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An Introduction to the Technology of Intra- and Interexchange Area Telephone Networks

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PREFACE

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GLOSSARY

ac	-	Alternating Current
ACP	-	Action Point
A/D	-	Analog to Digital Conversion (also Digital to Analog in Two-Way Circuits)
AEC	-	Automatic Echo Canceller
AIS	-	Automated Intercept System
AMA	-	Automatic Message Accounting
AMARC	-	Automatic Message Accounting Recording Center
ANI	-	Automatic Number Identification
AO&M	-	Administration, Operation, and Maintenance
AT&T	-	American Telephone and Telegraph Company
BER	-	Binary (or Bit) Error Rate
BH	-	Busy Hour
BOC	-	Bell Operating Company
BORSCHT	-	Battery, Overvoltage Protection, Ring, Supervision, Control Signaling (or Clock), Hybrid, and Test
BSRF	-	Bell System Reference Frequency
BSTJ	-	Bell System Technical Journal
CAMA	-	Centralized Automatic Message Accounting
CCIS	-	Common Channel Interoffice Signaling
ccs	-	Centi (Hundred) Call Seconds
CCSA	-	Common Control Switching Arrangement
CDO	-	Community Dial Office
CENTREX	-	PABX Operation Under the Control of a Central Office
CO	-	Central Office
CODEC	-	Coder/Decoder
CONC	-	Concentrator

CONUS - Contiguous or Continental U.S.

CPE - Customer Premises Equipment

D - Digital

DB - Data Base

dc - Direct Current

DCO - Dial Central Office

DDD - Direct Distance Dialing

DDS - Dataphone Digital Service

DISTR - Distributor or Sender

DSA - Digital (or DDS) Service Area

DS Format - Digital Signal Channel Format, as for 64 kb/s or 1.544 Mb/s Digital Transmission

EO - End Office

EPSCS - Enhanced Private Switched Communication Service

Erlang - Traffic Unit for Circuit Use (Same as 36 ccs)

ESS - Electronic Switching System

FDM - Frequency Division Multiplex

MF - Frequency Modulation

GOS - Grade of Service

GTE - General Telephone and Electronics Corporation

H - Hybrid

HU - High Usage

IDN - Integrated Digital Network

IP - Intermediate Point

ISDN - Integrated Services Digital Network

ITT - International Telephone and Telegraph Company

IXC - Inter-Exchange (e.g., Tariff and Mileage)

GLOSSARY (cont)

Junctor	-	Intra-Switch Connector
LAMA	-	Local Automatic Message Accounting
LCR	-	Least Cost Routing
LIU	-	Line Interface Unit
LL	-	Long Lines of AT&T
Loran C	-	Distribution System of Standard Time
MCI	-	Microwave Communications, Incorporated
MF	-	Multiple Frequency (Signaling)
MUX	-	Multiplexer
MW	-	Microwave
NAP	-	Network Access Point
NC	-	No Circuit (Condition)
NCC	-	Network Control Center
NCP	-	Network Control Point
NM	-	Network Management
NMC	-	Network Management Center
NOAC	-	Network Operations and Administration Center
NOC	-	Network Operations Center
NPA	-	Numbering Plan Area (Area Code)
OCC	-	Other Common Carrier
ONI	-	Operator Number Identification
PABX	-	Private Automatic Branch Exchange
PAM	-	Pulse Amplitude Modulation
PBX	-	Private Branch Exchange
PC	-	Primary Center
PCM	-	Pulse Code Modulation

POTS	-	Plain Old Telephone Service
PP	-	Primary Point
RC	-	Regional Center
RCA	-	Radio Corporation of America
RCVR	-	Receiver
ROC	-	Regional Operations Center
RP	-	Regional Point
RSM	-	Remote Switching Machine
RSS	-	Remote Switching System
RSU	-	Remote Switching Unit
RTA	-	Remote Trunk Access
SC	-	Sectional Center
SCAN	-	Scanner
SDC	-	Switched Digital Capability
SDM	-	Space Division Multiplex
SF	-	Single Frequency (Signaling)
SLIC	-	Subscriber Loop (or Line) Interface Circuit (or Card)
SNR	-	Signal to Noise Ratio
SP	-	Sectional Point
SPC	-	Stored Program Control
SSB	-	Single Sideband
SSN	-	Switched Service Network
STA	-	Station
STP	-	Signal Transfer Point
SW	-	Switch
SXS	-	Step-by-Step Switch

GLOSSARY (cont)

T	-	Trunk
Tandem	-	Typically a Switch that Carries Traffic Between Other Switches
TASI	-	Time Assignment Speech Interpolation
TC	-	Toll Center
T Carrier	-	Transmission Carrier System for Digital Signals (the Most Common is T1 Carrier with 1.544 Mb/s Data Rate)
TDCS	-	Traffic Data Collection System
TDM	-	Time Division Multiplex
TIU	-	Trunk Interface Unit
TP	-	Toll Point
TSP	-	Traffic Service Position
TSPS	-	Traffic Service Position System
VF	-	Voice Frequency (Channel)
V&H	-	Vertical and Horizontal Coordinates
WATS	-	Wide Area Telecommunications Service
XBAR	-	Crossbar Switch

AN INTRODUCTION TO THE TECHNOLOGY OF INTRA- AND INTEREXCHANGE AREA TELEPHONE NETWORKS

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This report presents an overview of the 1982 telephone network technology. Many physical facilities constitute the public switched telephone network. Their respective roles in support of voice services and related traffic are reviewed. Essential internal functions, such as accounting, timing, signaling, plus many others, are carried out by cooperative hidden subnetworks that exist within the larger overall public network. Engineering, operation and innovation of these facilities and functions will fall on all sides of exchange area boundaries.

1. INTRODUCTION

The telecommunications industry, and in particular the parts thereof concerned with operations of the public switched telephone networks, are currently in a rather opportune situation. As is known, the U.S. Courts have approved the divestiture of the Bell Operating Companies (BOC's) from the American Telephone and Telegraph Company (AT&T). This action has been accompanied by a variety of legal measures, many of which may be quite important in their own right, but nevertheless beyond the scope of this technical report.

Of interest here is the technological status of the nationwide telephone system. Clearly, the actual quality of service that is experienced by the customers depends on many factors, such as competing service demands, network conditions, and how efficiently existing network assets are utilized. This raises the first group of questions.

- o What are the physical facilities of the public switched network? What building blocks are involved in a typical telephone call? Which elements are most important for voice telephone traffic, now and in the foreseeable future?

But, even to answer these initial questions in a cursory way, a second set of questions should be considered.

- o What are the functions of the various facilities? Why and how do different entities interact? What groupings of said building

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blocks, be they hardware or software, serve what specific subsystem needs? If their unique operations resemble a "subnetwork" submerged in a hierarchy of other subnetworks, what are these hidden networks? What do they do?

A third family of questions with nontrivial technical impact pertains to establishment of boundaries of responsibility. It will be shown later that certain new regions, to be called "exchange areas," are to be defined. End-user service will apparently depend on intra- and interexchange (area) access, technical compatibility, and quantitative interworking of a variety of facilities.

- What technical issues will arise if these facilities fall in different BOC's or in domains of several interexchange common carriers? What system functions, service features, and subscriber performance levels will be affected by certain, more or less fortuitous, boundary placements between areas?

Being brief and limited in scope, this introductory report does not answer the above technical questions in any great depth. This report may even fail to ask all the significant questions. However, if every proverbial journey starts with a single step, then so must a technical introduction to the present-day intra- and interexchange area telephone network. The first steps taken here are those pursuant to the three sets of questions raised above.

2. THE PHYSICAL FACILITIES -- NETWORK BUILDING BLOCKS

2.1 Background

The United States telephone network is largely in the hands of the Bell System, i.e., the American Telephone and Telegraph Company and the Bell Operating Companies. There are by all means several thousands of Independent Telephone Companies, of which the four largest (General Telephone, United Telephone, Continental Telephone, and Central Telephone & Utilities) each boasts of over a million mainline subscribers. However, the share of services carried by the Independents is relatively small. According to various sources (Berry, 1981), the U.S. Independents serve around 37 million out of 187 million telephones, or 19% of all subscriber lines that carry around 17% of revenue-generating traffic.

Thus, roughly 80% or more of telephony is handled by AT&T and the BOC's. Not counting the rather unique AT&T Long Lines (LL), there are 22 BOC's in the 48 contiguous United States (CONUS). Their respective geographic coverages are listed in Table 1.

Table 1. Territories of the BOC's

Bell Operating Company (BOC)		States Served	
		All or Nearly All Of	Minor Parts Of
1.	Chesapeake and Potomac Telephone Company	District of Columbia, Maryland, Virginia, West Virginia	
2.	Cincinnati Bell		Kentucky, Ohio
3.	Diamond State Telephone	Delaware	
4.	Illinois Bell Telephone	Illinois	Indiana
5.	Indiana Bell Telephone	Indiana	
6.	Malheur Bell		Oregon
7.	Michigan Bell Telephone	Michigan	
8.	Mountain States Telephone and Telegraph	Arizona, Colorado, Idaho, Montana, New Mexico, Utah, Wyoming	Texas
9.	Nevada Bell Telephone	Nevada	
10.	New England Tel & Tel	Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	
11.	New Jersey Bell	New Jersey	
12.	New York Telephone	New York	Connecticut
13.	Northwestern Bell Telephone	Iowa, Minnesota, Nebraska, North Dakota, South Dakota	
14.	Ohio Bell Telephone	Ohio	
15.	Pacific Northwest Bell	Oregon, Washington	Idaho
16.	Pacific Telephone and Telegraph	California	
17.	Pennsylvania Bell	Pennsylvania	
18.	South Central Bell Telephone	Alabama, Kentucky, Louisiana, Mississippi, Tennessee	
19	Southern Bell	Florida, Georgia, North Carolina, South Carolina	
20.	Southern New England Telephone	Connecticut	
21.	Southwestern Bell Telephone	Arkansas, Kansas, Missouri, Oklahoma, Texas	Illinois
22.	Wisconsin Telephone	Wisconsin	

The long distance or toll traffic is carried by the LL and around a dozen Other Common Carriers (OCC). While the coverage of the AT&T LL is nearly nationwide, the OCC's tend to serve selected locations. The same observation pertains to offered services. While AT&T LL offers the longest list of services, the offerings of the OCC's are more selective (CCMI, 1982a). The situation is summarized in Table 2. There is a great variety of services buried in such a table, especially under the heading of 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 the AT&T Long Lines.

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 five years the OCC percentages have grown somewhat, but in all likelihood they have not doubled by 1982.

Another fact that Table 2 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 voice.

In summary, the main hulk of telecommunications services in the United States is Plain Old Telephone Service (POTS). It is provided (viz., owned, operated, administered, installed, engineered, and researched) by what used to be one large company, the Bell System. The technological review to follow will assume that gross fact as well known and will not dwell on details of minor networks and their administration.

2.2 The Nominal Voice Path

The terminal of a typical telephone subscriber is the familiar handset. Through it the subscriber accesses and uses the network. The latter entails establishing, maintaining, and disengaging a communications path to a perhaps similar voice terminal that can be anywhere in the network. The situation is as shown in Figure 1.

