helps to keep the network services going. Schematically, this view is shown in Figure 5-4. Note that AO&M stresses the technical operations and functions. There are many other operations necessary for reliable service that are nontechnical to various degrees. Matters such as accounting, billing, staffing, tariffs, legal matters, and so forth, are examples of a long, nontechnical list of needs. These aspects will be discussed in Section 6.4 that follows. Here it suffices to reflect on the hierarchal aspects of AO&M functions. One may be familiar with a two-level hierarchy, where the message transfer or telephone call level is supported by another, the so called signaling control or CCS (or CCIS) level. If so, then this two-level framework clearly cannot function without the support of the AO&M entities. AO&M can be viewed as a third level in the technological hierarchy so described. Or perhaps the technical AO&M levels may be further divided into specific constituent levels. An attempt to do so is made in Figure 5-5. The main thrust here is to emphasize that the AO&M level or levels provide support for the signaling level with its Signal Transfer Points (STP) and its Network Control Point (NCP) data bases, as well as for the voice/data message level with its large transmission and switching facilities.

In conclusion of this section, one is reminded that the functional mosaic of Figure 5-5 entails both good and bad news. The good news is the promise that modern data processing may give cost savings in this functional area for local area networks, as it has done for nationwide networks (Joel, 1982a). How much savings one should expect is not at all clear and remains to be determined. That brings one to the bad news. Automation for the different AO&M levels (see Figure 5-5) is not an easy undertaking. Given the complexity of the tasks and the rapidly evolving fields of automation, an economically efficient and orderly solution may demand a substantial initial commitment. To be comprehensive about the previously described AO&M levels, as an example, one must clearly and unambiguously define all levels and their functions. So far, adequate solution to this problem seems to exist only in certain sectors of the commercial world. AO&M automation could be leased from said vendors, but that may introduce only an artificial and temporary sense of competency. The real AO&M world is filled with fuzzy terminology and nonuniform definitions. The domains of terms and functions appear to overlap, to intersect, and perhaps even to contradict each other (see Figure 5-4 and 5-5, and Section 6.4).

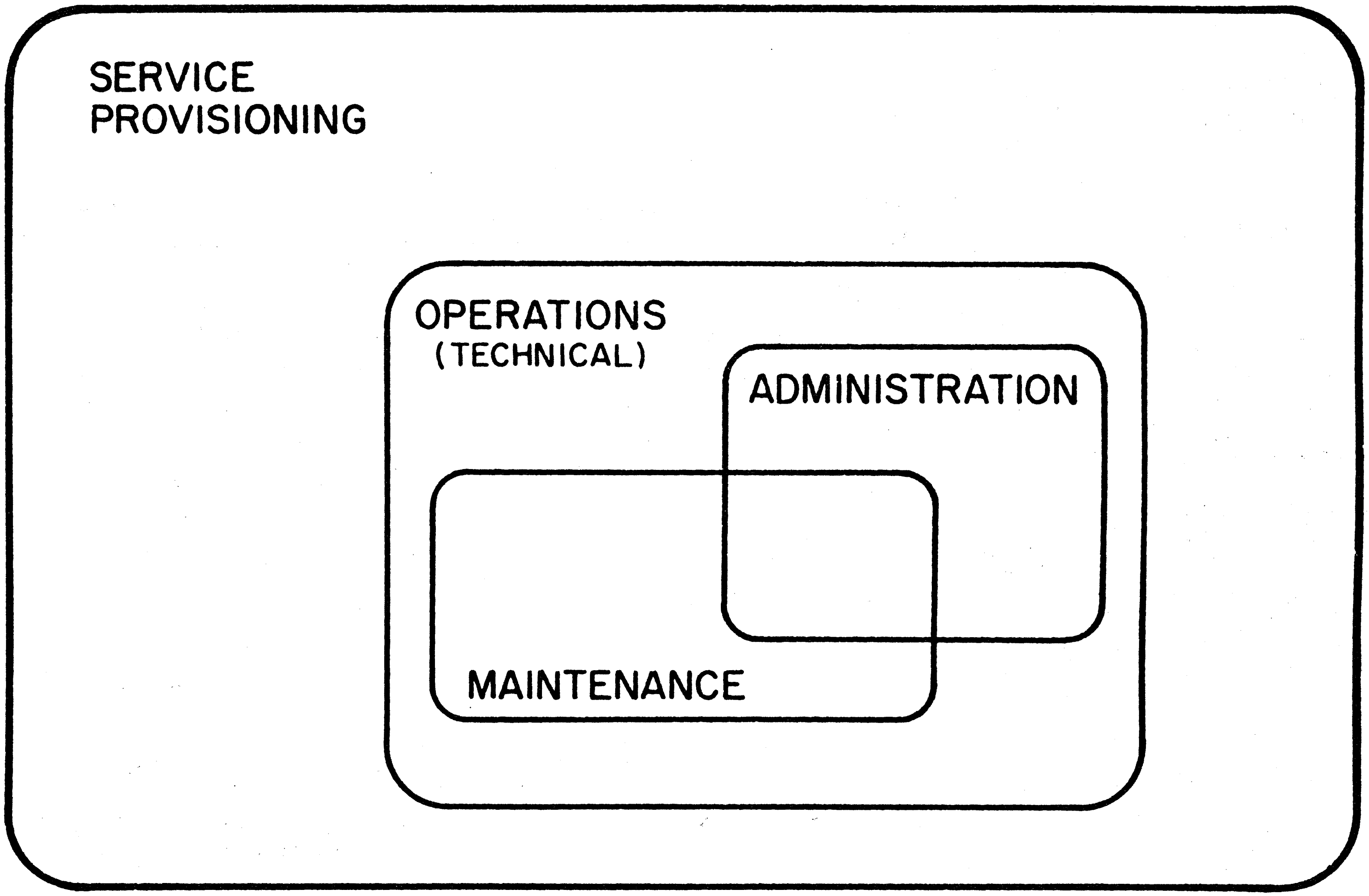


Figure 5-4. AO&M as a subset of service provisioning support functions.

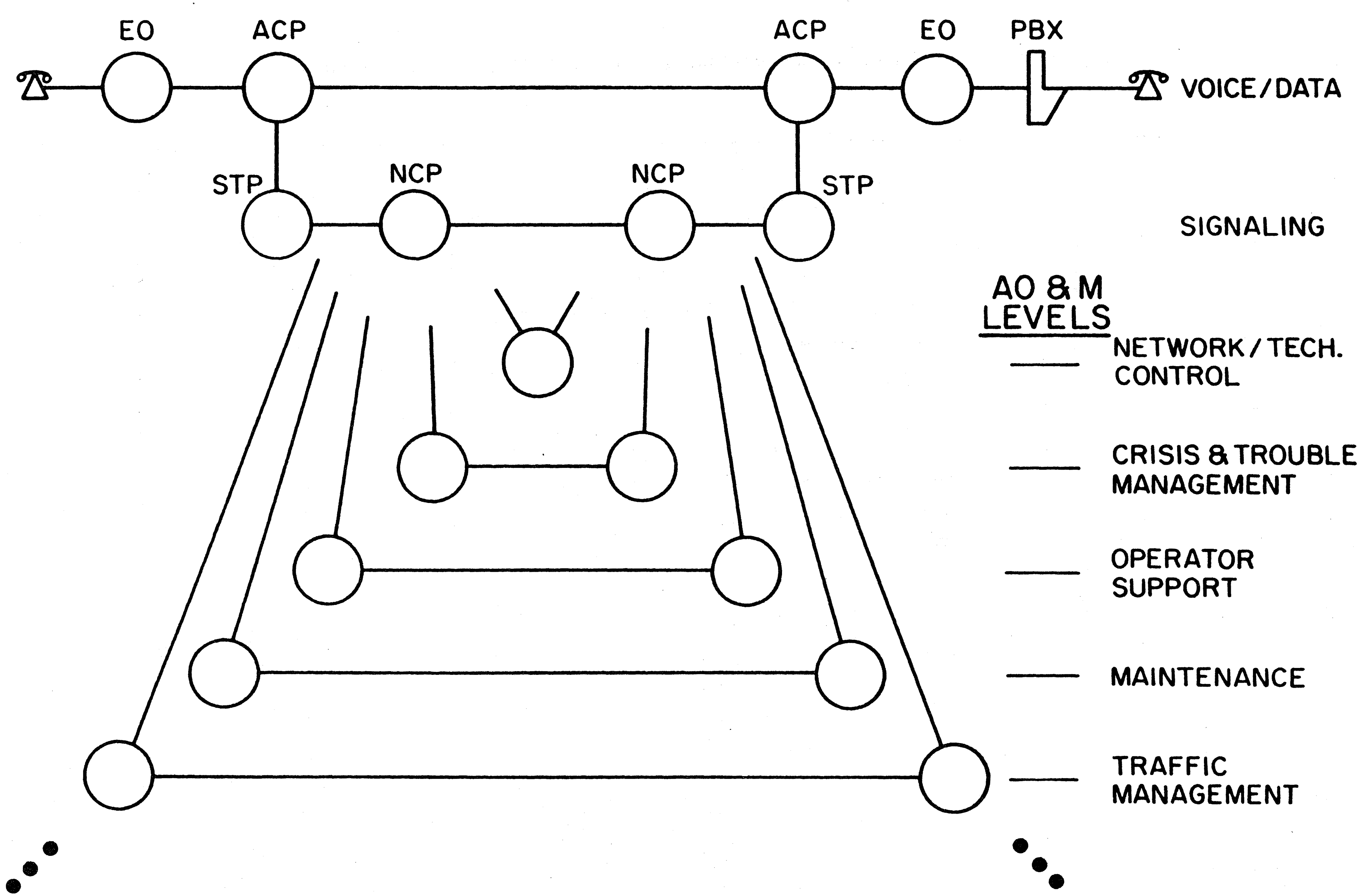


Figure 5-5. Expanded hierarchal view of AO&M levels.

5.2 Major Cost Elements

The acquisition of systems, while tantamount to acquisition of major equipments and services, entails much more. There are numerous ways of ownership, purchase, and lease. Different financing arrangements can lead to more expedient cost distribution over months, years, or other time intervals of concern to budget planners. The nature of such arrangements affects total local area cost. However, financing costs are beyond the scope of this section. Ownership and lease issues are also not to be discussed here. Matters to be discussed here pertain to major system components, individually or in aggregate, and the expenses warranted by technical personnel.

For purposes of relative cost comparison, one can list the local access area systems in six categories: switching, transmission, subscriber loops, assorted outside and support plant, personnel, and automation. Table 5-1 lists these six categories and identifies their typical subelements.

Under switching systems one includes all large and small switches that are the local responsibility. Tandem switches, be they single function (interswitch trunks only) or multifunction (interswitch trunks, toll network gateways, plus local loops) belong here. So do local DCO, also commonly referred to as End Offices (EO), and their subordinate customer switching systems such as PBX and Remote Switching Systems (RSS). The older generation switches are analog, circuit switching, electromechanical machines. The newer switches are electronic time-division systems with central processor controls. As such they are akin to the computer. Logical operations that are quite basic, for instance to make and break telephone connections, are supervised by intelligence that resides in the stored program. The latter, a synonym for software, is often accompanied by extensive memory and data base systems. It may be a considerable cost item, as far as the switching systems are concerned.

The second major item in Table 5-1 is constituted by transmission plant. It includes all trunks to gateways, all intra-AA interswitch trunks and tie-lines. In the case of long trunk lines and varying traffic demands, repeaters, concentrators, multiplexers (MUX), Subscriber Loop Carrier (SLC) systems, Digital Access and Cross-connect Systems (DACS), and assorted trunk driver and termination frames are also to be classified as transmission elements.

The third subsystem area listed is the subscriber loop, terminal, and related connection equipment.

Table 5-1. Major Local Area Cost Elements and Their Estimated Cost Percentages

Systems	Major Elements	% of Cost
Switching Systems	Tandems, Multifunction Local DCO's PBX RSS Software, Data Bases	10-20
Transmission Systems	Toll & Interswitch Trunks Concentrators, MUX, DACS Repeaters Terminations	5-10
Subscriber Stations	Local Loops Terminals	12-18
Outside Plant	Support Poles, Ducts Cables Manholes Land, Rights of Way Buildings Vehicles	25-35
Personnel	Management Administration Switchboard Operators Maintenance	20-50
Automation	To Be Determined	Not Included

The fourth area in Table 5-1 is the outside plant. By that one means the familiar telephone poles, ducts, support cables, rights of way, special buildings or huts, and special-purpose vehicles.

The fifth item is listed as personnel. This covers personnel that execute tasks ranging from management and administration to switchboard operation and all necessary maintenance.

The sixth and final item in Table 5-1 is identified as automation, but is not spelled out in any detail. The reason is that ADP systems and techniques have found little if any deployment in the local area AO&M for military telecommunications, at least in the past.

At the right side of Table 5-1 one finds a column of cost percentages. The numbers given represent extremely wild guesses of the relative expense incurred for a particular subsystem. They are based on old reports whose validity and relevance to AA's as a whole are doubtful at best (Nesenbergs and Linfield, 1976; Nesenbergs and McManamon, 1983). If there is any rationale for including these percentage ranges here, it should be to illustrate two points. First, in the absence of automated AO&M the main cost elements are personnel and outside plant. And second, if automation is introduced in a big way, it is likely to reduce only the AO&M personnel totals. If this causes the overall totals to change, then all percentages may also be altered. In absence of reliable numbers or their forecasts, only the relative ordering of costs or their ranking can be estimated. Such a ranking is attempted in Table 5-2. The highest cost items are ranked first, the lowest cost items last. Two rank lists are shown. The first one assumes the present situation of local areas where there is essentially no AO&M automated systems. The second list assumes automated AO&M, so much so that the outside plant costs more than the personnel. Of course, ADP and the automated office will require new and upgraded (computer science) personnel skills. The constitution of the two personnel groups in Table 5-2 are likely to be quite different in both education, training, and salary levels.

More specifics on these items are found in Sections 6.3 and 6.4, and in Appendix A, where the local area hubs, AO&M, and matters related to skill levels and labor costs are discussed.

Table 5-2. Ranking of Major Cost Elements With and Without Extensive AO&M Automation

Without Automation	With Automation
1. Personnel	1. Automation
2. Outside Plant	2. Outside Plant
3. Switching	3. Personnel
4. Subscriber Stations	4. Switching
5. Transmission	5. Subscriber Stations
	6. Transmission

6. ACCESS AREA DEFINING PARAMETERS

This report has recognized two broad classes of parameters that pertain to the access area (AA or DSNAA) definition. Basically, they may be called technical and nontechnical. The nontechnical descriptors have their roots in the National chain of command, the legal, economic, commercial, political, and even social arenas of the United States. Such questions as Post D&D (Deregulation and Divestiture) and its implication to DCA long distance and MILDEP local concerns were discussed in Sections 1 and 3. The non-technical factors will not be further emphasized in this section.

Technical system parameters will be emphasized here. Of course, this focus on "technical only" is not always sharp or even possible. Technical design considerations eventually lead to cost numbers, and dollars are known to open a veritable "Pandora's box" of nontechnical pressures. Nevertheless, it has been an engineering tradition to assess systems, their functions, and components on objective parametric terms. The rest of this section is concerned with key technical parameters and their costs, but does not go beyond general qualitative issues. Results can have considerable bearing on the characterization model discussed in Sections 7 and 8.

6.1 Size

Access area size is an important parameter and its implications may be far-reaching. For example, a single huge AA may span the entire United States by definition. Or, a thousand areas that vary in size to being quite miniscule, may be scattered over the map. In the first case there would be no need for a long distance backbone. In the second case the backbone would be enormous or other means for long distance connectivity would have to be found. Which definition would be preferred? Probably neither. As Calabrese (private communication, 1983) notes, extreme designs tend to drive the total cost for the DSN also to extreme levels. And there may be problems with survivability, as well as military commands, when the operational areas are either too large or too small.

Calabrese concludes that, based on now outdated GTE and other data, the Minimum Cost Design (MCD) for the DSN may consist of 50 backbone switches, and that the cost curve is relatively flat between 30 and 100 such switches. This leads Calabrese to infer that the 90-switch network be chosen as a "baseline" design because its cost increase over the MCD is around 4% and "intuitively" it would be more survivable.

What does the above suggest for access area sizes? Not a lot, because it remains to be determined whether there should be one (or two or three) hub switches per area. Or, if the areas are to vary in size, what rules whould determine the switch to AA assignments?

Arguments can be made that the AA boundaries, and hence their sizes, be chosen by considering such factors as:

- range of existing MILDEP properties and commander responsibilities
- distances that maintenance crews and equipments can cover in 1-2 hours under adverse conditions (e.g., under enemy attack, traffic congestion, poor weather, etc.)
- distances that single nuclear warheads are apt to obliterate or that would become untenable because of fallout, wind drifts, and related phenomena
- diameters of raincells that would absorb satellite radio signals at higher frequencies, if such is to be used, conceivably in dual space-diversity mode per access area
- if regional automated AO&M/NM functions are concentrated in data base centers, the boundaries of said regions may have to be considered.

There may be other arguments, such as tailoring the AA boundaries not to conflict with established or planned telephone company, U.S. Government, or other administrative regions.

There are seven Bell RHC. As shown in Figure 6-1, each RHC ranges in diameter from several hundred to a thousand or more miles and contains a group of states. The biggest in territorial size is No. 1, or U.S. West. The most subscriber access lines belong to No. 5, Bell Atlantic. The largest number of telephones are in the region of No. 7, Ameritech, and so forth. In the 48 contiguous states, the RHC's contain the 19 predivestiture BOC, which in the postdivestiture era are divided into 188 Local Access and Transport Areas or LATA's. This structure is emphasized in Figure 6-2.

One should note that the number of LATA's is not a hard-fixed number. In early 1984, there were tables of 183 LATA's. Recently, quotes of 185 to 190 have been noted. LATA's are known to cross state and even BOC boundaries (CCMI, 1985 a,b). The MFJ specifies that BOC's are to offer regulated telecommunications services within LATA's, while AT&T and other interexchange carriers offer services between LATA's. There are many other new provisions concerning Post D&D Bell System structure and activities. These may be found in Chapter 1 of AT&T Bell Laboratories (1984) and in McManamon (1985).

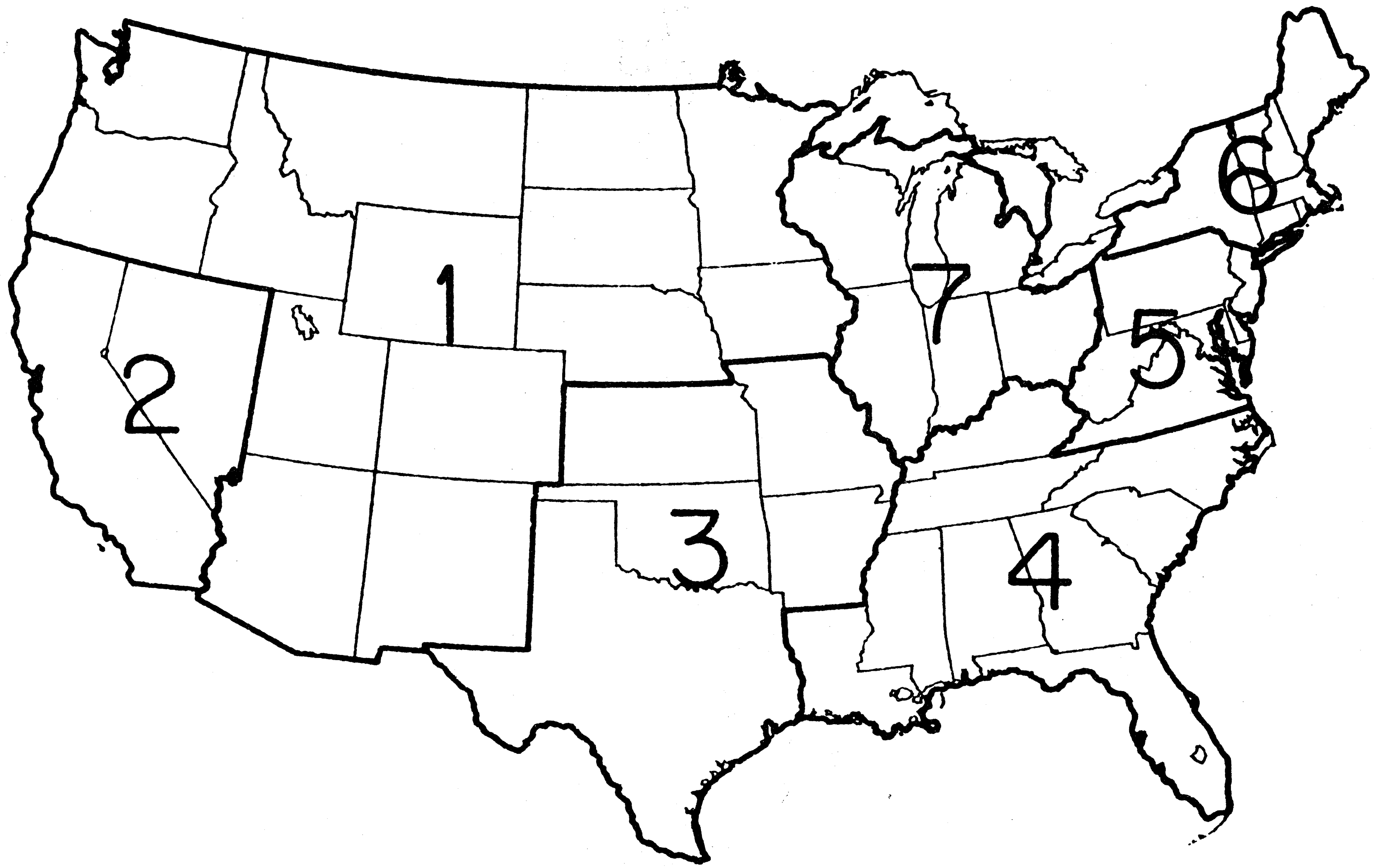


Figure 6-1. The geography of regional holding companies.

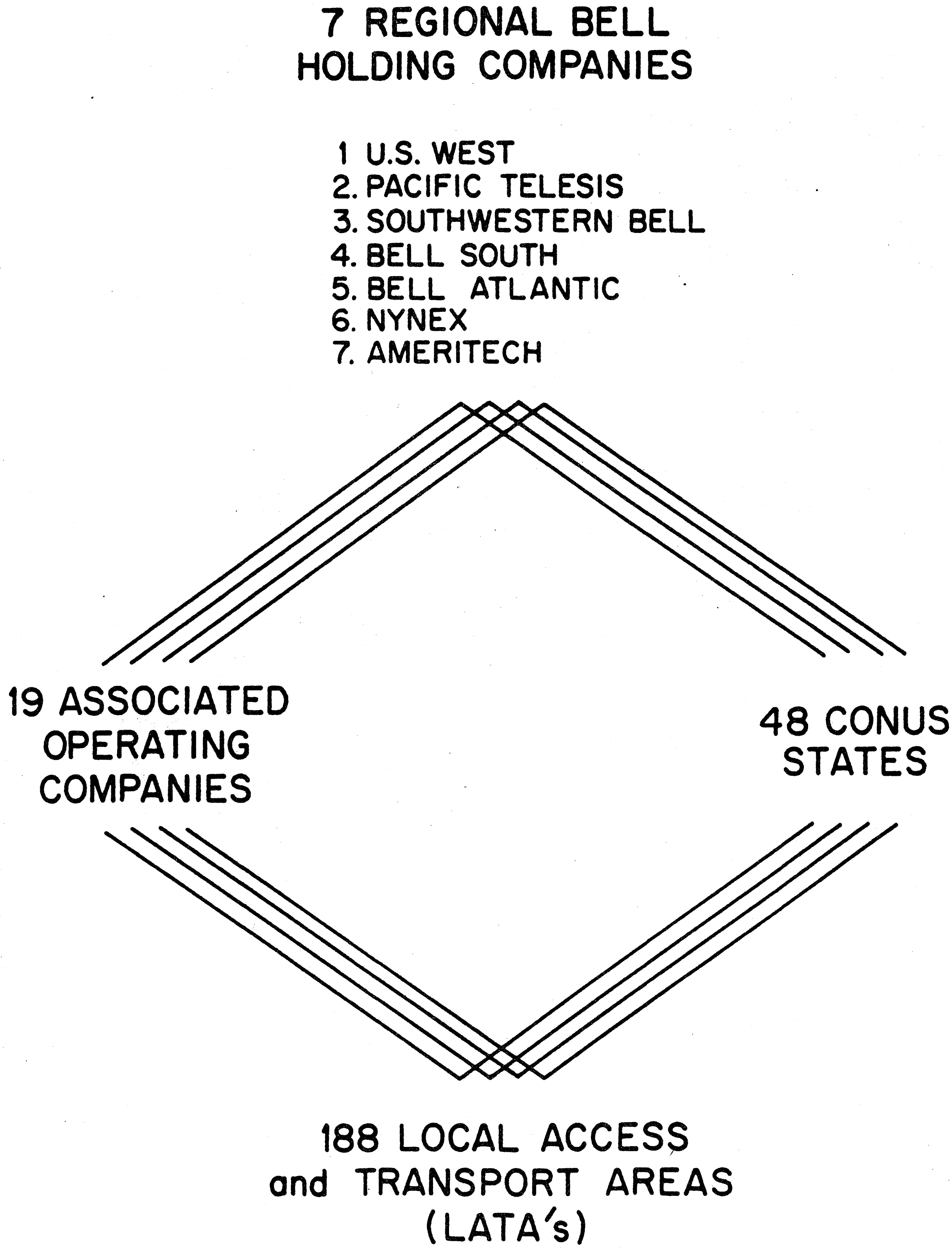


Figure 6-2. The corporate structure of the Regional Bell Holding Companies.

An illustration of the LATA partitioning of states is given in Figure 6-3. This particular graphic pertains to Indiana and shows 11 LATA's or parts thereof, which include:

Dayton	328
Evansville	330
South Bend	332
Auburn/Huntington	334
Indianapolis	336
Bloomington	338
Chicago	358
Louisville	462
Cincinnati	922
Richmond	937
Terre Haute	938.

Many of the Indiana LATA's extend into adjoining states, and those to the south into another RHC. One should also note that like in many states, Indiana contains a number of Independent Telephone Companies (ITC). See the differently darkened regions for GT&E, United Telephone, etc., in Figure 6-3. The LATA's overlap the ITC's in many ways geographically, but according to the MFJ decision, LATA rules do not apply to ITC's.

For long-distance calls, AT&T has divided the CONUS into 10 so-called signaling or switching regions (see Figure 6-4). Each region contains two Signal Transfer Points or STP's. These are the same 10 regions that were for years identified with the Regional Centers of the old five-tier Bell System switching hierarchy. As seen, the switching regions are only slightly smaller than the RHC territories. The Rocky Mountain region, for example, reaches from Mexico to Canada and thus is over a thousand miles across.

A set of 10 regions is used by the FTS. These regions are almost indistinguishable from another 10-tuple subdivision, namely that of the Federal Emergency Management Agency (FEMA). The 10-region FTS structure is depicted in Figure 6-5.

From the discussion of this section, one can ascertain that the size of individual areas is inversely related to the number of such areas needed to cover the CONUS. Moreover, the sizing arguments quoted in Section 6.1 raise various questions on the selection of the access area sizing preference. At this time, one is not prepared to answer these questions in any definite fashion. However, one may indicate as in Figure 6-6 that different considerations do favor different sizes.

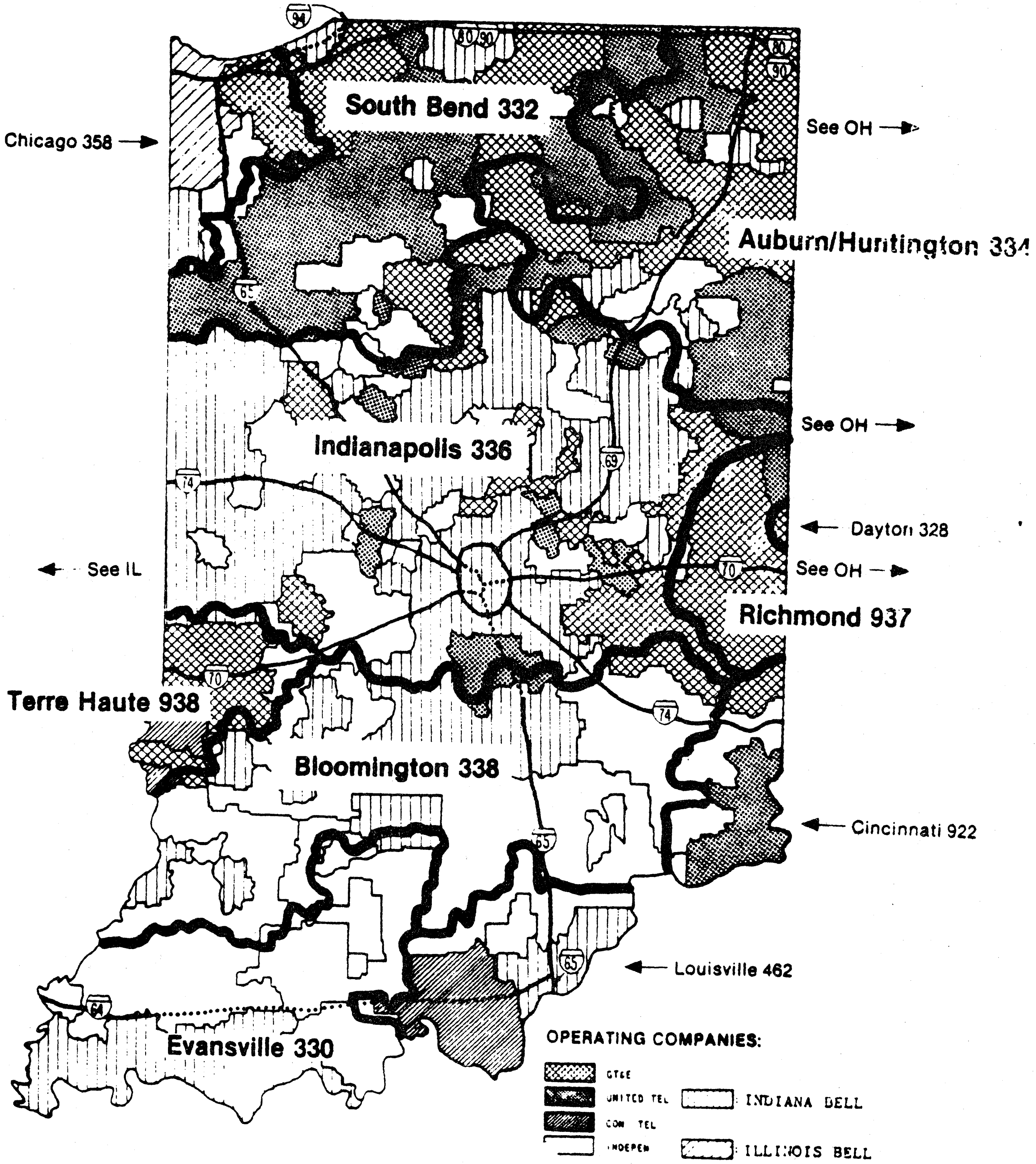


Figure 6-3. The 11 LATA's of the State of Indiana (from CCMI, 1985b).

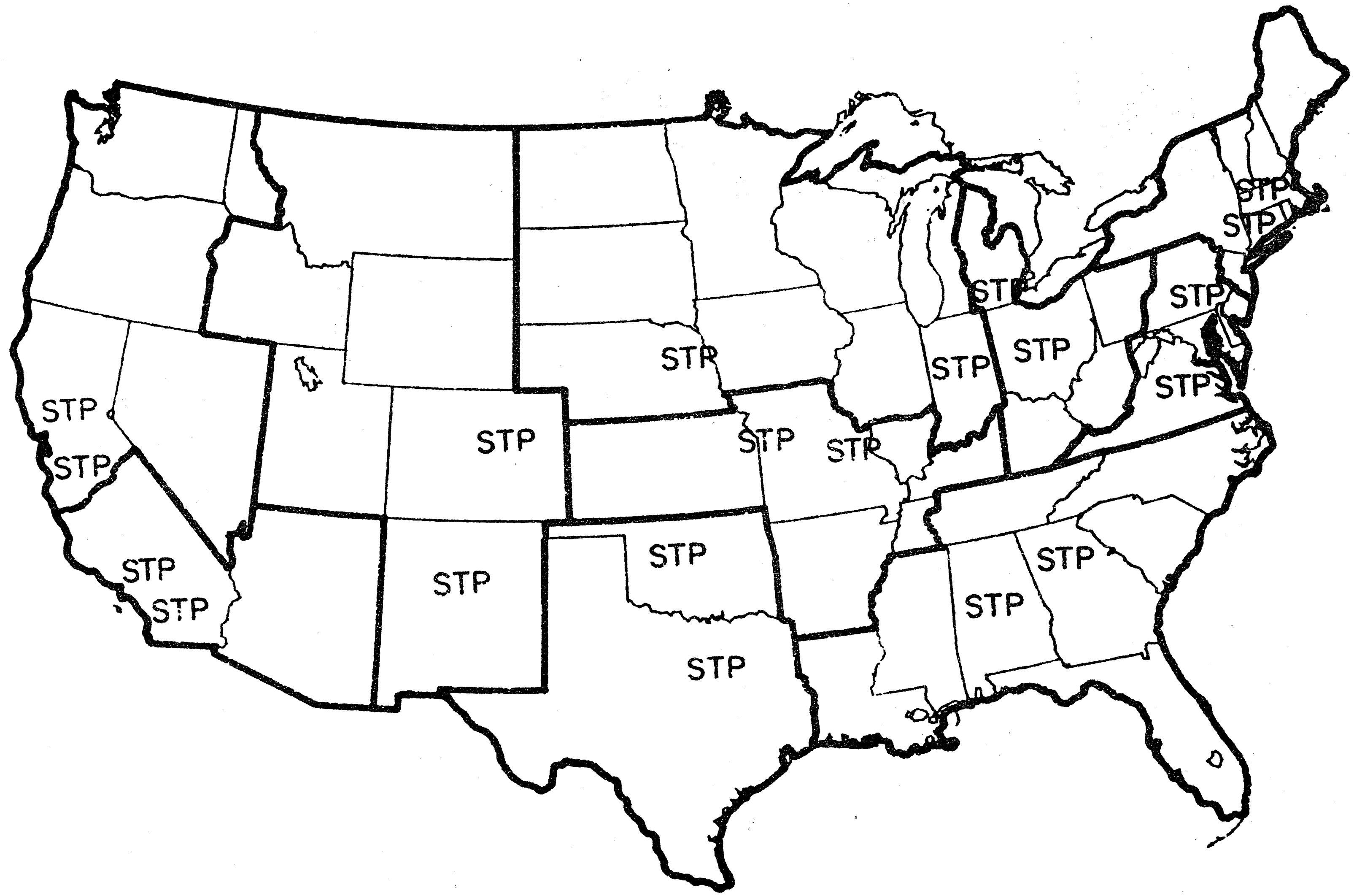


Figure 6-4. The 10 CCS signal switching regions.

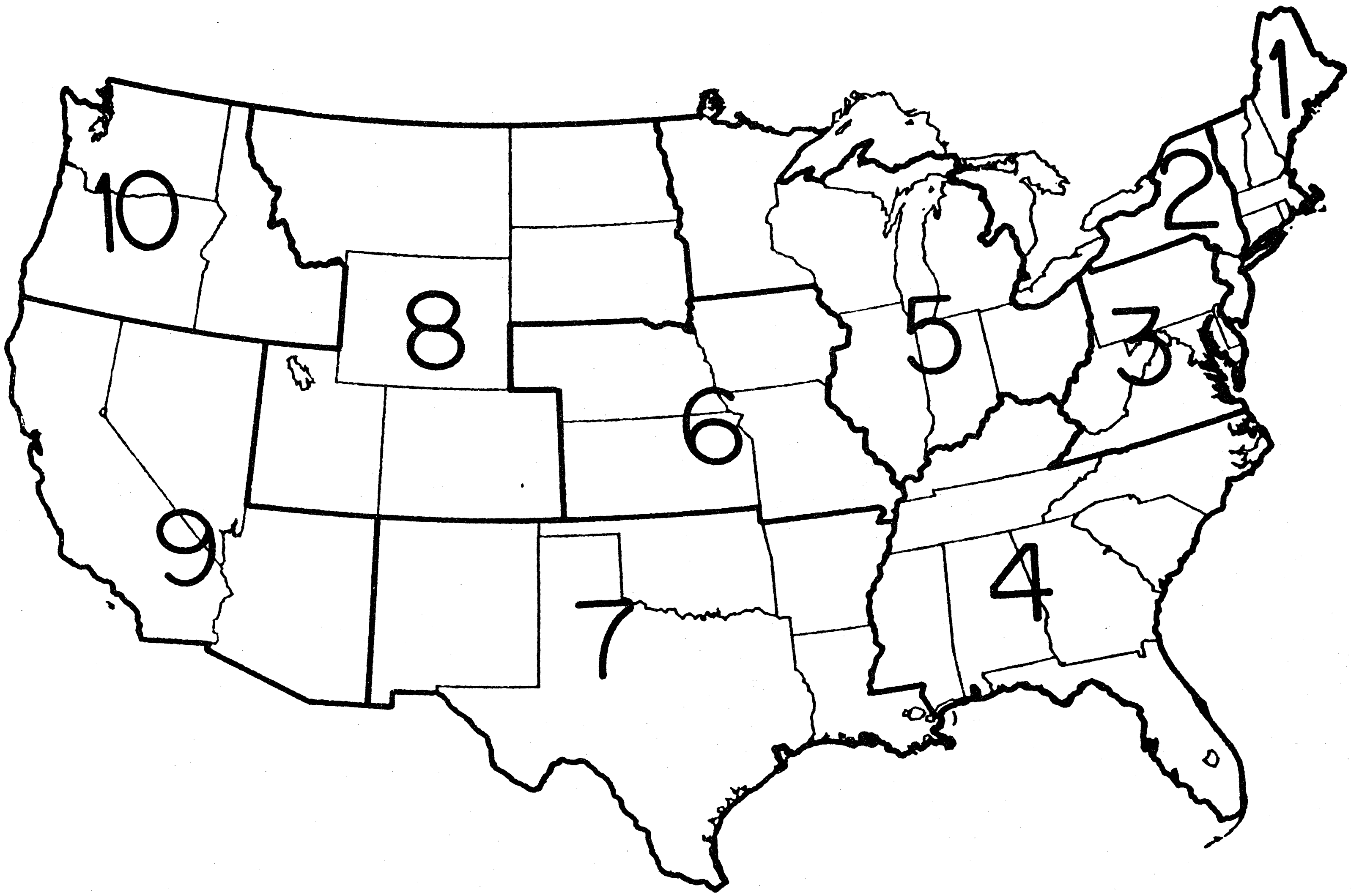


Figure 6-5. The 10 FTS regions.