At the left side of this figure, in either a residence or an office one finds the Customer Premises Equipment (CPE). The indicated telephone apparatus, which may include the main station and its extensions, connects through local loops,

Table 2. 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 Long Lines	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	

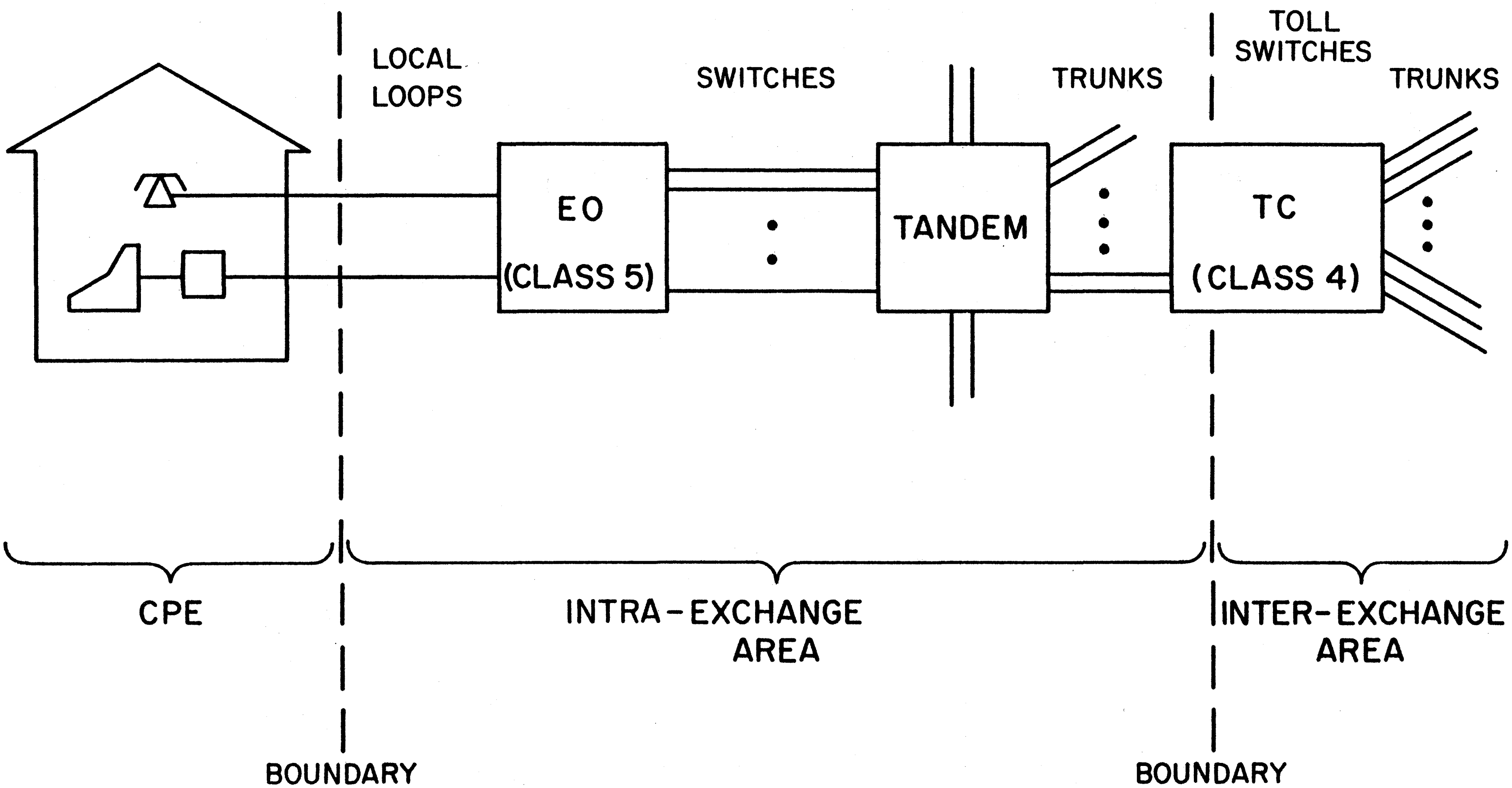


Figure 1. Subscriber telephone access to the network.

also called station or subscriber lines, to the local switching installation, like the Class 5 End Office (EO) shown. The local loops are typically two-wire (2W) twisted pairs, but there are exceptions, such as four-wire (4W) loops for data terminals and others. The loops are usually no more than a few miles long. They employ voice frequency (VF) transmission without the need for costlier amplifiers, modulators, coders, or range extenders. Within the customer premises, the loops are variously split to expedite terminal portability.

The local loop terminates at the telephone company's switching plant. Typically this is a Central Office (CO) or a Class 5 EO, as depicted in Figure 1. However, there are innumerable other cases where the loop homes on a Private Automatic Branch Exchange (PABX), a Private Branch Exchange (PBX), a Remote Switching Unit (RSU), a Community Dial Office (CDO), or some Wire Center within the, so called, Exchange Area. All these terms, starting with the "Exchange" itself are found defined in the references. The following list defines the more common local area switch terms:

Automatic Exchange - An exchange that functions without operators. Switching and routing is executed by electronic devices in response to operations caused by subscribers' equipment.

CDO - Community Dial Office, which is typically an automatic exchange serving a single community.

CENTREX - A PABX operation under the control of an EO. CENTREX allows local dialing, direct inward dialing, and automatic identification plus possible restriction on outward dialing.

CO - Central Office or Class 5 EO. Sometimes called Dial Central Office (DCO).

EO - End Office, namely Class 5 switching machine.

Exchange - A location established by communications common carriers for administration and billing of service in a specified area. The latter usually embraces a city, town, village, and surrounding areas.

Exchange Area - The unique area served by a particular exchange. It may consist of one or more central offices, as well as one or more wire centers.

Local Tandem - A switch that interconnects two or more end offices to each other, or perhaps to a Class 4 toll facility like the Toll Center (TC) in Figure 1.

PABX - Private Automatic Branch Exchange, usually a switch smaller than the End Office, but endowed with at least as many (if not more) features and functions. A typical PABX serves a corporation, an institution, or a plant and may resemble a CDO. A PABX usually homes to a single EO.

PBX - Same as PABX if automated. Otherwise manual customer switch.

RSU - Remote Switching Unit. A semiautonomous part of a switch remoted to a proximity closer to clusters of subscribers. The RSU usually consists of line interfaces, concentration stages, and a limited amount of processing modules.

Station - Subscriber terminal or telephone set.

Wire Center - A physical structure that houses one or more dial central offices.

Because of network growth, ongoing modernization and organizational dispersal, exact and up-to-date statistics on the U.S. telephone network are difficult to obtain and verify. The following rough numbers may suffice.

Slightly under 200,000,000 subscriber lines are served by around 22,000 Bell plus Independents' switching machines. This estimated number of switches apparently does not include the rapidly expanding family of distributed, small units such as PABX, RSU, and so forth. It does include the Class 5 End Offices, the tandems, the Class 4 Toll Centers (TC) and Points (TP), and all the higher classes. The classification of the Bell System switches and their numbers are given in Table 3. These five classes of switches form the familiar 5-tier hierarchy of the Bell Toll network (AT&T, 1980). In all classes, there is a distinction between a "Center" and a "Point." At a Center, by definition, operator assistance is provided only for incoming calls. At a Point, on the other hand, operator assistance is provided for outgoing calls or for none at all. Since operator assistance pertains to service nationwide, as to be discussed later, this Center versus Point distinction is not insignificant. Wire centers are sites or buildings in dense metropolitan areas that contain one or more switching machines. While the latest statistics on colocated machines are unavailable to the authors, their number is estimated to be under a thousand. More about wire centers will be said in Section 4.

According to 1981 data, most of the Bell System, and hence the entire U.S. switches belong to one of three switch families: the step-by-step (SXS), the cross-bar (XBAR), and the Electronic Switching Systems (ESS). The relative line and trunk serving roles of these switches are summarized in Table 4. Today's Bell System is estimated to have around 7 million trunks bundled in one-third million trunk groups. Note that two out of every three installations are still SXS. The

Table 3. 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).

Table 4. Percent Services Provided by the Big-3 Bell System Switch Families

Switching Machine Family	Percent Number of	
	Switches Themselves	Lines and Trunks Served
SXS	63%	47%
XBAR	16%	22%
ESS	21%	31%

SXS's are being gradually replaced by more traffic efficient switches, such as ESS (Browne et al., 1981).

Every generic switch family contains a series of machines, each with a range of capacity and upgrade capability. Typical extreme capabilities of commonly deployed Bell Toll switches are indicated in Table 5. Note the large traffic capability of the #4 ESS, as measured in Erlang units (AT&T, 1961). If one looks to the future, the emphasis must turn to the Stored Program Controlled (SPC) ESS machines plus relevant digital innovations. An attempt to summarize the ESS family tree (Dobriner, 1982) is given in Figure 2. Here, the abscissa is time. The points on the abscissa indicate the year when the first installation of a certain switch was made. For example, the very first ESS, the #1 ESS, was operationally cut-over in 1965. The first #4 ESS in 1976. The ordinate shows the number of systems in operation in 1982. For example, there are nearly 900 #1 ESS and over 100 #4 ESS machines in the field now. The growth curves for the systems have, of course, not been linear with time, but are so drawn for graphical ease.

The bubble pointing at each system in Figure 2 contains four lines of text. Line one is the name. For instance, the figure shows seven ESS machines, numbered 1, 1A, 2, 2B, 3, 4, and 5. There is also the Bell's Remote Switching System (RSS) and the Northern-Telecom's DMS-10. Line two gives the typical application and community for a switch. For example, #3 ESS provides local service to rural areas (Yates and Zahorodny, 1980). Line three in the bubble indicates the general range of lines and trunks, as the case may be, that the system may accommodate in practice. For instance, the #3 ESS can serve anywhere from 600 to 4,500 lines. Line four in the bubble displays the technology of the switching network or matrix. Two symbols are used. SDM identifies space-division-multiplex or switching via physical crosspoints. TDM stands for time-division-multiplexing and is often referred to as digital switching. It employs time and space modules in appropriate configurations.

Various loops, lines, and trunks constitute the transmission part of the switched network. In addition to the 200,000,000 subscriber loops, the inter-switch trunks provide huge country-wide connectivity. According to 1981 Bell estimates, there are nearly 7,000,000 trunks bundled into some 350,000 trunk groups. The channel mileage covered by this network must apparently be in hundreds of million miles.

Whereas the local loops use predominately 2-wire VF transmission, the majority of the toll trunks are said to be 4-wire. This is somewhat of a misnomer, because

Table 5. Representative Maximum Capabilities of Bell System Toll Switches

Type of Toll Switch	Approximate Maximum Capability		
	Erlangs Carried	Attempts Per Hour	Trunk Terminations
SXS (Intertoll)	300	5,000	1,000
#5 XBAR (Local/Toll)	1,000	20,000	4,000
#1 XBAR (Tandem)	1,500	45,000	10,000
#4A XBAR (Toll)	6,000	115,000	20,000
#4 ESS	45,000	500,000	100,000

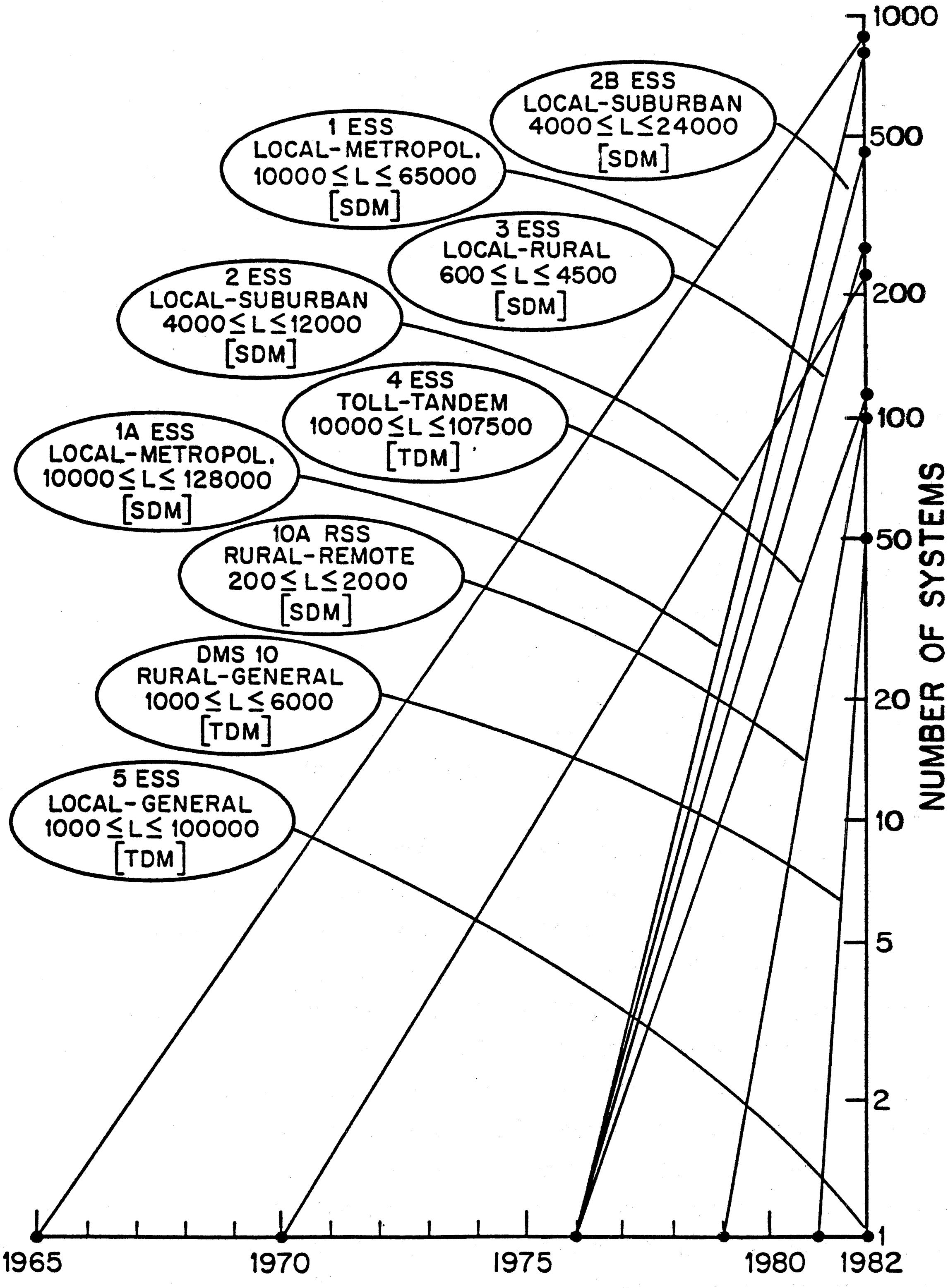


Figure 2. The ESS family.

today's carrier systems -- both analog and digital -- do not establish any through-paths via wire conduction. All sorts of carrier systems are employed. Historically there were multipair wire cables used between switches, and a small portion of these exist even today. Because of their four-fold metallic paths, they could support dc signaling among other functions. The new carriers, such as single-sideband (SSB) or frequency modulated (FM) microwave or the T-carrier (Bell Telephone Laboratories, 1970), do not possess this capability and must resort to other signaling techniques such as in-band signaling. More about signaling will be said in Section 3.6.