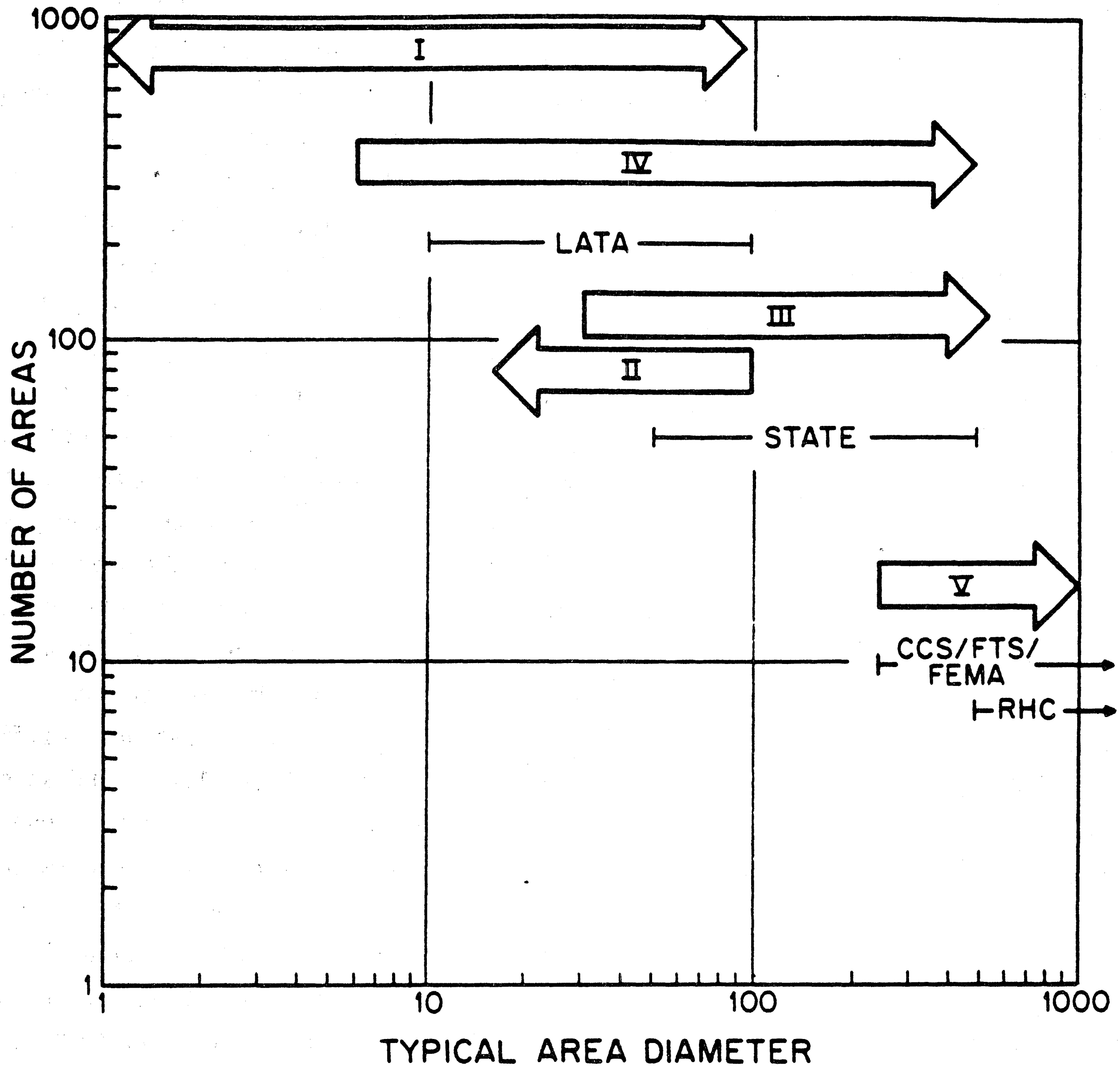


Figure 6-6. The numbers and typical sizes of area coverages.

Item II in the center of Figure 6-6 pertains to the earlier travel distance issue for maintenance crews. That distance should stay under 100 miles, or service restorability may become a serious detriment. On the other hand, item III concerning hub survivability may imply that hubs should be at least 30 mi or 50 km apart to have some chance of not both being simultaneously incapacitated. Therefore, if an area is to accommodate two or more hubs, the size of area per argument III might have to exceed 30 miles. But such suggestive factors as I - V in Figure 6-6 are not conclusive enough to determine the eventual optimum access area size algorithm. In fact, they are hardly more definite than the size distributions of LATA, CCS, FTS, or RHC. Compare Figures 6-1, 6-3, 6-4, 6-5, and 6-6.

It was noted earlier that economics of life-cycle costing favor the number of backbone switches between 30 and 100. Let us consider the hypothesis that there is on the average one AA per backbone switch. The intra-AA costs must decrease as the switch number increases from 30 to 100. At the same time, the inter-AA costs must be growing, for otherwise their sum could not remain constant. One could conceive a fixed, equal-size, layout for every AA, a sort of Military Standard floor plan, if one is permitted that expression. But, this is unlikely to be the lowest cost arrangement. Further cost reductions are likely if sizes of AA's are allowed to be unequal, not necessarily arbitrary, but optimized to suit local circumstances. This size optimization process has to include, unless shown irrelevant, such constraints as terrain, subscriber site distribution, telecommunications traffic, existing and planned switches, and gateways, support functions (AO&M), and so on.

The internal structure of AA's is therefore related to their sizing. One large area switch may obviate the need for extensive intra-AA trunking and interswitch tie-line plant. Many lesser switches would achieve the opposite effect, but may still be advantageous for different local needs. Thus to identify optimum local area network sizes, network design methods must be developed to come up with locally best structures. The initial investment in such design methodology is to be justified on its use in many areas and eventual cost savings in all implemented areas.

6.2 Relevant Topologies

The previously expressed approaches to local area coverage with appropriate networks have a topological interpretation. This interpretation is not a single topographical sheet. Instead, one must recognize a hierarchy consisting of many dimensions, sheets, or layers. One step in the direction of such a multilayered topology representation is offered in Figure 6-7. Starting from the top, one finds deployed military bases and sites that contain loci of some telecommunications activity.

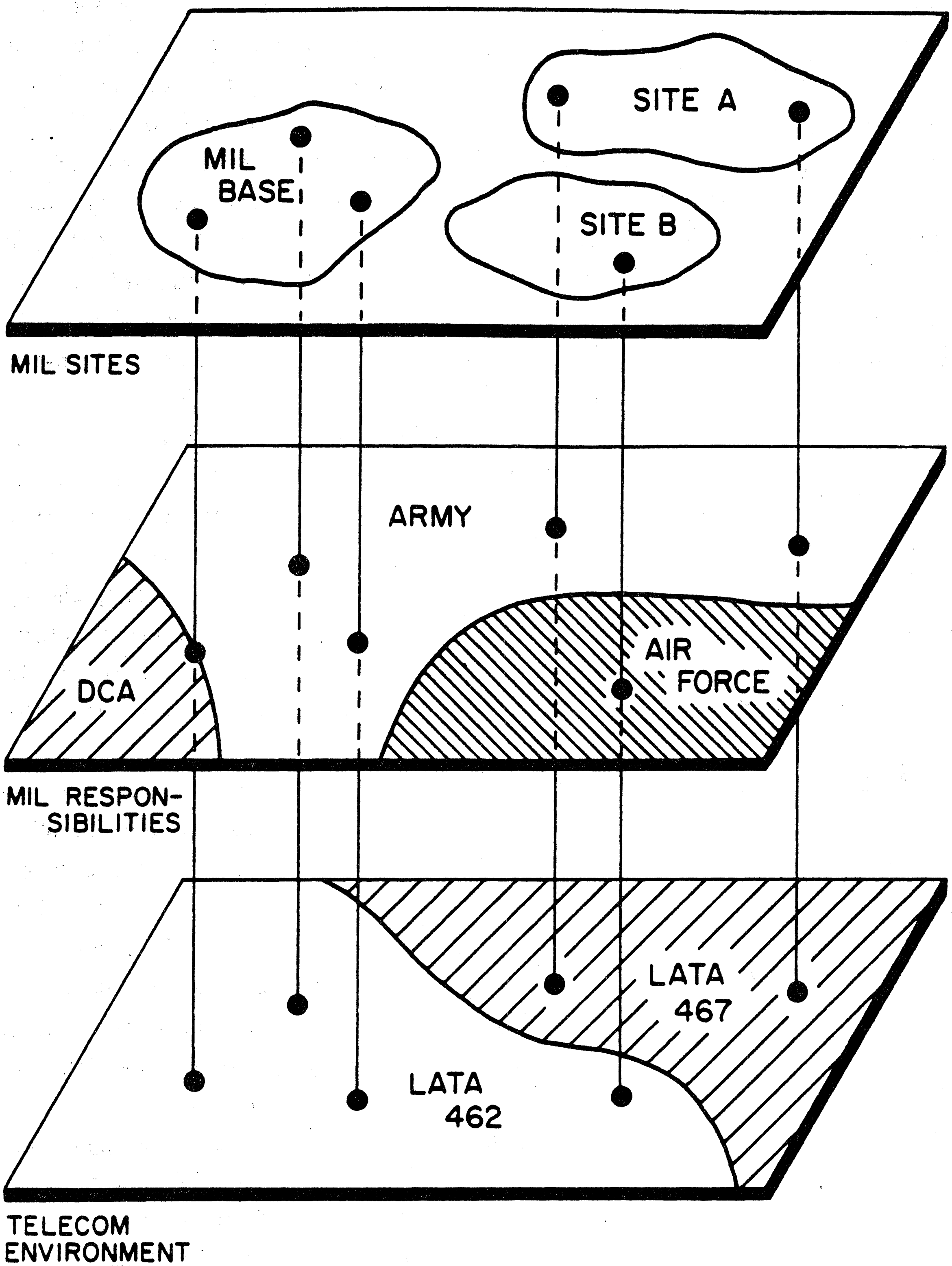


Figure 6-7. The subtopology of three administrative layers.

Without identification of the specific activities, said loci are shown as black dots. Going down the layering to the center of Figure 6-7, one finds the regions of primary military responsibility. Some sites may be the responsibility of a single agency or service, such as the U.S. Army, the Air Force, and so forth. Others might be shared. An example of such sharing occurs on the left-hand side of the military responsibility layer, where a point lays on the boundary between DCA and Army regions. Further down the page one finds a telecommunications environment layer that in this case depicts LATA boundaries. Other, closely related, commercial boundaries, such as RHC's, telephone companies, independents, OCC service regions, etc., do impact this commercial environment layer and can be drawn as additional layers, if one so prefers.

Technological facilities overlay another set of topologies over the landscape. This is illustrated in Figure 6-8. The black dots on the military bases are now identified as certain nodal facilities that may be major or minor switches, PBX's, AO&M centers (perhaps for a larger region), or gateways to terrestial or satellite long-distance networks. The local network connectivity, shown as the bottom layer in Figure 6-8, interconnects the nodes with different capacity links. It also shows the terminals (often subscriber telephone sets) with circled T's. A typical engineering domain is transmission and switching. As such, this domain consists of the two lower layers of Figure 6-8.

But, of course, there are still other technical or semitechnical structures. The regional activities that pertain to AO&M, as well as the general NM, are prime examples. Whether manual or automated, the regions of AO&M are apt to be differently partitioned. This issue is illustrated in Figure 6-9. Consider the AO&M Region II, as shown in the middle of the AO&M subtopology. It covers some, but not all, of the adjacent military sites. Thus, it projects in a unique fashion onto the responsibility regions of the MILDEPS and the telecommunications companies (see Figure 6-7). And its coverage of the nodal switching systems and interswitch transmission facilities varies from region to region (Figure 6-8).

Another important item in the postdivestiture era is the deregulated use of potentially many lease and service providers. This so-called multivendor environment is shown as the last topological layer. Leases from different common carriers will have to interface with leases from different switch manufacturers, software providers, automated repair services and, if one were to go so far, network management service providers that aid with economical traffic routing and concerns for traffic-handling capacities of the overall topology.

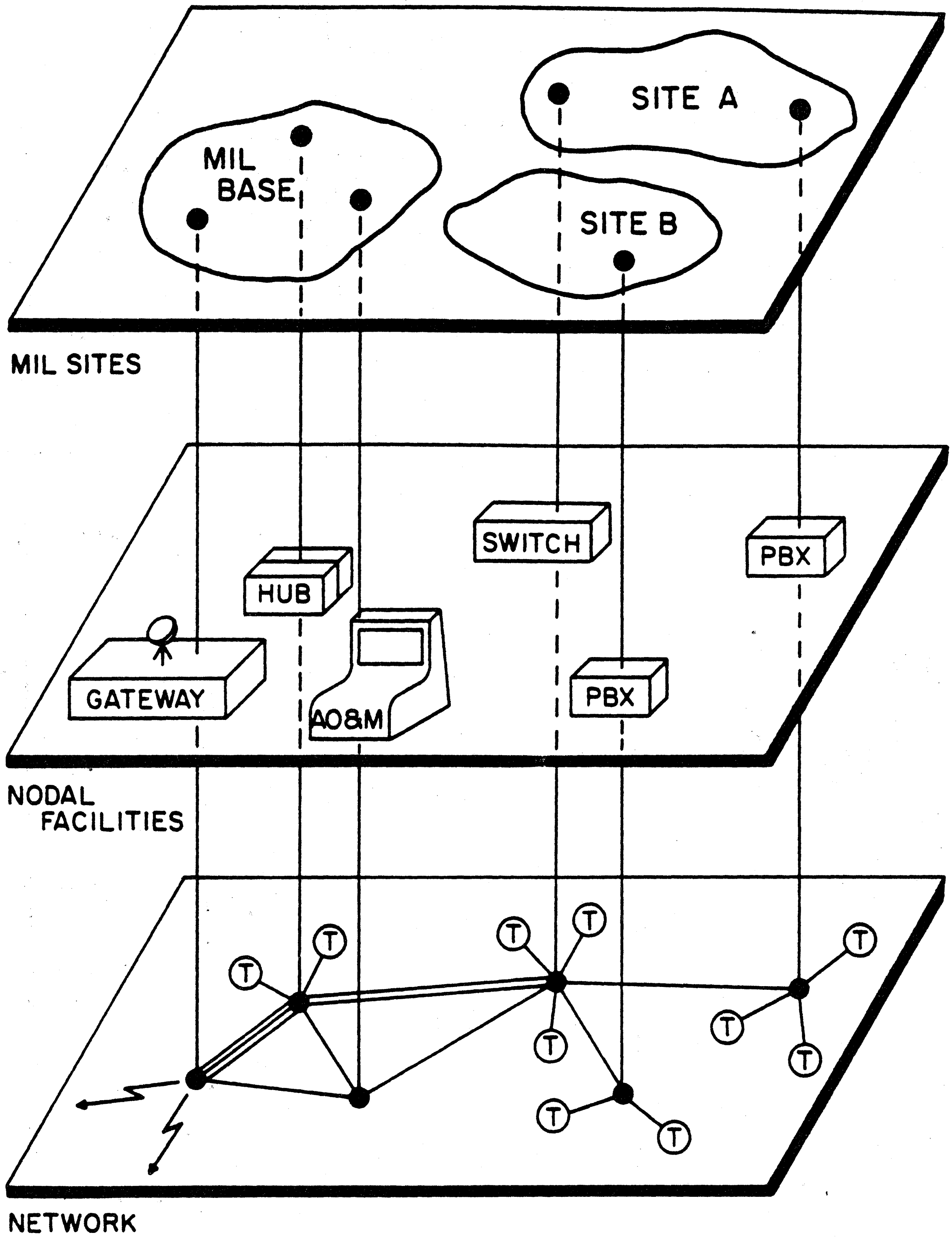


Figure 6-8. The subtopology of nodal facility and network layers.

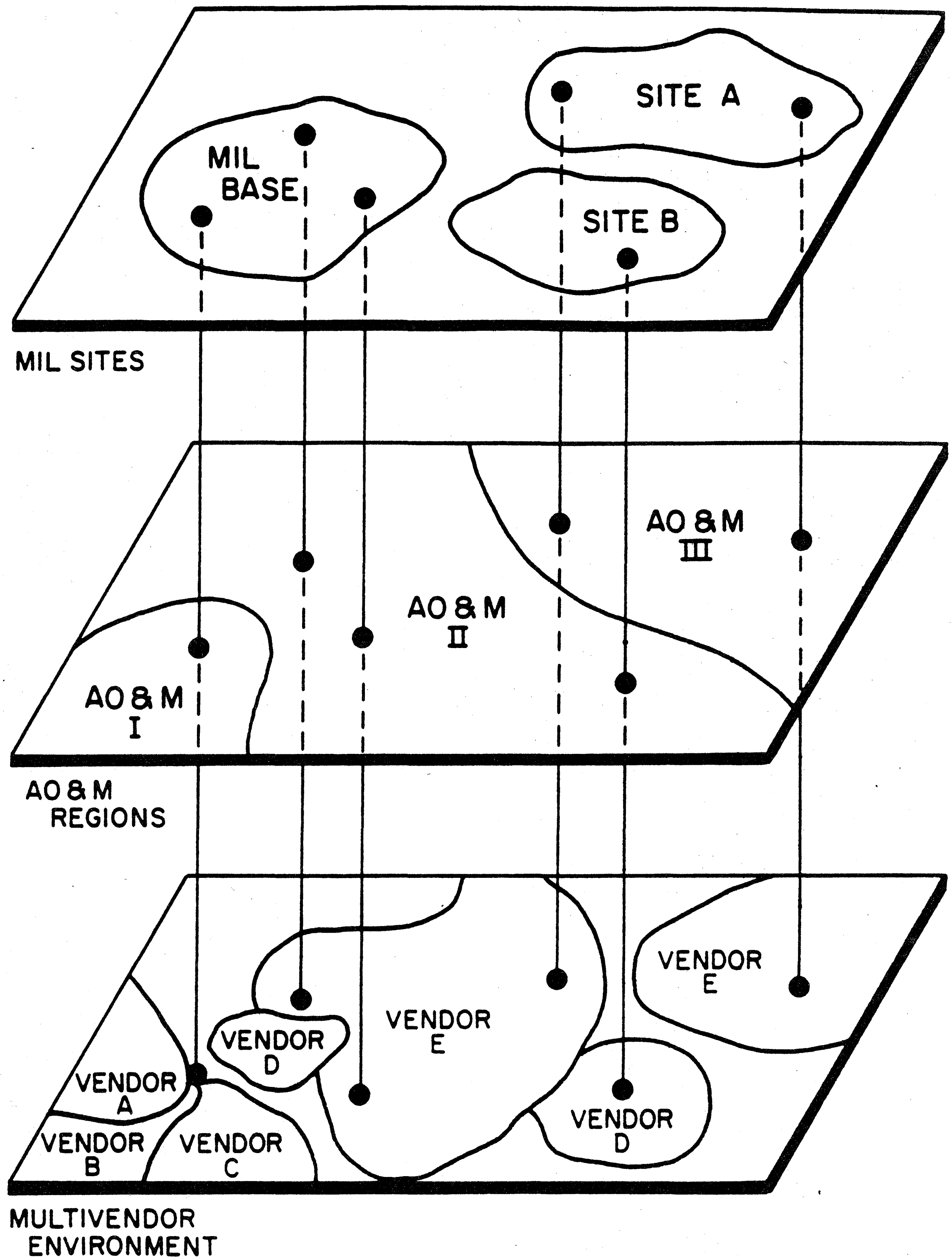


Figure 6-9. The subtopology of maintenance (AO&M) and multivendor layers

Taken together, the multilayered topologies of Figures 6-7, 6-8, and 6-9 represent what one believes to be the more significant regional definition parameters for the eventual access areas. The structures are far from simple in the CONUS. Their effects are far from being negligible. But what these interrelated effects are quantitively is currently not known.

Another topic that pertains to topology is the representation of "everything that is out there." Clearly, there are thousands of subscriber terminals (telephones) in every base of consequence. There are numerous switches, wire centers, and transmission facilities of different capacities. The description of such assemblage, even on a very local level, soon becomes unworkably complex. When faced with such problems in the past, the preferred approach has been to replace long lists with shorter lists. The abbreviations are generated by condensing or clustering adjacent sites. This concentration is usually around the most important lead areas, or those with maximum traffic intensity, or sites with the largest number of network elements. The geographical centers of the cluster areas are then weighted in proportion to their importance to network operations. Being few in number, the cluster points present a manageable set for network planning and design purposes.

Of the many criteria available for cluster definition, only two will be mentioned here. Both are based on subscriber or traffic uniformity over certain geometric regions. In the first case, the selected regions are rectangles or squares. Individual subregions are easily managed in terms of Cartesian or (x,y) - coordinates. The general approach may start by identifying squares with sufficient site density. If this is done as in Figure 6-10, part (a), the individual area elements may be around 0.1 to 1.0 miles on a side. As shown, there are 10 area elements, some of which are adjacent to each other. The adjacent elements are clustered in part (b), where weight numbers identify the number of equal size area elements that belong to each cluster point. As seen in Figure 6-10, if each area element has on the average x subscriber sites, then the process of going from (a) to (b) reduces 10x sites to 4 cluster points. While quite approximate and heuristic in nature, this approach can be very useful in practice.

Another approach worth mentioning is that of replacing individual rectangular area elements with triangles. This process is called triangulation. It has been used in geodesy and surveying. Perhaps it should not be too surprising that many civilian and military regions and bases are rather easily fitted by just a few triangles that represent areas of individually uniform density.

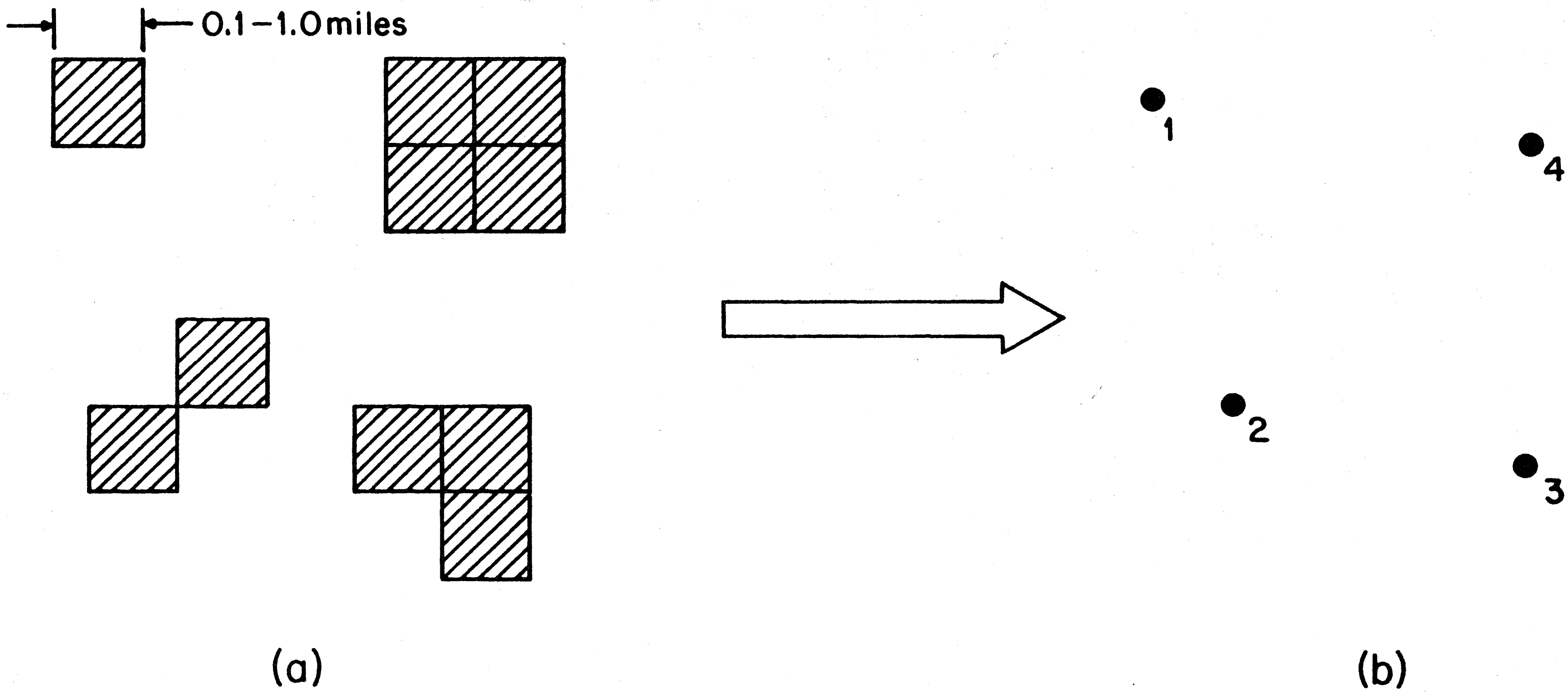


Figure 6-10. Rectangular area subdivision (a) and corresponding cluster points (b).

The principle of triangulation is based on the knowledge of the average distance from uniformly distributed points in a triangle (P_1, P_2, P_3) to any given point, say the origin 0. Then, as depicted in Figure 6-11, this average distance can be written as a known function $\overline{D} = F(P_1,P_2,P_3)$ on the three points of the triangle. The next step in application of triangulation may be to represent any local area as a collection of triangles, each with its own particular user density. This possibility for adjacent triangles is illustrated in Figure 6-12, where the coordinates of the hub are chosen to be the origin. Of course, adjacency is not a necessary conditon. Areas that are both noncontiguous, as well as contiguous, may be treated by this method. The point is that the average distance from any hub location to any region (so approximated by triangles) now can be approximated by a weighted sum

$$\overline{D} = W_1F_1(\ldots) + W_2F_2(\ldots) + \ldots$$

of the previously derived functions. If one prefers, there is the possibility of assigning to each triangle an effective central cluster point. But, because the mean distances to anywhere are known, the cluster representation may not be essential in the triangulation approach.

In the conclusion of this section one should be reminded that in the Recommendations, Section 8, applications to CSATS could be made of the simplifying techniques introduced above. Both clustering and triangulation methods may turn out to be efficient add-ons to the CSATS model discussed in Section 7.

6.3 Hubs and Switches

Local area economies are clearly affected by expedient use of the major nodal elements. Among such, see Table 5-1, one finds switching systems and related facilities. This section briefly reviews the importance of such items as tandem switches, local switches, PBX's, RSS, and so on.

Per definition, local switches carry only locally generated or locally terminating, or both, traffic. Tandem switches handle only tandem trunk traffic. As such they both are said to be single-function switching systems. If one combines the two functions into one local/tandem switch, one calls it a dual-function switch. This is a special case of systems that generally accommodate many traffic substreams, the so-called multifunction switching machines.

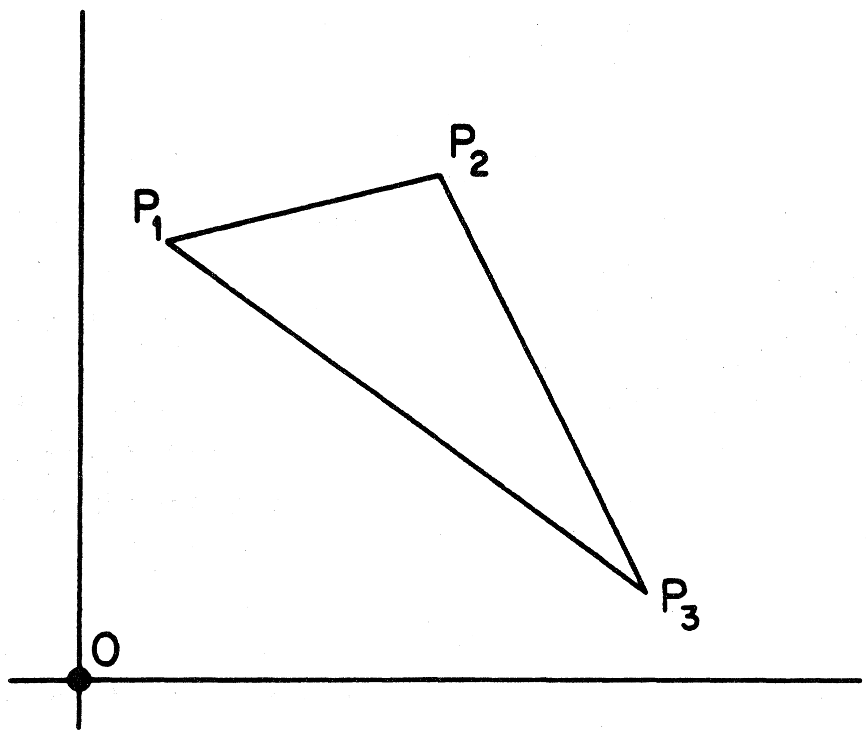


Figure 6-11. The principle of triangulation.

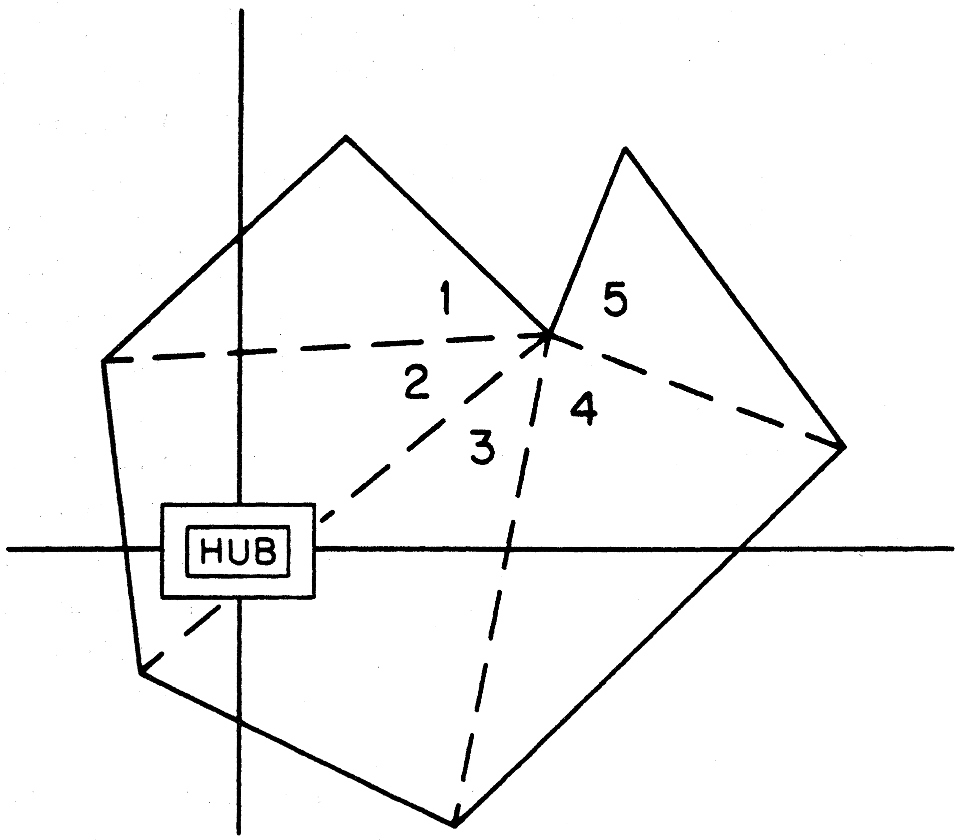


Figure 6-12. Application of triangulation.

Dual-function, local/tandem, switches are of particular interest to local area hub applications. Many older generation switches have been so deployed in the past. A notable example are the 50 plus AUTOVON switches that are four-wire analog circuit switches of the stored-program No. 1 ESS type (Joel, 1982). While much has been said about the polygrid toll network features of the so supported long haul connectivity, the AUTOVON switches are also capable of local termination, thus enabling four-wire end-to-end service.

Of present and future concern are the recently developed digital switching systems. Table 6-1 offers a brief summary of four relatively popular digital systems: the No. 5 ESS of AT&T, the Northern Telecom's DMS-10, GTE's No. 5-EAX, and ITT 1240. From the data provided in the quoted Arthur D. Little (1984) study for the Department of Commerce, it appears that there is considerable variance between these systems. For instance, only half of them are claimed to meet CCITT compatibility and interoperability standards. The maximum number of lines and the maximum number of trunks also vary widely, as shown, from a modest 6,000 to an impressive 150,000 lines. The traffic-handling capabilities are represented in five rows: the Busy-Hour Call (BHC) objective, the design baseline assumed holding time, the total Erlang load to be carried by the systems, the planned carried loads for lines and trunks (also in Erlangs), and the call blocking GOS objective. In about half of the cases in the table, the relevant traffic planning numbers are not available. Overall, nevertheless it seems that blocking probability should be around 1%, or as is often said, P.01, if the realized offered traffic remains within the design bounds.

The typical type of switching matrix is time-space-time or TST (McDonald, 1983). The matrices are suitable for deployment of Remote Line Units (RLU) with accompanying distribution (viz., to a limited degree) of program intelligence.

All switches of Table 6-1 work with the 64 kb/s PCM of the North-American format, but some are also capable of the European or CCITT adaptation. There are further features that pertain to the computer processing unit (CPU) architecture, software, and program languages. Here, all the switch manufacturers agree to differ. The proprietary control features are complex and expensive. They are alleged to have an impact on the statistics of system downtime--an important issue to the military network users. But so does the very last item in the table, the Traffic Service Position System (TSPS), which only in certain few systems is available in a totally integrated control concept.

Table 6-1. Selected Local/Tandem Digital Switching Systems (from an Arthur D. Little study for DOC, 1984)

Switch Characteristics	AT&T 5-ESS	NTI DMS-10	GTE 5-EAX	ITT 1240
CCITT Compatibility	✓	---	---	✓
Max. Number of Lines/Trunks	100,000/ 50,000	6,000/ NA*	150,000/ 25,000	100,000/ 60,000
BHC Objective	400,000	10,000	NA	NA
Assumed Holding Time	200 SEC	NA	NA	NA
Total Carried Load	30,000 E	1,000 E	NA	25,000 E
Planned Load Per Line/Trunk	.25 E/ .86 E	.20 E/ NA	NA/ NA	.27 E/ .80 E
GOS OBJECTIVE	.010	.040	NA	.005
Type of Switch Matrix	TST	TST	TST	Combined TS
Max. No. of Lines Per RLU	4,000	420	3,070	480
PCM Type American/CCITT	✓/✓	✓/—	✓/—	✓/✓
CPU(s) Architecture	Pair, Distributed	Pair	Multi, Distributed	Distributed
Program Language	C	HLL	PASCAL	CHILL
Est. Downtime Per 20 Years	1 HR	4 HRS	1 HR	1 HR
MTBF Estimate	25 YRS	NA	NA	NA
Integrated TSPS	✓	---	---	✓

*NA = Data not available.

A similar function and feature listing is possible for other system categories. Of most concern to local area networks may be the PBX or PABX systems. The two terms have become quite synonymous in recent years, even though originally the term PBX referred to a manual switchboard. PABX's have always been smaller in size than regular switches, i.e., their number of lines and trunks have been lower. But, lately that has been starting to change. Some PABX's have become large, at times larger than many EO. Furthermore, the PABX manufacturers have been more enterprising in adopting the rapidly advancing computer technology. As a result, the PABX typically may offer impressive menus of technical functions and service features to the customers.

Table 6-2 provides a glimpse at selected, so-called, integrated voice/data PABX's. The phrase "integrated voice/data" here alludes to the ability of the switch to handle both analog and digital terminations. The maximum number of such terminations or ports is seen to vary from 3,000 to 30,000 for the six PABX's illustrated in Table 6-2. Some of these PABX systems are nonblocking, but not all.

There are many PABX characteristics not included in the table. But, perhaps, more interesting to the reader is the item "cost per line" that is included. This cost, derived from the Arthur D. Little (1984) study, shows the cost to be remarkably uniform--$1,000 or slightly below. This type of cost information was not offered in Table 6-1 for larger switches due to lack of definite references. However, one does hear unsubstantiated claims that the tandem and local switch costs per line are more or less the same as those for PABX, that is around $1,000 per line.

Assuming this to be the case, the next question pertains to what parts of modern switches cost how much now and in the foreseeable future. There is no unique way of breaking up the switch into parts, components, or subareas, that may be 2,3,4 or X in number. Nevertheless, one such cost breakup is attempted in Figure 6-13. A seven-category breakup is shown, starting with the 1984 costs as 100% and projecting cost trends up to 1995. It is seen that at the present the largest cost item, slightly in excess of 20%, is interfacing, followed closely by installation and software. This is expected to change drastically in the future. Ten years from now, installation costs will be dominant. They will amount to roughly one-third. The second item, software, will represent around one-fourth of total cost then, and so forth. Some of electromechanical, hardware, and firmware categories--such as the switching network and the control--will become costwise rather minor. Individually, their 1995 relative costs will be in the 5% to 10% range.

Table 6-2. Selected Integrated Voice/Data (or Analog/Digital) PABX's (from an Arthur D. Little study for DOC, 1984)

PABX Characteristic	AIS System 85	NTI SL-100	GTE OMNI	ROLM CBX-II	INTECOM IBX	ZTEL PNE
Max. Number of Ports	7,000	30,000	3,000	10,000	8,200	12,000
GOS Objective	0 for 4,000 L.	0 for ? Lines	.010	Non-blocking	Non-blocking	Non-blocking
Telephone Set Types	Analog Digital	Analog Digital	Analog	Analog Digital	Analog Digital	Analog Digital
Cost Per Line	NA*	$600 - $1,000	$700	$800 - $1,000	$1,000	$800 - $1,000
2W/4W Loops	8W	-/4W	2W/-	2W/4W	-/4W	-/4W
Trunk Interfaces	** DS1, DMI	DS1, DMI	DS1	DS1, CPI (DMI?)	DS1, DMI (CPI?)	---
Data: Full Duplex	✓	✓	✓	✓	✓	✓
Modem Pooling	✓	✓	✓	✓	✓	✓
Terminal Rates ASYNC/SYNC	64/64 Kb/s	64/64 Kb/s	19.2/64 Kb/s	19.2/64 Kb/s	56/56 Kb/s	19.2/64 Kb/s
Switch and Control Architecture	Modular, Distrib. TDM Bus	Modular Switch, Central Control, TDM Bus	Modular, Distrib. Dual TDM Bus	Modular, Distrib. TDM Bus	Modular, Distrib. TDM Bus	Modular, Distrib. TST
Protocol Conversions	---	ASYNC to BSC, SDLC	ASYNC to X.25	ASYNC to BSC, SDLC, X.25	ASYNC to BSC, X.25	---
Required Environment	Switch-room	Switch-room	Switch-room	Switch-room	Switch-room	---

*NA = Data not available.
**DS1 = T1 format, DMI = digital MUX interface (AT&T), CPI = computer-to-PBX interface (NTI).

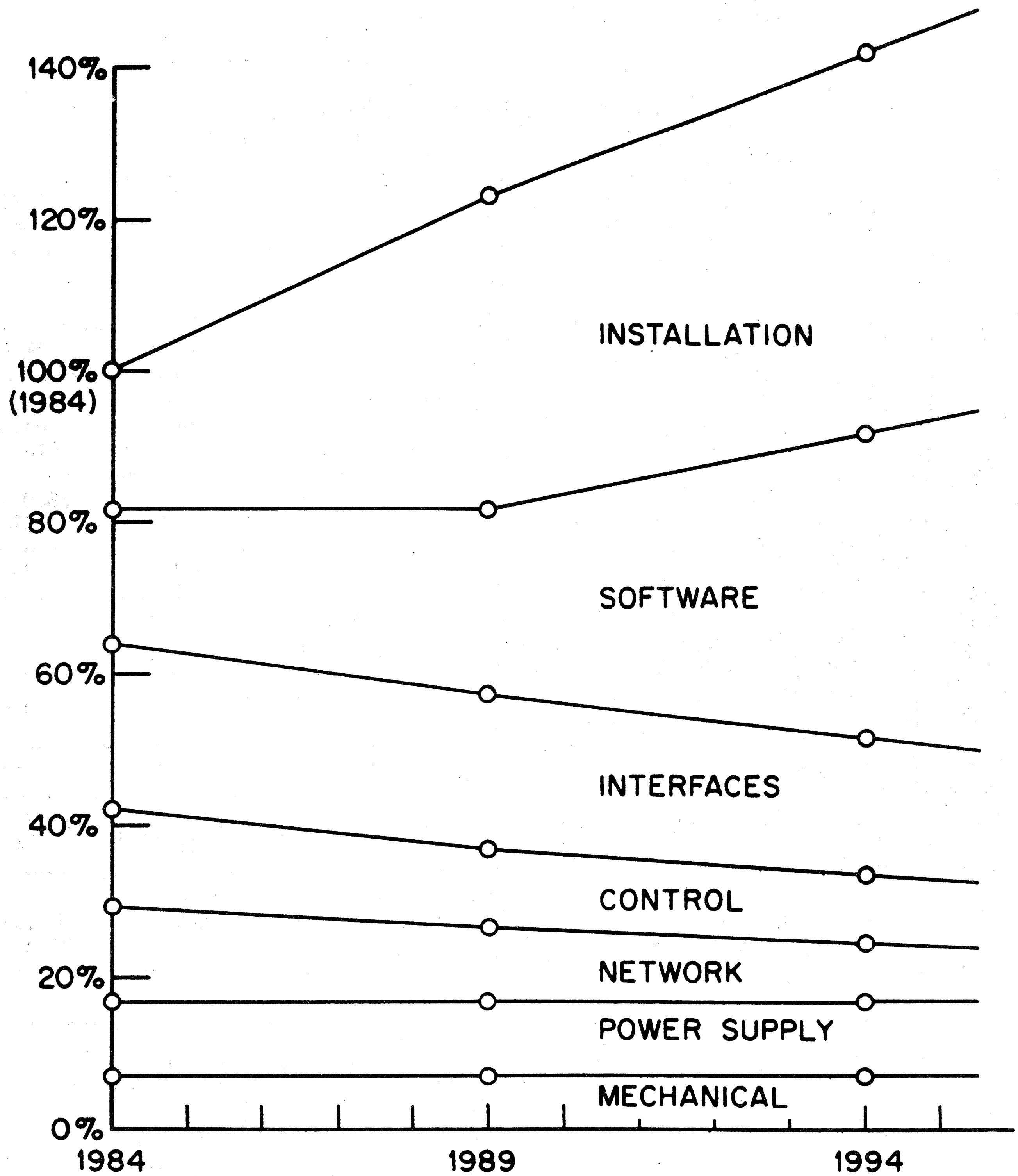


Figure 6-13. Relative future cost forecasts for digital switch subsystems.