The thrust for recent transmission technology developments is illustrated in Figure 3. As the length of a given line or trunk increases, one finds that different modulation/coding techniques have different cost profiles versus circuit length. For short lengths, such as below 5 miles, the baseband voice frequency transmission is the most economical. This is the technique used for most local loops. For very long lengths, and already starting above 30 miles, analog frequency division multiplex (FDM/FM) microwave carrier systems -- such as the TD systems at 4 GHz, and TH and TM at 6 GHz, and the TJ and TL at 10 to 12 GHz -- show considerable spectral capacity and hence cost advantages (Bell Telephone Laboratories, 1970). Single-sideband systems are quite competitive also and in some cases are preferred over FM.

Between 5 and 30 mile circuit length, however, one finds neither VF nor FDM to be optimum. Rather, pulse code modulation (PCM), such as used on the 24-channel, 1.544 Mb/s, T1 line is more interoperable with the variety of facilities that comprise the intra-exchange switching and processing plant. This explains why in the exchange area, which is typically no larger than 30 miles across, a current activity of PCM installations is taking place. On the long toll trunks the analog carriers prevail. While on the subject of trunk costs, another cost saving element should be mentioned: the Common Channel Interoffice Signaling (CCIS). CCIS is not only cheaper, it also increases the network speed, capacity, and overall service potential. At the present time only about 50% of the Bell intertoll network is CCIS. However, steady progress indicates that by 1990 no less than 90% of the toll network, from Class 4 switches up, should be served by CCIS.

Neither the switching nor the transmission networks represent the largest capital expenditure by AT&T. According to Table 6, the outside plant plus real estate, plus other equipments such as trucks, add up to 40% or more. Switching is the next largest item, but not by much over the subscriber station investment.

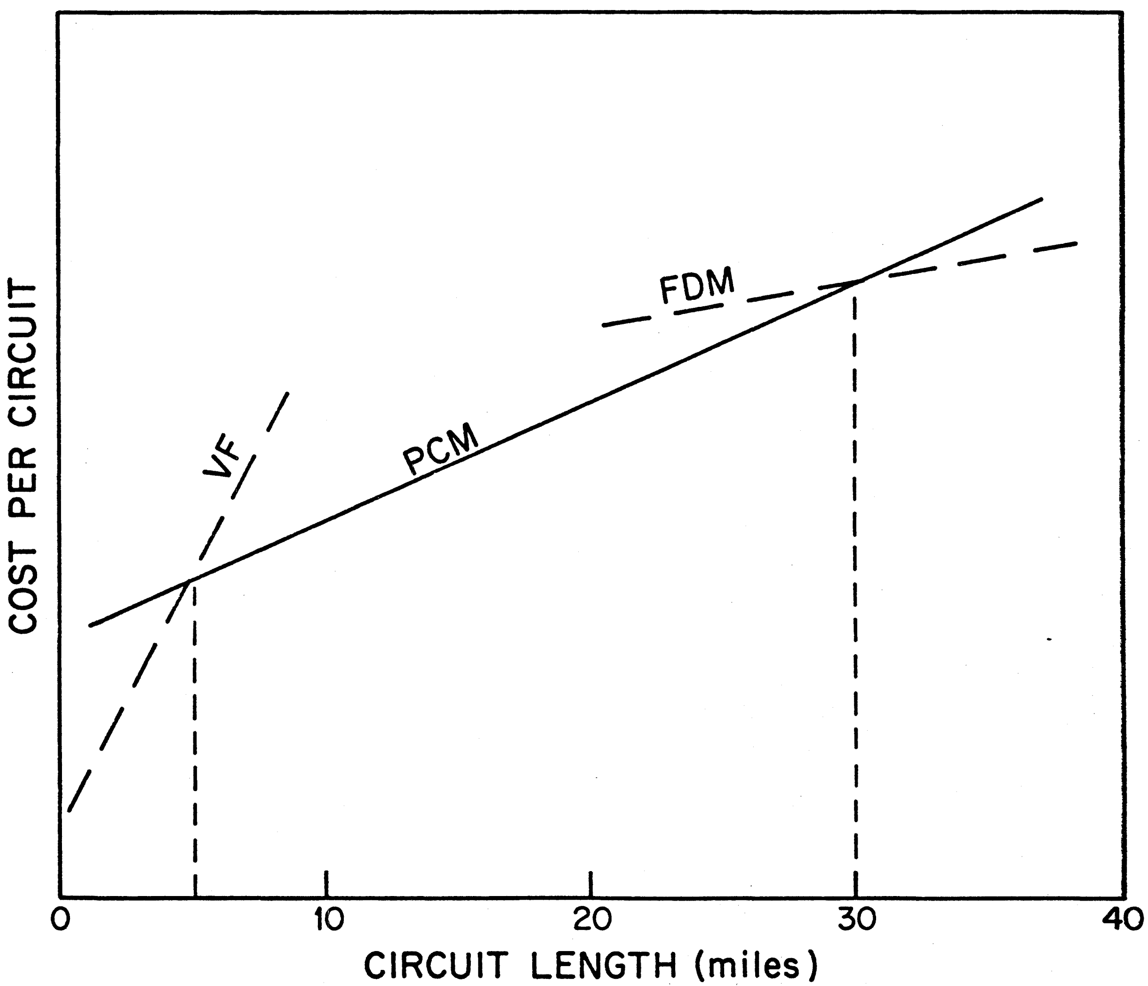


Figure 3. Relative transmission costs.

Table 6. Estimated Total (Local and Toll) Telephone Network Investment Percentages

Item	%
Outside Plant (Cables, Poles, Ducts)	29
Switching Machines (Hardware, Software)	24
Subscriber Stations (Loops, Terminals)	20
Transmission (Repeaters, Termination)	15
Real Estate (Land, Buildings)	10
General Equipment (Miscellaneous)	2
Total	100%

Switching investment presents a unique recent and growing puzzlement to the outside observer. Quotes are often heard that 25 to 75 percent of modern switching system costs are associated with software. Yet specifics of software are well kept company proprietary secrets. This leads to obvious interface difficulties between systems from different manufacturers. Besides cautioning the reader not to underestimate the complexity and cost of communications software (IEEE, 1982), not much can be added here. The estimated cost percentages of a typical 10,000 line switch hardware are presented in Table 7. The cost elements projected here reflect initial purchase, installation, break-in, and essential maintenance.

2.3 The Main Physical Elements

For the purposes of this section, the main elements are those whose influence extends outside their immediate area and far into the network. For instance, number verification and address signaling even for a single long distance call may range from a local exchange, through the BOC, and to the long lines. Likewise, remote testing of various line and trunk modules may stretch across many state and administrative boundaries.

An often occurring important element is BORSCHT. As illustrated in Figure 4, BORSCHT is associated with individual subscriber loops. Thus, allowing for an indeterminate number of main line stations whose BORSCHT's support both residence and business extensions, there must nevertheless be around a hundred million of BORSCHT installations in the public telephone network. The acronym itself stands for battery, overvoltage protection, ring, supervision, control signaling (or clock), hybrid, and test. However, as seen from the figure, the implementation order to the features needs not be alphabetical. To protect the rest of the facilities against lightning and power line voltage surges, overvoltage protection must be next to the exposed wires. Test provisions for automated maintenance are variously dispersed.

As long as the 2W loop is served by a 2W switch, there is no need for the hybrid (i.e., for the H in the BORSCHT). However, it is needed when the 2W loops or lines have to interface 4W facilities. The provision of battery power enables loop supervision, as in detection of on-hook and off-hook status changes. Control signaling handles dialed numbers and associated addressing information. Ringing alerts the local station and returns ringback to the originating station, as the case may be.

Table 7. Estimated Hardware Cost Elements for a 10,000 Line, Space Division, Stored Program Switch Procurement

Item	%
Switch Network	35
Memory	18
Line and Trunk Circuits	15
Control Unit(s)	10
Power	8
Maintenance	5
Other	9
Total	100%

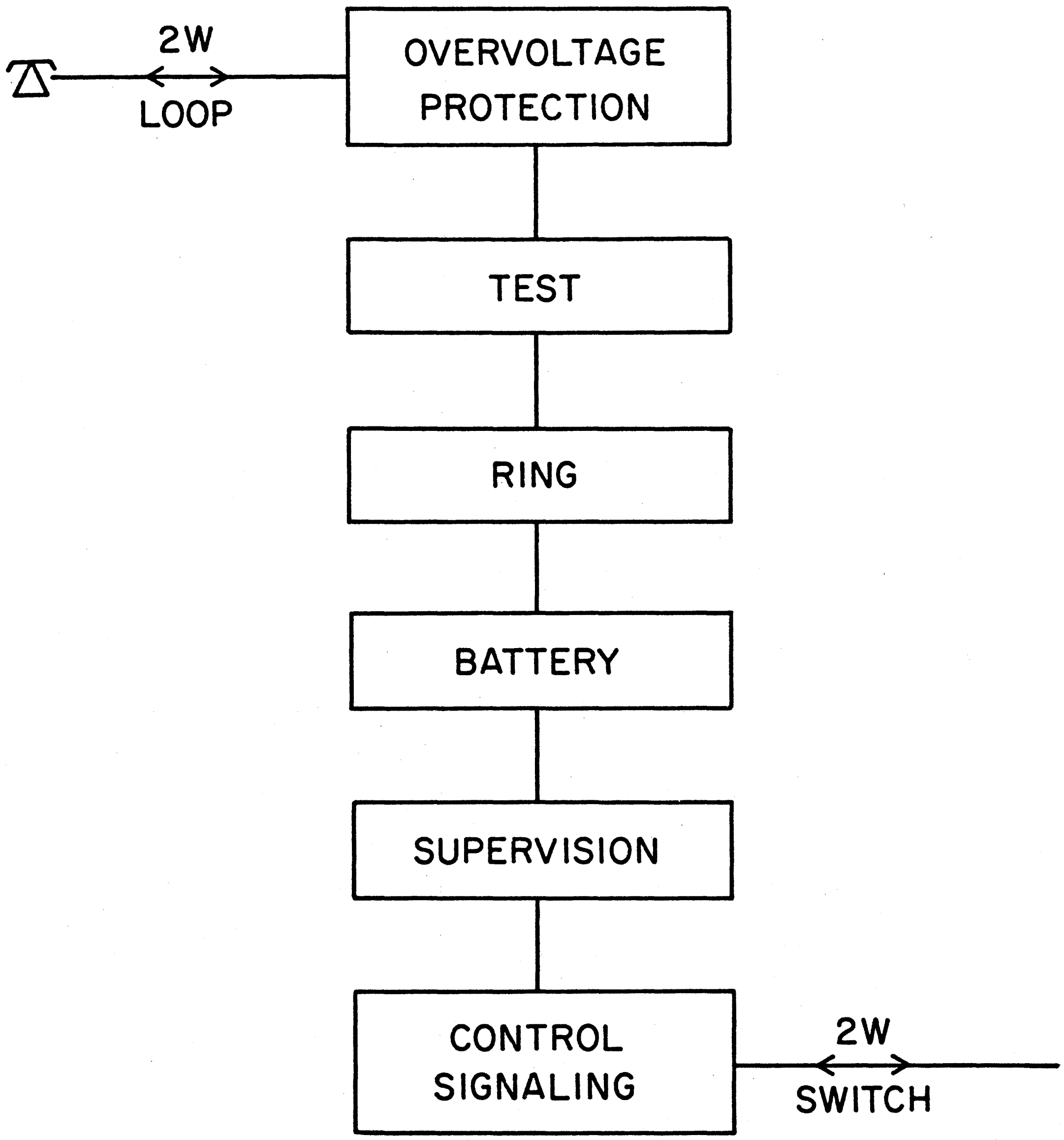


Figure 4. BORSCHT without the hybrid.

A more current and innovative BORSCHT deployment is given in Figure 5. As shown, a 2W subscriber loop enters an integrated circuit implemented BORSCHT, here called the Subscriber Loop Interface (or Integrated) Circuit (SLIC). It contains the hybrid (H) plus filters needed for subsequent analog-to-digital (A/D) and digital-to-analog (D/A) conversion. The actual conversion is an equivalent four-wire operation. It takes place in the digital or D channel bank. Both μ-law (North American) and A-law (European) compandings are possible, with the μ-law predominant in the USA (Dooley, 1979). The toll-side output of the D channel bank is a multiplexed T-carrier that dispatches 64 kb/s PCM signals in the DS-0 format, or their aggregates, such as the 1.544 Mb/s (24 channel) DS-1 format. The T-carrier provides clocking to the channel bank. Two options of signaling are provided in Figure 5. The first one is the well established in-band signaling at the local switch level. Within the DS-1 format it inserts signaling bits in the eighth bit of either every frame or of every sixth frame, depending on the D channel bank encountered. The other signaling option is CCIS. It disassociates control signaling information from the PCM T-carrier system and sends it via a CCIS Terminal to the independent CCIS data network.

The details of a D channel bank may vary between manufacturers and their models. However, their overall functions are quite similar (Billhardt et al., 1980). The D channel bank faces hybrids (with or without filters) on one side and the T-carrier on the other. The bank consists of individual channel units and common equipment. The multitude of channel units is nominally subdivided into groups of 24 for North American operation. The various units are interconnected to the common equipment via a mix of analog and digital bus systems. Such a standard D channel bank structure employs Pulse Amplitude Modulation (PAM) and is illustrated in Figure 6. Note the insertion and extraction of the signaling information at the PCM codec.

Another important element that is finding more and more applications in the nationwide network is the automatic echo canceller (AEC). Every time a 2W circuit interfaces a 4W circuit, echoes can be generated, reflected, and transmitted down the line (Neigh, 1979). If the network was unchanging with static communications paths, constant or fixed echo cancellers would suffice to reduce echo levels to specified low levels. However, a switched network allows no such easy solution. Various terrestrial and satellite channels are not only switched in and out, but on their own suffer time-varying impedance, transfer function, and loss changes (Askenazi et al., 1982). To adapt rapidly and to cancel echoes caused by such variations, the AEC's have been developed and are being deployed in ever increasing

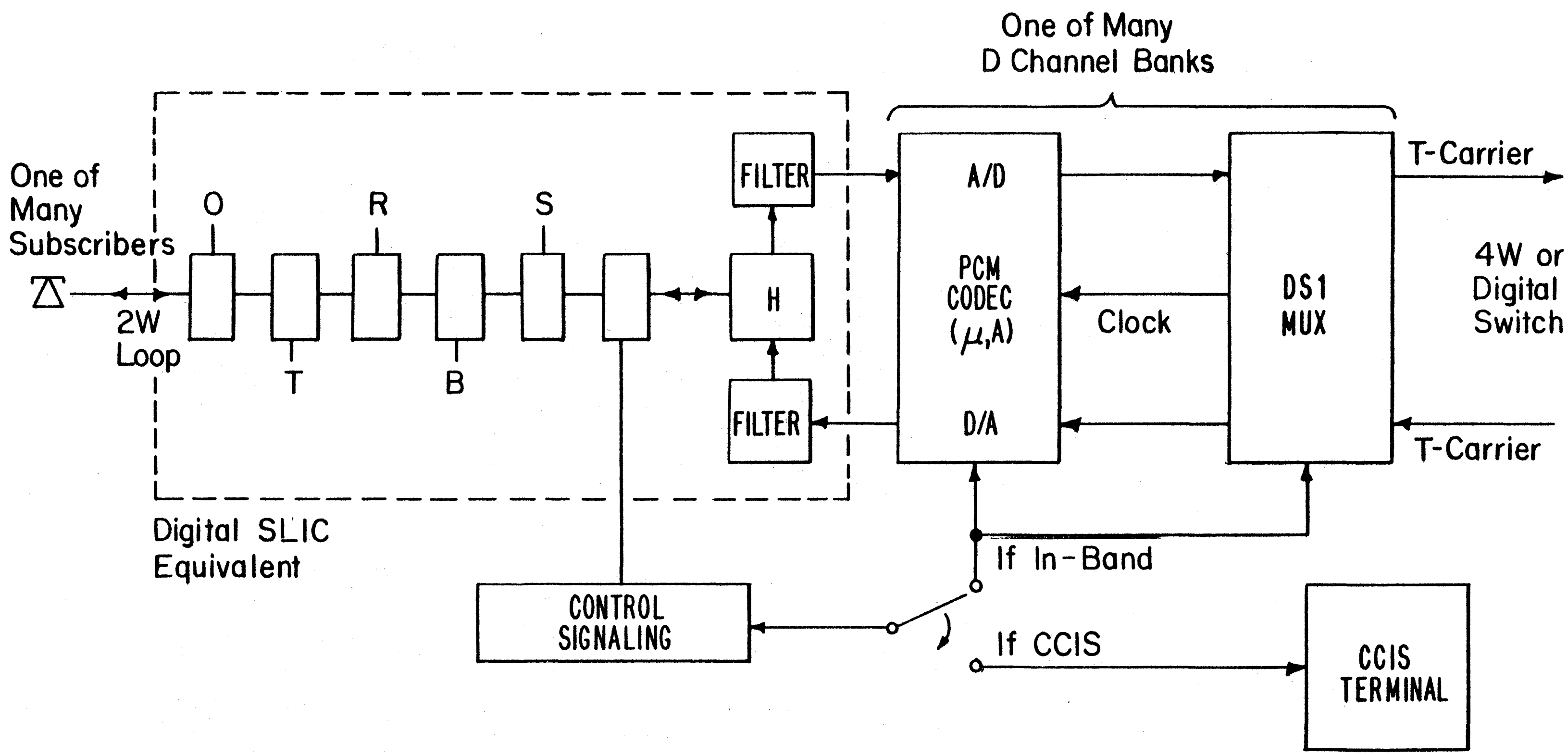


Figure 5. A SLIC implementation of a full BORSCHT for PCM switching.

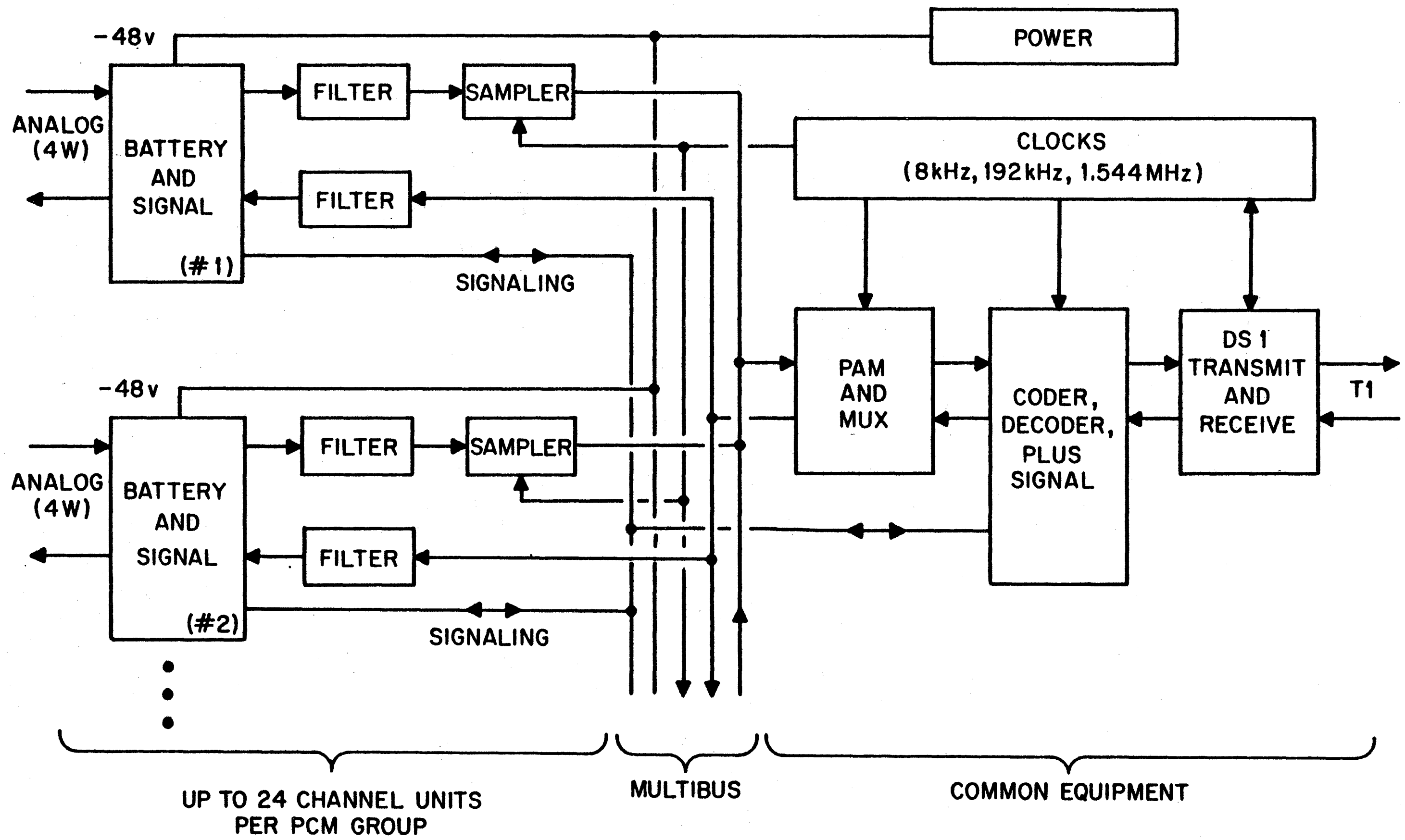


Figure 6. The D channel bank for in-band signaling.

numbers through the Bell network. Two examples are illustrated in Figure 7. In part (A) a 4W digital subscriber is accessing a 4W or digital switch, but has to contend with an existing analog 2W loop. In modern service installations working through older facilities such situations are typical. As seen, part (A) requires AEC's in two places, both times on the 4W side of the hybrid or its equivalent.

Unfortunately, the simple fact of AEC installation as given in (A), may be far from adequate for a nationwide network. The problem is that an indefinite large number of AEC's in series tends to degrade the end-to-end channel performance. What is needed is a control process that enables certain AEC's and disables others. Usually this enabling/disabling control is required at the interior toll switching machines, but there are exceptions due to the great variety of the network. Part (B) of Figure 7 shows an AEC enabler serving a local 4W switch that still has 2W loops and tie-lines. Note that, due to the network-wide nature of potential calls, these AEC controls must be communicated across the network.

The discussion of main physical network elements must emphasize the importance of switching machines. Figure 2 and Tables 3 to 5 have established a significant assortment of switches in the Bell System alone (AT&T, 1961; Joel, 1976 and 1977; UCLA, 1982). Since all said switches serve different types of lines and trunks, interoperability and compatibility must be carefully engineered between existing and new installations. Perhaps the most easily understood, and certainly one of the oldest, is the 2W analog circuit switch (IEEE, 1977). Typical interface requirements of such a switch are graphically summarized in Figure 8. This figure depicts the unfolded version of a switch, where lines appear on one side and trunks on the other. The lines terminate on the line distribution frame, which contains among others a line interface unit (LIU) or card for each line. In this case, all the lines are 2W loops and all the LIU's are of the same 2W kind.

At the opposite side of the switch in Figure 8 one finds the trunk distribution frame. It contains the trunk interface units (TIU), of which there may be a considerable variety. For example, the older multipair tie-lines, if viewed as trunks, may be of either 2W or 4W type. The TIU's are different for the two. Furthermore, whenever a trunk is of the 4W category, special hybrid provisions may be required to enter the crosspoints or x-points of the 2W switch matrix. As shown in Figure 8, four-wire circuits may be switched without hybrids by doubling the number of active crosspoints. However, all such arrangements must be made on the switch in advance. Upgrades, which involve extensive hardware (e.g., junctor) or software modifications, are unavoidably costly and time consuming.