One should not view Figure 6-13 as a negative assault on software. While people, machines, and organizations will work hard on software, trying to reduce their costs in the process, software will be a great boon to progress. The new enhanced capabilities of future systems, and quite assuredly so in the local access areas, will be a consequence of software developments to come.

The control intelligence will continue its trend toward decentralization and distribution toward lesser remoted facilities. This trend exists now and is seen in such unit deployment as the RSS or the Remote Switching Units (RSU). An illustration thereof is given in Figure 6-14. Note the dual (for reliability) micro control units at the remoted RSS network. Such units, or their equivalents procured or leased by multivendors, should have considerable service and cost impact on the local access of the future.

Another relatively novel system development, but with more anticipated impact on tandem traffic, is the DACS. It is also called the Digital Cross-connect System (DAX) in some circles. The DACS provides per-channel electronic cross-connection (not switching) for up to 127 T1 digroups of the DS-1 format. This corresponds to a total capacity of 3048 DS-0 channels, 64 kb/s each. See Figure 6-15 for an illustration of the DACS. The control intelligence that resides largely in the controller and in the operations support systems is augumented with Very Large-Scale Integration (VLSI). Immediate and innovative DACS local access area advantages are seen for central office switch, hub, applications, and maintenance (Western Electric, 1980; Kaskey, 1982). More advances and diversification in the DACS or DAX arena can be anticipated shortly.

A final innovative equipment description to be offered here relates to the application of concentrators. Concentration, a sort of statistical compression of many sources into a lesser number of channels, has been around for a long time. It often represents a profitable improvement on the old art of multiplexing. For telephony, and in particular for the subscriber plant of a local service area, a welcome addition has been the pair-gain system. This can be implemented in several ways. A common implementation is the SLC-96 system shown in Figure 6-16. It is capable of taking up to 96 local lines as an input and delivering their traffic to a remote switch via two T1 lines (i.e., 48 PCM channels). A third T1 line is often used by SLC-96 as a reliability backup or for other needs. There are other variants, such as SLC-48, but the arrangement depicted in Figure 6-16 appears to be the most commonly deployed both for local voice and data terminals.

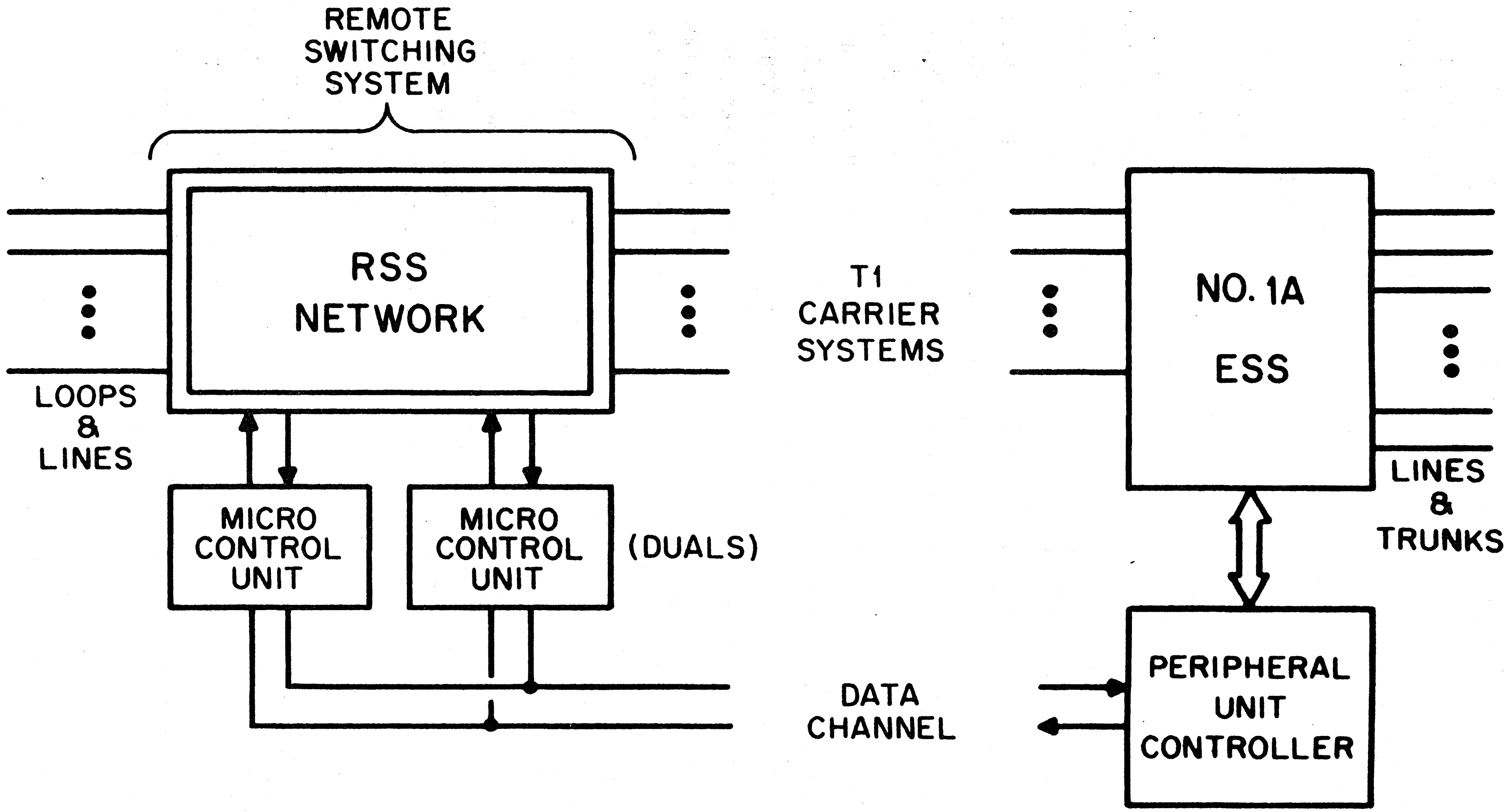


Figure 6-14. Typical installation of the Remote Switching System (RSS).

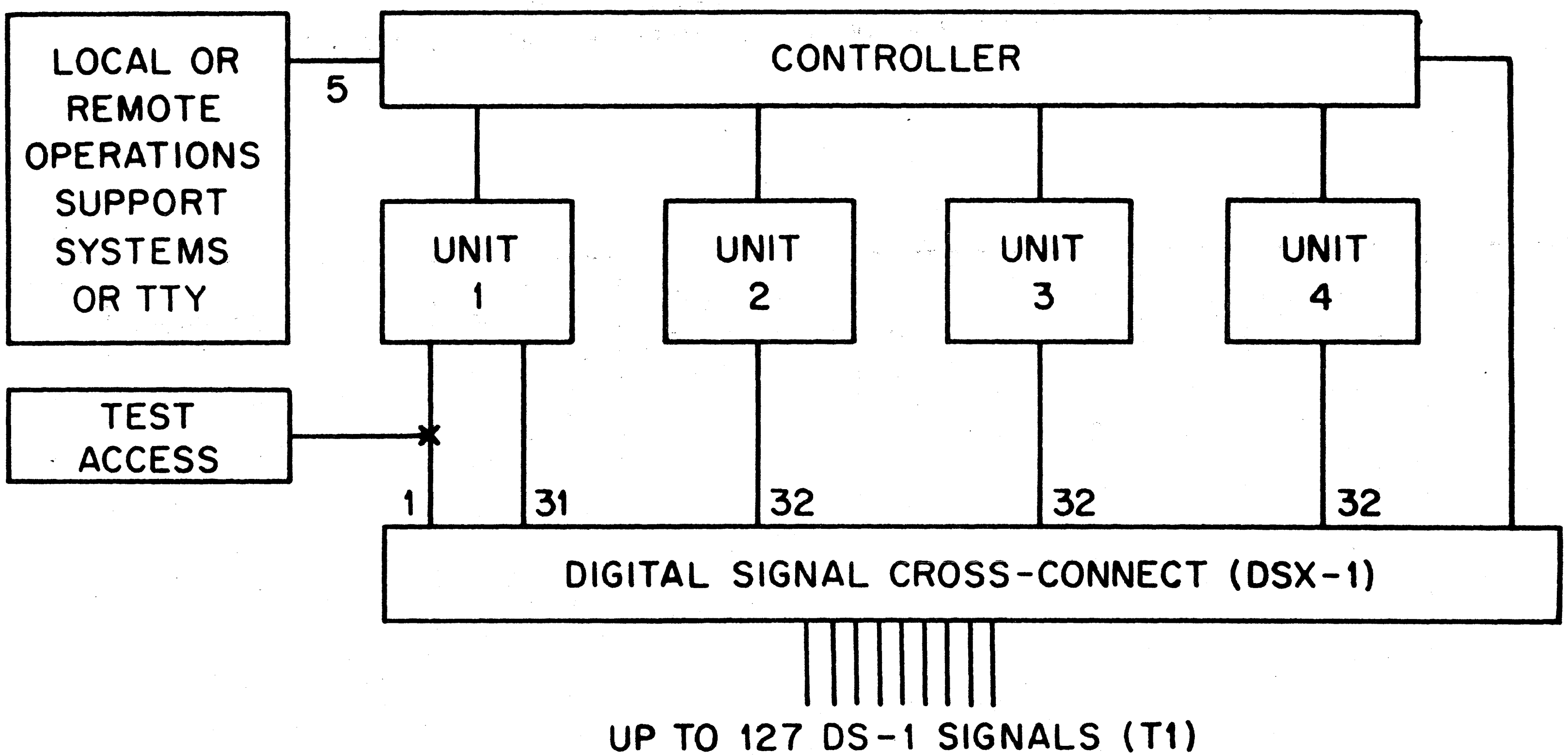


Figure 6-15. The Digital Access and Cross-connect System (DACS).

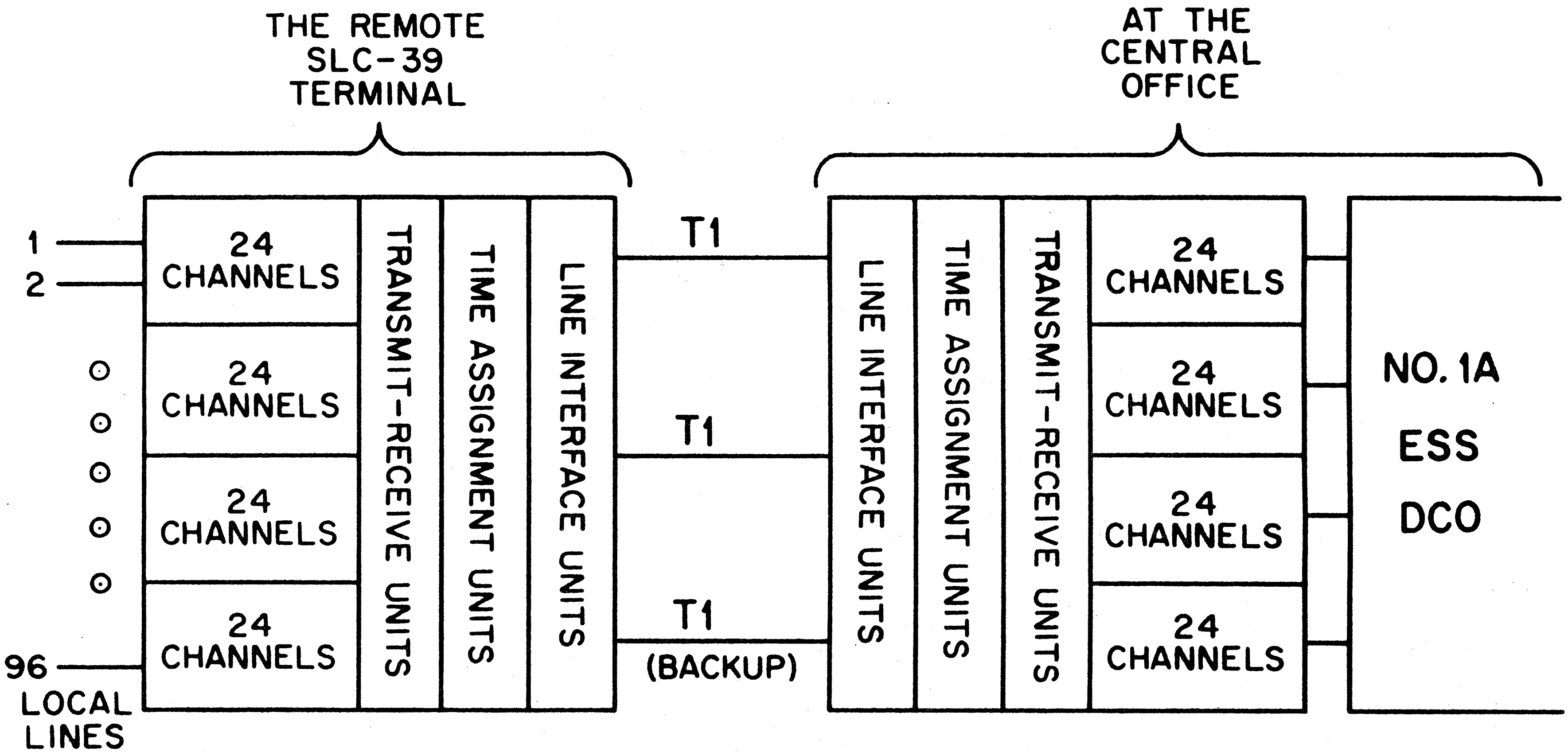


Figure 6-16. The pair-gain system implementation as a Subscriber Loop Carrier (SLC-96).

In the conclusion of this section on nodes, hubs, and switches, one should comment on the economic aspects of facility sizing. Let us assume that in a given locale there are now 6,500 telephone subscribers. Should one order, buy or lease, a switch whose capabilities in terms of matrix, CPU, or mainframe size are exactly matched to 6,500? Common sense says: "No." Perhaps, a capability for some 10,000 total terminations should be provided to allow for rapid variations in service demand, maintenance outages, and so forth. The situation is illustrated in Figure 6-17. It can be interpreted in many ways as the "allocation versus reserve" of a resource. At the local switching system the resources in question could be: the mainframe terminations, directory number assignments, memory size allocation, CPU speed and cycle time margins, etc. The spare percentages for these resources affect the economics in both good and bad ways. If service requirements change rapidly and unpredictably, bigger percentages should be allowed for spares to alleviate the expenditures of frequent upgrades. To answer the question quantitatively at a local area, a quantitative analysis must take into account factors such as:

- fixed period leases of hardware, software, and pertinent services
- modifications or upgrades of leases
- purchase costs of hardware and software, perhaps tailored for different size and type of systems
- trade-in or upgrade cost of equipments of different categories
- interoperability and remoting costs
- changes in manual and automated operating costs
- assorted management, switchboard, administration, maintenance, training and other expenses.

This list may not be complete. However, as given it may represent a considerable cash flow burden when the local hub/switch sizing is done in a less than optimum manner.

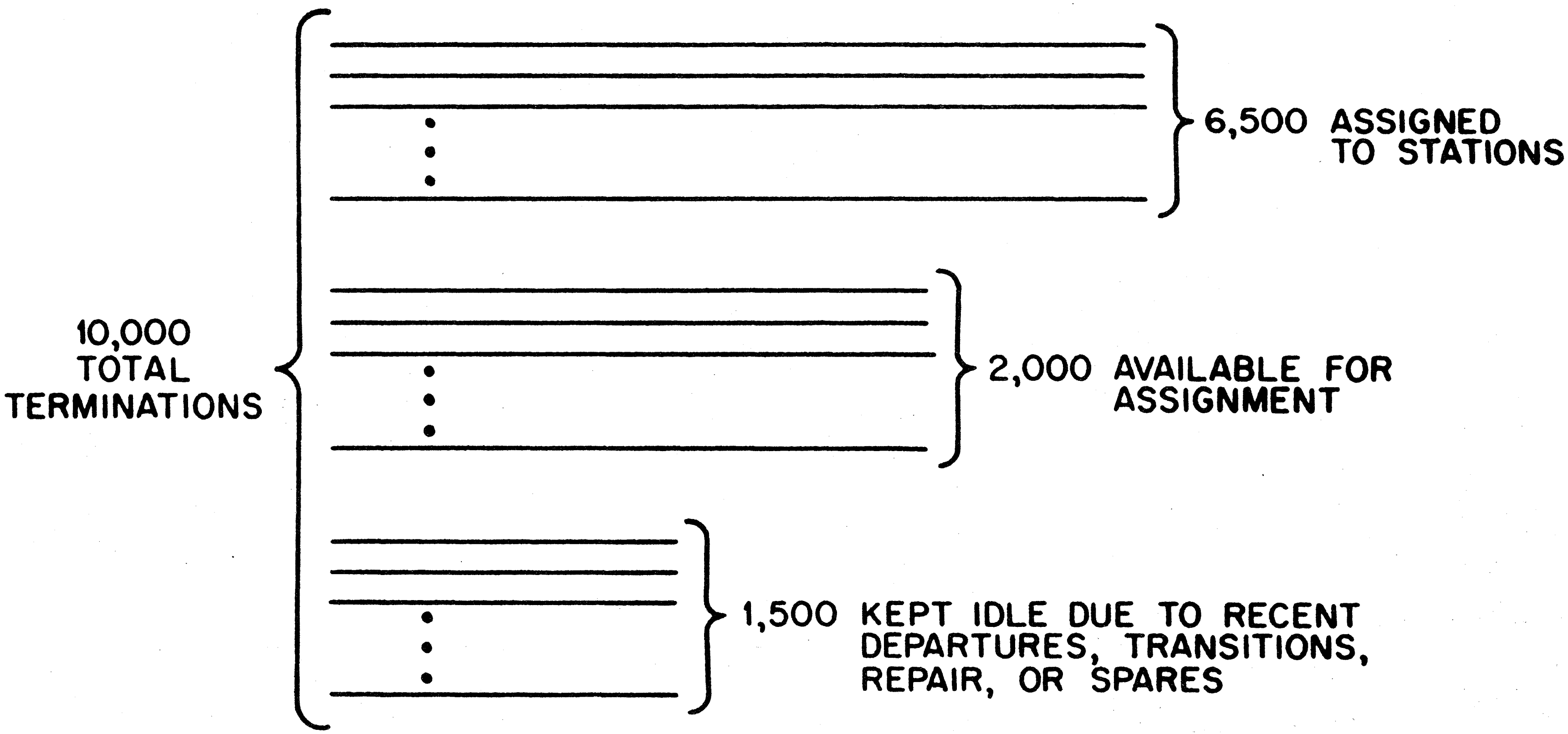


Figure 6-17. The issue of mainframe termination sizing and assignments.

6.4 AO&M/NM and Control

Section 5.1 presents an important functional element, described by the acronym AO&M. The letters stand for Administration, Operations, and Maintenance. The adjunct NM stands for Network Management, as seen in the caption of this section. Figure 5-4 suggests that AO&M is a technical part of telephone (or telecommunications) service provisioning. In this section, we take a closer look at AO&M. The objective here is to describe it in terms of other more familiar physical and procedural parameters.

As a starting point consider Table 6-3. It shows seven operations, together with their descriptions, and a typical time scale for these operations. The first operational category listed is Network Management. It deals with traffic control in almost real time, providing congestion avoidance by alternate routing and related techniques. In the local network of an access area, this operation may be often referred to as technical or tech-control. On the local level, as distinguished from nationwide or worldwide DSN connectivity, there are usually very few options for routing. But, if multiple homing and departures from star architectures were used in the AA's, this could become a more significant function in the future.

The next entity in Table 6-3 is Network Administration. Typically performed on a subdaily schedule, it is also concerned with traffic. While collecting traffic data, usually for the Busy Hour (BH), this activity extends to identification of equipment shortcomings and initiation of local remedies. Facilities can be reconfigured, different frame assignments made, and maintenance crews alerted. Maintenance itself is a separate, final operational category in this table. It can be triggered by tech-control, network administration, as a follow-up on implementation, or per standard corporate or MILDEP maintenance policy.

Three other categories are important in this ever-changing world of military requirements. They are the engineering planning, both short- and long-range, and the design and implementation consequences of these plans. Procurement, vendor liaison, acceptance testing, construction, installation, personnel hiring, training, etc., are all needed in system acquisition. But so are other support functions, such as accounting, billing, office automation, crisis management, cut-over teams, data bases, end-user GOS and Quality of Service (QOS), forecasting of new needs, inventories, tariff reviews, and so forth.

Table 6-3. Functional Examples of Network Operations

Operation / Descriptive Synopsis	Typical Time Scale
Network Management (NM)	In Near-Real-Time
Controls overload by alternate routing and reassignment of traffic to already installed equipments. If local, same as tech-control.	
Network Administration	Hourly - Daily
Monitors traffic, keeps BH statistics, flags office (switch) degradations, plans and executes line/trunk assignments. Initiates installation requests.	
Operator Administration	Daily - Monthly
Forecasts and provides operator service forces necessary for each hour, half hour, and if need be, for each quarter hour of the day.	
Long-Range Planning	Up to 20 years
Establishes most economic network growth and replacement strategies.	
Network Design	Within 5 years
Estimates where, when, and how much of specific network elements will be needed.	
Implementation	From Days to Years
Makes stress-dependent ASAP and slower planned economical changes, field construction, testing, and dismantling.	
Maintenance	Continuous, Varied Pace
Repair, replacement, diagnostic testing, sometimes routine, otherwise under stress.	

It is apparent from this expanding list of activities that, if one so desires, a very long list indeed could be generated by illuminating every detailed subactivity in Table 6-3. There are three reasons why one should not pursue such a detailed approach. First, the complexity would soon get out of hand. Second, there does not seem to be a uniform set of definitions for these terms and activity items. The DOD, AT&T, GTE, MCI, the Independent Telco's, etc., all appear to differ in their terminologies. And third, most of these entities are not essential, or certainly not equally important budget-wise to the Access Area networks.

The financial resources required by AO&M of local networks can be compared to the AO&M resources of long-distance, DSN type, networks. At the present time the local fraction is around one-third and apparently growing. A 10-year trend from 1978 to 1988 is indicated in Figure 6-18. Here both the local and the long-haul network AO&M costs are further split into personnel and automation parts. It is implied that automation is growing. From a 25% slice of the AO&M pie in 1978, it is estimated that 50% will be exceeded by 1988. New types of personnel skills will be needed to work with the coming automated systems. More on AO&M automation will be presented in Section 6.5. Here, emphasis is to be placed on AO&M personnel, its costs, and skill levels.

Appendix A presents a background for skill levels and related labor costs. Differences in skill-level qualification and pay-scale structures are shown between military and civilian technicians and other support personnel. The E/O classifications for military personnel and the GS rates for Government civilians are shown to depend on the technical categories of the individuals, as well as on the experience (i.e., longevity) of the individuals. But that is not meant to imply that the pay scales are uniform or easily predictable in the commercial sector. Information on major telecommunications and computer corporations is partly available. Figure 6-19 shows the total hourly salary, benefits, and overhead for several major companies. It is based on data from Teleconnect magazine, (1984, p. 8), that is further quoted to come from such sources as the Eastern Management Group. The apparent $50 plus range of AT&T, GTE, and WU versus the approximate $30 for IBM and MCI is alleged to be due to different labor union contracts.

However, from the financial AA planning point of view, little if any significance can be assigned to pay tables unless one can identify individuals with specific tasks. As an example, consider Network Administration (see the second

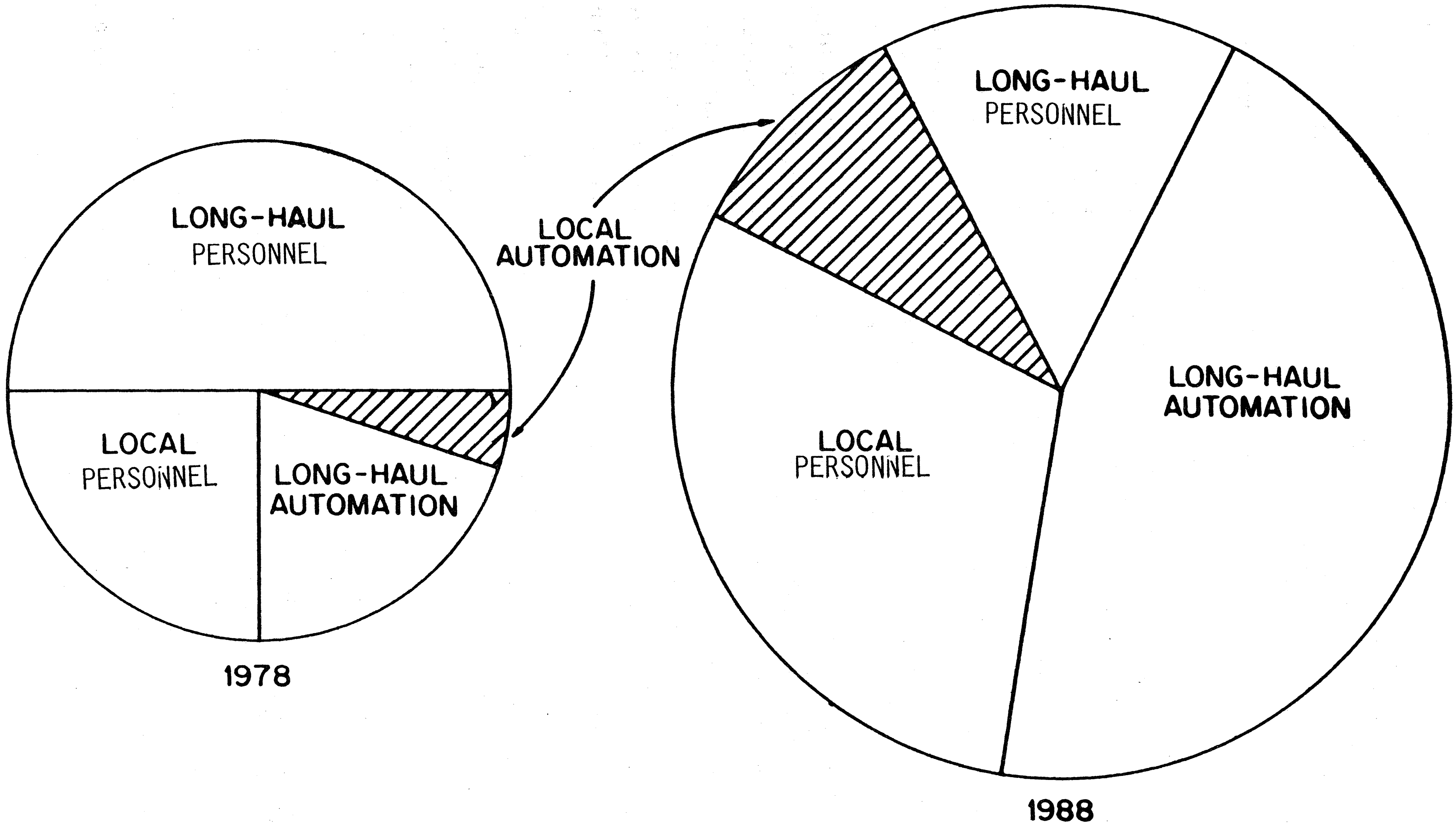


Figure 6-18. Ten-year trends for relative AO&M expenditures.

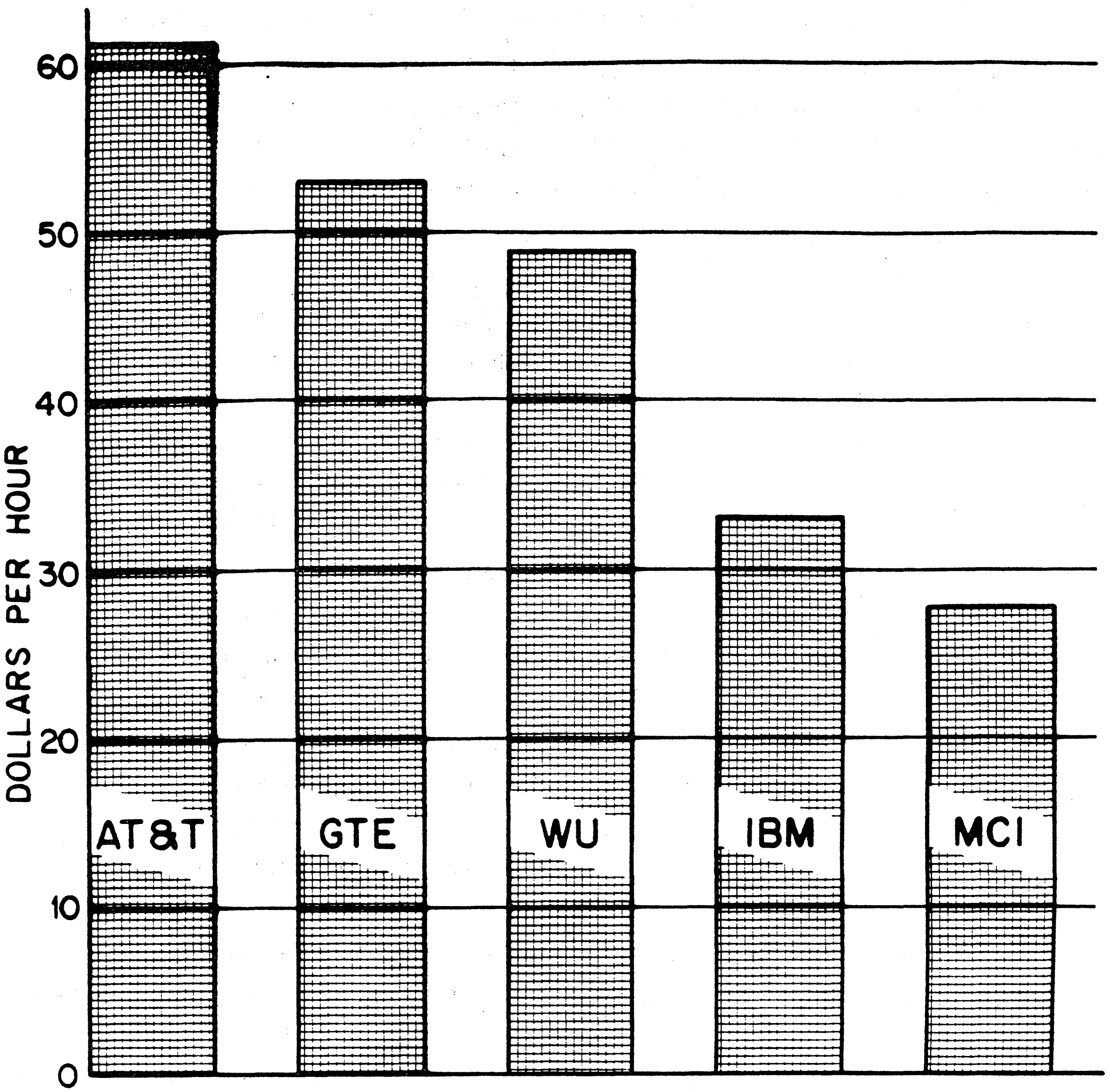


Figure 6-19. Commercial hourly pay for installation and maintenance of various equipments including salary, benefits, and overhead.

item in Table 6-3) for a relatively large local area. This function, also called supervision, office supervision, or dial administration by various parties, is recognized as an "enhanced tech control." If the AA in question is busy enough, this network administration involves an office team plus automation. The functions of this team may be divided into six groups. These are shown in Figure 6-20. The numbering of the task groups is purposely done in an upside-down fashion. This is done to emphasize the funnel-like role of item #1, Data Administration. It appears that to administer a local AA network, its subscribers, and its interfaces, many records and data are kept by many people and in several machines. These data are also widely used, thus they must be accurate and up to date. All the other task areas in Figure 6-20, such as item #2, "Equipment Utilization," or the last one #6, "Personnel Administration," rely on the information of the data base. And, of course, outputs of items #2 to #6 form inputs to that data base. Item #3 deals with plans and preparations for network changes and additions. Transition to new network architectures is managed here. More current everyday problems with customer service, complaints received, and their disposition are handled under item #4. The tasks in grouping #5 keep watch of the central office and subordinate (PABX) switch performance. This includes general, ongoing monitoring, as well as particularly focused tests or automated diagnostics. Finally, item #6 returns to the personnel questions by recognizing the administration of personnel itself.

The staffing of a typical, up to 20,000 customer AA, work center is illustrated in Table 6-4. The duty descriptions and staffing levels are approximate. They can vary among locations and are always subject to personnel doctrines of area command authorities. Other work centers, perhaps dedicated to repair, maintenance, network engineering, and so forth, can be considered. Depending on scope of tasks, their staff levels also vary widely--perhaps more than the 12 to 40 range shown by the total three work centers of Table 6-4.

When specifying AA boundaries, the question immediately arises about AO&M/NM and related control responsibilities, for in an AA neighborhood one can perceive two types of remote switches. In the first category may be the switches that home on the AA hub. In Figure 6-21 this type of switch is identified by solid black circles. The other type of switches are those that avoid the hub. They may home instead on the DCO of the regional telephone company. In Figure 6-21, this second

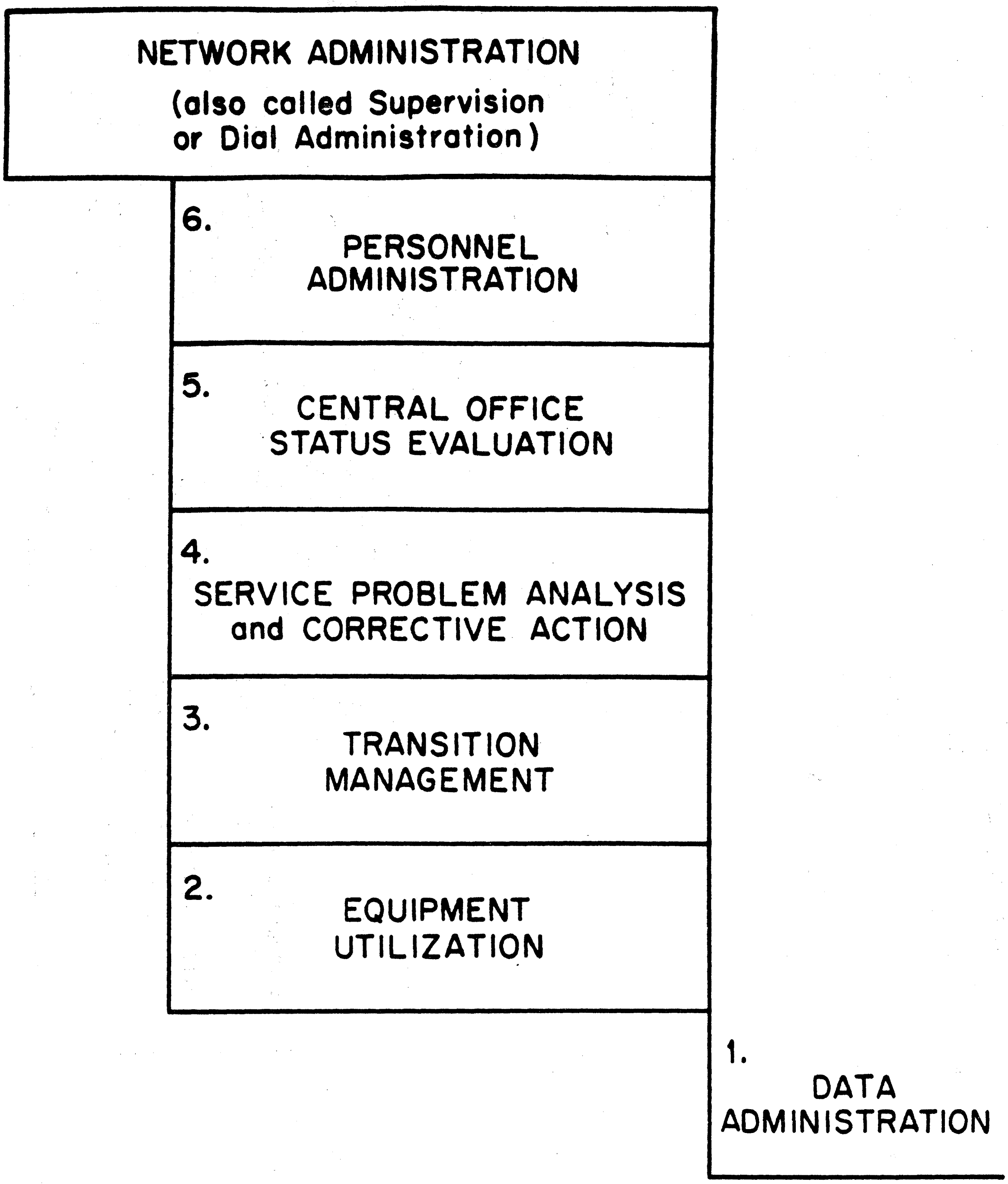


Figure 6-20. Functional tasks in network administration.