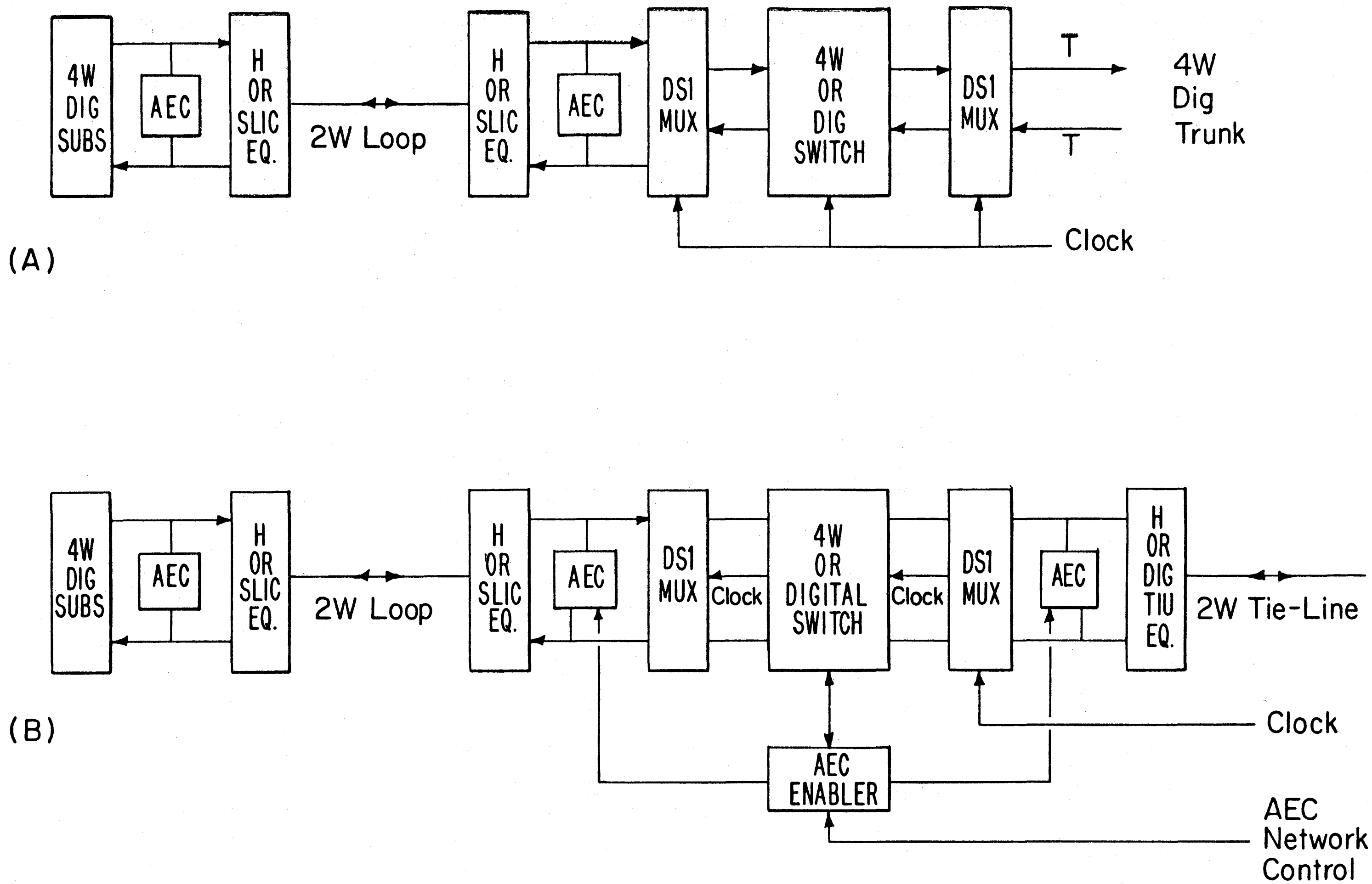


Figure 7. Deployment of automatic echo cancellers.

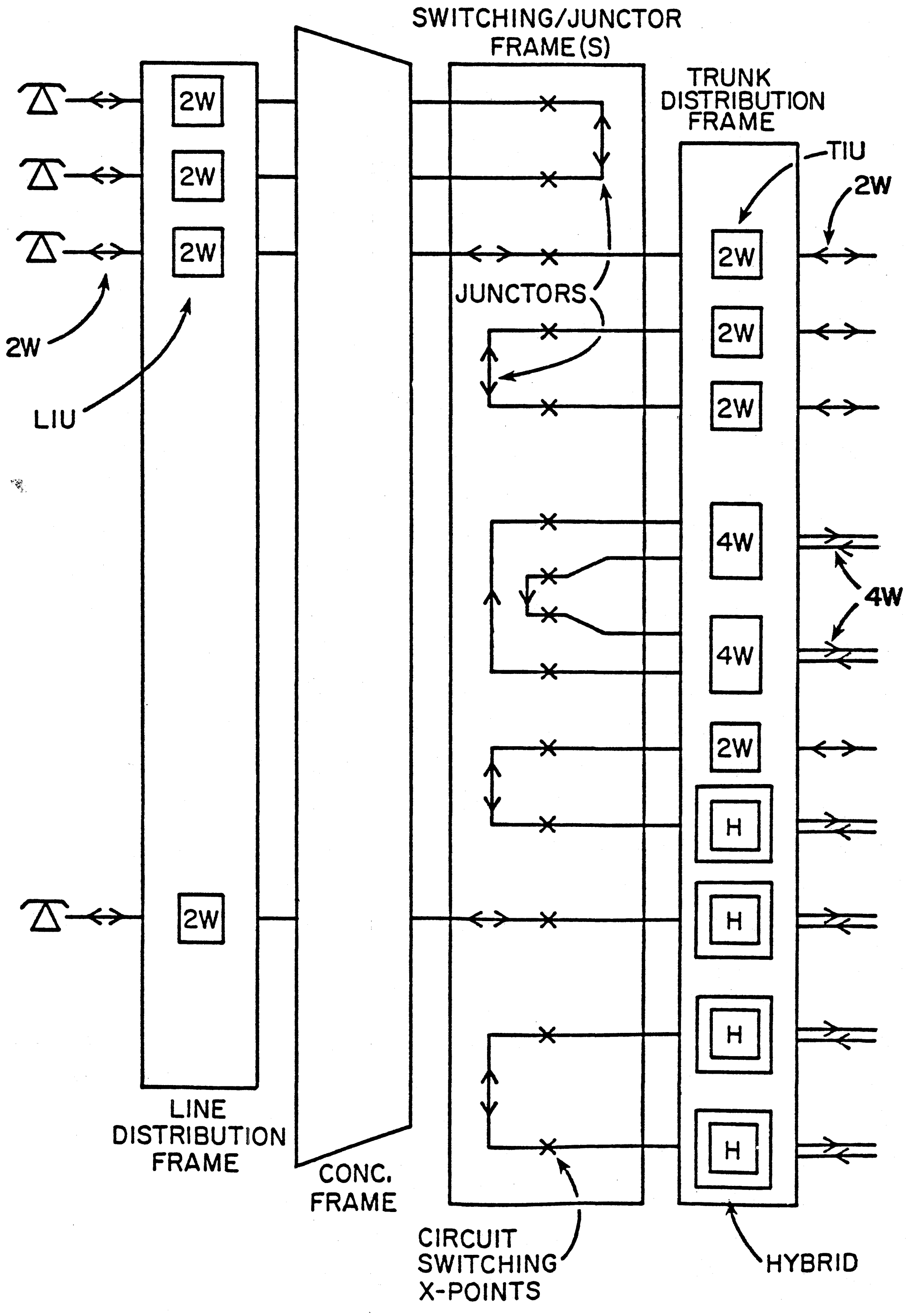


Figure 8. The unfolded configuration of an analog 2-wire circuit switch as used for voice circuits.

Between the switching/junctor frame, also called the x-point matrix, and the trunk distribution frame one seldom if ever employs concentrators other than Time Assignment Speech Interpolation devices (TASI). One simply does not engineer blocking trunks. However, a concentrating frame is often found on the line side of the switch matrix. The effect of concentration on telephone traffic is to block occasional call requests and to reduce the grade of service (GOS). When several blocking switches are involved in making a cross-country call, their end-to-end GOS effect tends to be additive and often results in poor service. Modern ESS and TDM switches can be designed to be nearly nonblocking, except during the most severe traffic surges.

A circuit switch that performs four-wire (not 2W) switching must have different peripheral (line and trunk) frames. For an unfolded analog switch, this is illustrated in Figure 9. Here, a single line represents a 2W half duplex, and a pair of arrows drawn in different directions represent a full duplex operation over four wires. Again 2W local loops are assumed as is typical. But to enter a 4W switch, the 2W loops must go through hybrids. As shown, the H's precede the concentration frame, but this need not be always so. Concentration can be performed at two-wire level, to be followed later by the hybriding, echo cancelling, and even related BORSCHT functions. The trunk distribution frame of a 4W circuit switch is different, as it requires hybrids where the 2W-switch does not, and vice versa. The matrix of the 4W switch requires twice as many x-points and twice as many junctors as does its 2W counterpart for the same number of lines and trunks.

The SDM switch, such as described in Figure 9, serves as a basis for structuring many circuit switches. Figures 10 to 12 show the general outlines of #1 XBAR, #5 XBAR, and the #1 ESS. Several things should be noted. The line switch networks in the cross-bar switches include the line distribution frames (including necessary interface units), concentration, and numerous stages of mechanical switch modules. The assorted markers, senders, and registers are concerned with control signaling and perform a rather detailed list of functions. The #1 ESS of Figure 12 is still a circuit switch, employing concentration and switching stages (the latter being space-separated networks of ferreed (BSTJ, 1964) switches), but its main novelty is the high-speed electronic central control, aided by stored programs and routines. To pass the control and signaling information between the inherently slow ferreeds and the considerably faster electronic controls, #1 ESS employs an extensive array of scanners, distributors, controller circuits, plus other service circuits.

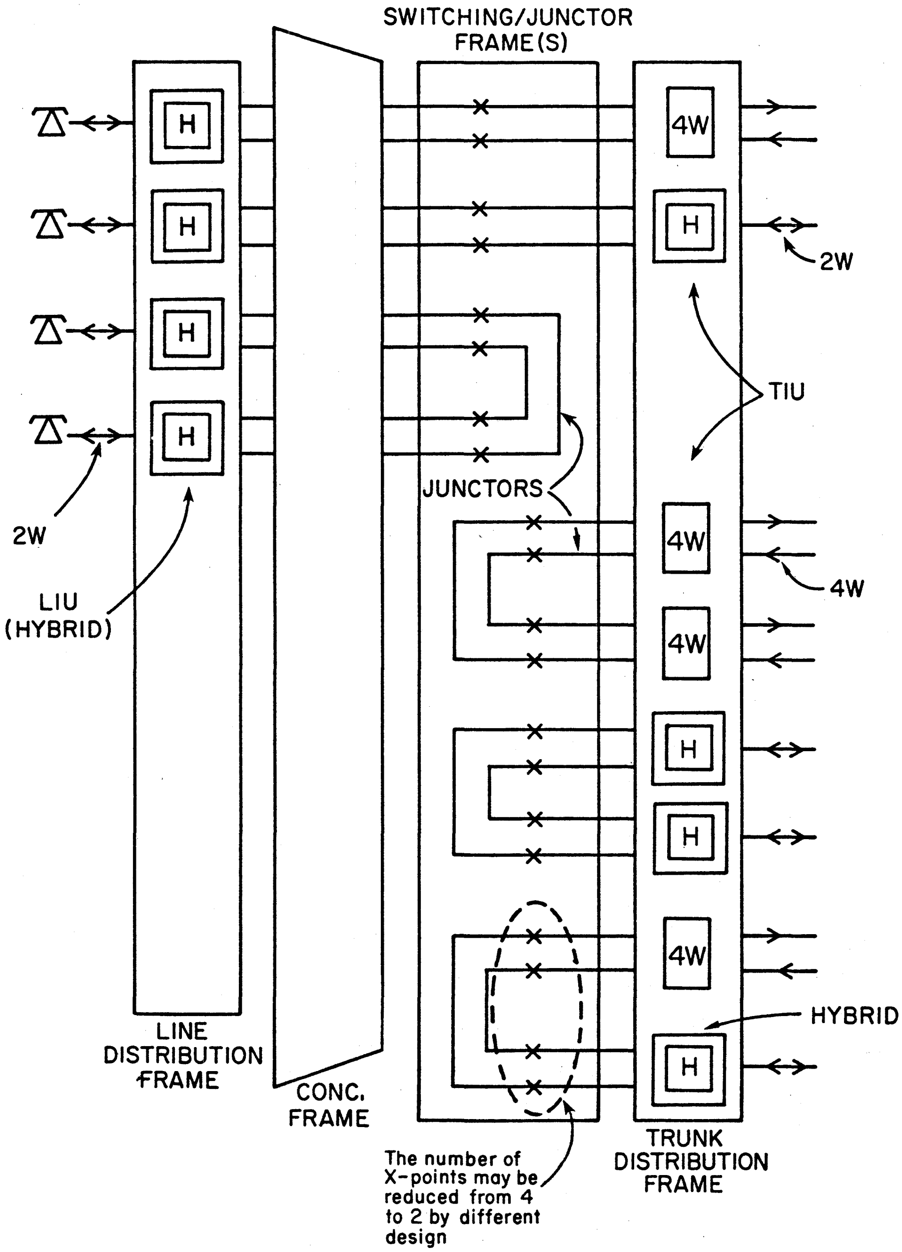


Figure 9. The unfolded configuration of an analog 4-wire circuit switch as used for voice channels.

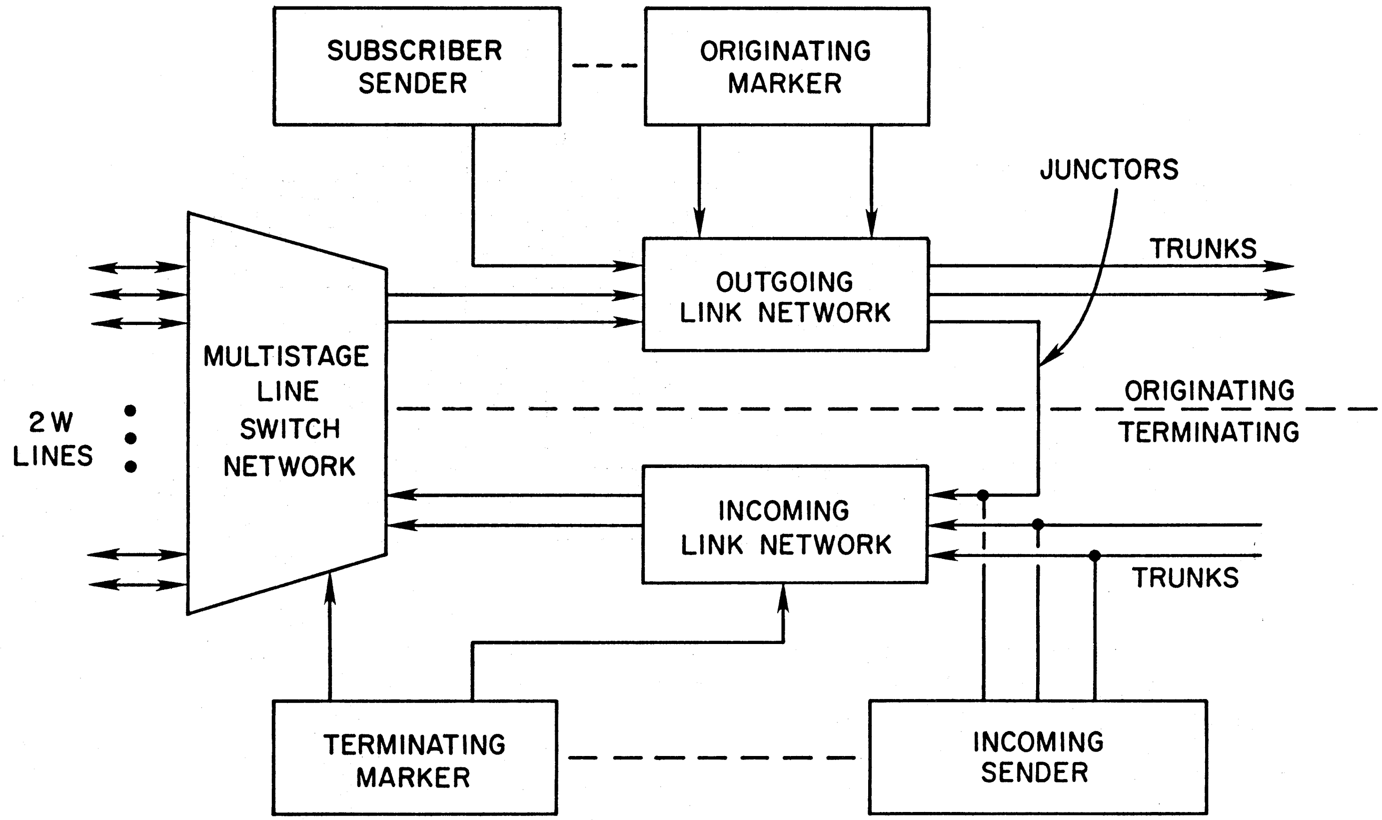


Figure 10. Outline of a #1 XBAR switch.

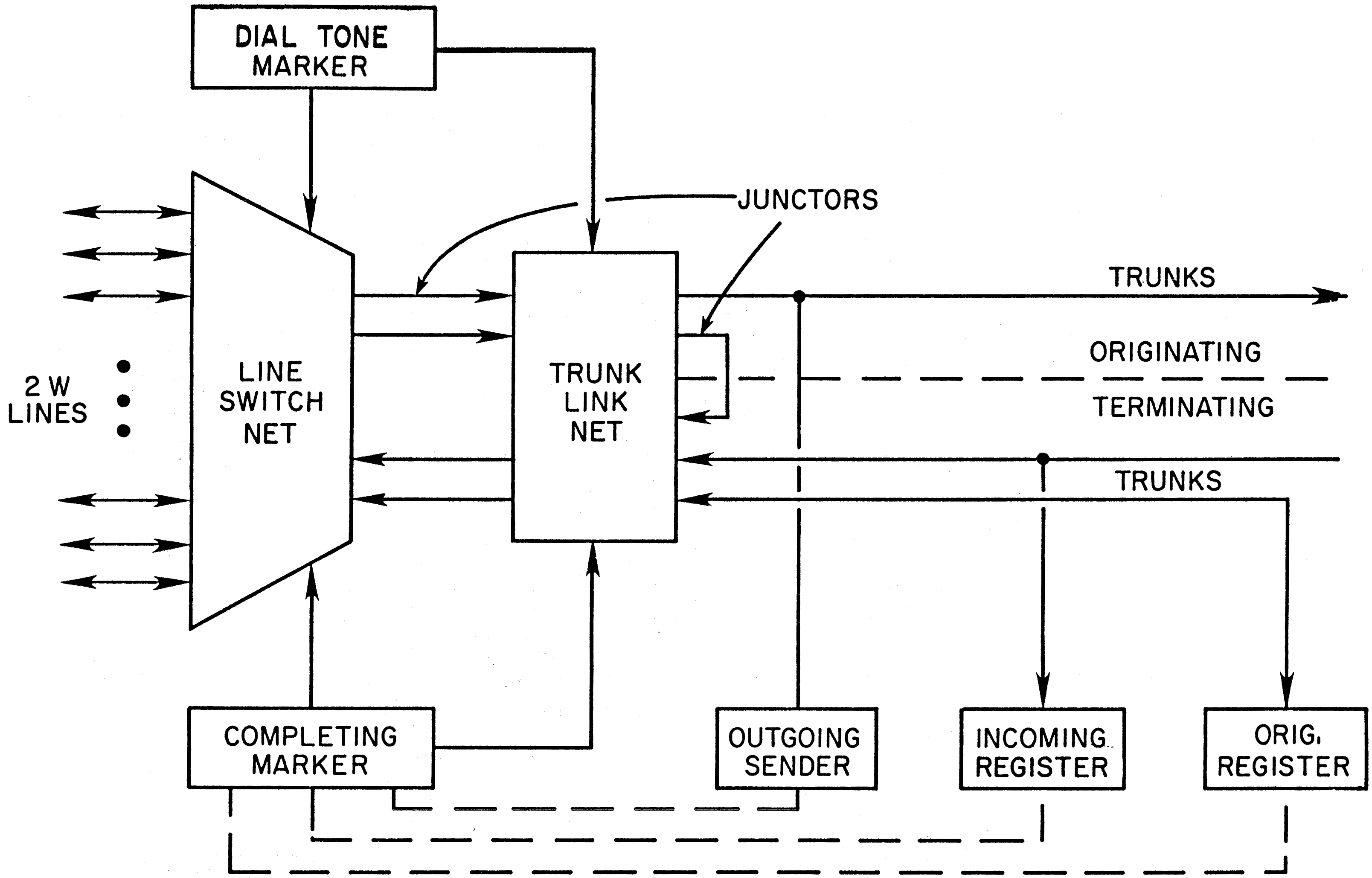


Figure 11. Outline of a #5 XBAR switch.

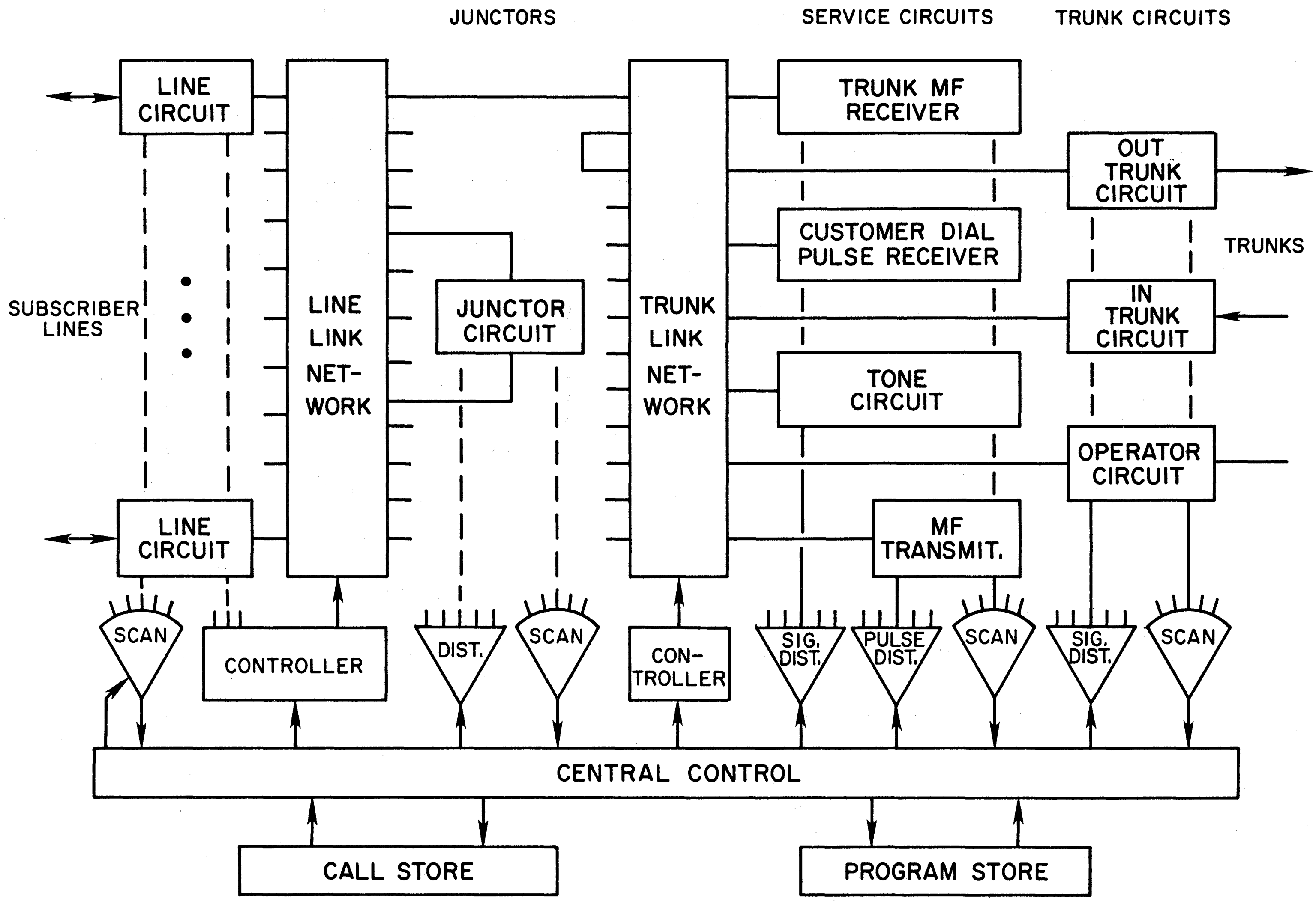


Figure 12. Outline of a #1 ESS switch.