Table 6-4. Examples of Work Center Tasks and Staffing

Switchboard Work Center		Administrative and Technical Support Work Center		Financial Management Work Center	
To staff operator consoles for up to 20,000 lines. Specified operator GOS. Local and long distance (LD) support. Various LD network interfaces: AUTOVON, WATS, FX, FTS, etc. Assist with telephone directory updates.		To interface with Telcos and vendors, to assure contract compliance. New customer service. Prepare and update service authorizations. Staff and user service training. Monitor publication of telephone directories.		To pay for purchased services and leased systems. To handle reimbursable and direct customer funds. Telco, carrier and customer billing. Prepare management reports and issue financial authorizatons. Limited economic analysis plus financial training.	
Staffing:		Staffing:		Staffing:	
Chief/Overseer	1	Chief	1	Budget Officer	1
Senior Telephone Operator	2-5	Secretary	0-1	Secretary	0-1
Telephone Operators	3-16	Communications Specialists	1-3	Procurement Clerks	1-3
		Communications Clerks	1-4	Account Clerks	1-4
Total	6-22	Total	3-9	Total	3-9

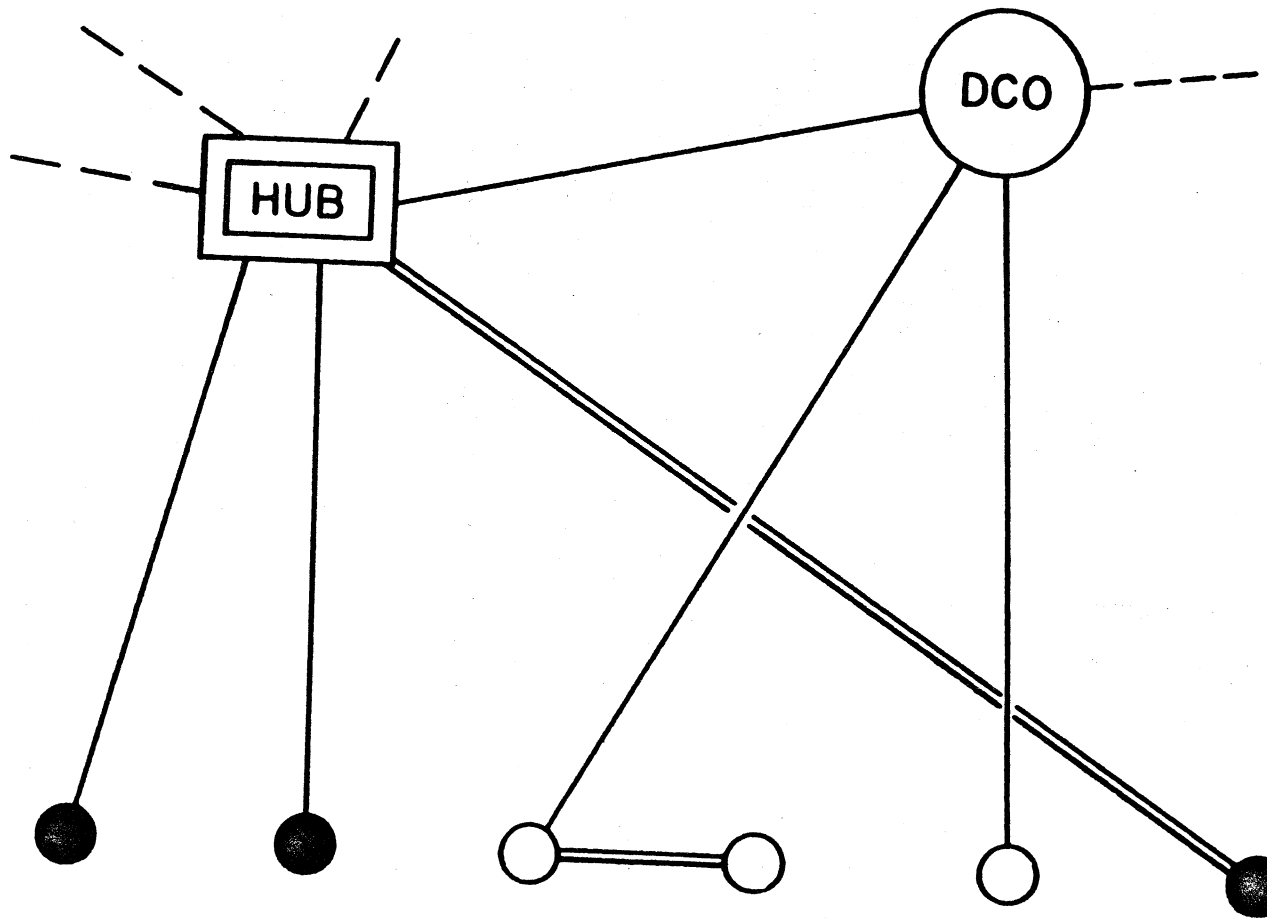


Figure 6-21. Two types of local area switches.

category of switches is indicated by hollow or empty circles. At times these hollow circles have been called "orphans." The AO&M/NM and control responsibilities of the orphans may be separate and different. This issue needs further study. But so does an even bigger AO&M problem that is likely to arise in large regions containing many access areas.

Consider Figure 6-22. In this stylized drawing, the half-dozen rectangles depict hub service areas. As shown, each rectangle contains one hub and several remote switches (black circles) that home on that hub. Each area also may contain a few orphans, whose AO&M functions must be somehow subscribed for. But more important than that appears to be the issue of boundaries between assumed large AO&M regions. One can justify that, using future automation as an argument, the CONUS could get along with a few centralized AO&M facilities. Thus there would be a few very large AO&M regions. Each would contain several, if not many, hub switches and the associated rectangles of Figure 6-22. But if so, there may be other good (e.g., MILDEP or administrative) reasons why the AO&M boundaries should depart from the hub service area boundaries. Then different crews, military or civilian, would have responsibility for different remote switches in the area of the same hub. As a matter of simplicity, can such a confusion be tolerated in access area planning? Perhaps arbitrary boundaries are not to be desired. Instead, AO&M regional boundaries, AA boundaries, hub service boundaries (including disposition of orphans), plus others, should be coordinated for economy and performance reasons. This coordination is likely to result in complex tradeoff between cost, military unique requirements (e.g., survivability), and local network architectures. Automated network design and evaluation tools will be needed to identify and assess best alternatives.

6.5 Automation, Service, and Other Parameters

The purpose of this section is to recognize the importance of automation now and in the foreseeable future. Of course, automation is not the purpose of AA existence. The purpose, as repeated throughout this report, is to meet the MILDEP requirements for telecommunications service. To provide that service one must use the most viable, most efficient, and most economical tools available. One such tool, or rather a conglomerate of tools, is automation. In the last 10 years in the United States, automation's role has grown dramatically and there is no reason to believe that its rate of growth will diminish in the future. Instead, one should be prepared for many novel and innovative AA applications of automated

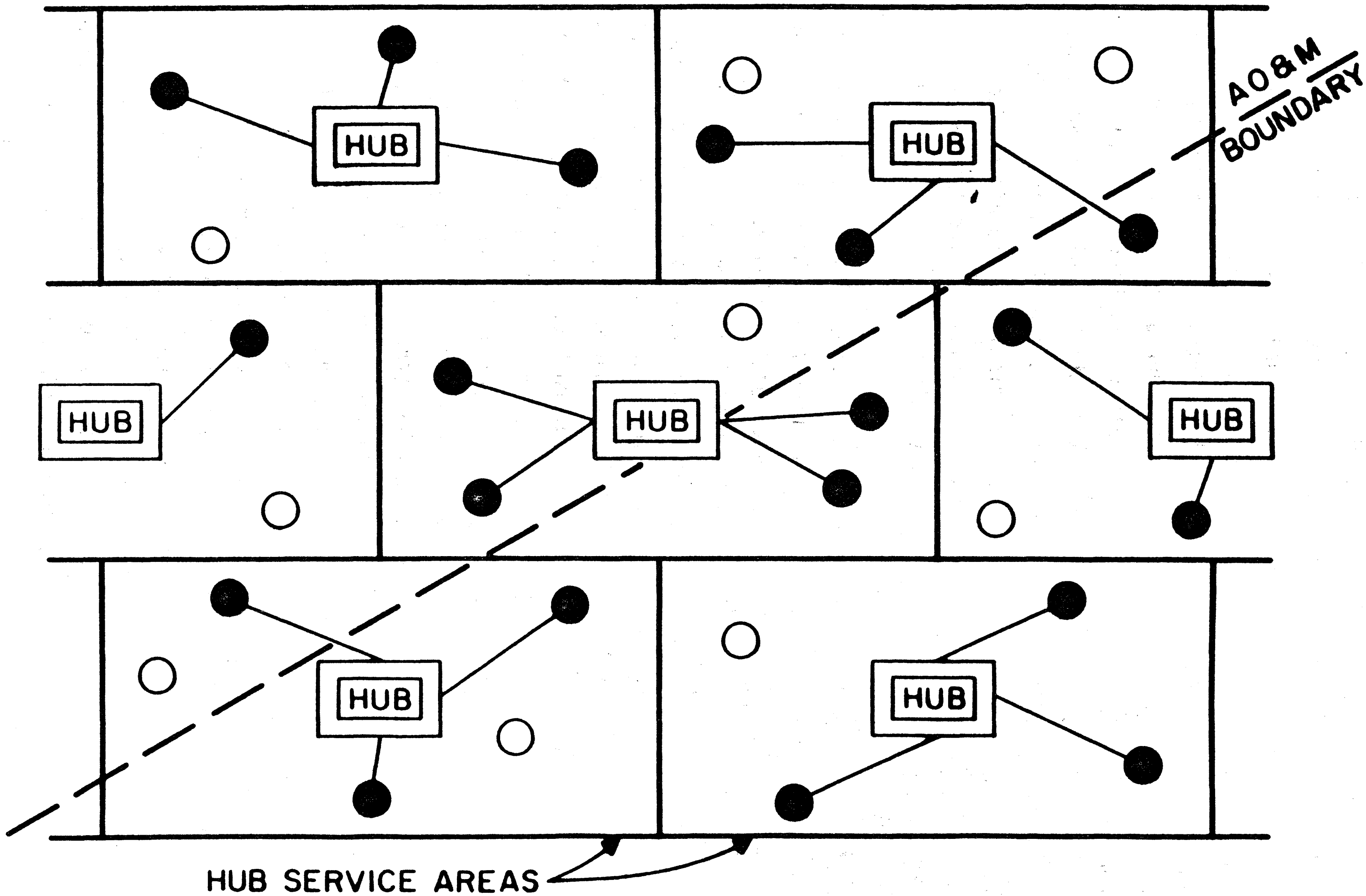


Figure 6-22. AO&M regions may be larger with different boundaries from hub service areas.

systems. It is certain that there will be new hardware, new software, new sophisticated ADP users, and a new generation of automation vendors, brokers, and lease providers operating in a future world of distributed intelligence.

As an illustration of automation inroads into the communications systems, consider Figure 6-23. This diagram identifies six prime components of service provisioning. At the top, right side, there is the local area service (e.g., telephone) system itself. Occasionally it requires repairs, modifications, and improvements. It is the job of the other five components to see that these repairs, modifications, and improvements do in fact get carried out. First, in the upper left corner of Figure 6-23 one finds the activity called "forecasting." It identifies needs and puts them in as numerical a form as is possible. The numbers may pertain to traffic volumes, service statistics, complaints, and listings of facilities with deficient or surplus capacities. The forecasting element is darkened in the figure to emphasize the fact that it is a candidate for application of ADP systems.

Other prime candidates for automation are data bases, inventory management, system process monitoring, and remote control maintenance. These areas are also shown darkened at the bottom and at the right side of the figure.

But what specifically will be under software control from 1985 on, say in 1990, 1995, and so on? There are already numerous computer systems that manage with or without active human interaction to perform such functions as switch network controls, routing, networking, on and off-line hardware management, diagnostics, and various application softwares (e.g., record keeping, billing). These (at least partly) automated areas will continue automation at an increased pace. Furthermore, many tasks that in the military locations still receive manual (i.e., human) attention will almost assuredly become automated or at least be considered as serious candidates. Examples may be personnel files, all documentation, training material, job aids, personnel practices, and so forth.

Automation is to be a factor not only for existing systems, but also for new, to be procured, to be planned, to be installed, and to be broken in systems. Figure 6-24 divides this installation problem into two phases: preinstallation and postinstallation. The ADP prospects differ for the two phases. This fact is indicated by the darkened blocks in Figure 6-24. Before installation, for instance, the existing and future forecast data for traffic, as well as surrounding networks, should be automated. Likewise, automated models should be applied in the search for solutions when a set of incompatible requirements arises.

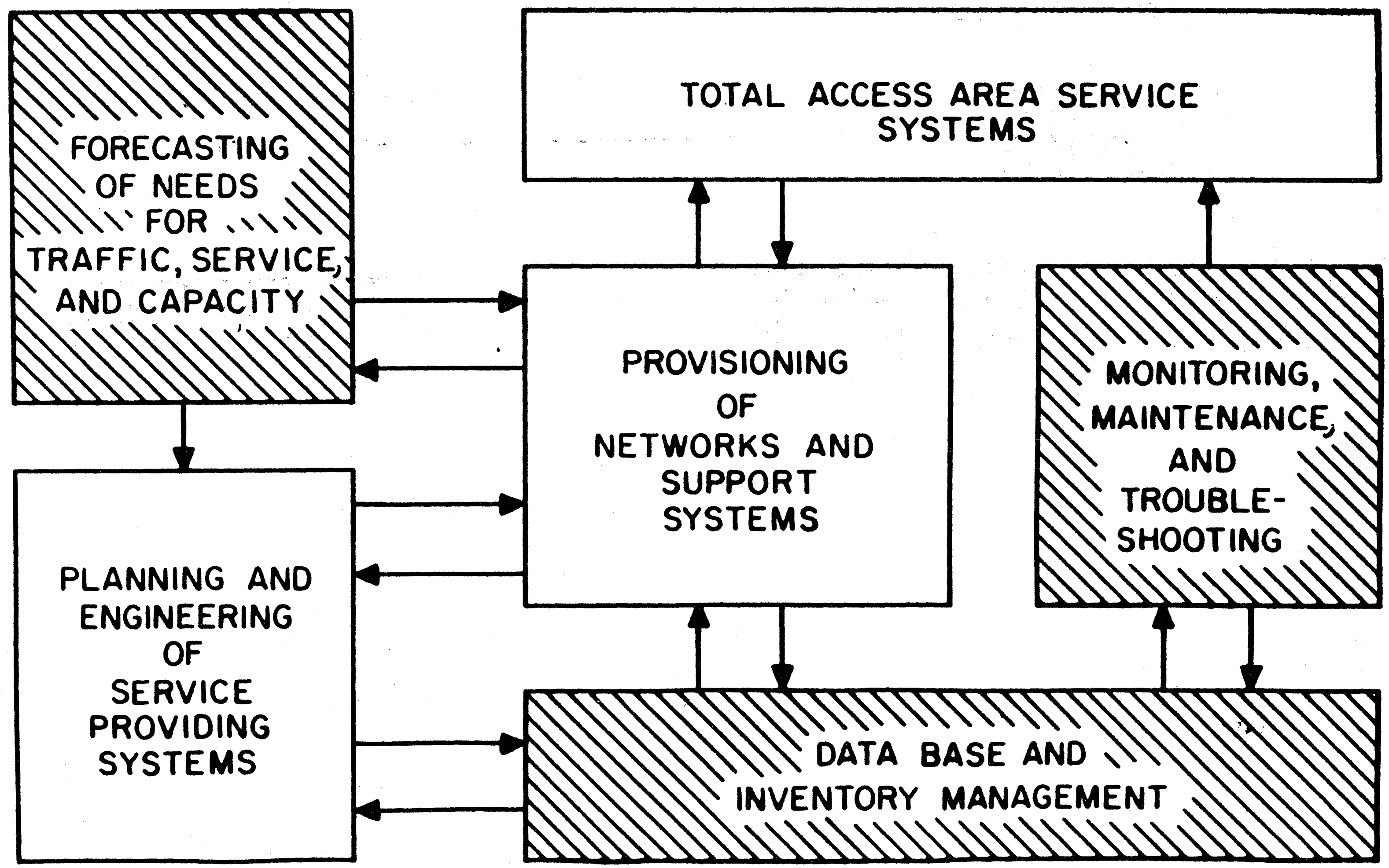


Figure 6-23. Provisioning of survivable and endurable local area grade of service.

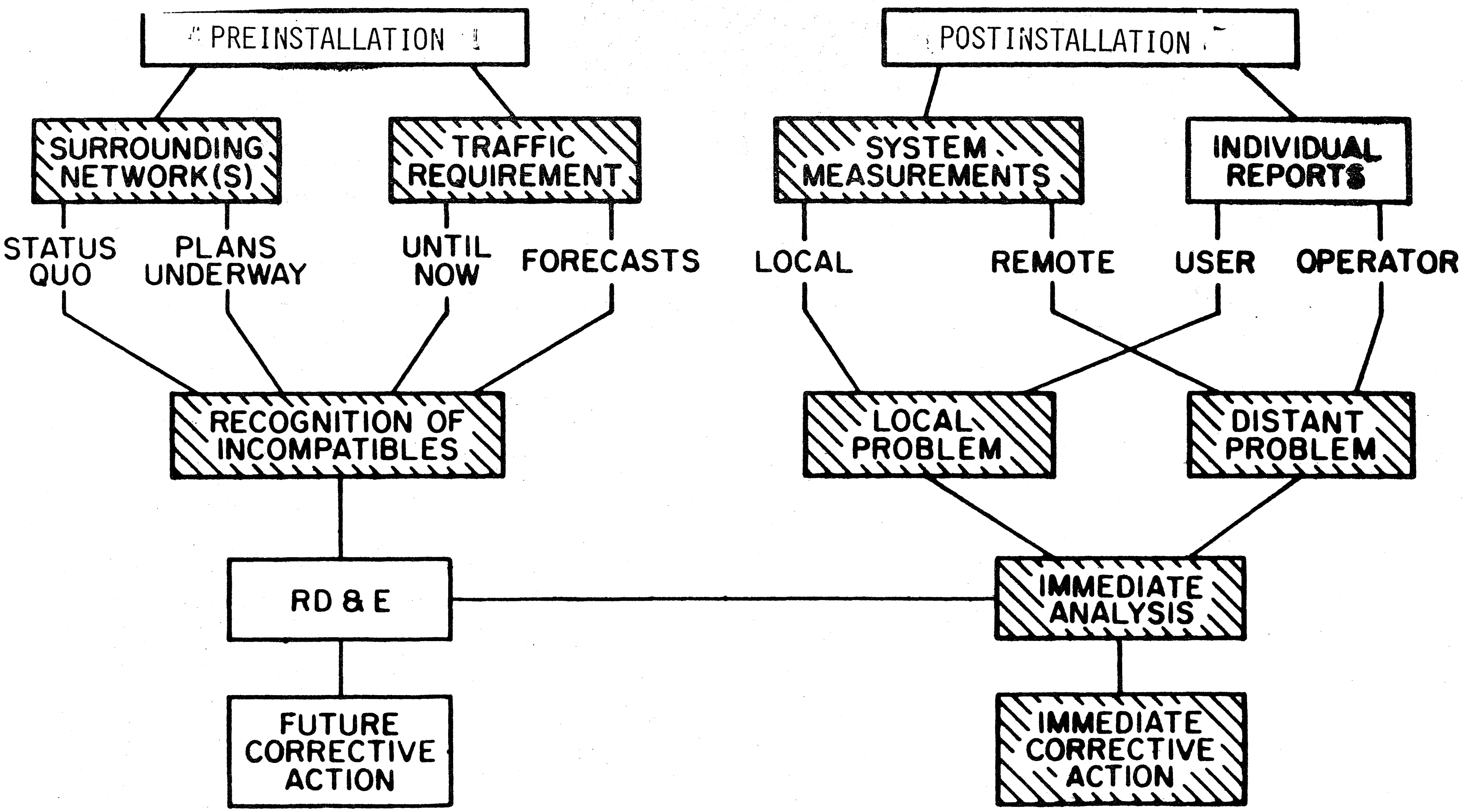


Figure 6-24. Installation problems and their resolution for a typical AA network element.

After installation, the situation is different. Local and remote diagnostics can be automated to varied degrees. The procedure can be called local if it resides entirely in the same access area. It can be called remote if its execution reaches across two or more AA's. Analytical models resident in ADP systems, as shown by darkened squares in the figure, can often identify simple problems and suggest simple immediate actions. Or if uncapable of quick solutions, the postinstallation problem can be forwarded to engineering departments for an in-depth RD&E effort.

Automated support systems are seen to perform many tasks, especially in the future. Separate systems may be resident in locations called the Operations Centers (OC). Since many automated systems will be capable of distributing their control over wider areas, some current manual OC's may be phased out when automation arrives. Other centers may see their functions expanded and modified. For a prognostication of what may be in store, one may look at the PSTN of today. Already before divestiture the Bell System had started an extensive deployment of automated OC's to carry out large and complex system tasks. Not all of them promise to have a significant impact on the military AA's, and certainly not immediately. However, to various degrees some OC's may be serious AA contenders in the future.

Figure 6-25 asks this question in a graphical way. It lists some of the more familiar AT&T automated aids, as identified by application areas (e.g., network, central office) and by the system's acronym (e.g., LMOS or Loop Maintenance Operations System). Since there are many acronyms in this figure, Table 6-5 offers a brief listing of their meaning. It would seem that the Network and Transmission OC systems will have to be different for AA's than for long haul networks. Likewise, in the postdivestiture world under the Special Service OC one should either replace or append Other Common Carrier System (OCCS) with Central Provisioning from Multi-Vendors. Other changes would ensue accordingly.

To emphasize the potential scope of these network related automated systems, one can consider briefly the Total Network Data System (TNDS). It is described in a special issue of the Bell System Technical Journal (Bell Telephone Laboratories, 1983). The TNDS consists of over 100 Operating Systems that encompass 13 major component systems. They cover from local loop/terminal to national network management. Overall, the TNDS is distributed over 38 or more OC's and resides in centralized computer systems, operating company mainframes, and in minimcomputer-based systems. Of the 10,000 (plus) AT&T and operating company switches,

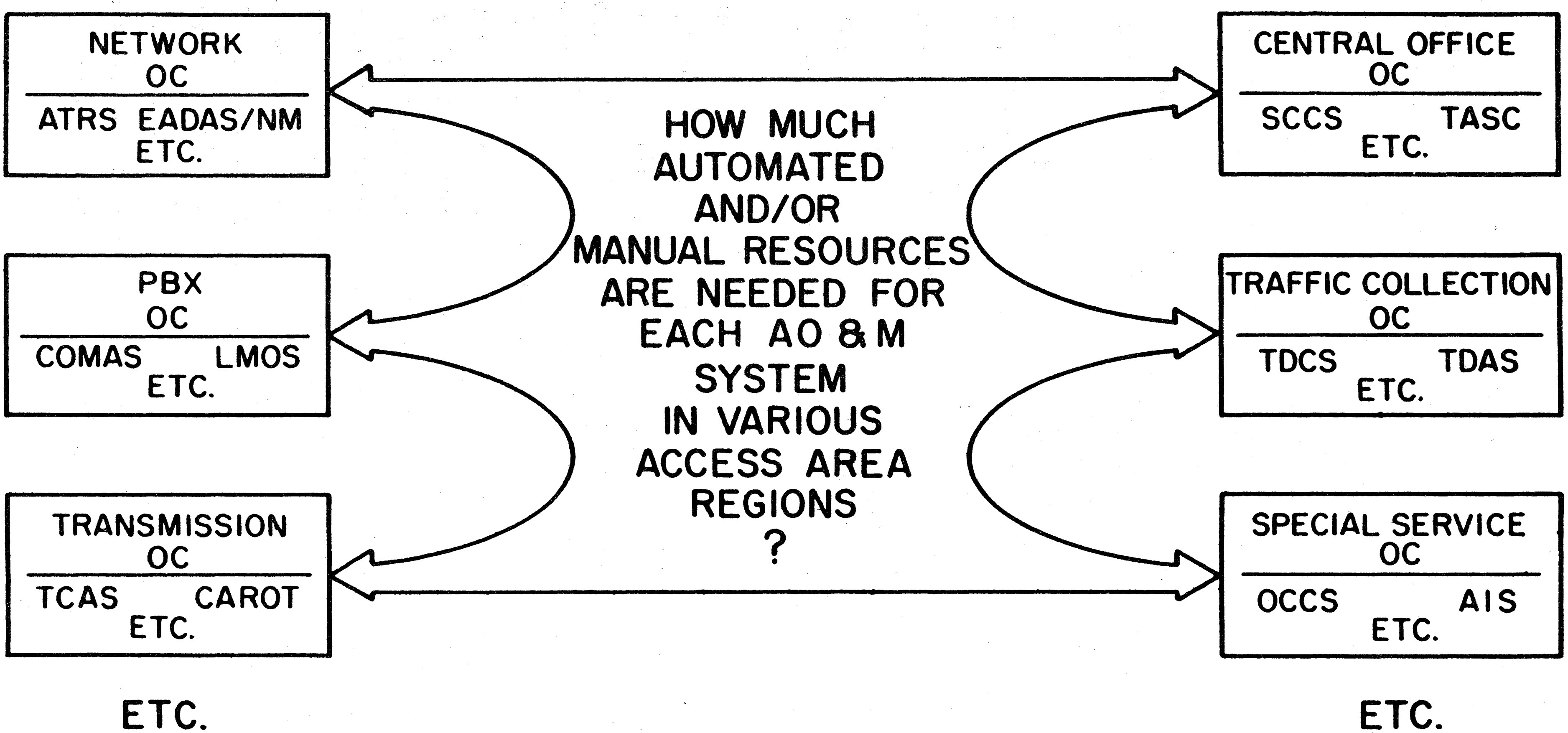


Figure 6-25. Partial list of operations centers that may be candidates for future access area automation.

Table 6-5. Definitions of the System Acronyms Found in Figure 6-25.

AIS	=	Automated Intercept System
AO&M	=	Administration, Operations, and Maintenance
ATRS	=	Automated Trouble Reporting System
CAROT	=	Centralized Automatic Reporting on Trunks
COMAS	=	Computerized Maintenance and Administrative Support System
EADAS/NM	=	Engineering and Administration Data Acquisition System/ Network Management
LMOS	=	Loop Maintenance Operations System
OC	=	Operations Center
OCCS	=	Other Common Carrier System (for Central Provisioning)
SCCS	=	Switching Control Center System
TASC	=	Telecommunications Alarm Surveillance and Control System
TCAS	=	T-Carrier Administration System
TDAS	=	Traffic Data Administration System
TDCS	=	Traffic Data Collection System

approximately 7,000 were connected to TNDS in 1983. At that time (see p. 2168 of the BSTJ special issue), in excess of $2(10^9)$ lines of TNDS software code were generated.

The access areas, of course, have no rationale or need to go after so huge an automated system--at least not yet. However, the writing appears to be on the wall: DSN and AA's should get ready to benefit from the automation explosion of the future.

In the absence of clear-cut numbers for the coming automated AO&M and related systems for AA, one would like to proffer some conclusion and assessment. Albeit qualitative, such an assessment is endeavored in Table 6-6. It contrasts what one expects to be the three leading advantages with three disadvantages.

First, there is the labor expense. With automation, the commercial sector has found ways to reduce the number of clerks, technicians, and secretaries to such an extent as to more than surpass the increased capital needs for the software systems, hardware, and more skilled computer professionals. Item one therefore, appears to be a plus for military access areas as well.

Second, control automation has increased the efficiencies of facilities and subsystems in existing telephone networks. It is anticipated to do likewise in the DSN and its access areas. However, there is a potential problem here. When working close to their ultimate capacity, systems have a reduced margin for error. Trouble can be caused by glitches in the equipment, unsuspected traffic surges, or even by control computer outages. When pushing local AA network efficiencies close to 100% of their relative capacities, such glitches should be planned for. This includes need for quick reaction by humans and machines, plus automated surveillance of traffic, switched network, and control system status.

The third criterion addresses the wisdom of following the technological trends in the marketplace. It may be financially expedient to select from many vendors an ADP item to buy or to lease. However, that does not ensure service survivability in case of war or related stress. In fact, reconstitution and maintainability of automated AO&M systems procured from the multivendor sector represents a big survivability question. It should be investigated.

Table 6-6. Pluses and Minuses of Automation for AA Network AO&M Systems

ADVANTAGES	DISADVANTAGES
1. Less expense for traditional technicians, clerks, and other labor.	1. More expense for software systems and increasingly skilled data processing staff.
2. Increased utilization efficiencies that enable network elements of all kinds to work closer to their design capacities.	2. Increased sensitivity to traffic and equipment irregularities, causing more quick reaction needs for automated surveillance of both traffic and network status.
3. Agreement with the present general trend for future automated technologies and new services.	3. Issues of service survivability in stressed conditions.

7. CSATS MODEL

Geographical consolidation of local services is quite common in the commercial sector for telephony and other modes of telecommunications. To promote a rational quantified methodology for DOD, the erstwhile U.S. Army Communications Command (currently, the Army Information Systems Command or AISC) developed a service area and network optimization model for CSATS.

The computer-implemented CSATS model aids network planners to determine which Government facilities should be included, and which should be excluded, in the local administrative telephone systems on the basis of specified cost elements. As described subsequently in Section 7.1, a mathematical programming formulation is adopted in the model. When executed, it leads via statistically-heuristic hybrid solution techniques to the identification of optimum or near-optimum configurations for local service input scenarios. The criterion for optimality is cost. Several categories of cost, associated with either lease, ownership, or tariffed arrangements, are possible in the CSATS model.

The basic references for CSATS are found in recent Army documentation (Louthain, et al., 1983). Applications to certain limited area optimizations have been made (Priest, et al., 1983; Priest and McCoy, 1984; Louthain and Auchard, 1984).

7.1 Model Description

The CSATS model is a tool geared toward answering the local area question: which potential military subscribers, sites, facilities and/or activities should be included in a--to be specified--CSATS, and which should be excluded. The excluded entities must receive their service from other available vendors and thus are still part of the cost equation to be optimized. In the model, cost is the primary decision variable. Other factors, be they military unique requirements (e.g., survivability) or general concerns (e.g., end-user service), may be indirectly introduced as either "equivalent" cost or as preset input variables.

The total cost is the sum of individual cost elements. In particular, this sum can be broken up into four dominant costs:

(1) the total excluded (non-CSATS) site costs

(2) the total CSATS personnel costs

(3) the total CSATS backbone (i.e., interface to the outside world) costs

(4) the total CSATS system hardware and software cost.

The four cost classes, (1) to (4), are not exclusive, not independent, and can be approached as long lists of many cost subelements. Ownership and lease considerations are factors common to all four.

As an example, consider the problem of including or excluding a site S into a service area of a hub switch H. Depending on number of subscribers, traffic generated, and local plus distant communities of interest, the inclusion of S can decrease (1) by an amount to be determined. At the same time, items (2), (3), and (4) would be increased by inclusion of S. The model is capable of calculating the economic effects of such exclusion versus inclusion, by going through a comprehensive list of major and minor cost elements. But, the model can do much more. For instance, it can treat a long list of sites, $S_1, S_2, \ldots, S_N$, with different characteristics and calculate their impact when an arbitrary subset is connected to the hub. By using a random trial (Monte Carlo) methodology, the model seeks the most cost-effective service subset to the given hub. This statistical method of search is by no means exhaustive. However, if repeated a sufficiently large number of times--say in the 100 to 1000 range--one has increased confidence that the best realized arrangement is near the ultimate optimum.

A number of assumptions are made to make the model simpler, easier to apply to various geographies, and less dependent on a myriad of obscuring details. The key assumptions are:

(a) Network connectivity architecture is assumed to be the one level distributed star. There is a single hub at the center of the star and the remote (included) switches concentrate all their traffic through that hub. There are no direct tie-lines between remote switches. Individual subscribers home on exactly one switch, the latter being a remote switch or the hub itself.

(b) A potential site and subscriber list forms the initial list from which a certain subset is selected for inclusion in the star network. The to-be-selected facilities need not be adjacent, geographically homogeneous, nor must they belong to the same community-of-interest. It is the job of the cost-optimizing algorithm to identify entities that constitute the best CSATS configuration.

(c) Any type of switch may be specified for the hub (or concentrated gateway), which has a preassigned location. Only three remote switch types are permitted. This allows different manufacturers, call-carrying capabilities, numbers of lines and trunks, costs, as well as specified needs for maintenance. Switches may be existing or new, purchased, or leased.

(d) The determination of the number of trunks in each trial configuration can be done by several means: (i) For known offered traffic using Erlang GOS tables; (ii) for unknown traffic, standard telephone company estimates may be utilized; (iii) or the number of trunks can be preassigned, as would be the case for already existing installations.

(e) Community-of-interest assumptions on traffic seem to emphasize the preference of CSATS for far away traffic and deemphasize local CSATS traffic.

(f) To estimate AO&M costs, the model allows different category costs for managers, administrators, switchboard operators, and maintenance people. This personnel requirement cost avoids use of automated AO&M systems, is claimed to be quite simplistic, and thus is "the weakest part of the operating model."

(g) It is assumed that CSATS implementation nearby, or for that matter anywhere in the CONUS, has negligible effect on the excluded (non-CSATS) sites, their services, and costs.

(h) Since the number n of unique entities that are candidates for inclusion can be in the hundreds or thousands, and the total number of all their combinations is 2^n, an exhaustive search over all possibilities is out of the question. Instead, a statistical search over a random sample in the n-dimensional space is assumed. If one wishes, selected fixed n-vectors can be entered and their relative optimality compared with others.

(i) Large numbers of random trial runs unavoidably lead to expensive computer usage. The indicated maximum number of run limits are around a thousand combinations for up to 120 remote switch sites and around ten thousand combinations for up to 240 subscriber activities. Any or all of these sites or activities may be preassigned or left to be randomized by the program. It is also claimed that the true unknown optimum configuration is either very near the best found network solutions or, if not, its cost sensitivities are uniquely isolated or perhaps degenerate, thus constituting an undesirable risk in implementation.

(j) The automated model is implemented in a large software package, written in FORTRAN, but as quoted by its authors is "not user-friendly." It requires in excess of 170K of CDC 6500 memory.

The user of the CSATS optimization model deals primarily with the input and the output of the model. Thus the functional application of the CSATS is as illustrated in Figure 7-1. So far the discussion here has dwelt on the model itself. In the remaining part of this section, a brief description of the input and output is offered.

The input preparation and specification for CSATS is not a minor issue. There are some 170 parameters or items to be entered. This task can be broadly divided into seven parts or major sets. The scope of these parts is outlined in Table 7-1. If a certain item is not entered, default values will be provided whenever possible by the model itself. However, if impossible, the user is prompted to provide the necessary input data. The details for the input are beyond the scope of this outline. They may be found in the CSATS documentation and especially in the User's Manual (Louthain, et al., 1983).

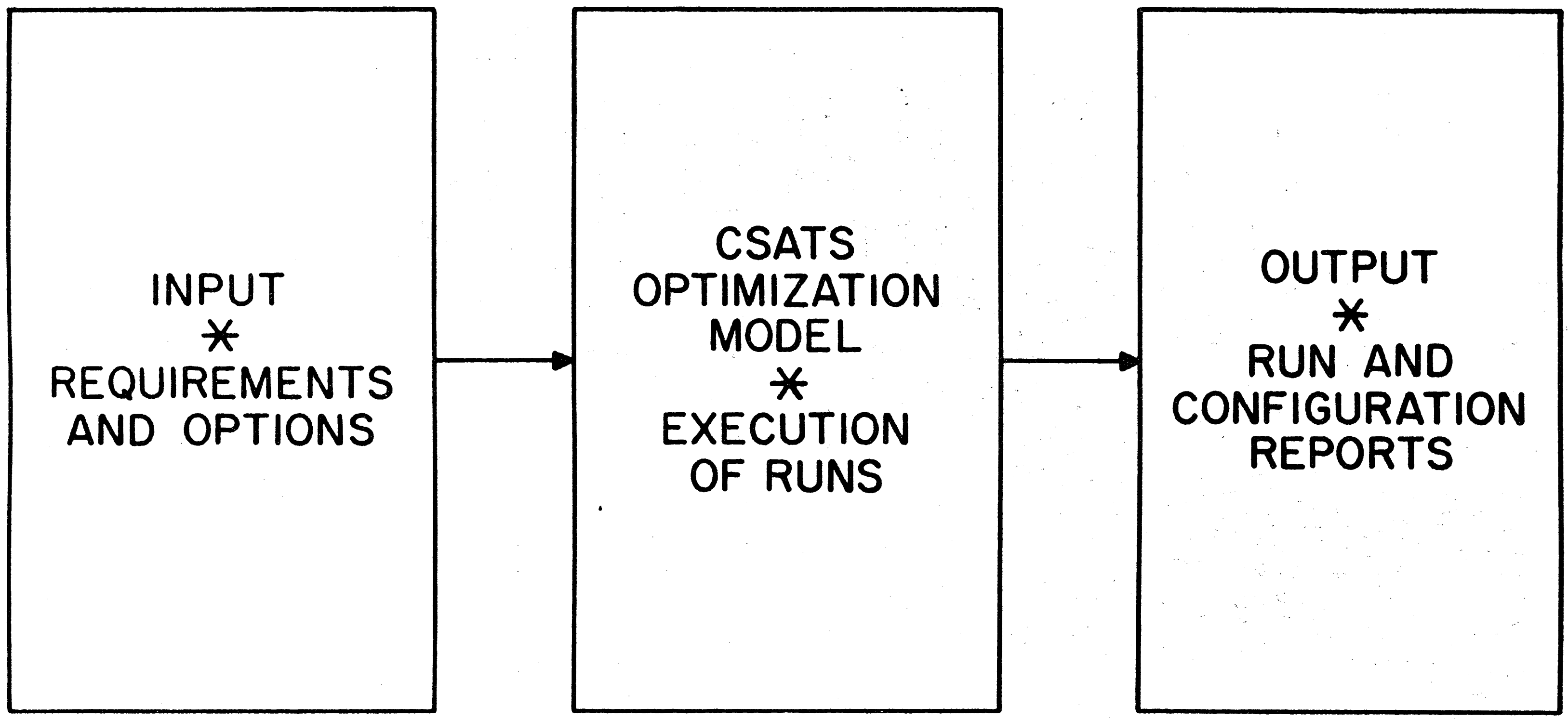


Figure 7-1. Functional application of the model.

Table 7-1. Overview of Input Requirements

Major Input Sets	Number of Items	Data Detail Examples
I. Run Options	17	Run Identifiers, Nomenclature Sample Sizes, Random Seed Plot Options WATS Factors Etc.
II. Basic Parameters	38	Switch Data PBX, Subscriber Data Fixed, Variable, "Bump Up" Sizes Etc.
III. Subscriber Detail	14	Site Locations Line Requirements Site Nomenclature Etc.
IV. Tariff Data	26	Private Line Intra/Interstate Fixed Monthly Connectivity WATS Rates Etc.
V. General Cost Data	20	Existing and Lease Flags AO&M Factors AUTOVON and FTS Outside Plant Etc.
VI. General Traffic Data	25	Number of Different Lines/Trunks Offered In/Out CCS DDD, AUTOVON, FTS CCS Etc.
VII. Foreign Exchange Data	32	FX Number of Subscribers FX Traffic Records FX Mileage Etc.

Two types of output are generated by the model. They are the Run Reports and the Configuration Reports. The Run Reports commence with a repetition of entered input data and continue during the run by informing the user of the progress made in the execution of the run. Assuming that everything progresses satisfactorily, the execution of the model produces the real output--the sought after configurations, their costs, and numbers pertinent to them.

The Run Report essentially covers all or most of the entered items listed in Table 7-1. This includes flags that identify such conditions as purchase/lease, existing/new, or, if data is not specifically entered, the default values used by the model. It summarizes in uniform tables the number of trunks, number of subscribers, the known or estimated traffic in CCS, and associated line (mile) capacities at identified remote switch sites. In summary, this listing represents a correct acceptance and augmentation by the model of the input data. And that includes cost breakdowns that are known to exist at all the lesser switches considered. These are one-time or yearly (or even 10 year) committed equipment costs, yearly per line or per trunk costs, one-time outside plant costs, yearly personnel costs (broken out separately for management, administration, switchboard operators, maintenance, and so on), and other identifiable cost items.

Judging from the available documentation, the time consumed for input data processsing amounts to several seconds. This is followed by the cost configuration runs that appear to consume around a minute per each sample run. As noted earlier, individual runs can address preassigned configurations or they can go after unpredictable sample configurations that are picked by Monte Carlo method from the random seed identified in Table 7-1.

As the number of sample runs increases, from 10 to 100 and so forth, a significant amount of computer time is consumed. It is therefore quite reasonable to limit the number of sample runs to, say, 100. At the conclusion of these 100 runs, the model has generated a hundred cost profiles for these hundred connectivity samples. For local area networks of reasonable size the connectivities are quite distinct and their costs differ from each other. The one particular network with the <u>lowest cost</u> is identified as the Optimum Configuration.

Several issues pertain to the computed Optimum Configuration:

- Depending on statistics of random events, the <u>true optimum</u> may differ by an unknown amount from the computed one. However, one must recognize that both true and computed optima exist only for the given model and its preassigned input data. Since both are imprecise in practice and rapidly changing in the technological, economic, and military sense, the distinction between optimum networks may be blurred.

- Military unique requirements may dictate changes or indicate configuration preferences that differ from the computed Optimum Configuration.

- The costs of existing network layouts should be and ordinarily are part of the search for the lowest cost network. Due to the dynamic nature of telecommunications, if the proposed new "optimum" does not lower the cost by 10% below the existing, then the prudent thing may be to make no major changes. Leave the network as it is.

- If the model user realizes that a particular cost element of great concern at location X is not properly incorporated in the model, the model appears to allow additional cost items. An example may be the Post D&D tariffs. Because of their volume and complexity, automated data bases may be needed, as may be an unspecified amount of software changes.

To conclude this section on the CSATS model, the following output illustrations are presented.

First, as the model either randomly or deterministically processes configurations and computes their costs, a large sample set of cost numbers is generated. The frequency distribution of these costs can be plotted with the plotting routine that is part of the CSATS model. An example of such a plot is shown in Figure 7-2. Here the abscissa represents the total 10-year configuration cost in units of 10^7 = $10 million. The ordinate is the frequency or density of the number of configurations that have produced the cost numbers on the X-axis. In this plot of Figure 7-2 one is primarily interested in the lowest possible cost. Thus, the configuration that yields the lowest value (in this plot around $50 million) is the "optimum" of those considered. Whether one can find other configurations that produce even better results, and say reduce the cost to $45 million ,is not known. One could attempt to answer this question by exhaustive runs, but the cost of such a program appears prohibitive in all practical cases of interest.

A second plotting capability of the CSATS model allows the user to display network configurations that either already exist, or are optimum, or even suboptimum. An illustration of such a configuration plot is given in Figure 7-3. This particular plot, not necessarily related to the frequency polygon in Figure 7-2, was derived for the Boston Defense Metropolitan Area Telephone System (DMATS) study and represents the lowest (optimum) total cost over 10 years. Note that both axes in this figure are miles. The plot can be accompanied by various qualifiers and details--both in print-out or on the same plot--that identify and describe the sites considered. These may be the minimal site set, required remote switch locations, potential remote switch locations, hub switch site, identification of remote switch type, and other area sites.

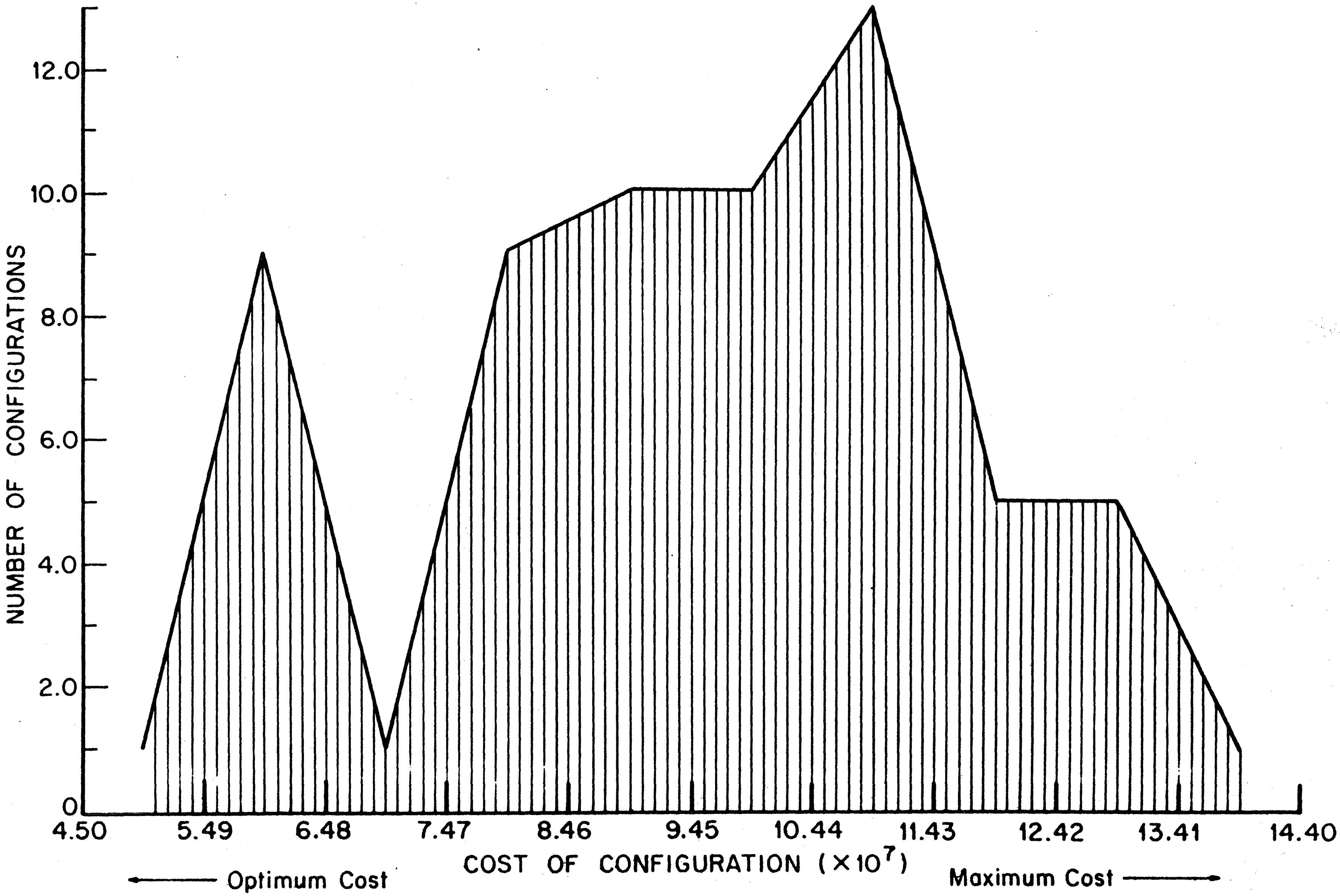


Figure 7-2. Frequency polygon for alternative configuration costs (Louthain, et al., 1983).

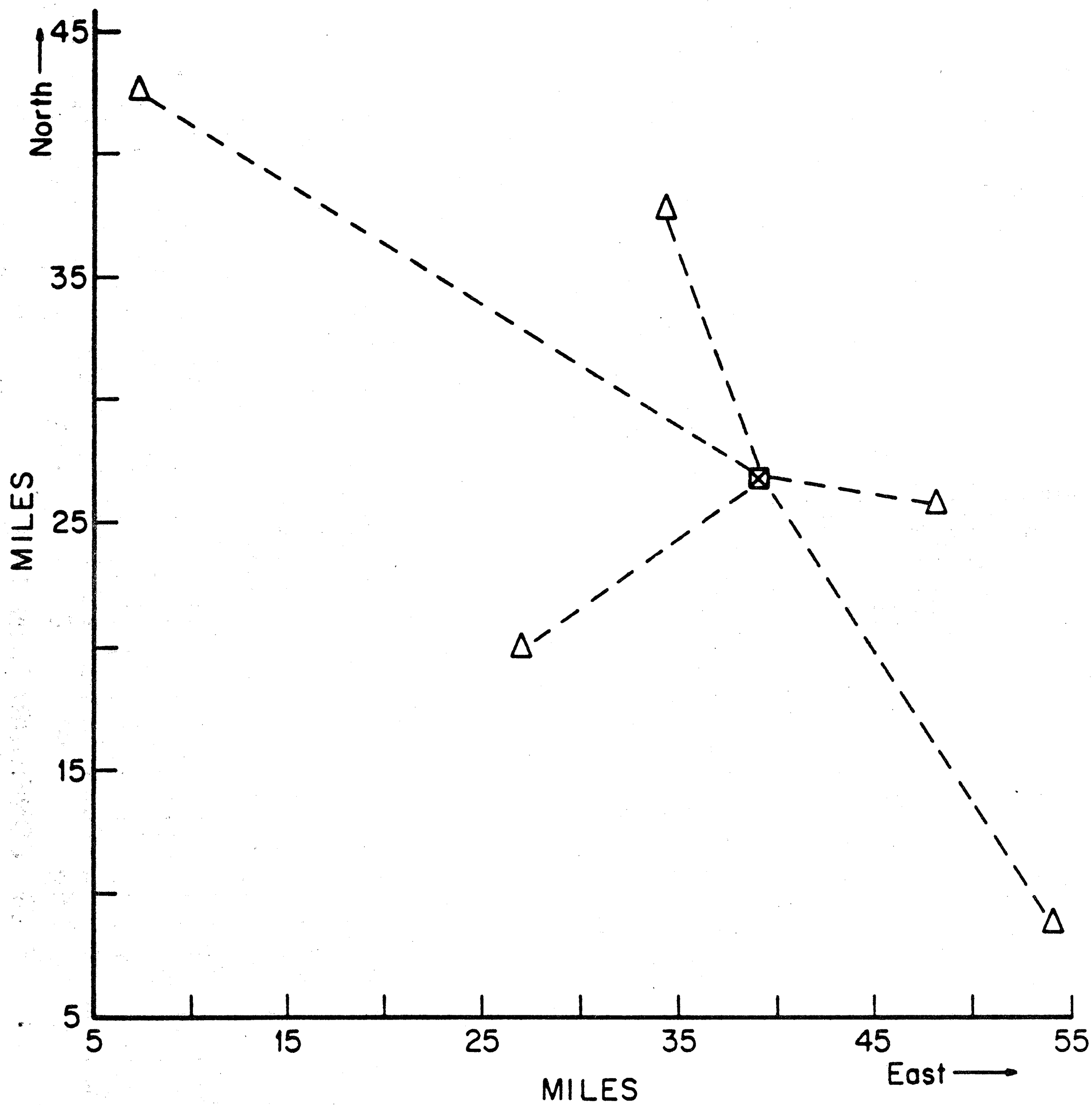


Figure 7-3. Optimum configuration for telephone system sites (Louthain, et al., 1983).

Every configuration, be it optimum or suboptimum, is within a potential service area of a hub. Moreover, when certain remote sites are included in the consolidated service of that hub and others are excluded, one ends up with so-called, orphan switches. This possibility is illustrated in Figure 7-4, where solid black circles denote included switches and empty circles denote orphan switches. As stated earlier, the orphaned remote switches are not served by the hub. Instead, they home to other nearby tandem or end offices. The cost of the orphan service is an integral part of the total cost optimization process.

7.2 Limitations and Constraints

The CSATS model appears to be a very valuable tool in the development of telephone network configurations and optimal coverage of given service areas. The general characteristics of this model were described in Section 7.1. A scrutiny of these characteristics reveals certain limitations and constraints that are likely to surface if the CSATS were to be used as a quantitative access area definition tool.

One of the first limitations to be noted, see Figure 7-4 and elsewhere, is the star network architecture with a central switch, or hub, at its center. This does not allow for a critical user's homing to several hubs, or for generally alternate access to the backbone whenever the one hub experiences operational difficulties. Lack of multiple homing raises the issue of service survivability for the local areas. It must be addressed in future applications of the CSATS optimization model.

Another constraint of the optimization program is the built-in assumption of a known fixed location for the central switch. There may be regions where considerable economic or other advantages could be the result of relocating the central hub. This issue is illustrated in Figure 7-5. Clearly, if only a few selected sites are candidates for hub relocation, there may be enough time and resources to do computer runs for each of the candidate sites. However, as the number of potential sites increases one becomes more and more interested in an enhanced algorithm that would more rapidly identify the most promising sites for hub relocation, and, perhaps by some heuristic method yet to be developed, estimates the cost sensitivities of hub displacements.

Given an arbitrary service area, the assumption of a single hub may be challenged on logical grounds. Perhaps the area is too large and two, three, or more hubs would offer cost and technology advantages. The possibility of adding an extra hub without modification of the total area is depicted in Figure 7-6. Note that if single homing is still the rule, then to the exclusion of orphans, two hubs must imply two separate service domains in the area shown.

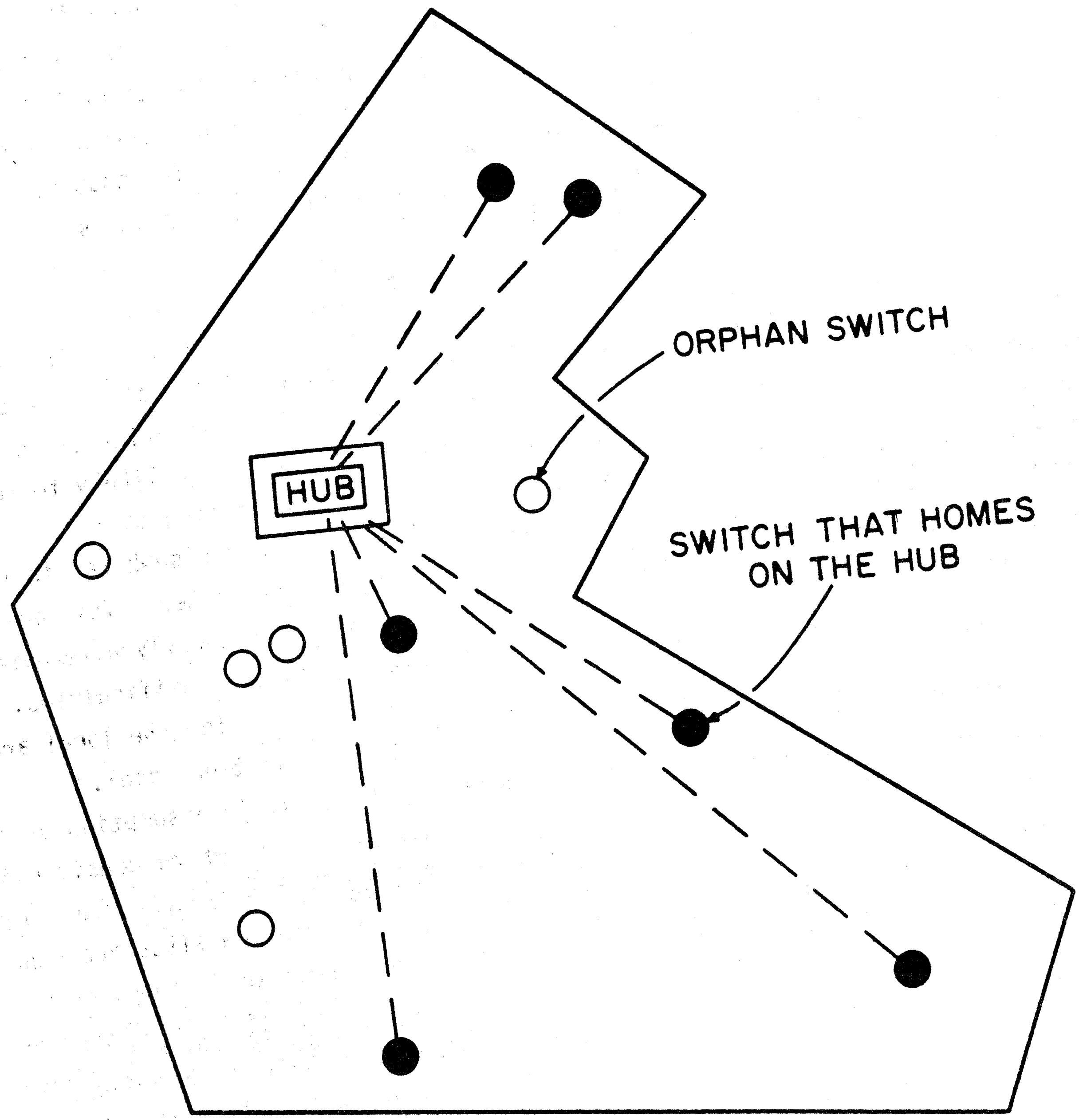


Figure 7-4. Included and excluded (orphan) remote switches in a service area of a hub.

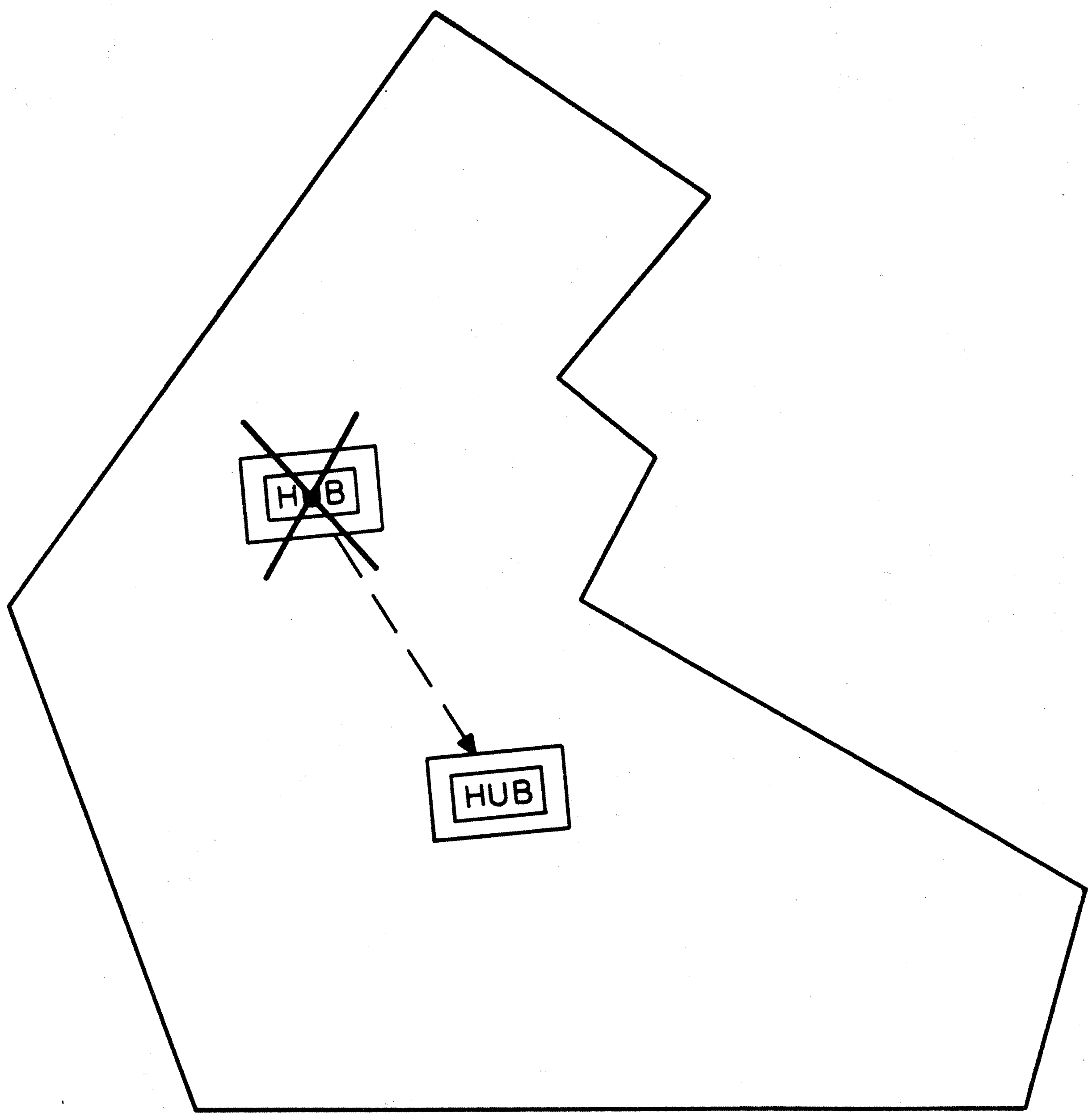


Figure 7-5. Relocation of the hub.

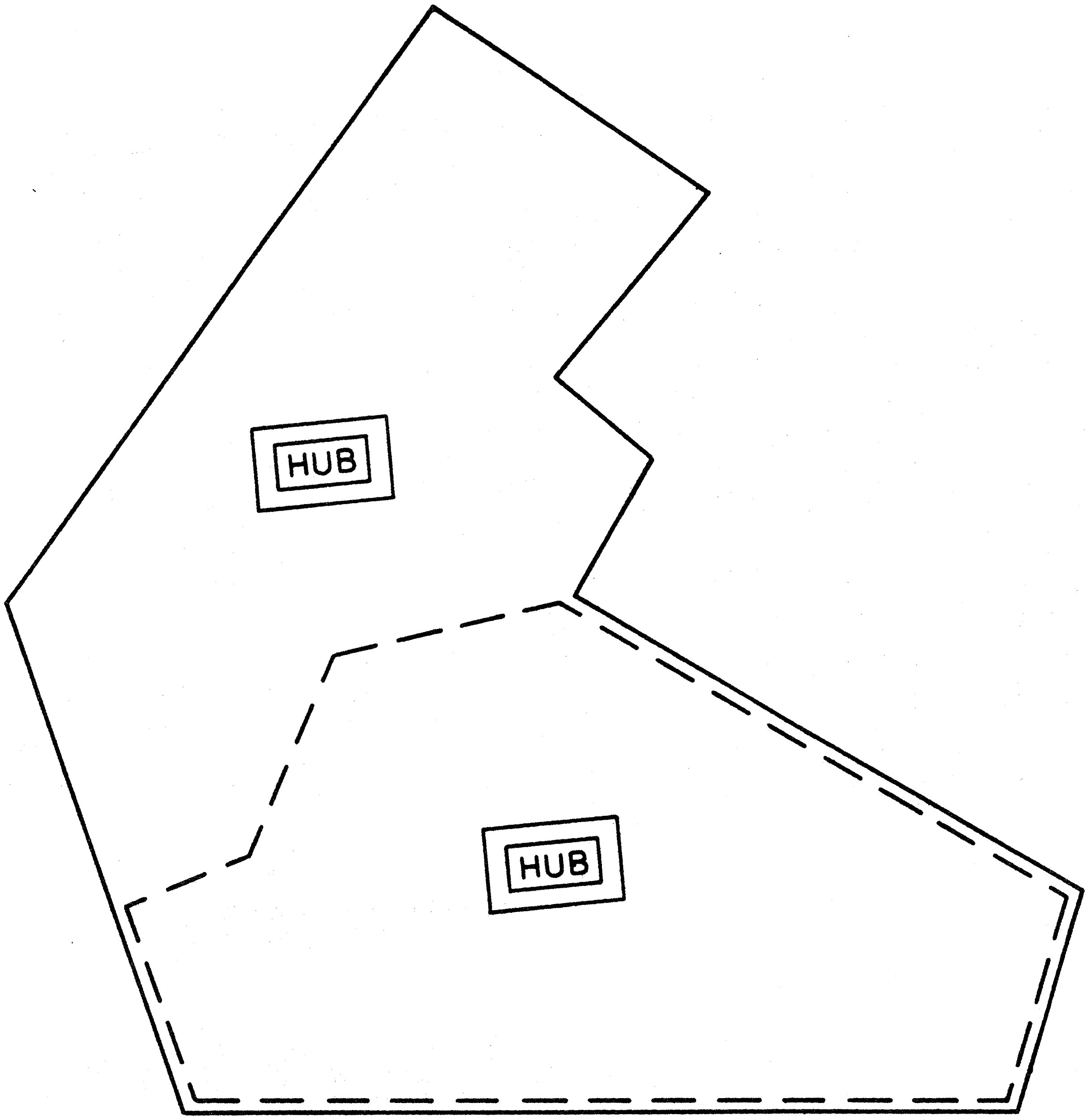


Figure 7-6. Introduction of additional hubs leads to separate service areas.

Of course, addition of arbitrary hubs may modify the access area boundaries in several ways. One can envision new subareas added to the hub or hubs in question, while some other subareas are deleted. The simplest of such possibilities is illustrated in Figure 7-7. At issue is the identification of two types of sites: those whose addition would benefit, most likely, if jointly considered with the subtraction of other sites from the hub service area.

While on the subject of CSATS limitations as they pertain to access area modification, it may be prudent not to overlook the removal of economically unjustified hub switches. When this is done, some previously serviced remote switches may become orphaned. They may be left in that state, i.e., at the mercy of the local public telephone networks and their facilities, or they may be connected to the fringes of other nearby hubs. In this manner, see Figure 7-8, except for abandoned orphans, the remote switches become dissolved and absorbed into other areas of service.

One can continue the identification and listing of CSATS weaknesses, but that type of exercise is inherently unfair. The point is that the Monte Carlo method is just one approach to what is generally recognized as a complex and difficult problem. To make the procedure practical and affordable in terms of computer time and money, simplifications have to be made. And as far as we know, some such constraints have to be enacted on all other heuristic large network design methods or the problems grow too big to handle.

7.3 Optimization Criteria

One would like to assert that an access area and its network can be defined and perhaps implemented according to some comprehensive quantified and optimized criteria. Unfortunately, that assertion is far from reality. While dollar numbers are certainly quantitative, there are other factors that are basically qualitative and subjective in character. For instance, survivability, restorability of service, adaptability to stress management, various military unique requirements, service quality, probability of blocking GOS, delays, etc., are but selected parameters whose mapping into dollars has been the subject of uncertainty and disagreement.

Let us assume that some "equivalent cost" criterion, such as the CSATS total cost, is agreed upon. Unfortunately, this does not imply that the optimization problem is now trivially solvable. The next difficulty centers on the meaning and usefulness of an optimum configuration. The point is that the configuration labeled optimum is no more than a goal architecture. It represents a target to

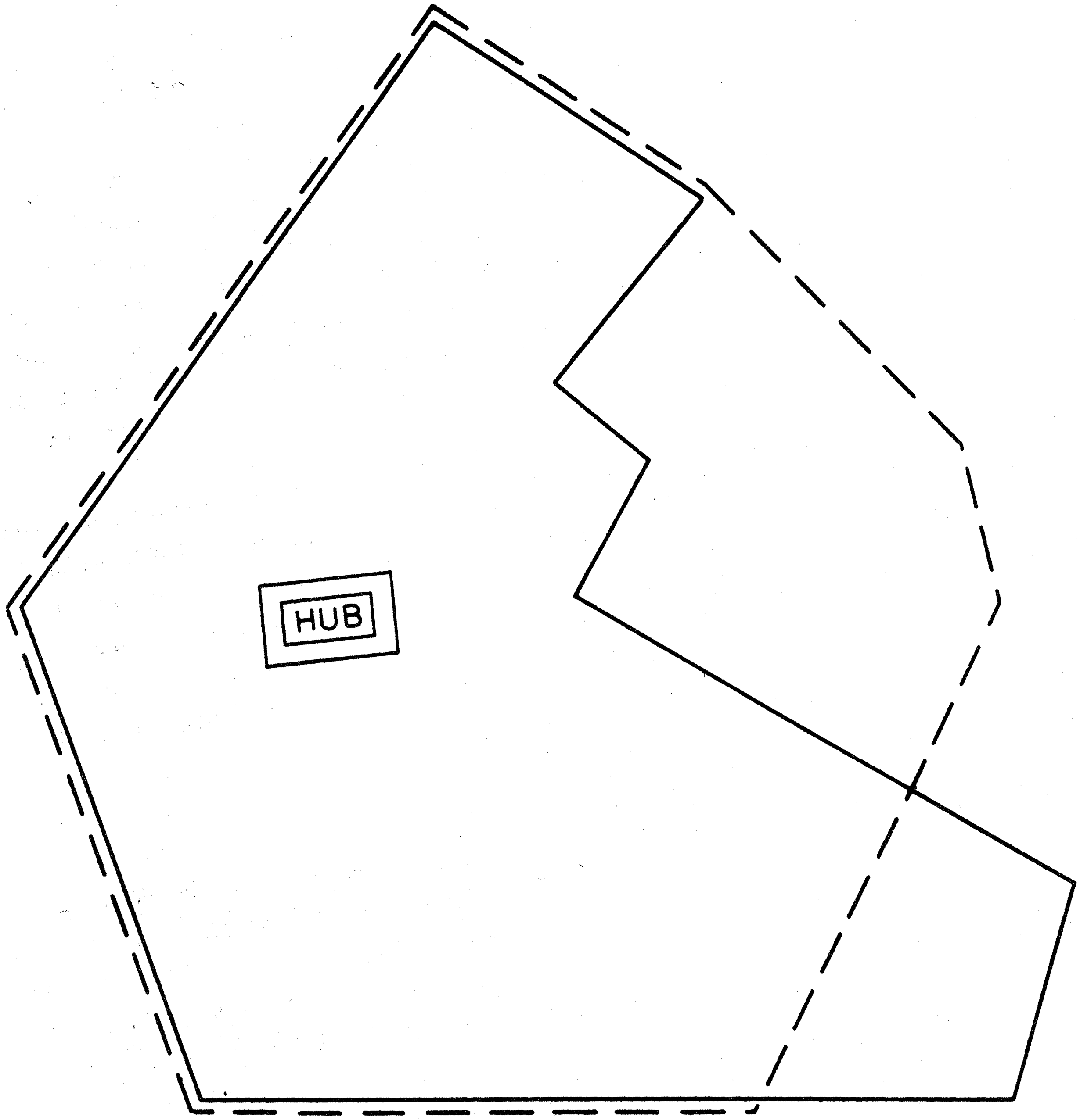


Figure 7-7. Modification of a hub's service area.

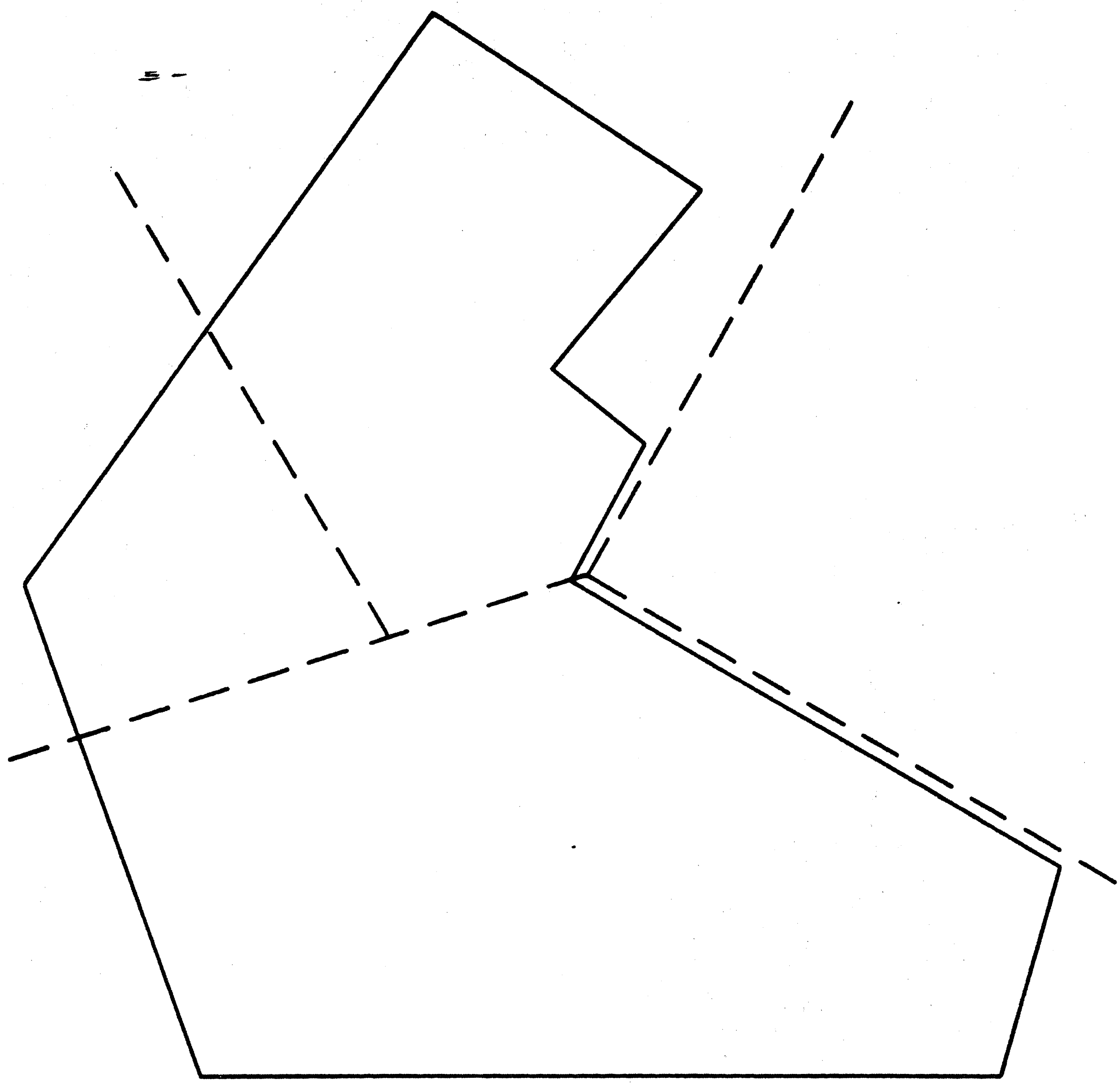


Figure 7-8. Dissolution of a service area.

shoot for. How one advances toward said goal, how many years should the activity take, what is the preferred funding strategy, and so on, are questions neither asked nor answered in the CSATS model.

Given a goal architecture, a traditional approach has been to establish an annual expenditure profile and to approach the goal in steps consistent with said profile. In as much as the budgetary policies of different military departments are known to differ, the transition profiles may have to be individually optimized for each local area.

8. RECOMMENDATIONS

The first thing to stress is that this study does not recommend any particular definition for all access areas. Nor does it recommend any fixed structure or formalism for such definition, as would be the case if one were to revive the previously once popular DMATS concept. What this study does recommend are methods of characterization for the local service area networks. The total outlook of this methodology is to be comprehensive, so as not to shortchange the future requirements while attending to the complex details of present day-to-day affairs. At the same time, the current Post Deregulation and Divestiture telecommunications situation, rules, and tariffs, are to be emphasized and further changes forecasted when possible.

It is recommended that quantitative (i.e., numerical and factual) methods of local network optimization be pursued. The general framework is to be as outlined in Figure 8-1. In the center of the plan one is strongly advised to put and to keep the network optimization process itself. Its function is to generate one (or more) optimal (or near optimal) network designs for each candidate area.

The recommended composite process requires several inputs. First, on the left side of Figure 8-1, one finds the human interface. It is needed to:

(1) List known network design input data, such as geography, subscriber classes, traffic statistics, given or fixed MILDEP quantities, and others.

(2) Provide boundary conditions and broad bounds for design variables or unknowns (e.g., maximal or minimal region sizes, initial or annual costs, survivability concerns, etc).

(3) Take a first look at the problem to ascertain whether a quick, perhaps obvious, solution may be apparent.

(4) If negative on item (3), decide on computer related resources (i.e., money and time) to be allowed for the computerized network optimization runs.

(5) Select the appropriate algorithm, or a sequence of algorithms, to be run within the constraints of item (4).

(6) During the execution of a particular algorithm, monitor the progression of partial results.

(7) Inspect the final output lists and graphics and assess both their veracity and their usefulness to the network optimization tasks at hand.

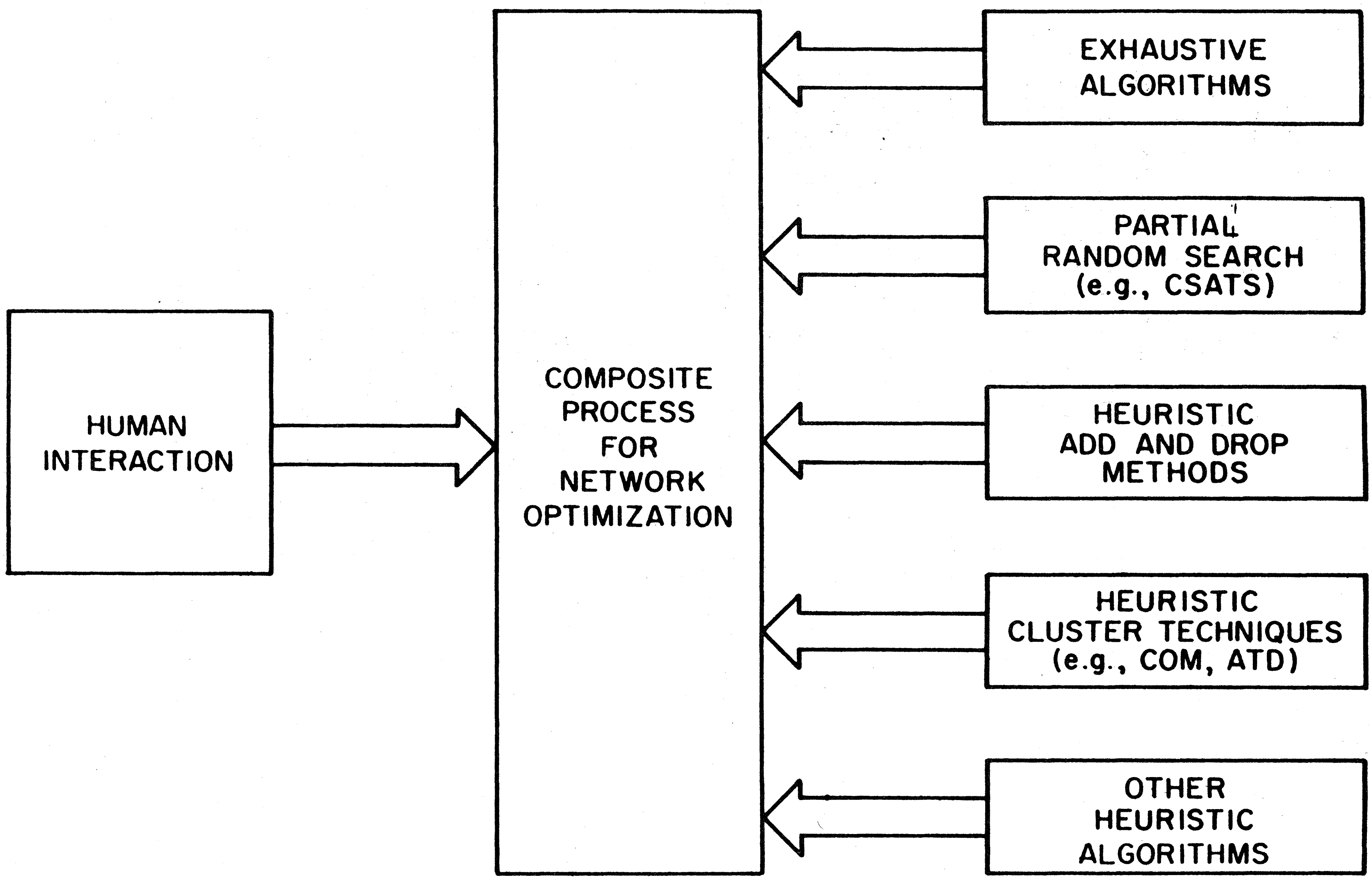


Figure 8-1. The network optimization framework.

From the above, it is recognized that the central composite process for network optimization (see again the center of Figure 8-1) should be an orderly selection, execution, and supervision of any of several algorithms. There are five algorithmic blocks identified on the right side of the figure. None of them appear by themselves to be the exclusive answer to the access area network optimization problem. From the documentation available to the authors, the random search of the CSATS method seems to have an advantage today. It is therefore the recommended algorithm here. In the future, or given other algorithmic tools, occasions could certainly arise where other algorithms could come to the forefront.

Specific scenarios may call for specific considerations. For example, if local configurations are small, containing only a few nodes, then exhaustive techniques may be quite practical. Or, if the nodes form a repetitive or symmetric topology, the human analyst may recognize that there are basically only a limited number of distinct equivalence configurations. Then again, exhaustive methods may be possible.