The most innovative present switches are of the time-division or TDM design (Vaughan, 1959; Joel, 1979; IEEE, 1979). They combine time switching modules with space switching modules and achieve a great range of operational effectiveness. The TDM switches are usually nonblocking, have full availability, and have the versatility to adapt to various service, traffic, and feature requirements. And through all that they appear to remain remarkably cost effective.

From previous Figure 2 one notes that the Bell System has fielded three types of TDM switches.

- Over 100 No. 4 ESS machines serve toll and tandem functions in the network and are made by Western Electric.
- Around 50 DMS-10 Northern Telecom's rural and general function switches have been installed by the Bell System.
- The very first No. 5 ESS is being put into service in 1982. It is a versatile, end office size, machine made by Western Electric and intended for local and general purposes.

Detailed descriptions of Bell System switches are found in the literature, in particular in the Bell System Technical Journal (BSTJ), its special issues, and in various general articles (BSTJ, 1964, 1977a, b, and 1981; Bruce et al., 1979; Johnson et al., 1981; Orcutt, 1981; Leppert et al., 1982). What is perhaps not so widely publicized is the availability of TDM switching machines from non-Bell independent manufacturers. One of the most recent non-Bell fully digital switching machines is the GTD-5 EAX, designed by GTE Automatic Electric Labs (Mnichowicz and Zelinski, 1982). Similar to its digital 4W predecessor, the GTD-3, the new GTD-5 represents a family of Class 5 (local) and Class 4/5 (toll) machines. The total number of its lines and trunks can range anywhere from 500 to 150,000. The GTD-5 is alleged to have a traffic carrying capacity of 1,300,000 ccs/hr $\cong$ 36,000 Erlangs, where one ccs equals 100 call seconds.

Figure 13 outlines the GTD-5 system. Several features are noteworthy. The machine consists of a base unit and remote facilities. The latter includes one or more RSU's that can operate relatively independently away from the base unit, largely due to its duplicated peripheral processor power.

While the RSU uses a small number (perhaps 2) of time switch modules, the main switch matrix can employ up to 32 time switches. These modules are tied together by a space switch, thus forming a time-space-time (T-S-T) network. This network is completely nonblocking and provides full availability. To assure that the central control is not overloaded, it is structured in a parallel fashion. The

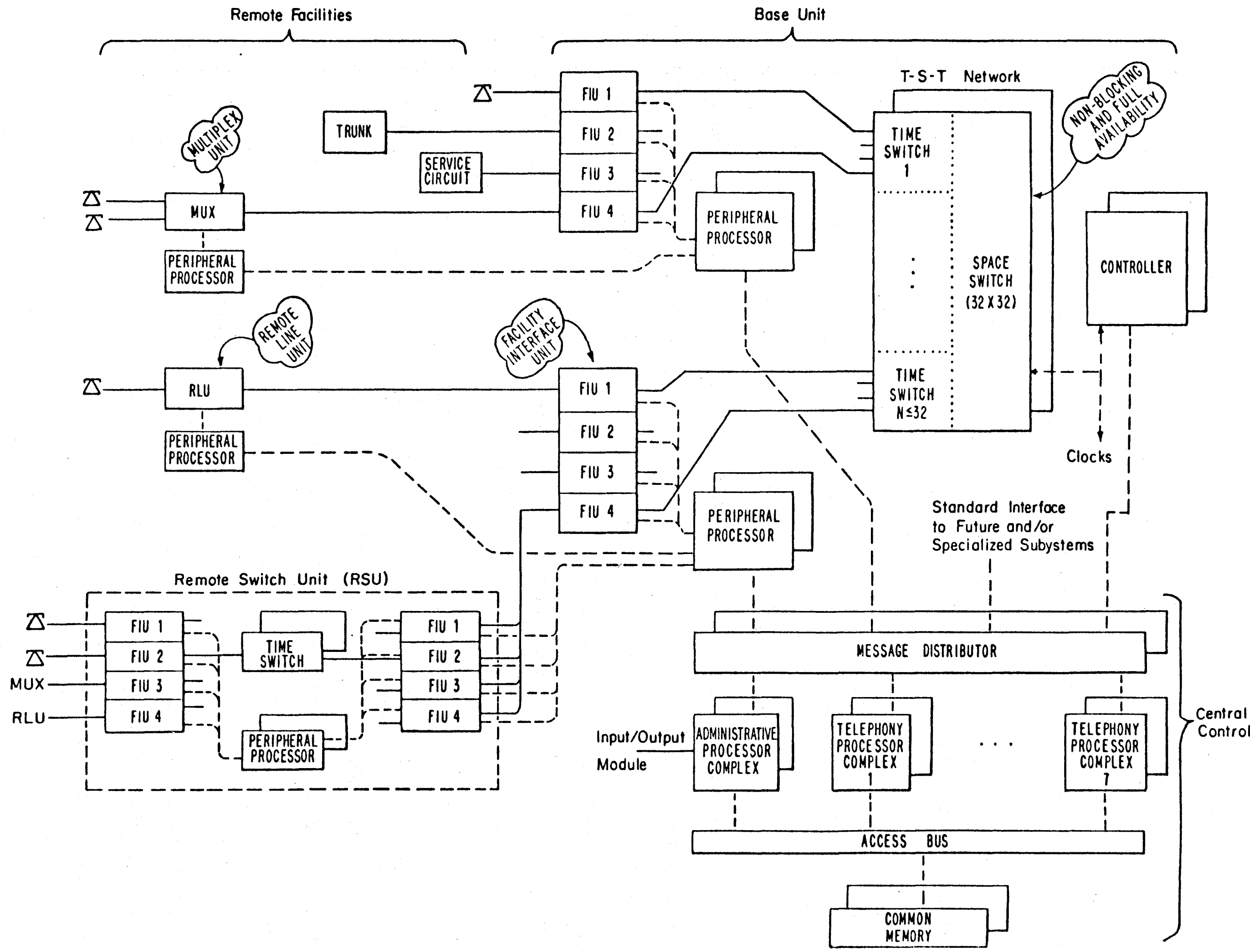


Figure 13. Outline of the GTD-5 EAX.

central control always contains one administrative processor complex and, depending on the required traffic statistics, anywhere from one to seven telephony processor complexes. All the processors and complexes are duplicated for backup reliability and speed. Likewise, duplication is applied to all the parallel buses and data interconnect highways within the GTD-5. Many hardware units are identical modules. This is claimed to reduce costs in production, installation, and maintenance.

Special GTD-5 software has been written and tested. It is designed for the multi-processing architecture that encompasses distributed peripheral processors and a variety of application programs, but strives for commonality with common administrative system, common central data base, and common command analysis tables. The data base administration scheme appears to be quite unique in the way it can generate, update, grow, and examine the entire data base on-line. If this is a forerunner of future software development, then software must be recognized as a major communications network element.

In the conclusion of this section on the main physical elements of the telephone network one must recognize the importance of the transmission systems. The transmission systems employ a variety of physical media, such as open wire, bundles of twisted wire pairs, coaxial and other conducting cables, terrestrial microwave, satellite radio, optical fibers, etc., for transport of both analog and digital modulations. The U.S. telephone transmission network is quite huge. Together with the outside plant, the transmission facilities account for nearly half of the total telephony investment (Table 6). It is said (Bellamy, 1982), that the Bell System alone has deployed enough wire to go to the sun and back three times. While enormous and important, the transmission network is not further elaborated in this report. After all, the transmission network is not hidden. It is highly visible and well documented elsewhere (Bell Telephone Laboratories, 1970; AT&T, 1980).

3. THE TELECOMMUNICATION FUNCTIONS -- HIDDEN NETWORKS WITHIN THE NETWORK

3.1 Background

The fundamental function of a communications network is to provide marketable communications services. The network must therefore transport voice and other signals at a cost that can be balanced by subscriber derived revenues. Both subscriber and network operator benefit when the optimum technologies are used, now and in the forecastable future (Hunnicutt and Robrock, 1981; Myers, 1982).

In Section 2, it was established that the network is quite complex. It consists of many subsystems, or building blocks, and their functioning and interaction involves a great amount of technology. It has been customary to handle the technological sub-world by identifying and bundling together separate functions that are performed by various network elements. The so deduced subnetworks often take on a life and identity of individual networks. The BSRF, CAMA, CCIS, and TSPS are subnetworks to be discussed. They are examples of hidden networks within the extensive telephone network.

3.2 Centralized Automatic Message Accounting

Centralized Automatic Message Accounting (CAMA) grew out of relatively local Automatic Message Accounting (AMA) systems, also known as LAMA's. Today's Bell network contains around a hundred CAMA centers, each serving typically in the neighborhood of one to two hundred end offices. An illustration of a typical present-day CAMA installation is shown in Figure 14. Locally, CAMA is supported by either a toll or a tandem switching machine, the list of possibilities including: SXS intertoll, #5 XBAR, XBAR tandem, #4A/4M XBAR, #1 or 1A ESS, #4 ESS, and even TSPS.

The output of a CAMA is a prepared and mailed customer's bill. To do so, special CAMA trunks feed call detail, such as calling number, called number, service category, and call duration (if needed) into the AMA registers. The AMA contains its own master clock that normally establishes start and stop times of a call. The installation also contains an operator's console, called the control position, and automated index files for the served area. The AMA center accumulates all monthly statistics on magnetic tapes, which are periodically shipped by transport vehicles to the revenue accounting office, and thence to the printing, billing, and bulk mailing facility. For long distance, international, or other interstate calls that involve conflicting information and the resolution of such conflicts, remote CAMA offices may interoperate with each other. This may be done through the switched network (seldom) or through special signaling circuits.

The trucking operation in Figure 14 is considered inefficient and wasteful. Plans call for replacement by telecommunications in the next generation of CAMA installations. This next generation is said to be forthcoming in the near future,

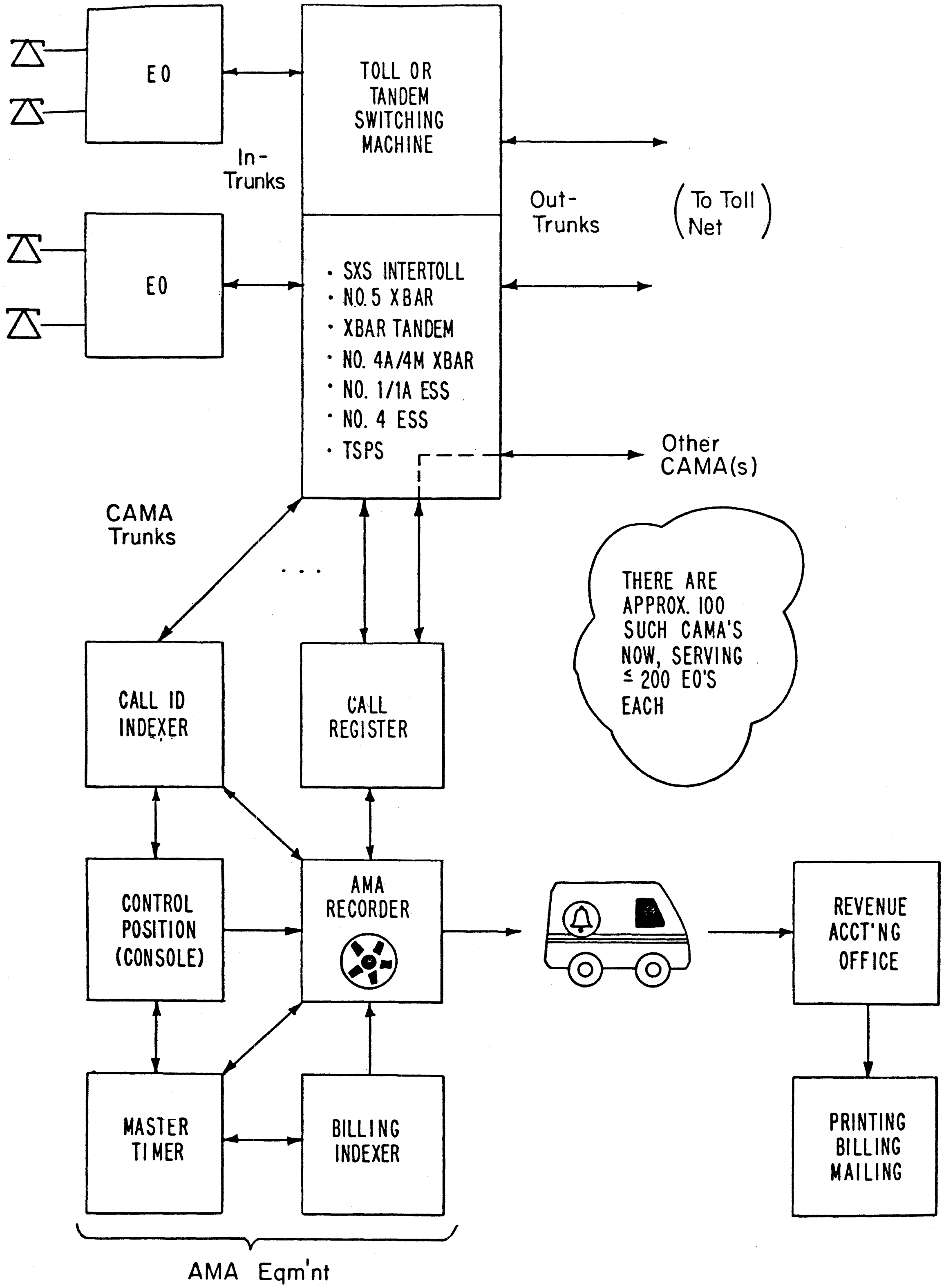


Figure 14. A typical 1980 CAMA installation.