For larger networks the exhaustive task can grow faster than a simple polynomial in n (where n is the number of nodes). The CSATS model, which uses random search or Monte Carlo methodology, is to be recommended over all heuristic methods identified in Figure 8-1. The reason for this is as follows. Algorithms, such as ADD and DROP, were created primarily for computer networks (Kuehn and Hamburger, 1963; Feldman, et al., 1966; Schwartz, 1977; Tanenbaum, 1981). Substantial modifications and enhancements appear necessary to make said algorithms suitable for the local telephone problems. Likewise the heuristic techniques, such as the Center of Mass (COM), or the Average Tree--Direct (ATD), or similar methods, all appear to be too computer/communications network related. The CSATS model, on the other hand, pertains to telephone networks. It already exists as part of the U.S. Army Imformation System Command assets. It should be utilized to the extent reasonably possible and not be subject to reinvention or duplication, fully or in part. However, if appropriate, it could and should be improved.

The list of potential CSATS improvements is presented in Table 8-1. The list identifies six improvement areas labeled (A) to (F). Not all areas are of equal importance and there may be issues that are left out in such a short table. Also, this being an initial listing of recommendations, new and quite significant improvements may be uncovered as the CSATS model is worked on.

Table 8-1. Recommended CSATS Improvements

Improvement	Description and Scope	Urgency
(A) Extensions of Network Model	Multiple homing. Arbitrary number and location of hubs. Variation of service areas.	A real technical need now
(B) AO&M	Automation versus manual operations. Combinations and tradeoffs. Software. Centralization versus distributed control, maintenance.	Technical need before 1990
(C) Military Unique Requirements	Survivability. MLPP. Data bases for MILDEP traffic types, volumes, and communities of interest. Future operational plans and forecasts.	Up to the MILDEPS now and in the future
(D) Post D&D Environment	Automation of tariff data bases. Additional custom cost items. Lease versus purchase options.	Present need to sharpen cost projections
(E) Heuristic Short Cuts	Heuristic subroutines to shorten computer runs. ADD, DROP, clustering, and other algorithms. Triangulation, isograms, etc.	Present and future pressure to reduce CSATS computer costs
(F) User Friendly	Easy input, output, and operator interaction. At host and remote locations.	Mainly for future popularity with users

Improvement (A) deals with extensions and modifications of the network model. This is a technical tool needed now. It will enable treatment of topologies different from the current star/star architectures. In particular, it should permit areas to include one, two, and, if need be, three hub switches. These could be single function (i.e., tandem to outside world only) or double function (i.e., tandem plus local service). The locations of the hubs should be either given parameters (as it is in the present generation CSATS for a single hub), or they could be variables to be determined in the optimization process. Under item (A), multiple homing should be allowed. Remote switches should be capable to deploy trunks to several hubs and hubs should have capability to exit an area via several gateways. This multiple area connectivity, while departing from the star/star layout, would provide means to survey a family of networks that have significantly different survivabilities. Finally under (A), as the number of hubs is varied, so perhaps the local service area itself and its boundaries should be varied. Details of these technical issues and a listing of recognized CSATS limitations were reviewed earlier in Section 7.2.

The second grouping of proposed CSATS improvements pertains to AO&M, plus overall network management (NM). In the present, as was the case in the past, the AO&M functions for military local networks are performed manually by skilled personnel. If this manual mode is to continue in the future, its various full and partial deployments must be realistically included in the CSATS. The alternative to manual operation is, of course, automation. The economic advantages of modern data processing to access area AO&M may not be as significant now as is the case for the nationwide merged switching and transmission network. However, the general trend toward automation is so pervasive and the software developments so rapid, that this is a promising area to watch. Specific areas to incorporate in the CSATS are: various combinations of automated and manual operations, different software packages and their updates, as well as centralized and distributed AO&M functions over a large range of region sizes and shapes.

The third CSATS improvement, item (C), is to incorporate military unique requirements. Issues, such as survivability, MLPP, MILDEP traffic requirements, and deployment plans, belong in this category. It is up to the MILDEPS to decide which factors are to be included, then provide for their quantification as objective numbers so that they can be fed into the automated CSATS model. Otherwise these factors will remain subjective and qualitative elements for human manipulation, not excluding the interactive human role in Figure 8-1.

The fourth recommended improvement for CSATS is (D), the automation of Post D&D economy and tariff data base. To reflect the business environment for military telecommunications, an extensive automated data base must be availed to the CSATS model. At the least, this data base should provide instant access to:

(1) Common Intra-LATA Interstate Rates.

This includes direct-dial message toll services, their discounts and surcharges. Private-line rates for all series 1000, 2000, and 3000 channels, including their mileage, termination and applicable arrangement charges. Point-to-point DDS.

(2) Intra-LATA Intrastate Rates.

For all states that contain one or more access areas, this should include all rate elements listed under item 1. Plus local loop and line, two-wire and four-wire, available equipment/feature, maintenance Service and Equipment charges, and available options.

(3) State Maps and Available Services.

Maps show LATA boundaries, numbers, and their overlap on local operating telephone companies. Also points of presence for various Common Carriers, Resale and Other Carriers, and their pending future availability of services.

(4) Inter-LATA Rates.

This includes all series of private-line services available from various carriers, such as AT&T-C, MCI, GTE, USTS, WU, SBS, and other satellite services. Lease of related equipments. Measured use services from the above and other carriers, as well as WATS rates.

(5) Purchase and Lease Options.

Purchase versus lease is an important tradeoff for transmission, switching, concentration, multiplex, and related hardware and software. The data base should be as updated and as complete as is possible. It should include a listing of prices plus costs from the Post D&D multivendor markets in the United States. Even if specific industry bids may result in numerical departures, approximate default numbers are needed.

There are innumerable sources for the development of such an automated Post D&D data base. However, one quick and effective way may be to start by subscribing to advertised and apparently available tariff automation on tapes from such companies as the Center for Communications Management, Inc. (CCMI, 1985a and 1985b).

Item (E) of Table 8-1 asks for shortcuts in the CSATS execution. Clearly, the random searches incorporated in the existing CSATS can be quite time consuming. They provide little feeling for why certain types of configurations are preferable or what the sensitivities of certain parametric changes are. It is not known what heuristics are most promising for local area application. Several routines, such as ADD, DROP, and identification of clusters, have been described previously in this section. Other approaches to be explored may be along the lines of triangulation (see Section 6.2) and the use of isograms.

In triangulation one identifies triangular regions that have a common service requirement, such as uniform subscriber density. For most approximation purposes this can be done with a reasonable number of triangles per region. The average distance from a point P (viz., a switch) to uniformly distributed points in a triangle is a relatively simple function of the three vertices of said triangle. It follows that the average distance from any given region, that consists of several triangles, to a point P is nothing more than a weighted sum of the simple three-point functions. Triangulation thus can be employed to roughly assess the effect of switch, hub, etc., displacements.

Isogram refers to a line on a map along which some quantitiy remains constant. Typical everyday examples are temperature, rainfall, altitude, and so on. For CSATS application isograms could identify loci of constant least cost if a certain activity were to be placed at each of the alternative points. An example is shown in Figure 8-2. Here one could place a new subscriber anywhere in the plane and the resultant least connection cost to the nodes A,B,C,D would vary as indicated. Subregions with low isograph values are low-cost candidates for new subscriber locations and have low return potential for an additional service facility, such as a switch. High subregions have the converse effect on both subscriber and switch relocation. The intuitive and heuristic aspects of isograms could be incorporated in future CSATS with time saving effects.

The final recommendation in Table 8-1 is (F) or User Friendly. It refers to the substantial advantages, if not the crucial need, to make the CSATS model easy to use. The model is worthless if not used. And since its use covers inputs, outputs, and operator interactions, all should be made as user friendly as is possible with the present day ADP systems. This should be done for activities right at the main computer facilities, as well as at remote operator sites that have access through any available communications lines or networks to the hosts.

In accordance with the intent and spirit of the recommendations of this section, a Memorandum of Understanding (MOU) was drafted in October 1984. This MOU was the result of cooperative technical discussion between the System Analysis Section (SAS)

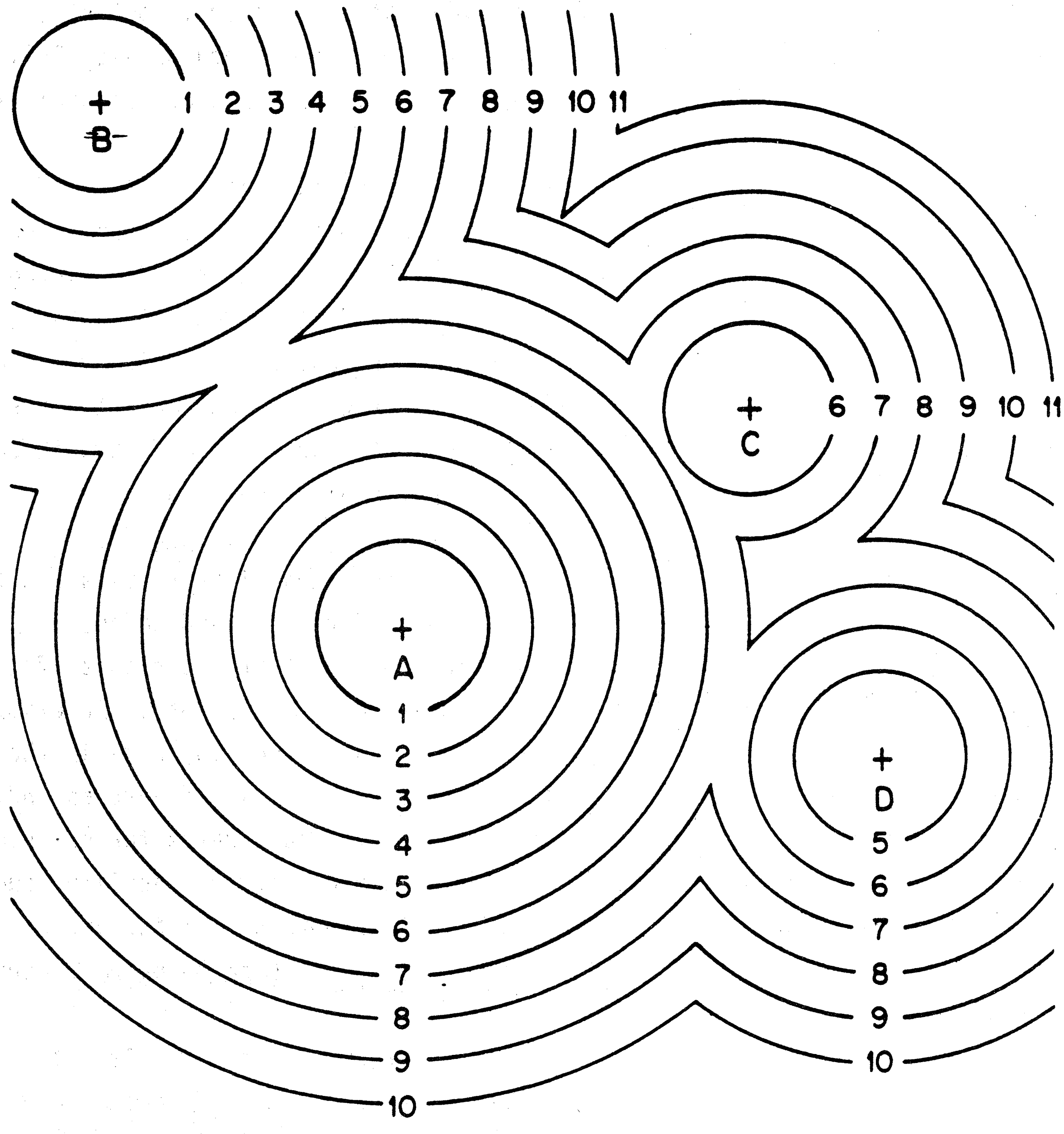


Figure 8-2. Cost isograms for connectivity to existing nodes.

of the U.S. Army Information System Command (USAIC) at Ft. Huachuca, AZ, and the Institute for Telecommunication Sciences (ITS) in Boulder, CO.

The main point of the MOU is that SAS and ITS are in agreement on the premise that the DSNAA characterization effort should be strengthened with the available CSATS computer model, plus the potential improvements that this model appears to offer. For this purpose, SAS and ITS have identified joint and separate work areas that should be undertaken in the next few years. The primary responsibilities of the two organizations and the durations of the tasks are summarized in the conclusion of the MOU.

As conceived, there are eight task areas identified in the MOU: a(1) to a(4), b(1), b(2), c and d. One particular task appears quite essential for this interagency plan to succeed. That is Task c, the implementation and usage of interactive remote processing, computer communications links by active program participants. One can expect the main host machines to retain their residence at Ft. Huachuca, AZ. They are to support interactive terminals initially at SAS in Ft. Huachuca and at ITS in Boulder, CO. However, as the program evolves and more MILDEP representatives become interested in access area optimization, interactive links to other locations (e.g., USAISMA in New Jersey and DCA in Virginia) would be possible and potentially useful.

The eight tasks listed in the MOU need not remain forever the entire scope of this endeavor. Some could be modified, as would very well occur in the search for improved heuristic methods in regional area structuring and partitioning. Others, like the user-friendly enhancements, could see extensive growth corresponding to startling developments in the marketplace. And nobody should be really surprised if new, now deemed unimportant, task areas were to assume importance as the program progresses. If one is allowed to speculate on the future, such new tasks may well deal with automation and structuring of support (such as AO&M) services.

9. REFERENCES

ANSI (1983), American National Standard for information systems - data communication systems and services - user-oriented performance parameters, X3.102, American National Standards Institute, February.

ANSI (1984), Draft American National Standard X3S35 (135), Revision 4, Measurement methods for user-oriented performance evaluation, American National Standards Institute, September.

AT&T Bell Laboratories (1984), Engineering and Operations in the Bell System (Technical Publication Department of Bell Laboratories, Murray Hill, NJ).

Bell Telephone Laboratories (1971), Transmission Systems for Communications (Western Electric Company Technical Publications, Winston-Salem, NC).

Bell Telephone Laboratories (1978), Special issue on loop plant, BSTJ 57, pp. 797-1223.

Bell Telephone Laboratories (1983), Special issue on the Total Network Data System, BSTJ 62, Part 3, pp. 2123-2478.

Bohacek, P. K. (1982), Stored program controlled network, BSTJ, 61, No. 7, Sept.

CCITT (1980), Specifications of signaling system no. 7, Recommendation Q.701-Q.741, Fascicle VI.6, VIIth Plenary Assembly, November.

CCMI (1985a), Executive Telecommunication Planning Guide (McGraw-Hill Information Systems Co., Ramsey, NJ).

CCMI (1985b), Guide to IntraLATA Communications Services (McGraw-Hill Information Systems Co., Ramsey, NJ).

Defense Communications Agency (1981a), Worldwide digital system architecture, Final Report, December.

Defense Communications Agency (1982), Worldwide digital system architecture, Transition Plan, June (confidential).

Defense Communications Engineering Center (1982), FY 83/FY 89 DCS RDT&E program, Technical Report 2-82, May (confidential).

Feldman, E., F. A. Lehner, and T. L. Ray (1966), Warehouse location under continuous economies of scale, Management Science 12, pp. 670-684.

Flanagan, J. L., M. R. Schroeder, B. S. Atal, R. E. Crochiere, N. S. Jayant, and J. M. Tribolet (1979), Speech coding, IEEE Trans. Commun. COM-27, No. 4, April.

Hatchwell, J. A., J. A. Stine, and G. R. Thomas (1981), Worldwide digital system architecture and preliminary transition plan, Mitre Corp. Report No. MTR-81W00175, DCA Contract No. F19628-81-C-0001.

Joel, A. E. (1982a), A History of Engineering and Science in the Bell System: Switching Technology (1925-1975), (Bell Telephone Laboratories).

Joel, A. E. (1982b), The integrated digital toll network, Bell Laboratories Record, January.

Kaskey, B. (1982), Developments in switching, Innovations in Telecommunications, Part A (Academic Press, Inc., New York, NY).

Kitawaki, N., M. Honda, and K. Itoh (1984), Speech quality assessment methods for speech-coding systems, IEEE Commun. Magazine 22, No. 10, October.

Kuehn, A., and M. Hamburger (1963), A heuristic program for locating warehouses, Management Science 4, pp. 21-32.

Linfield, R. F., M. Nesenbergs, and P. M. McManamon (1980), Command post/signal center bus distribution system concept design, NTIA Report 80-36, April (NTIS Order No. PB 80-188113).

Long, N. G. (1978), Loop plant modeling: overview, BSTJ 57, pp. 797-806.

Louthain, N. H., L. Auchard, and J. Davis (1982), Metropolitan area telephone service optimization model, U.S. Army Communications Command Report SA-305-82.

Louthain, N. H., L. W. Auchard, and J. R. Davis (1983), Metropolitan area telephone system optimization model--user's manual, U.S. Army Communications Command Report SA-303.1-82.

Louthain, N. H., and L. W. Auchard (1984), St. Louis defense metropolitan telephone system program evaluation--addendum, U.S. Army Communications Command Report SA-231-84.

Mabius, L. (1984), Telecommunications and information change: can we deal with it?, Government Executive, June.

McDonald, J. C. (1983), Fundamentals of Digital Switching (Plenum Press, New York, NY).

McManamon, P. M. (1985), Telecommunications Quality of Service in the Post-Divestiture Arena, Cyberlink Special Report (Cyberlink Corp., Boulder, CO).

Miles, M.J. (1984), Sample size and precision on communication performance measurements, NTIA Report 84-153, August (NTIS Order No. 85-114270).

Nesenbergs, M., W. J. Hartman, and R. F. Linfield (1981), Performance parameters for digital and analog service modes, NTIA Report 81-57, January (NTIS Order No. PB81-176455).

Nesenbergs, M., and R. F. Linfield (1976), Parametric cost alternatives for local digital distribution systems, OT Report 76-95 (NTIS Report No. PB258510/AS).

Nesenbergs, M., and P. M. McManamon (1983), An introduction to the technology of intra- and interexchange area telephone networks, NTIA Report 83-118 (NTIS Order No. PB83-241893).

Priest, R. H., J. G. McCoy, M. H. Louthain, J. R. Davis, and L. W. Auchard (1983), Boston defense metropolitan area telephone system program evaluation, U.S. Army Communications Command Report SA-224-83.

Priest, R., and J. McCoy (1984), St. Louis defense metropolitan area telephone system program evaluation, U.S. Army Communications Command Report SA-231-84.

Raack, G. A., E. G. Sable, and R. J. Stewart (1984), Customer control of network services, IEEE Commun. Magazine 22, No. 10, October.

Schwartz, M. (1977), Computer-Communication Network Design and Analysis (Prentice-Hall, Inc., Englewood Cliffs, NJ).

Stavroulakis, P., and G. S. Tjaden (1975), Analysis of new telecommunications services via system attributes, Conference Record of ICC '75, vol. III, pp. 47-3 to 47-6 (San Francisco, CA).

Tanenbaum, A. S. (1981), Computer Networks (Prentice-Hall, Inc., Englewood Cliffs, NJ).

Teleconnect magazine (1984), September.

Telephony (1984), Long haul transmission: a comparison, Telephony Magazine, December.

U.S. Bureau of the Census (1979), Statistical Abstract of the United States: 1979 (100th edition), Department of Commerce, Washington, DC.

Western Electric Company (1980), Digital access and cross-connect system ... DACS, Transmission Product Bulletin.

Western Electric Company (1982), Defense switched network access area concept development, Final Technical Report, submitted to U.S. Army's Communications Systems Agency, Ft. Monmouth, NJ 07703, Contract No. DAA-307-81-C-0725.

APPENDIX A

Skill Levels and Labor Costs

The field of telecommunications encompasses both communications and electronics. It includes the functions of program formulation, systems engineering, installation, policy planning, inspection, evaluation and direction of communications operation, and maintenance activities. Included in these areas are supervisory, advisory, and technical responsibilities for engineering, construction, installation, operation, and maintenance of communications, electronic systems, and equipment. This includes radio, wire, computerized communications, and other means used for electrical and visual transmission, and the reception of information or messages. The field also includes the operation and maintenance of automatic digital switching equipment and associated peripheral devices.

Many of the occupations in the commercial, military, and civil service telecommunications fields are similar in education, experience, physical dexterity, and the duty requirements for a particular position. In this section we present a comparison between occupations in the military, civil service, and commercial telecommunications industry. The following provides a comparison between the various disciplines of management, engineering, nonprofessional, and clerical positions. The information provided in this appendix has been obtained from U.S Civil Service Commission (CSC, 1972), U.S. Air Force (USAF, 1984), and U.S. Army (USA, 1984) personnel classification documentation.

Figure A-1 is a chart of the General Schedule (GS) annual salary rates by grade as of July 1, 1984. Within each GS grade there are 10 steps. The basic pay indicated on the chart is for a step 5 within a particular grade. These salary rates are established by the President of the United States (OPM, 1984). In addition to showing the annual pay for a particular grade at step 5, the figure also incorporates a range of benefits to which the Federal employee is entitled. These benefits provided by the Federal Government include such items as a percentage of retirement, health insurance, group life insurance, work disability, etc. These benefits amount to approximately 36.4% of the annual salary. The annual salary of the Federal employee is limited by law to $66,400 per annum as seen in grades 16, 17, and 18 on the chart. This limits the total pay and benefits allowable to a GS-18 to $90,570 per annum.

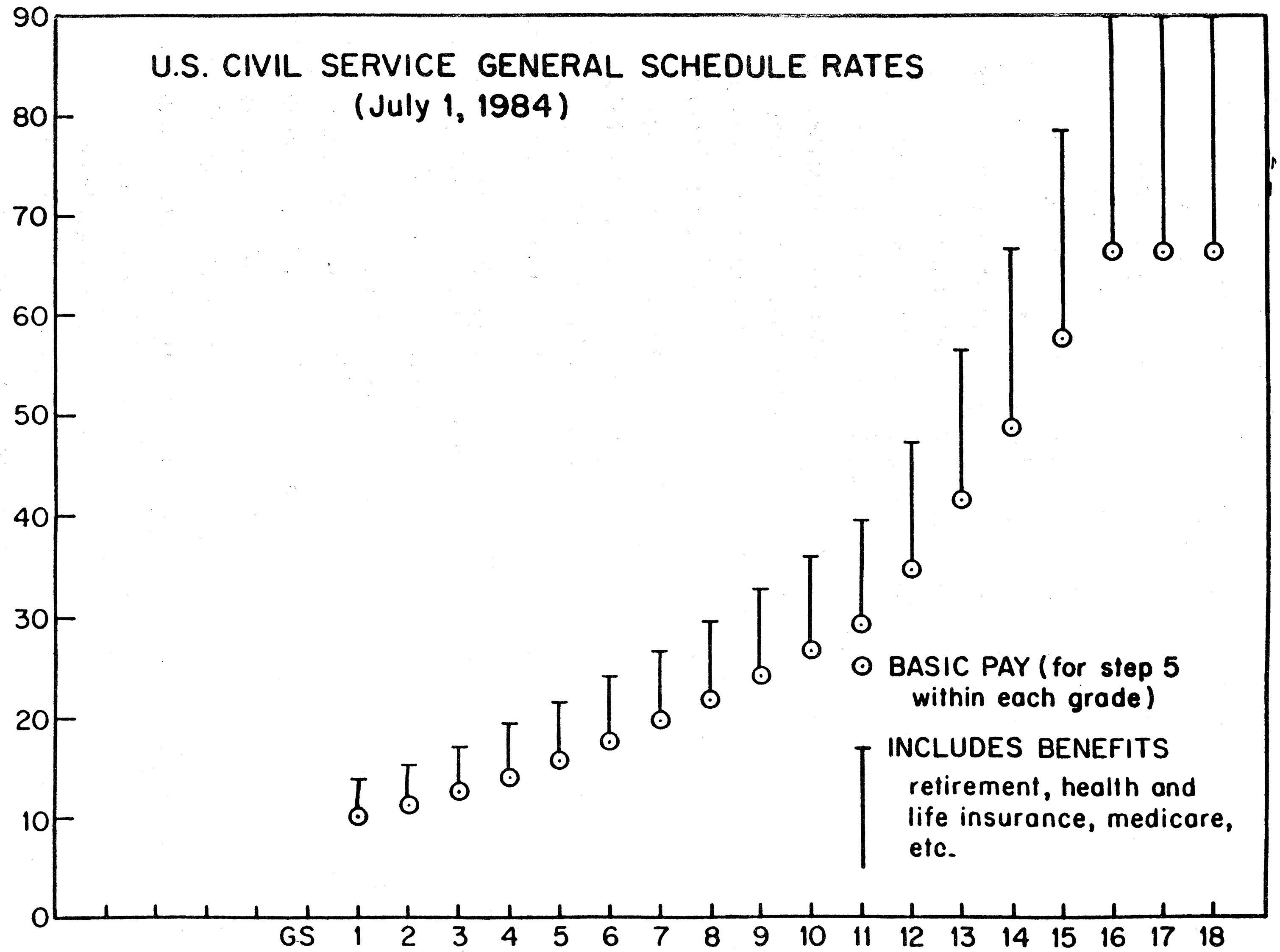


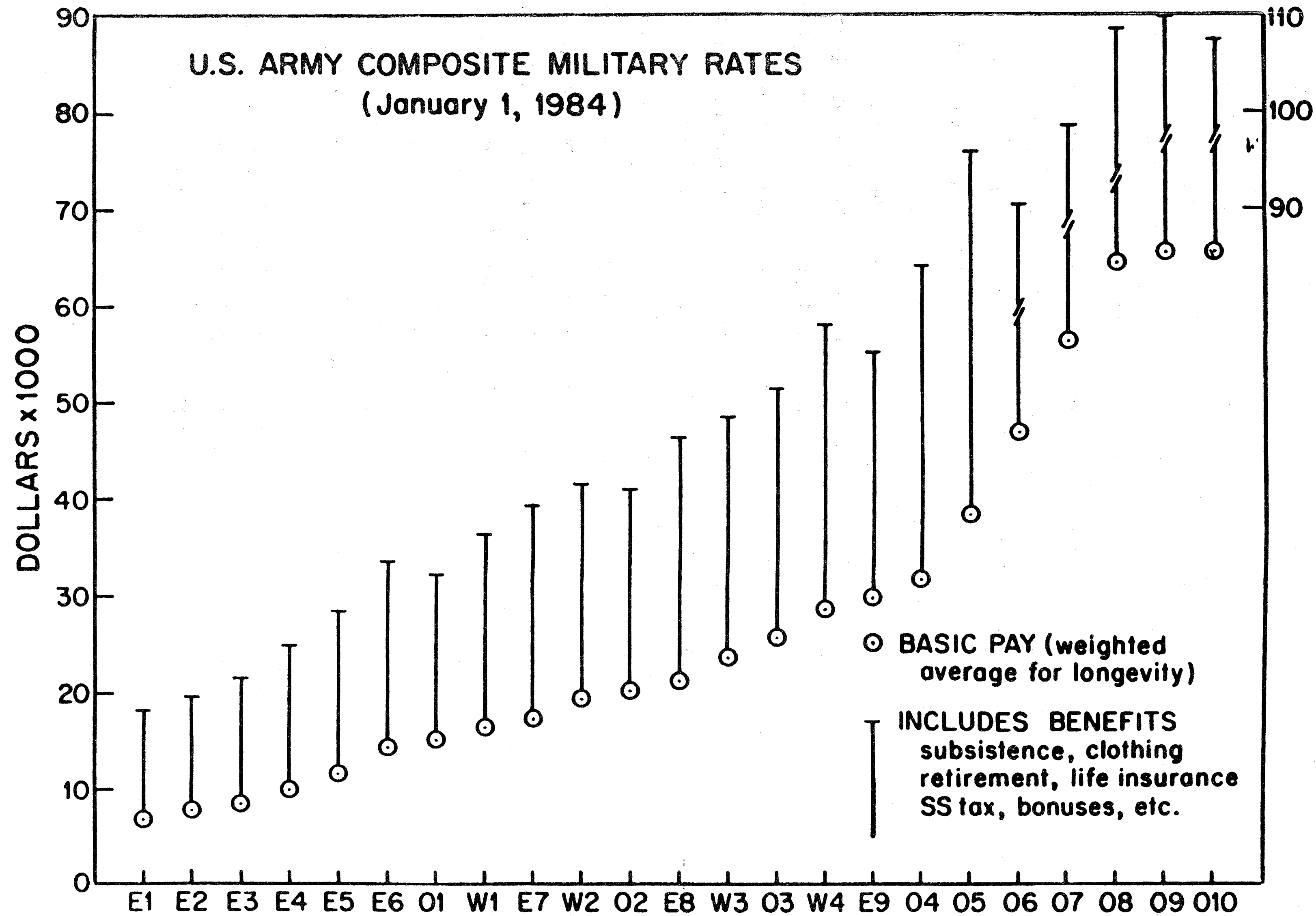
Figure A-1. U.S. Civil Service General Schedule salaries.

Figure A-2 is a chart of the U.S. military salary rates under Title 37 of the U.S. Code. The maximum basic pay is again limited to $66,400 as for GS employees. As shown in Figure A-2, the basic pay shown is for officers, warrant officers, and enlisted men with approximately 20 years of service. The chart has been developed by salary and not by rank for an easier comparison with the civil service grades. As seen in the chart, however, the amount of benefits, again provided by the Federal Government, exceeds that of the civilian employee. Benefits for military personnel include items such as incentive and special pay, uniform and clothing allowance, family separation allowance, social security tax, death gratuities, life insurance, reenlistment bonuses, basic allowance for quarters, retirement, etc. The maximum for military personnel is then about $110,000 as seen for a Lt. General.

Figure A-3 is a chart of commercial salaries for occupations that generally follow those functions in the military and civil service areas that are of interest. Figure A-3 has been drawn from recent Bureau of Labor Statistics (BLS) publications adjusted to 1984 dollars by annual rates of inflation. Length-of-service and other benefits are not included. The range of basic pay has been drawn from the BLS report covering two communications common carriers. The three job categories shown in Figure A-3 cover several disciplines. For instance, operators are covered in each of the categories and as the salary range increases, the experience of the operator increases from in-training to experienced to supervisory operator. A direct comparison between commercial industry personnel, military, and civil service personnel in the same job classification is impossible because no classification standards are available.

Table A-1 is a subjective comparison of those job titles and salaries in the private sector with civil service grades. A judgment of what the private sector position should involve compared to the position-classification of a civil service position is implied in this comparison.

Table A-2 is a listing of Air Force Specialty Codes (AFSC) and job titles equated to Civil Service General Schedule positions and grades. These comparisons have been developed with the aid of position descriptions, excerpts of which will



Fiqure A-2. U.S. Military salaries.

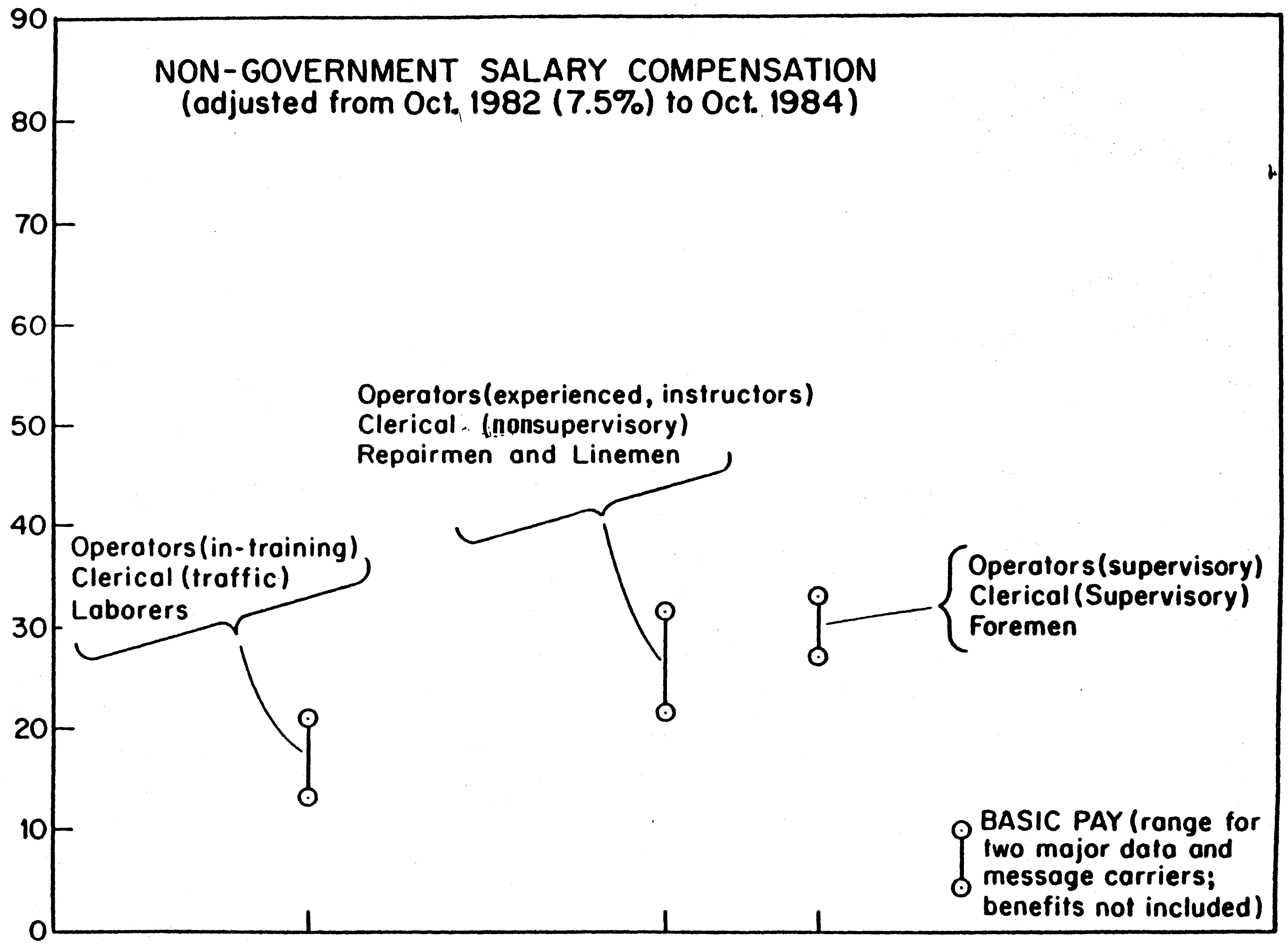


Figure A-3. Commercial salaries.

Table A-1. The Enumeration Equivalence of Private Sector and GS Grades

Private Sector 1984 Position Title	1984 Salary w/O benefits	GS 1984 GS Equivalent	1984 Salary w/o benefits
Operators...			
Chief Operators	$ 21,700	GS-9	$ 23,700
Instructors	23,100	GS-7	19,400
Experienced	18,500	GS-5	15,700
In-training	12,500	GS-1/3	11,100
Clerical...			
Supervisors	28,800	GS-9	23,700
Nonsupervisors	20,600	GS-5/7	17,500
Traffic	18,200	GS-3	12,500
Construction, Installation, & Maintenance...			
Linemen	29,800	GS-9	23,700
Foremen	24,600	GS-7/9	21,500
Technicians	24,200	GS-7/9	21,500
Repairmen	19,300	GS-5/7	17,500

Table A-2. Air Force Specialty Codes, Their Job Titles, and Civil Service Equivalents

AFSC #	E or O	TITLE	GRADE	TITLE
99000	E-1	Basic Airman	GS-1	Engineering Aid
29110	E-2/3	T/C Operations Specialist Helper	GS-2	Engineering Aid
29130	E-4	T/C Operations Specialist Semi-skilled	GS-3	Engineering Aid
29150	E-5	T/C Operations Specialist	GS-4/5	Engineering Technician
29170	E-5/7	T/C Operations Supervisor	GS-7	Engineering Technician
29190	E-7/8	T/C Operations Superintendent	GS-9	Electronics Engineer
29100	E-9	T/C Operations Manager	GS-9/11	Electronics Engineer
OR				
3021/3024	0-1/4	C-E Systems Officer	GS-9/13	Electronics Engineer
3031/3034	0-1/4	C-E Maintenance Officer	GS-9/13	Electronics Engineer
3051/3055	0-1/5	C-E Engineer	GS-9/14	Electronics Engineer
3011/3016	0-4/6	C-E Systems Staff Officer	GS-13/15	Electronics Engineer
3091/3096	0-5/6	C-E Director	GS-14/15	Electronics Engineer

C-E - Communications-Electronics
E - Enlisted Personnel
O - Officer Personnel

be discussed later in the text. A subjective judgment was required for this table due to the different ways the position descriptions are written.

Table A-3 equates military rank (Captain, Major, etc.) to GS grade (11, 12, etc.) according to base protocol.

Table A-3. Military and Civil Ranking as per Base Protocol

MILITARY	1st Lt.	2nd Lt.	Capt.	Major	Lt. Col	Col
CIVIL SERVICE	7*/9	11	12	13	14	15

*dependent upon individual base protocol

The following excerpts are taken from Air Force (USAF, 1982) and U.S. Civil Service position-classification standards (CSC, 1971). Air Force career fields have been organized into a number of specialty areas such as Telecommunications Operations (291xx), Airborne Communications Systems (294xx), Ground Radio Operations (293xx), Automatic Digital Switching (295xx), etc., through which an airman may pursue his/her career. For this comparison, Air Force airman qualifications have been taken from the Telecommunications Operations Specialty Area (291xx) in that it most closely represents the civil service electronic/electrical disciplines. A representation of some of the Air Force airman specialty areas is shown in Figure A-4. Officer specialty codes are divided into similar functional areas such as the Communications-Electronics Career Area (Utilization Field 30), which is used in this comparison.

Basic Airman - Is the entry level where an individual has selected the discipline in which he/she intends to progress through the military system to both learn a trade and to advance upward in rank, if he/she successfully completes the prescribed training (description of this position is unavailable).

Engineering Aid (GS-1) - Learns the basic methods, techniques, and procedures for one or a few simple tasks. As trainees, GS-1 aids receive very close supervision.

T/C Operations Specialist - Accepts and processes incoming and outgoing electrical record messages in telecommunications centers and communications terminals: operates telecommunications and cryptographic equipment and telephone

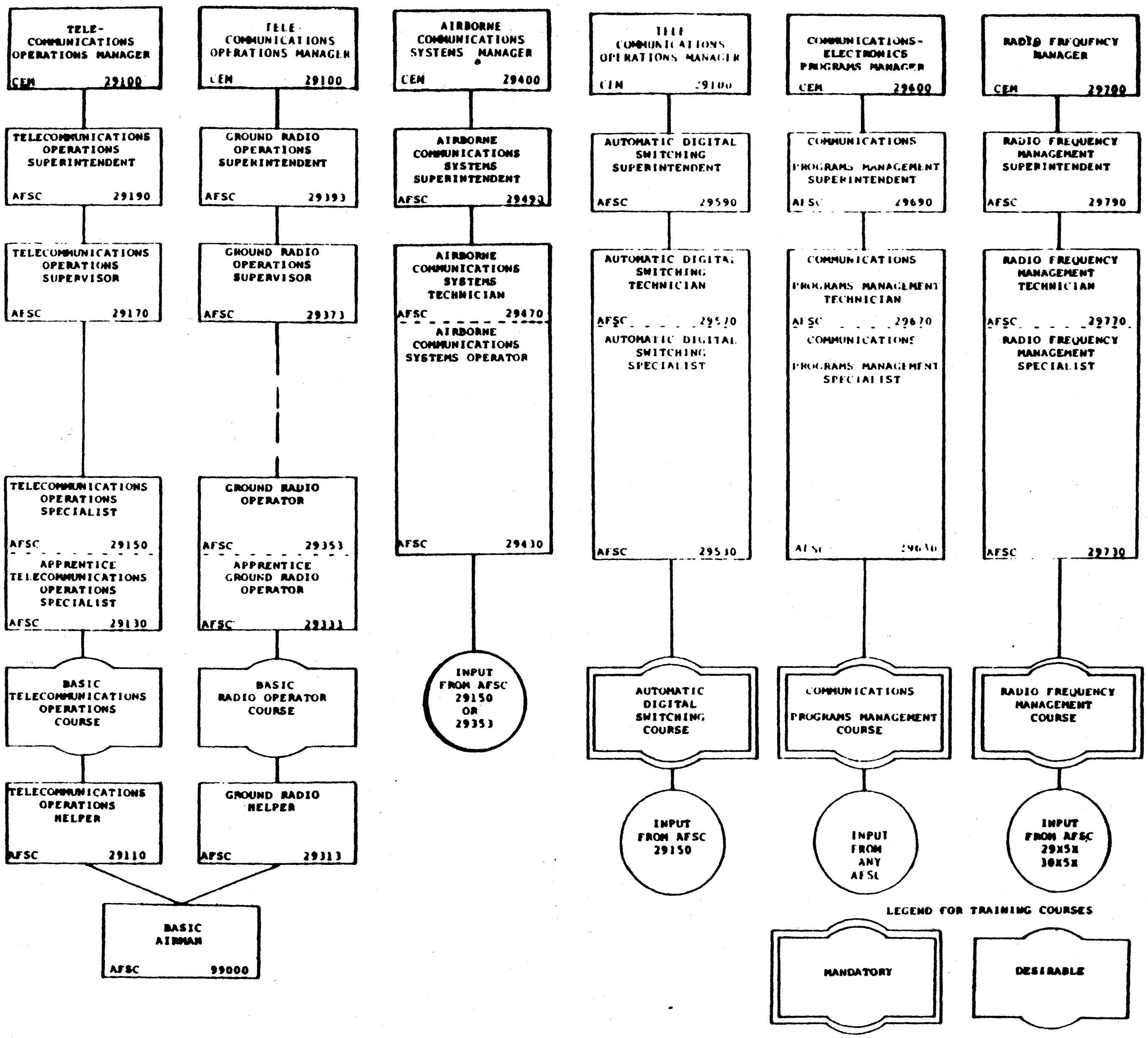


Figure A-4. Airman communications operations career field chart.

switchboards. Knowledge of standard telecommunications operations, concepts, principles, and procedures is required. Knowledge of telecommunications operations equipment maintenance methods required to perform operator maintenance is desirable. Completion of high school with a course in typing is desirable. Experience in functions such as the operation of telecommunications operations activities is mandatory.

Engineering Technician (GS-4/5) - Uses a variety of standard references, guides, and precedents to obtain needed information to adapt methods and procedures. At GS-4 the work involves primarily application of established practices; at GS-5 employees are typically required to select and adapt methods and procedures. Nonroutine technical problems of the type previously encountered by the technician in the course of the work are typically resolved independently.

T/C Operations Supervisor - Supervises telecommunications centers communications terminals, telephone switchboards, and telecommunications operations personnel. Plans, schedules, monitors workloads and duty assignments. Establishes and improves work standards and procedures to ensure full utilization of personnel and economy of operations. Analyzes reports pertaining to record communications. Knowledge of telecommunications functions, teletypewriters, tape and card readers, tape and card punches, magnetic tape transports, and associated peripheral devices, telephone and switching center operations, reporting forms and procedural publications, and established operating procedures is mandatory.

Engineering Technician (GS-7) - Applies initiative and resourcefulness in planning nonroutine assignments of substantial variety and complexity. Selects appropriate guidelines to resolve operational problems not fully covered by precedents; is required to develop revisions to standard work methods and procedures, modify parts, instruments, equipment and takes actions or makes recommendations based on preliminary interpretation of data or results of analysis.

T/C Operations Superintendent - Superintends record and voice operations of telecommunications centers, communications terminals, and telephone switchboards. Plans and schedules work assignments, workloads, and the submission of reports. Ensures full utilization of personnel, equipment, time, and supplies allotted to telecommunication activities. Coordinates with other agencies and organizations concerning procedures to improve communications effectiveness.

Electronics Engineer (GS-9) - Independently performs a wide range of tasks within the functional area; makes engineering determinations and applies judgment in the selection, interpretation, and application of relevant rules, standard procedures or precedents. Assignments require independent analysis and solution. Demonstrates sound judgment in dealings with engineers who represent contractors and others in his field.

T/C Operations Manager or C-E Systems Officer - Manages telephone, teletype, computer, radio, and communications center operations, radio frequencies, and communications security programs. Initiates communications-electronics (C-E) systems programming and budgeting actions, and commands or supervises C-E systems activities. Develops and improves methods and procedures for message, data, and voice communications. Coordinates with supported units to ensure that their communication needs are met.

Electronics Engineer (GS-11/13) - Solves problems involved in securing optimum operation of a generation or transmission system. Develops or evaluates adequacy of maintenance programs, training material and equipment, operating manuals, and repair procedures. Makes continuing contacts as an engineering advisor and as the representative of his/her organization in interpreting and applying policies and requirements.

C-E Maintenance Officer - Manages installation, maintenance, and modification of C-E systems and equipment. Implements material, production, and quality controls. Establishes and monitors performance standards and procedures. Identifies technical problems involving the siting, installation, or modification of C-E equipment and takes corrective action.

Electronics Engineer (GS-11/13) - SAME AS ABOVE

C-E Engineer - Applies established engineering principles to implement and maintain operational C-E systems. Develops and manages in-service performance evaluation and maintenance standards for operational C-E systems. Performs staff functions requiring engineering expertise, such as planning and programming C-E systems.

Electronics Engineer (GS-12/14) - Resolves technical problems, even in those areas where guidelines are lacking. They are regarded as knowledgeable advisors within their functional and specialty areas. Plans and coordinates programs or projects for which they must be innovative and original. Devises methods and procedures that are normally adopted for use and become the activity's established precedent.

C-E Systems Staff Officer - Administers and plans C-E activities, including the installation, operation, and maintenance of C-E systems and equipment; provides staff supervision and technical advice on C-E matters; initiates programming and budgeting actions. Translates broad command and control operational requirements into C-E requirements, including development of performance specifications for C-E systems, facilities, and equipment.

Electronics Engineer (13/15) - Is a widely recognized expert used as a consultant by engineers and managers outside the immediate organization on unusually difficult and controversial matters where the opinion of an engineer of high repute is considered vital. Determines which approach to take for the major revamping of a strategic communications network for an area with several large urban and industrial complexes. Devises methods, procedures, and approaches that have agency-wide influence in the subject-matter or functional area and in related areas.

C-E Director - Directs and monitors the development and implementation of C-E programs including definition, programming, procurement, budgeting, installation, and operation and maintenance. Commands major C-E activities and serves as senior advisor to commanders and to officials in combined, joint service agencies.

Electronics Engineer (GS-14/15) - SAME AS ABOVE

Figure A-5 is a representation of the three segments under comparison in this appendix and is drawn from the information presented herein.

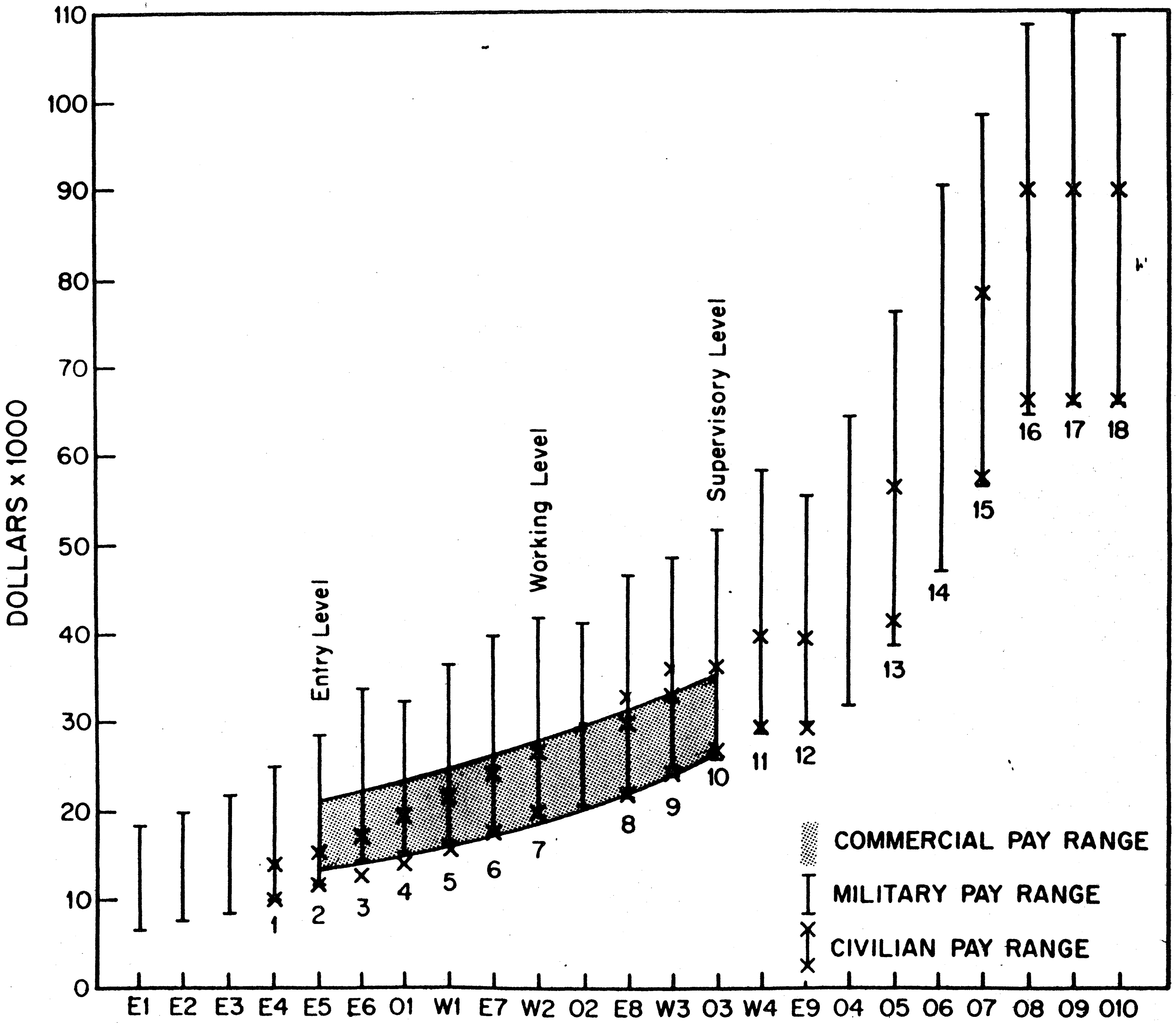


Figure A-5. Composite of military, civilian, and commercial salaries.

REFERENCES

CSC (1972), Position-classification Standards, United States Civil Service Commission.

OPM (1984), Office of Personnel Management, Supplementary Salary Table 69.

USA (1984), U.S. Army Career Management Fields, Communications Electronics Career Progression.

USAF (1984), U.S. Air Force Documentation, AFR 39-1, Airman Air Force Specialty and AFR 36-1, Communications-Electronics Career Area.

APPENDIX B

Traffic at a Local Circuit Switch

B.1 Introduction

The amount of offered traffic by and large determines the quality of service at any fixed telephone switch installation. A quantitative measure of the offered traffic is the unit of Erlang (E). The quality of service is described in terms of GOS. Both predicted and measured GOS values are used to depict the probability of frequency of blocked call attempts in either planning or measurements, respectively. There are other relevant factors that affect one's perception of GOS, such as user behavior when blocked, secondary characteristics of offered and carried traffic (e.g., call duration, frequency, and correlations), and constraints imposed by the switching system design.

In what follows, the pertinent factors are identified for a local circuit switch. The local switch may be known by several other names, such as the DCO, the EO, the Central Office (CO), or even the Class 5 switching center. Not every key issue or question will be raised here. However, by staying the indicated course, the GOS concerns by military end users and network operators are likely to remain in the foreground. If additional concerns become important, they should be addressed on their own merits.

To proceed quicker through the introduction and definitions of terms, this brief document uses the "method by example." The starting point is a prototype DCO switch illustrated in Figure B-1. On the left side of this figure there are a total of 6,400 telephone subscribers. Through individual subscriber lines or loops they are connected to either the DCO itself, or to its lesser switches (the two PBX's), or to the associated four concentrators (CONC).

Between the CONC's, the PBX's, and the switch, the numbers of serving trunks are shown in Figure B-1. Thus, the uppermost group of 600 lines is shown to be concentrated by CONC 1 onto 48 trunks that home on PBX 1. On the subscriber side this PBX serves two concentrators with a total of 60 high-capacity tie-lines, as well as 1,600 directly connected station loops. To reach the DCO, PBX 1 employs 144 trunks.

Similar line and trunk counts are given for PBX 2. Finally, in the example of Figure B-1 about a half of all subscribers reach the switch directly, without going through the private branch exchanges. On the network or toll side of the switch, connectivity to distant toll switches must be provided. In the example, shown, 192 trunks head for a remote Switch 1 and 72 trunks to Switch 2.

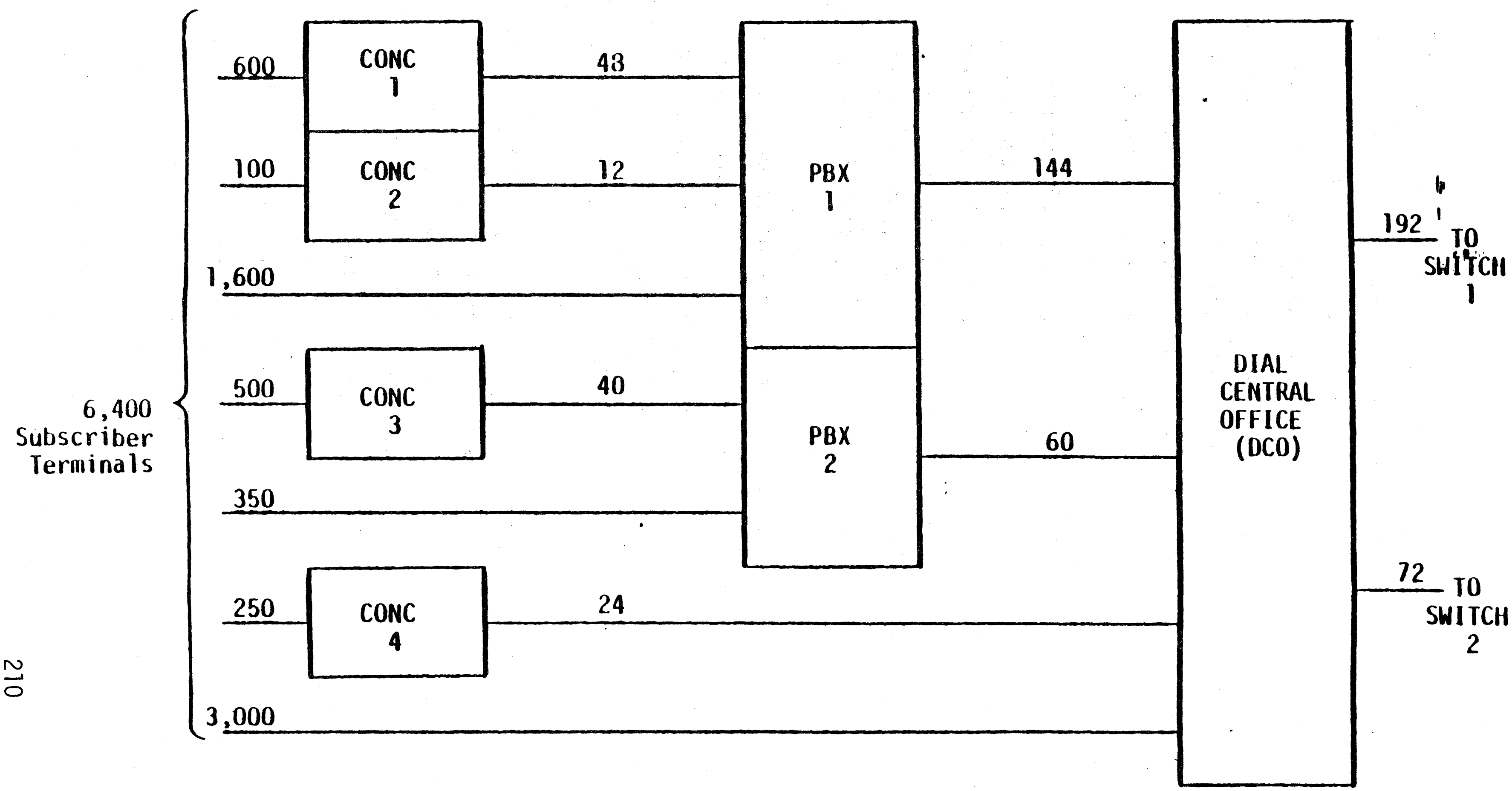


Figure B-1. The number of lines and trunks.

Given the line and trunk wiring plan, such as that of Figure B-1, the traffic handling statistics may be summarized as follows:

(1) If the average or total offered traffic is known for the 6,400 subscribers, one may ask about the blocking GOS for a typical call. The traffic can be uniformly generated or perhaps not. There can be more incoming than outgoing calls, or vice versa. Certain groups of subscribers may prefer to call within certain communities of interest. But the main point is that the traffic generators and the service providers are given. The GOS numbers are unknown and to be determined.

(2) If the average offered traffic is known, as in (1) above, and if one has the permitted GOS numbers as targets, one may ask whether and how should the network be modified. Trunks can be added, deleted, or redirected. Switch and PBX capability can be changed by elimination of internal switch blocking. New concentrators can be added with different concentration ratios, and so on. The main question here addresses the configuration and sizing of the network. When is the topology good enough for the traffic needs, when is it not so, and what changes are required.

(3) A question derived from the previous (1) and (2) may assume the network and its GOS objectives as given and may seek a "wider range" of permitted traffic. The need for such wider range arises in several ways. For instance, future growth, sudden military activities, stress conditions, recovery from congestion, new technology, and the reality of costs due to frequent upgrades or downgrades, all warrant a traffic sensitivity assessment of a given configuration.

To answer questions (1) and (3) quantitatively for DSN, or even to ask these questions in a meaningful manner, more user and system details may be required. Selected examples of such details are discussed in the next sections.

B.2 Traffic Details

The offered traffic constitutes the load to be handled by the switch network. To specify the load, Table B-1 presents two types of descriptors: primary and secondary. The primary descriptors, such as the fixed BH, uniform offered load, and the infinite number of sources, are often used and seem quite adequate for typical

Table B-1. Descriptors of Offered Traffic

Primary	Secondary
Busy Hour (BH) - fixed, time consistent.	Time varying or bouncing BH, day-to-day or location-to-location. Time zone effect on BH. Peak factors in excess of normal BH. Military operational impact on BH.
Offered Load - uniform average, per line or total	Nonuniform user groups, such as offices, residences, etc. Means (and distributions) of arrival rates and holding times. Originated outward, inward, and intra-switch loads. Intraconcentrator, intra-PBX, and specific CONC to specific PBX loading.
Traffic model based on infinite number of subscribers	Actual finite counts of subscribers at concentrators and smaller PBX's.

service estimation. They enable the use of simple GOS formulas, tables, and design rules. However, there are cases when more detailed traffic characterization is in order. The secondary descriptors of Table B-1 strive to complete the picture in greater detail.

The military user groups at different bases may or may not have the same BH. Variations, perhaps quite extensive, may be due to time zone differences and agency missions. The recognition of any "average busy season busy hour" concept may be nearly impossible. The estimation of the traffic peaks, their occurrences, and dynamics across the CONUS may not be trivial, but is needed to assess the end-user GOS at local switches.

The military and other Government departments may also present user groups with pronounced traffic nonuniformities. Clearly, offices with specific daily routines tend to call accordingly. The function of the office determines who is likely to call out or in, and so forth. Information dispensing operation, for example, may result in the majority of calls being incoming. In such situations outgoing-only trunks would serve doubtful purpose.

The assumption of a constant offered load is tantamount to infinitely many subscribers. This may be quite appropriate for the larger switches and PBX's. However, the smaller concentrators with a small number of main stations pose a different issue. If half of the stations are busy, it is only the remaining half that can initiate or receive calls. If the per-line load is unchanged, this may infer lowered offered load, higher effective GOS, or implementation savings.

As a specific illustration of the secondary load descriptors, consider an example appropriate for the 6,400 lines of Figure B-1. Let all lines have the same uniform traffic generation statistics. Assume that during the BH:

- Each line generates 0.015 E of outward traffic that is headed beyond the local switch to either Switch 1 or 2.
- Each line receives 0.022 E of inward traffic that arrives from the toll network and is handled by the local DCO.
- Each line originates 0.010 E of intraswitch traffic, which terminates among the 6,400 subscribers. Since each call in this category ties up two terminals, the total average number of busy loops due to these intraswitch calls is 2(.010)6,400 = 128.

It follows from the uniformity of the offered traffic and the above numbers that the total offered load per individual line and trunk groups can be estimated for Figure B-1. The resultant numbers are graphically summarized in Figure B-2. The quantities, such as the 115E between the local switch and the PBX 1, show the offered traffic intensity in Erlangs for this particular trunk group. Whether the

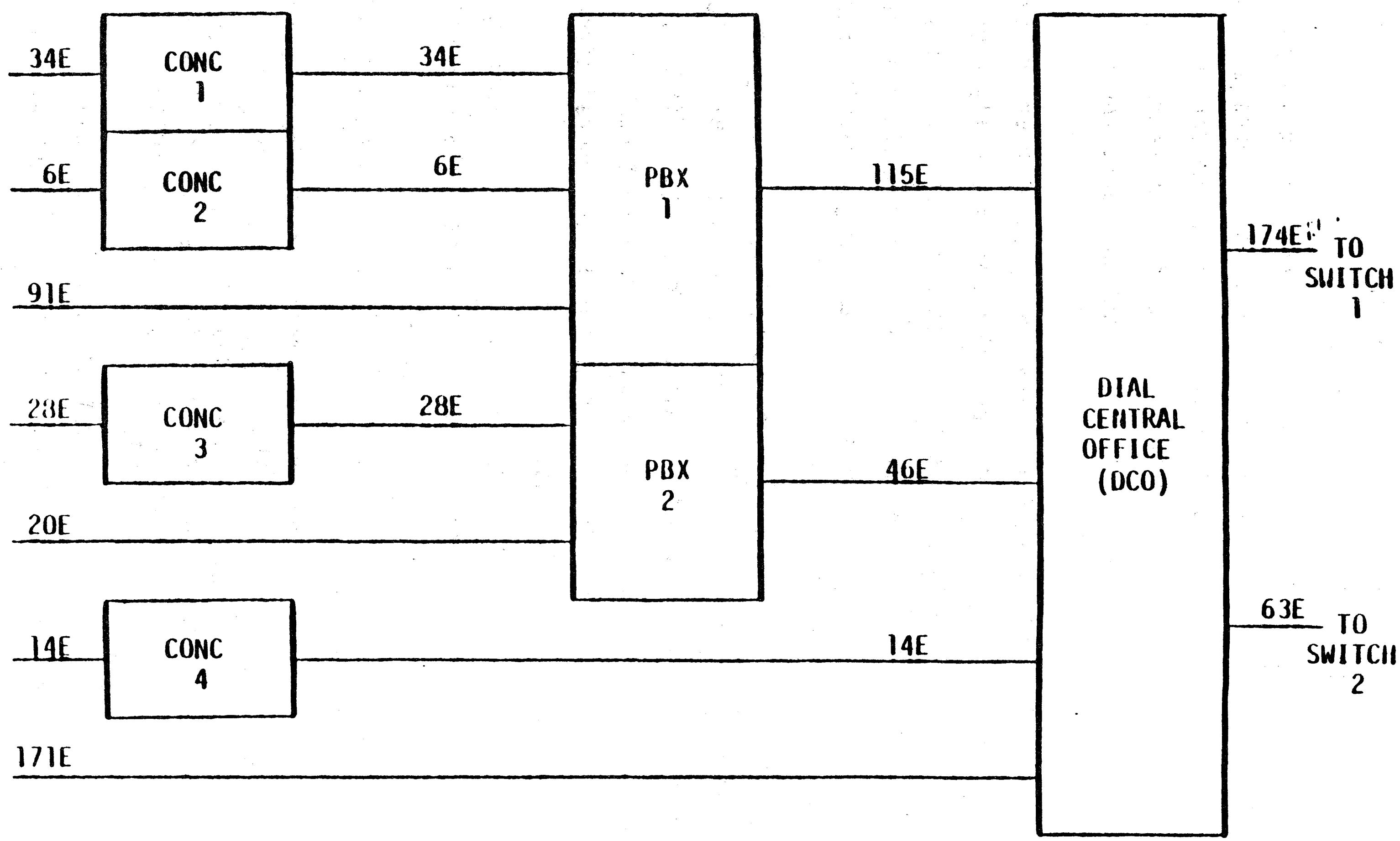


Figure B-2. Approximate offered loads in Erlangs (E).

144 trunks (See Figure B-1) are sufficient to provide required GOS, or what the resultant loss or carried loads would be, must be established by traffic engineering that looks more closely at the details of the switched network server elements.

B.3 Network Details

The network details to be emphasized here are those that pose realistic potential for blocking. If the number of servers (e.g., trunks, registers, dial tone generators, etc.) is considerably lower than the number of service users (e.g., subscribers), then the chances of a call not getting through, namely being blocked, are increased. The GOS is thus worsened.

Table B-2 identifies generic points where blocking events can occur. Of interest to local switch networks are three elements: the line concentrators, the PBX, and the Class 5 switch itself.

Line concentrators have been made by Western Electric Company since the late sixties. The latest technology is represented in the SLC-96 type of systems. Such CONC's, by definition, cannot perform circuit switching. As a result, when a subscriber of a CONC unit (such as CONC 1 in Figure B-1) dials the number of another subscriber served by the same line concentrator, the call must go to the PBX or switch and then be returned back. Two CONC to PBX trunks are used up by such a call. This fact was fully realized in the past, so much so, that concentrator serving trunks were in danger of being over-engineered in the field.

The blocking events at PBX and the switch can, at least in principle, be caused by the same three phenomena: shortage of appropriate serving trunks, internal switch matrix blocking (also identified with availability limitations), and insufficient speed capacity of call-processing devices. Depending on the vintage of the switch, such time-shared devices as line finders, selectors, markers, senders, receivers, registers, translators, and various pulsing equipments may be of concern here.

Failures or inoperative conditions, including slow-downs of modules, are not explicitly identified in Table B-2. But their presence should not be ignored. The end-user GOS is clearly degraded as the number of inactive servers is increased.

Another issue not to be ignored in switch service specification is the fact that all serving trunks are not identical. As deployed, certain trunk facilities may be two-way (i.e., can be seized from either end), while others can only be one-way. When looking out from a given switch or PBX, such one-way trunks are said to carry only outward or inward traffic, as the case may be. Furthermore, not all trunks are equally available to the public or private dialers. Some are dedicated to private networks, such as FTS, etc., "hot lines," or for use by operators, or even kept in reserve, or be under test. When one keeps a detailed account of all lines and trunks

Table B-2. Potential Blocking Elements at a Local Switch

Blocking Points	Due to Shortage or Limitations of
Concentrator (CONC)	CONC to PBX or CONC to switch trunks
PBX	PBX to switch trunks or PBX matrix limited availability (i.e., internal blocking) or Limited capacity of PBX processor control, and service modules.
Class 5 Switch	Toll trunks to other switches or Limited availability within the switch matrix (i.e., internal blocking) or Limited capacity of switch processors, control signaling, translation, and related service units
Other Toll Switches	Toll network - beyond the scope of local switch blocking

at a switch, a complex listing emerges. To keep matters as simple as possible, a candidate summary of lines and trunks is outlined in Table B-3. It applies to the same configuration introduced first as an example of the local switch in Figure B-1.

Any other tabulation format could be used instead of that depicted in Table B-3. The format is not the main issue here. What matters instead is that the serving trunks come in different categories and in different group sizes. They carry different amounts and types of traffic to distinct nodes, such as the toll switches, PBX, and concentrators. Their GOS tends to differ, but must be engineered to meet the common minimum performance goals.

The two lesser switches of Figure B-1, namely the PBX's numbered as 1 and 2, have their own unique line and trunk summaries. These summaries are given in Table B-4 and B-5, respectively.

On the subscriber (or station, or loop) side of the PBX, the concentrated lines normally carry more traffic than the direct lines. But, there are exceptions where the directly homed subscribers are excluded from concentration because of their extraordinarily high traffic intensity or because of the critical-user status in the NCS. In any case, when estimating the blocking GOS at the PBX's and the Class 5 switch, the mix of concentrated and unconcentrated lines must be properly taken into account.

On the network side of the PBX, a similar issue pertains to the variety of trunks. If restrictive, this phenomenon must be incorporated in the GOS assessment.

B.4 Traffic Engineering

Given representative details of offered traffic and the networking of the Class 5 switch, the tasks of the system analyst fall into three types. As outlined in the Introduction above, either (1) the GOS, or (2) the network, or (3) the traffic streams can be treated as unknowns to be optimized. Most basic of the three is the GOS estimation. It is briefly discussed in the remainder of this document.

For clean call arrival, holding time, and service facility models, mathematical blocking probability formulas, tables, and algorithms have been generated. A sample of several such models is illustrated in Figure B-3. As defined, none of the models appear to resemble the local switch operation. The biggest difference seems to arise in the nonhomogeneity of offered traffic substreams (See Figures B-1 and B-2, and Table B-1) and server facilities (see Tables B-3, B-4, and B-5). When one attempts to include the indicated end-office variety into the mathematical formalism, the models rapidly become too complicated.

Table B-3. Line and Trunk Summary for the Local Switch in the Assumed Example

SUBSCRIBER SIDE

SUBS. LINES	CONC #	TERM @ SWITCH
250	#4	24
3,000	--	3,000
3,250		3,024

NETWORK SIDE

SWITCH TO PBX'S				TRUNK CATEGORY	SWITCH TO OTHER SWITCH			
#	#	#2	#1		#1	#2	#	#
		36	48	TWO-WAY	60	72		
		12	30	INWARD	72	--		
		12	60	OUTWARD	48	--		
		--	4	RESTRICTED	6	--		
		--	2	RESERVE	4	--		
		--	--	OTHERS	2	--		
		60	144		192	72		

Table B-4. Line and Trunk Summary for PBX 1

SUBSCRIBER SIDE

SUBSCRIBER LINES	CONC #	TERMINATIONS AT PBX
600	#1	48
100	#2	12
1,600	--	1,600
Total: 2,300	2	1,660

NETWORK SIDE

TRUNK CATEGORY	NUMBER
TWO-WAY	48
INWARD	60
OUTWARD	30
RESTRICTED (SPECIFY)	4 (PRIVATE)
RESERVE (SPECIFY)	2 (TEST)
OTHERS (SPECIFY)	--
Total	144

Table B-5. Line and Trunk Summary for PBX 2

SUBSCRIBER SIDE

SUBSCRIBER LINES	CONC #	TERMINATIONS AT PBX
500	#3	40
350	--	350
850	1	390

NETWORK SIDE

TRUNK CATEGORY	NUMBER
TWO-WAY	36
INWARD	12
OUTWARD	12
RESTRICTED (SPECIFY)	--
RESERVE (SPECIFY)	--
OTHERS (SPECIFY)	--
	60

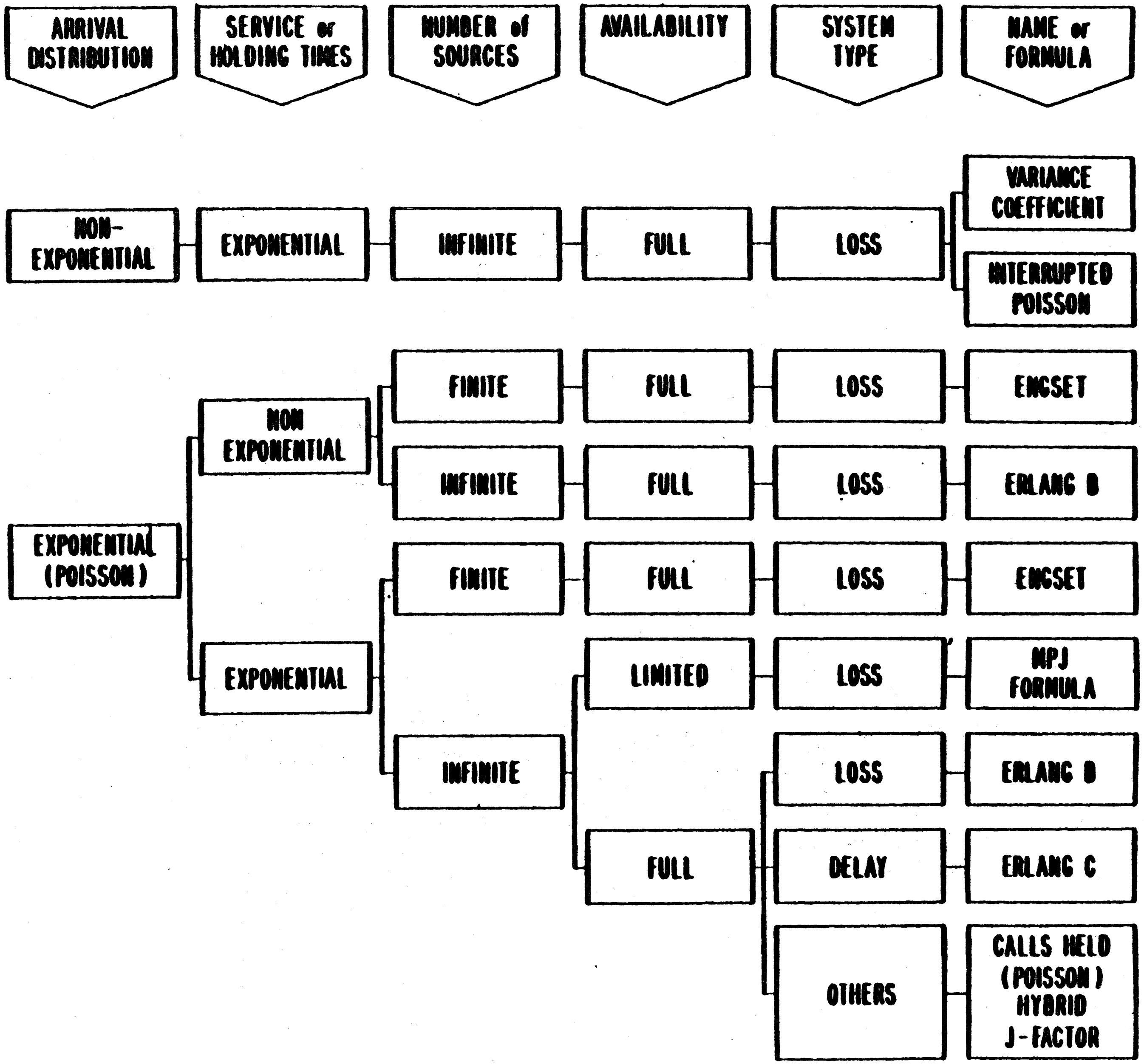


Figure B-3. Mathematical service models.

As a practical matter, other traffic engineering tools are needed. Computer runs, simulation, and--whenever possible--adherence to observed network behavior, all seem useful. Fortunately, the Bell Telephone Laboratories have long been the leading pioneers in this endeavor. With their resources and arsenal of methodology, techniques are apt to be devised to assess well enough the GOS levels for the telephone traffic through the local switch.

The GOS assessment task should answer many specific traffic questions. Table B-6 summarizes the service questions of main end-user concern. Answers to the above questions can be generated (i.e., computed, simulated, measured, verified) in numerous ways. Likewise, their presentation to a switch installation planner can come in different forms. An illustration of a possible presentation is shown in Table B-7. This table addresses the same items a, b, and c, that were introduced earlier in Table B-6 under the GOS problem area.

The estimation of Table B-7 pertains to the previous line and trunk configuration of Figure B-1, plus the approximate offered loads of Figure B-2. The blocking probability estimates in Table B-7 are generated by two methods. The results vary considerably. The GOS forecasts for individual substreams of Method II are two to seven times larger than those of Method I.

Method I exploits the Erlang B formula, tabulations of which are widely available. It assumes no internal switch or PBX blocking. The double-loop at a concentrator is handled by a proportional increase in concentrator load. No toll network or distant Class 5 area blocking is included. The numbers of servers are exactly as shown in Figure B-1.

Method II starts by modifying the number of server trunks in accordance with the detailed line and trunk summaries of Tables B-3, B-4, and B-5. The concentrator problem is approximated by a 10% reduction in server availability. The trunk group effectiveness is reduced by roughly 5% between PBX and the switch, while the toll trunks are not reduced for this GOS estimation. The earlier Erlang B formula is used in Method II only for switch-to-switch toll trunking. At the CONC-to-PBX service facilities the finite user Engset formula is utilized. This is easily done at CONC 2, because of its small number of trunks. At other concentrators, due to the larger number of server trunks, the Engset tables or curves were not available. In these cases, the Poisson characterization of lost calls held is accepted as a quick and convenient approximation. The lost calls held numbers are also employed for the PBX-to-switch trunk groups. To reflect potential congestion or limited availability within switches, Method II postulates 0.1% blocking within PBX's and 0.5% blocking within the DCO.

Table B-6. Grade-of-Service Questions at a Class 5 Switch

Problem-Area	Specific Quantity to be Determined
(1) Probability or Frequency of Blocking (GOS)	a. Average end-user GOS for the BH b. The worst end-user GOS for the BH c. Identity, topology, and hours of all below average GOS substreams d. Percentages of GOS blocking at specified server facilities, such as trunk groups, line concentrators, PBX's, and switches (including internal switch limitations) e. Guaranteed GOS levels for critical users, including Hot Line, MLPP, and others
(2) Needed Network Modifications	f. Number and types of serving trunks to be added or deleted g. Configurations and deployment schedules for line concentrators (CONC) h. Configurations and deployment schedules for PBX's and switches themselves i. Upgrades of switch and PBX control, processor, software, and other service unit capacities j. Military unique network modifications to assure the needs of critical users
(3) Traffic Flow Planning	k. Percentages of extra (if any) BH capacity to be assigned to traffic peaks, future growth, testing, facility malfunction, routing, multihoming, Government (military) unique uses, or to be kept in a general-purpose reserve.

Table B-7. Examples of Several GOS Estimates

Estimated GOS Quantity	GOS (%) Derived by	
	Method I	Method II
a. Average End-User GOS	1.4	3.7
b. Worst End-User GOS	4.8	21.6
c. Specific Selected Worst Traffic Substreams with GOS Below Average:		
CONC 1 - CONC 3	2.8	21.6
CONC 1 - PBX 2	1.7	13.6
CONC 1 - Switch 2	3.8	12.8
CONC 2 - CONC 3	3.2	16.1
CONC 2 - Switch 2	4.2	7.3
PBX 1 - CONC 3	2.0	14.1
CONC 3 - CONC 4	2.5	15.0
CONC 3 - Switch 1	3.2	14.6
CONC 3 - Switch 2	4.8	15.1
PBX 2 - Switch 2	3.7	7.1
CONC 4 - Switch 2	3.5	6.2

Like in Method I, the GOS results of Method II include no toll or distant other-end blocking. In a symmetric end-to-end long distance call, the incorporation of blocking at both ends may approximately double the average end user percentages.

The variation of numbers in Table B-7 suggests the following tasks to the Government local switch planner. First, a standard traffic engineering method is quite desirable. (It need not be the previously introduced Method I and II.) Second, using this standard method, GOS levels must be established at any switch in question. Third, in the interest of Government DSN subscribers, their average, worst, or substream unique GOS numbers are to be established. Detailed assured service estimates must be made for all critical users. If the numbers are adequate for Government's unique requirements, the configuration is acceptable. If not (see the high levels of GOS percentage in Table B-7), then there is a genuine need for either network or traffic flow modification (see the problem areas of Table B-6).