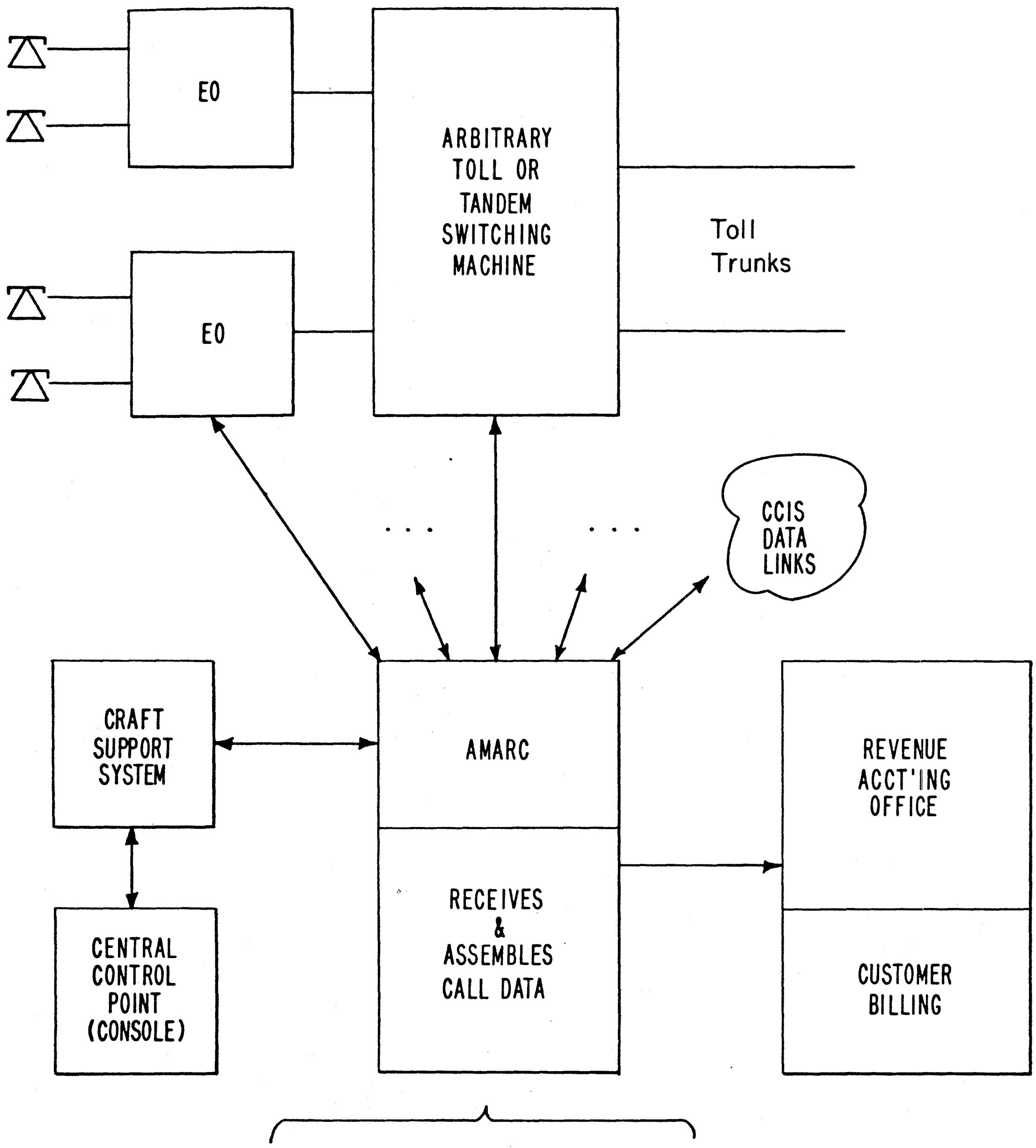
perhaps by 1990. An illustration of the CAMA of near future is given in Figure 15. Besides the absence of trucks, the new center implements a special machine called the AMARC (short for AMA Recording Center). A particular AMARC, dubbed the No. 1A AMARC, is quoted to serve three times as many customers, handle three times as many calls, have eight times the memory, and be otherwise preferable when compared to the older CAMA processors (Kleber and Perkinson, 1980).

According to Bell publications, there should be no more than 50, #1A AMARC equipped, centers needed. They will be compatible with all toll and tandem switches. Inter-AMARC communications will take place over the, by then rather ubiquitous, CCIS packet data links. These data links, plus the CAMA nodes, will constitute a necessary accounting network within the Bell's nationwide network.

3.3 Bell System Reference Frequency

The Bell System Reference Frequency (BSRF) is distributed through the network by the, so called, BSRF distribution system. The reference frequency is needed for transmission of all synchronous data streams, as well as for digitized voice (PCM). The most prevalent data service is the Dataphone Digital Service (DDS) with binary data rate options of 2.4, 4.8, 9.6, and 56 kb/s, plus 1.544 Mb/s. This service is available in the DDS Service Area (or DSA). It covers all significant geographical centers of the USA, including the Primary plus Multiple Rate Centers of the Bell System. Also, the general trend towards the Integrated Digital Network (IDN) and the Integrated Services Digital Network (ISDN) provides an impetus towards synchronous operation of essential network nodes (Cooper, 1979; IEEE, 1980).

The BSRF network distributes the required frequency reference as outlined in Figure 16. Four strata constitute a four-level hierarchy for the synchronization of CONUS digital connectivity. At the highest level, that is at stratum 1, one finds the AT&T Long Lines redundant underground installation in Hillsboro, MO. This center is generally known as the BSRF Standard. Its uncertainty or error rate is less than 1 in 10^{11}. To have further confidence in BSRF's accuracy, a LORAN C time standard link is used to keep in touch with the best available standard, the Naval Observatory clock in Washington, DC. From Hillsboro, MO, the reference signal is distributed via broadband analog transmission facilities to stratum 2. Stratum 2 consists of #4 ESS's variously deployed in the toll network. As backups, internal clocks are made available to stratum 2 switches, as well as to the next -- lower level -- stratum 3. At this level one finds the Class 5 EO's,



There should be no more than 50 of these, because, for instance, the No. 1A AMARC is said to:

- Serve 3 times the EO's
- Handle 3 times the calls
- Have 8 times memory capacity
- Have faster processors

than do the older AMA's.

Figure 15. The CAMA of the future.

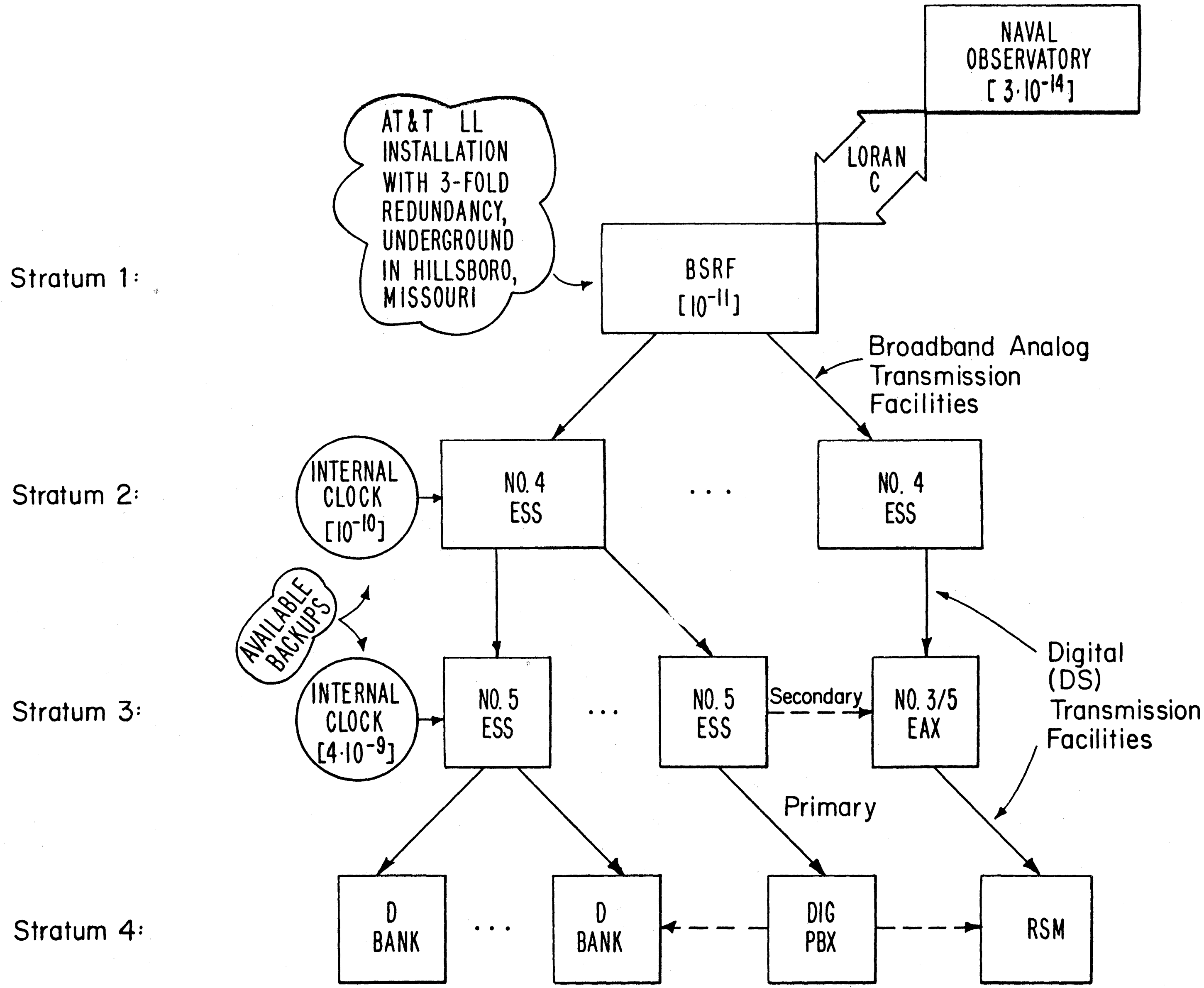


Figure 16. The hierarchy of the BSRF distribution network.

which in TDM would translate to #5 ESS and #3 or #5 EAX. Further down the ladder, at stratum 4, one finds digital channel banks, digital PABX, and appropriate remote switching machines (RSM). Usually, no backup local timers are provided at stratum 4. As noted from Figure 16, digital transmission facilities are utilized to transmit the reference frequency from stratum 2 down. When the signal proceeds from stratum 1 to 2, to 3, to 4, one claims to be on the primary distribution path. Otherwise, the path is called secondary.

The operational requirement of the BSRF is to provide synchronization with specified bit loss/gain bounds. For the familiar T1 line, the requirement translates to a network-wide frame sliprate budget. In the DS-1 format with $8 \times 24 + 1 = 193$ bits/frame, where frame duration is 125 μs, one simply counts how often bad frames or frame slips occur. For an arbitrary transmission path, with any length and signal-to-noise ratio, the BSRF requirement is no more than one slip in 10 hours. For a toll switch, the number of slips should be negligible. For EO's, again, no more than one slip per 10 hours. Thus, if one uses a synchronous circuit with or without interruption, the end-to-end requirement is no more than one slip in 5 hours.

The final note on BSRF concerns its territorial dispersal. The highest strata, 1