Consider any given set of link and node outages. Suppose further that this outage scenario separates the originally connected network into $j \geq 1$ disjointed pieces or subnetworks. If the total number of terminals is T, let T(1), T(2), ..., T(j) be the number of terminals in subnetwork 1, 2, ..., j, respectively. Then the T(i) terminals in the i-th piece can only talk to each other. Consider next the entity

$$D[\{i,I(j)\}] = \min\left\{\frac{T(1) + T(2) + \ldots + T(i)}{T}, \frac{T(i+1) + T(i+2) + \ldots + T(j)}{T}\right\}$$

It depends on i, as well as on the integer assignment I(j), to the collection of subnetworks. To include all cases, let $0 \leq i \leq j$. Then there are j+1 choices for i, and j! choices for I(j). Entity $D[\{i,I(j)\}]$ has possibly (j+1)! different values in the interval $[0, \frac{1}{2}]$. We define "disjointedness" D as the largest of these (j+1)! values:

$$D = \max D[\{i,I(j)\}].$$

When the network is connected one has j=1 and D=0. Otherwise, for $j \geq 2$ one obtains a single valued number in the range $\frac{1}{T} \leq D \leq \frac{1}{2}$.

When no links or nodes are disabled, one may use subscript zero and the identity $D_0=0$ to mean that no part of the user terminal population is disconnected from the main of the network. States $D_1 \geq 0$, or $D_2>0$, ..., may denote that outages of the first kind (subscript 1), such as for a single severed link may or may not alter the network connectivity. Outages of a second kind (subscript 2), such as for disabled nodes or link groups, if larger than zero, mean that some subnetwork must now be disconnected from the main network.

Larger D values signify that more terminals are rendered unreachable from the central core of the network. For the same outage index i, smaller D_i values are thus desirable. They stand for higher survivability.

The second survivability component, P, refers to probability of blocking or, as it is commonly known, the grade of service. Since blocking is apt to vary considerably from one part of the network to another, some meaningful average, or worst case "bottleneck" formula appears needed. In what follows, the worst-case approach is used to generate a unique P number.

Blocking can occur both when a system is damaged or not. Ideally, one could postulate that a sound local area network is nonblocking and thus $P_0=0$. Larger P values imply more blocking somewhere in the network. They denote a worsening of communications and less survivability in the same environment.

The pair (D,P) quantifies survivability and makes partial configuration comparisons possible on the basis of numbers.

Let (D,P) and (D',P') be two survivability vectors for two topologies, S and S', of the same system. Then, given link and node outage state i, one says that S is more survivable than S', subject to i, if $D_i<D_i'$ and $P_i<P_i'$ both hold. If the inequalities hold for all i, then S is more survivable under all circumstances. If there exist outage states i and j, under which the inequalities are reversed and differ, then the discrimination is not clear cut. If $D_i=D_i'$ and $P_i=P_i'$ hold, the two survivabilities are the same, conditional on i.

In practice, some outage states are more likely than others. Thus, the outage of a single link is more likely than that of two or more links. Single nodes are apt to fail more frequently than two or more nodes. Quantitative comparison of systems, therefore, can be done initially by analyzing the single link outage and the single-node outage impacts.

The approach is illustrated in Figure C-1, which shows the number of node outages as the ordinate, and the number of link outages as the abscissa. All squares depict the same network, with the same nodes, links, and capacities.

For an undamaged topology, with zero link and zero node outages, Figure C-1 assumes a connected network (i.e., D=0) and no blocking (i.e., P=0). As link outages and node outages are increased in number, there eventually comes a point beyond which either D>0 or P>0 materializes. At that instance, one has either a disjointed, or disrupted network, or call blocking somewhere in a perhaps connected network.

Which of the two, D>0 or P>0, manifests first or disrupts the network more again depends on several factors. One factor is the presence (or absence) of multiple backup links. The link capacities is another factor. If, for example, the network is assembled of numerous circuits, but all with relatively low capacity, then (D=0, P>0) may occur ahead of (D>0, P=0). On the other hand, huge capacity on most links may suffice to guarantee that (D=0, P>0) never occurs.

Let $T=T_1+T_2+...+T_N$ denote the total number of terminals in the military service area. Let E be the number of exterior gateway or outside lines. Then, as long as the lowest link capacity, $C_{min} \geq 1/2[T+min(T,E)]$, network connectivity implies absence of blocking in that network. Then, of course, D=0 implies P=0 and connectivity is tantamount to survivability.

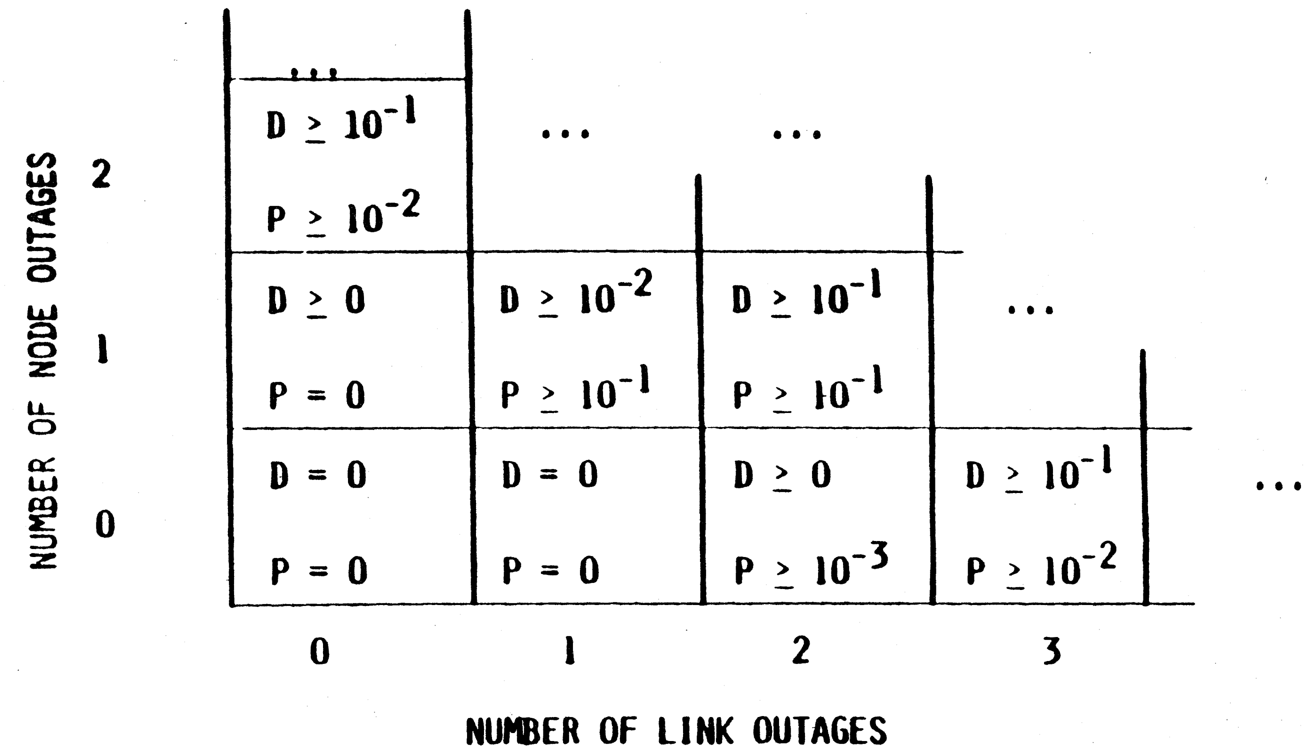


Figure C-1. **The (D,P) contour as a function of link and node outages.**

At the other extreme one may consider small individual link capacities. Suppose now that the highest link capacity, C_{max}, is quite small such as

$$C_{max} << T/2,$$

but that there is an abundance of alternate routes and backup links. One feels that under these conditions blocking (i.e., $P>0$) should precede network disconnection (i.e., $D>0$).

In the extreme case, such as on Christmas Day or Mother's Day, the public switched network may be extremely blocked and yet connected, i.e., $P>0$ and $D=0$. Then, in the additional presence of any subnetwork outages, grade of service appears to be the more realistic measure of network survivability.

C.2.2 Determination of D

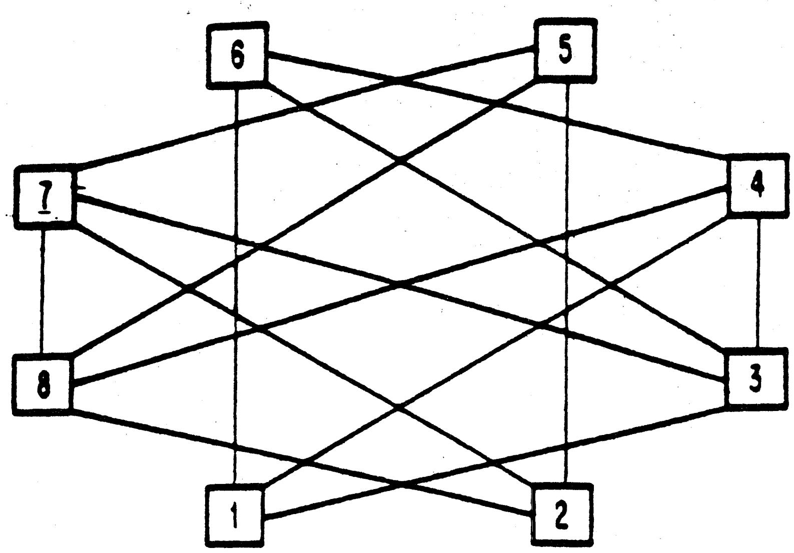
Determination of D involves analysis of topology. Sometimes it is easy, at other times, difficult. Consider a scenario where link cuts comprise the most outages, and examine a network such as shown in Figure C-2, part a). What is the least number of link cuts that separate this eight-node apparently connected network into two or more disjoint subnetworks? What are the corresponding $D>0$ values that occur first? The answer to the first question is: two link cuts. They should be administered to the links (3,7) and (4,8), causing $D=0.5$. The validity of the claim is seen from the simple equivalent topology of part b), Figure C-2.

To this writer's knowledge, there is a scarcity of algorithms to solve such problems. For larger networks, with many nodes and many links, simple enumeration of all possible cases may consume too much time. New computer algorithms may be needed.

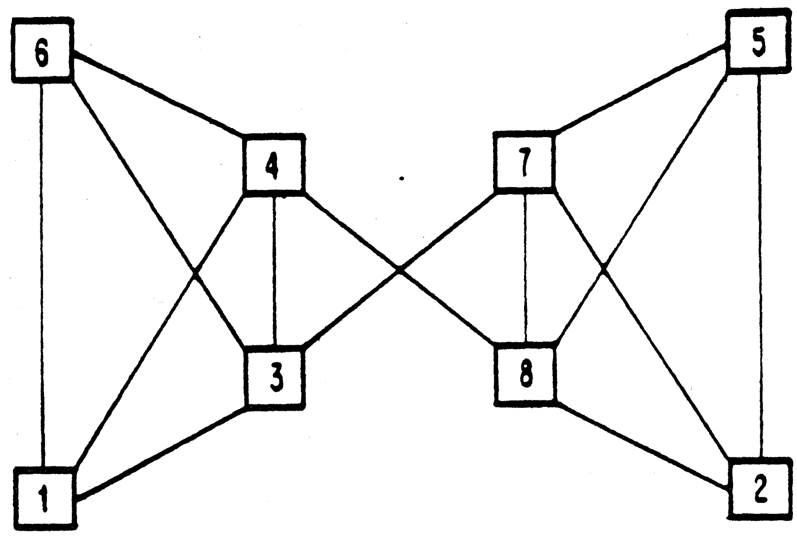
The access area situation tends to alleviate these complexities for two reasons. First, the AA networks are relatively small. That is, the number of nodes and higher level links is typically under 10. Quick inspections then may reveal connectivity flaws and disconnectivity, i.e., $D>0$, possibilities. And second, the access area network layout is under the control of area commanders. Commanders can purposely adhere to simple and well-connected network architectures.

C.2.3 Determination of P

This section determines several examples of GOS or probability of blocking, as they might occur in access area network applications. The analysis applies to the switch and concentrator levels of the network hierarchy.



a) Sample Network



b) Equivalent Topology

Figure C-2. A sample network and its equivalent topology.

To make matters as simple and applicable as possible, the networks are selected to possess simplifying symmetries or to be small in size. The latter assumption corresponds, in an approximate way, to the size scale envisioned for all of the small AA networks. Furthermore, all the switches are assumed to be intrinsically nonblocking and fully available.

As the initial example, consider the symmetric loop or ring network. Let the geometry and notation be as given in Figure C-3. There are a total of $N \geq 3$ identical switching nodes. Each serves the identical number of T/N terminals. The links between the nodes are all of the same uniform capacity C=T/4 in both directions. For the unimpaired network (without outages), this is the minimum capacity necessary to guarantee nonblocking operation in all traffic cases. When a single link is severed, this network is still connected and D=0. When two links are severed, the network is cut in two, with $1/N \leq D \leq 1/2$.

A single link outage, however, can degrade the service. Figure C-4 shows the worst-case loss in the loop network that has suffered a single link cut. The abscissa is T, the total number of terminals. The ordinate is the offered load, a, per terminal in Erlangs. This load a is assumed to be identical for all T terminals. A total of N nodes and N links is presumed to comprise the loop. However, N does not affect the worst-case loss. Thus, N does not appear explicitly in Figure C-4.

The curves, denoted as P=5%, 1%, and 0.2%, represent the "T and a" loci where the blocking probability has these values. The computation is based on the previously mentioned individual link capacities of C=T/4. When no links are out, this represents the minimum nonblocking capacity assignment. Increase in C leads to lower P values. In particular, if one set $C \geq T/2$, then single-link outages still imply P=0.

In Figure C-4 a simultaneous increase in load/line and in number of terminals is possible for fixed P. This is true, because the link capacity is proportional to T. If C were held constant, however, then a different picture would emerge. The product, aT, would then be roughly constant and equal to twice the load that generates the P value of interest. For example, if C=24 and P=1%, then, from the Erlang B loss formula, aT=2(15.3) Erlangs. Hence, $a \cong 30.6/T$. For T=300, this yields a = 0.1, or approximately 6 minutes of talking activity per individual telephone terminal per hour. In most military applications, one expects the traffic intensity to be of this order of magnitude.

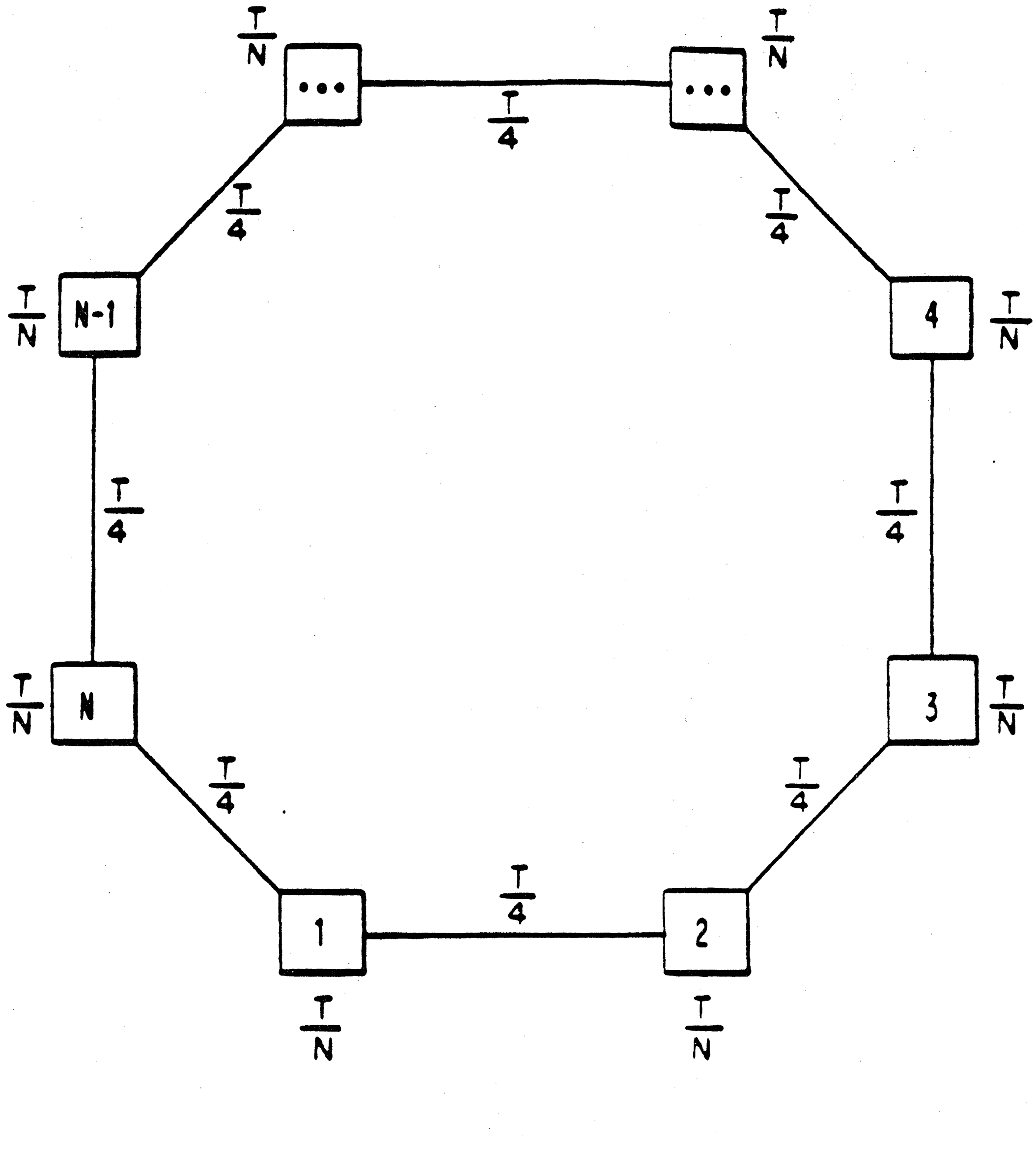


Figure C-3. Loop network with uniform links and nodes.

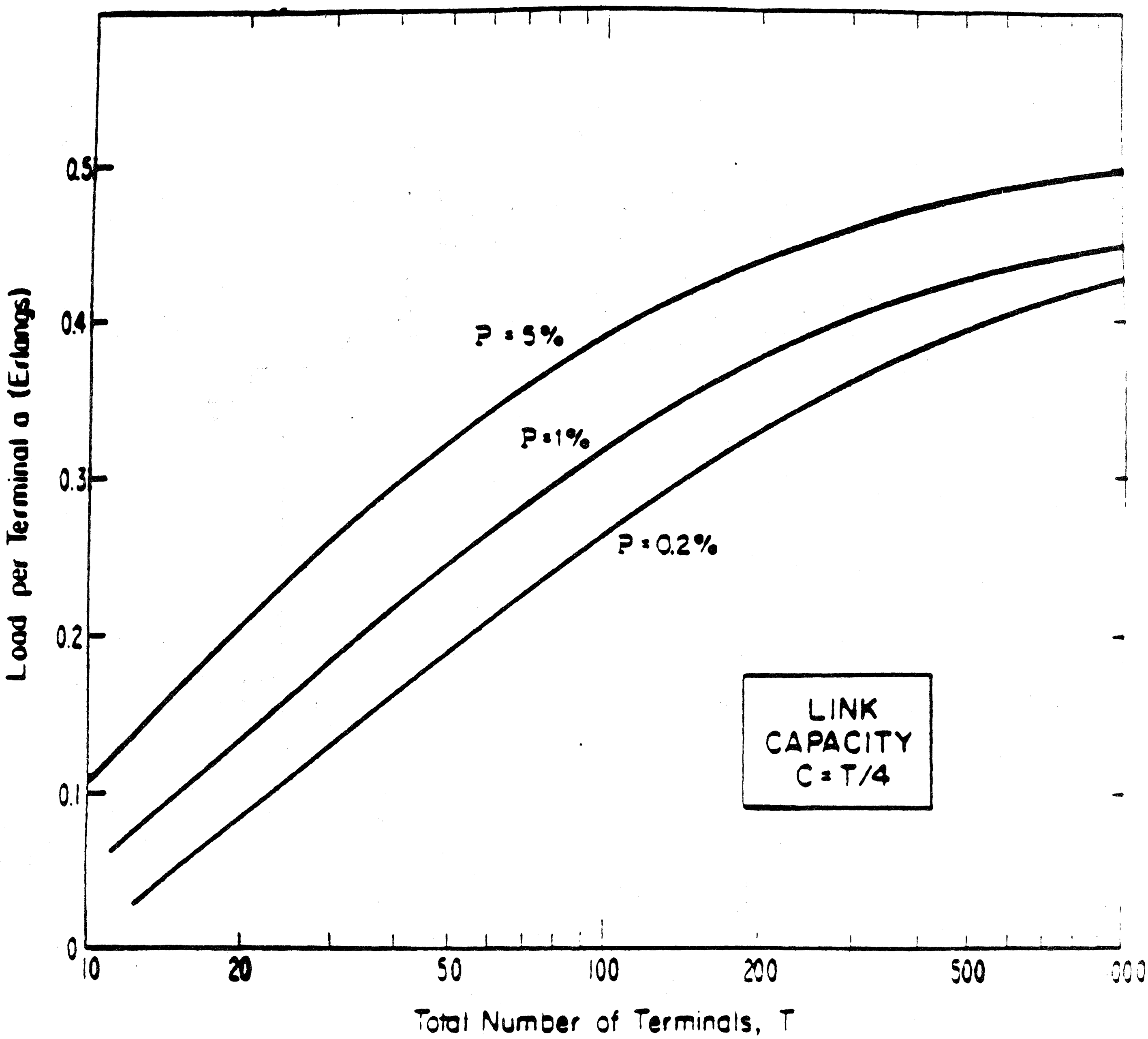


Figure C-4. Worst-case probability of blocking for the uniform loop network with a single link outage.

The characterization of the "worst case" of blocking deserves several comments. The effect of cutting one link in Figure C-3 is indistinguishable from cutting any other link. That follows from the uniform symmetry of the loop. The most congested bottleneck must occur diametrically opposite the cut. Because then the realizable maximum of one-half the terminals may want to communicate to the other half across the bottleneck.

The situation becomes far more complex for more general topologies. The nonuniform loop may be the next illustrative example, as shown in part (A) of Figure C-5. This is a network of four nodes and terminals. The number of channels

$$T = 24 + 12 + 8 + 6 = 50$$

per each link are indicated in Figure C-5 to be 15, 10, 4, and 3, respectively. This network is nonblocking when all links are intact. Outage of a single link can produce some blocking.

The worst case occurs when the 15-channel link gets severed [see part (A) of Figure C-5]. Then all three of the remaining links may become congested to the point of blocking. The most severe bottleneck is the link with capacity $C=3$. Since the call requests can number no more than $\min(18,32)=18$, and there are only three channels available, the blocking probability P is clearly nonzero. If the 18 terminals on one side of the bottleneck offer 0.1 Erlangs of load each, and if approximately one-half of requests go to the other side of the bottleneck, the $P \cong 5\%$.

Multiloop topologies may be configured to enhance connectivity and survivability. It is unfortunate that their analysis becomes rapidly so difficult. Consider part (B) of Figure C-5. Here, the node and terminal sets are the same as in part (A). However, one link has been removed, two new links have been added, and the total link capacity has been reduced from 32 channels in part (A) to 28 channels in part (B).

It is claimed by inspection, that the most severe cut in (B) is that of the 12-channel link, and the most severe bottleneck is comprised of two parallel 2-channel links, as shown. The number of contending terminal set pairs is $\min(12,26)=12$. The number of server channels is four. The approximate blocking probability [under the same ground rules as in part (A) of Figure C-5] is now $P=2.5\%$. Thus, in part (B) despite reduction in total number of channels, survivability appears to be increased in both the D and P sense.

For more complicated multiloop networks, the determination of P becomes quite involved. We shall not pursue that generality here. Rather, the following section describes the survivability plus other aspects of the structured network configuration.

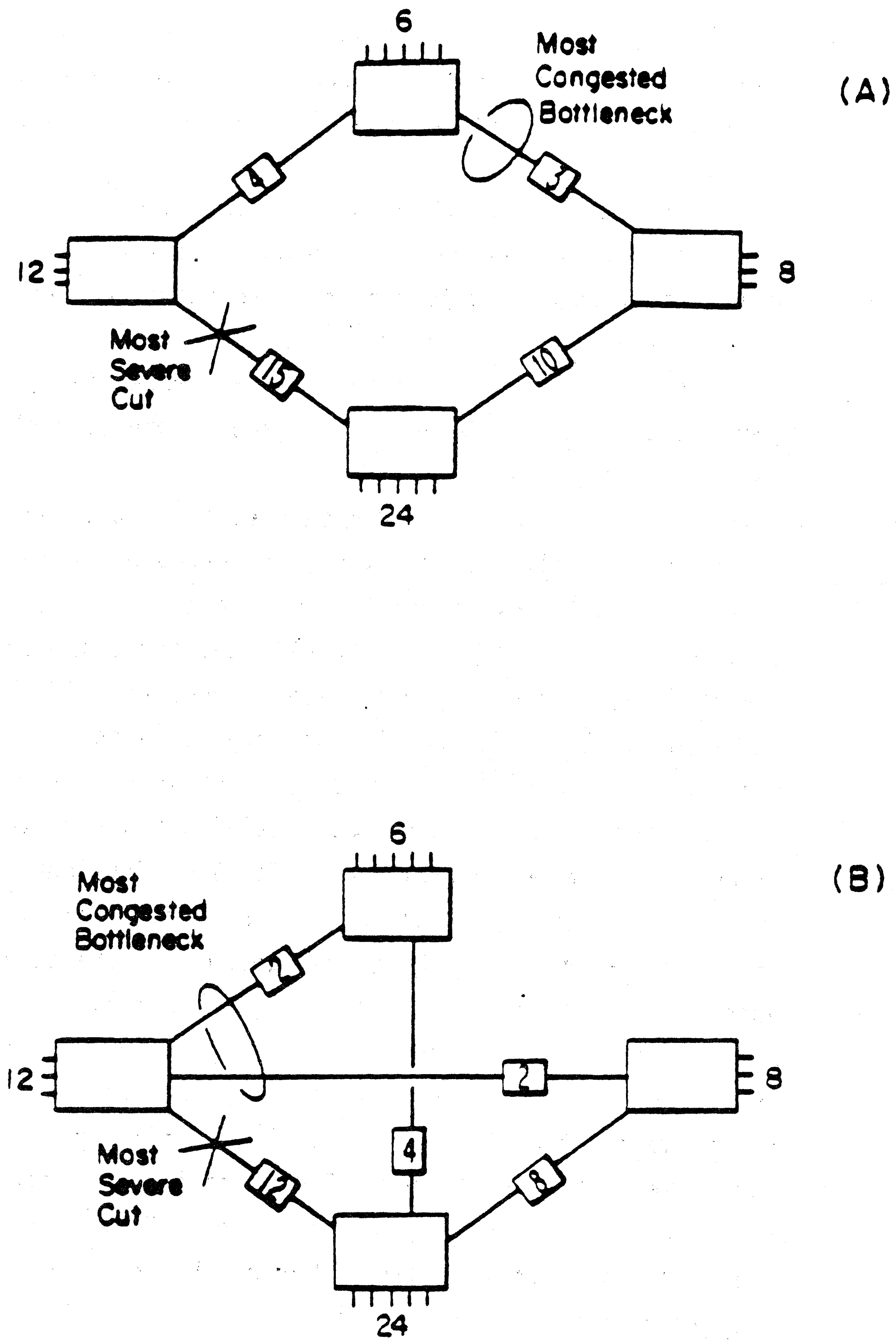


Figure C-5. The most severe cuts and bottlenecks in simple networks.

C.3 Structured Configuration Networks

C.3.1 Disconnect survivability of structured configuration networks

This section considers the structured configuration, as depicted earlier for an arbitrary number of N nodes in Figure 4-7 of Linfield, et al., (1980). Clearly, incapacitation of any single node does not degrade the connectivity of that network. For a single node outage, D=0.

For two node outages D can either be zero or larger than zero. If one or both of the two deleted nodes are in the $\{3,4,\ldots,N\}$ set, then D=0 still holds. The network is connected with a multiloop or star configuration. Only when both nodes 1 and 2 are out, is D>0. In that case everything is disconnected. One could define this catastrophy as D=1.

For single link outages, D=0 remains. It takes at least two link outages to separate any switch, or group of switches, from the rest of the network. For example, two simultaneous outages of C_{1N} and C_{2N} would separate node N from the network, causing D=1/N. On the other hand, N-2 simultaneous outages of links C_{23}, C_{24}, ..., C_{2N} fail to sever the network.

The outage of one node plus a simultaneous outage of one link can also disconnect the network. For instance, switch n ($3 \leq n \leq N$) becomes isolated when either node 1 and link C_{2n}, or node 2 and link C_{1n} are out.

One concludes that it takes two of any outage kind, nodes or links, to produce D>0 in the structured configuration. It may be reasonable to assume that two outages are considerably more likely to take place than three or more outages. This suggests a probabilistic estimate, $Pr\{D>0\}$, of any disconnect event whatsoever. At a given time, let:

P_n = probability of individual node outage

P_ℓ = probability of individual link outage.

Assume that the outage events are independent of each other. Then for $P_n \ll 1$ and $P_\ell \ll 1$,

$$P\{D>0\} = P_n^2 + 2(N-2)P_nP_\ell + (N-2)P_\ell^2$$

is the disconnect probability of the structured configuration network.

C.3.2 Grade-of-service survivability

Many networks are designed to offer some nonzero blocking even when there are no outages of any kind. Design decisions are made on the basis of traffic statistics, users requirements, and system economics.

Given no link or node outages, the structured configuration can be sized for various degrees of congestion. It depends on the number of server channels $\{C_{12}, C_{13}, \ldots; C_{1N}, C_{23}, \ldots, C_{2N}\}$, as well as on the traffic generated by the $\{T_1, T_2, \ldots, T_N\}$ terminals, whether P=0 or P>0 applies. In what follows, we review the $P \geq 0$ grade of service, survivability aspects of the structured configuration.

To simplify matters, assume the network configuration shown in Figure C-6. It has N=4 nodes. The number of terminals are structured to obey the inequality

$$T_1 \geq T_2 \geq T_3 \geq T_4.$$

For uniformity, modularity, and speed of installation, Figure C-6 postulates identical link capacity C for all five links. The present goal is to examine the effect of various C choices on the worst-case probability of blocking P.

According to Section C.2.1, $C \geq (T_1+T_2+T_3+T_4)/2$ suffices to guarantee nonblocking, i.e., P=0, as long as there is total connectivity or as long as D=0 holds. It is also clear that such high C value is not always necessary. Smaller values will often achieve the same objective. For instance, the link capacity

$$C + (T_1+T_3+T_4)/3$$

implies P=0 for all traffic conditions of the structured network of Figure C-6, and subject to no outages of either nodes or links. The actual minimal necessary capacity is even smaller. It is given by a rather cumbersome formula. That formula plus other related link capacity formulas are summarized in Table C-1.

Table C-1 applies for P=0, or nonblocking, or perfect grade-of-service conditions of the structured configuration only. In the first column one finds N, the number of nodes. The N=4 case is that of Figure C-6. The general N case assumes $N \geq 3$. The links that join the nodes are all of the same capacity.

The second and third columns of Table C-1 show the number of link and node outages assumed for that particular row.

The fourth column depicts the minimum capacity necessary to ensure P=0, for all conceivable traffic load conditions. In the extreme, all the terminals may want to call each other until there are no idle (on-hook) terminals left. This capacity, see Figure C-6, is assumed to be a fixed constant for all 2N-3 links. In the text above, the minimal necessary capacity was denoted as C_0.

The fifth and final column of Table C-1 presents a simple workable upper bound on the minimum C_0. Being of the form

$$C + (T_2+T_3+\ldots+T_N)/(N-2),$$

this upper bound offers a single formula for all $N \geq 3$. That formula is sufficient to give P=0 under the number of link and node outages indicated.

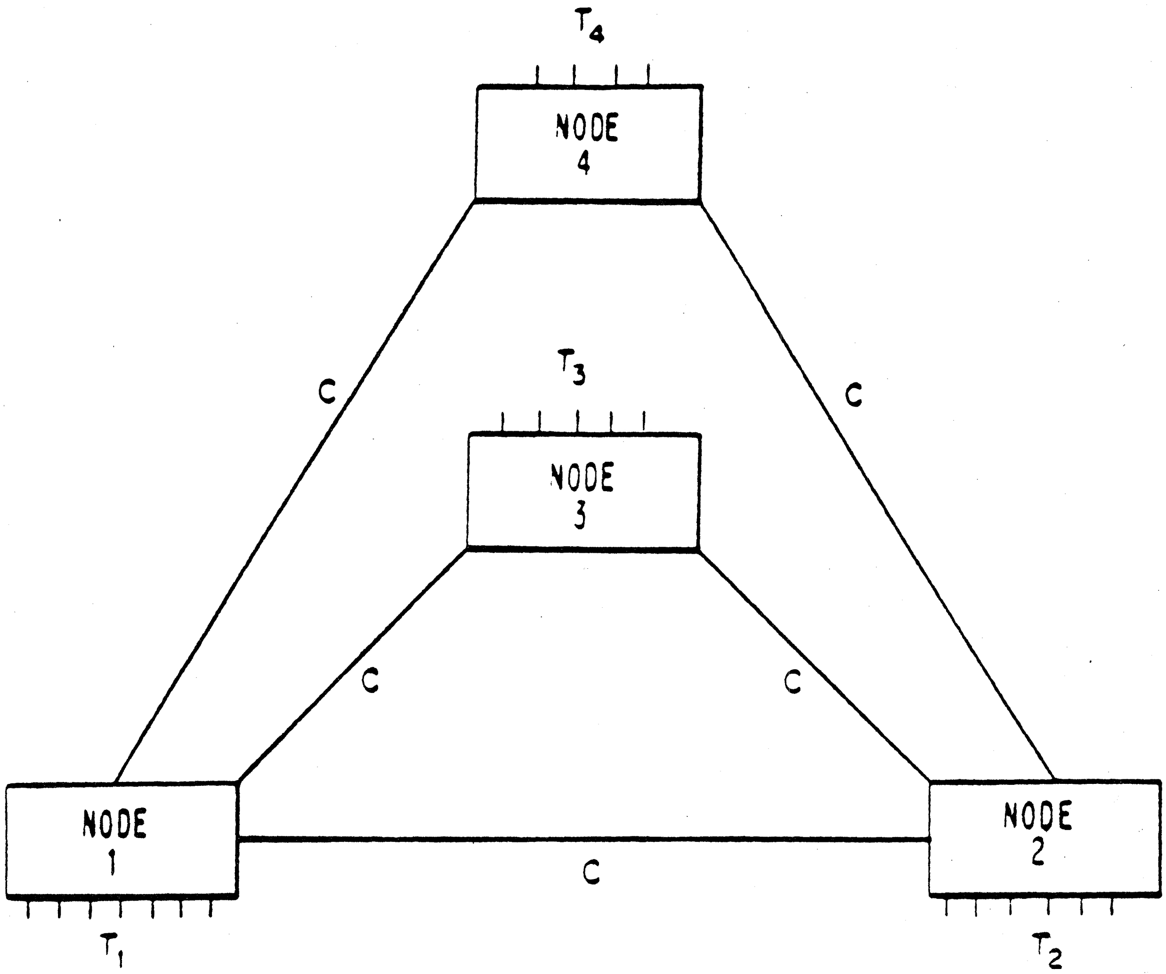


Figure C-6. A simplified four-node structured configuration.

Table C-1. Necessary and Sufficient Link Capacities for Various Size Networks

N	Outages: Link	Outages: Node	Minimum Capacity Necessary for P=0	Sufficient and Simple P=0 Capacity
3	0	0	$1/2 \min(T_1, T_2+T_3)$	T_2+T_3
	0	1	T_2	
	1	0	$\min(T_1, T_2+T_3)$	
4	0	0	$1/3 \max[\frac{3}{2}T_3, \min(T_1, T_2+T_3+T_4), \min(T_1+T_4, T_2+T_3)]$	$\frac{T_2+T_3+T_4}{2}$
	0	1	$1/2 \max[2T_3, \min(T_1, T_2+T_3)]$	
	1	0	$1/2 \max[2T_3, \min(T_1, T_2+T_3+T_4), \min(T_1+T_4, T_2+T_3)]$	
N	0	0	$\frac{1}{N-1} \max_{I_N}[\frac{N-1}{2}T_3, \min(T_1+\sum_{I_N} T_i, T_2+\sum_{I_N^c} T_i)]$	$\frac{T_2+T_3+\ldots+T_N}{N-2}$ (Conjectured)
	0	1	$\frac{1}{N-2} \max_{I_{N-1}}[(N-2)T_3, \min(T_1+\sum_{I_{N-1}} T_i, T_2+\sum_{I_{N-1}^c} T_i)]$	
	1	0	$\frac{1}{N-2} \max_{I_N}[(N-2)T_3, \min(T_1+\sum_{I_N} T_i, T_2+\sum_{I_N^c} T_i)]$	

Thus, it is alleged that $(T_2+T_3+T_4)/2$ is sufficient to guarantee nonblocking operation of the structured N=4 node network under all or no outage or single outage cases.

Several explanations may be appropriate for the general N formulas in Table C-1. The formulas contain symbols I_N and I_N^c, where N=3, 4, 5, ... The I_N represents an arbitrary integer subset drawn from the integer space $S=\{3, 4, 5, \ldots, N\}$. Typical examples of I_N are Φ (the empty set), $\{3\}$, $\{4\}$, ..., $\{3, 4\}$, ..., $\{3, 4, 5\}$, ..., or even S (the entire space). Superscript c, as in I_N^c, denotes the complement of I_N,

$$I_N^c = S-I_N.$$

The general N, minimum C, formulas are rather clumsy to use, even for relatively small N. Simpler functions of $\{T_1, T_2, \ldots, T_N\}$ are desirable. The last column, as noted earlier, represents such simplifications.

So far, the emphasis has been on P=0. It remains to carry through similar capacity assignment analysis for P>0 values of interest. Recommended values are:

P = .2% - for enhanced operation,
= 1% - for normal operation,
= 5% - for degraded operation.

For all such practical P values, and assuming the structured network configurations for access area networks, a worst-case survivability analysis can and should be performed.

REFERENCES

Linfield, R. F., M. Nesenbergs, and P. M. McManamon (1980), Command post/signal center bus distribution system concept design, NTIA Report 80-36, April (NTIS Order No. PB 80-188113).

FORM **NTIA-29**
(4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

	1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.
	NTIA Report 85-185		

4. TITLE AND SUBTITLE MILITARY ACCESS AREA CHARACTERIZATION	5. Publication Date November 1985 6. Performing Organization Code NTIA/ITS.N1
7. AUTHOR(S) Robert F. Linfield, Martin Nesenbergs	9. Project/Task/Work Unit No. 9104562
8. PERFORMING ORGANIZATION NAME AND ADDRESS National Telecommunications and Information Admin. Institute for Telecommunication Sciences 325 Broadway Boulder, CO 80303	10. Contract/Grant No.
11. Sponsoring Organization Name and Address U.S. Army Information Systems Management Activity Ft. Monmouth, NJ 07703	12. Type of Report and Period Covered NTIA Report 13.

14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report addresses the concepts, the justification, and the eventual configuration of military access areas. Many factors enter into this access area characterization effort. The key factors emphasixed here are: the current telecommunications environment in teh United States and abroad, the military (in particular, the U.S. Army) telecommunications requirements, pertinent architectures of present and future networks, and teh associated major cost elements for access areas. An attempt is made to define the term "access area" in a quantitative and unambiguous way. To that end, many defining parameters appear needed to specify both the facilities and the functional elements of significance.

16. Key Words *(Alphabetical order, separated by semicolons)*
access area; cost; military communications; network architecture; performance; switches; traffic

17. AVAILABILITY STATEMENT	18. Security Class. *(This report)*	20. Number of pages
☒ UNLIMITED.	Unclassified	267
☐ FOR OFFICIAL DISTRIBUTION.	19. Security Class. *(This page)* Unclassified	21. Price: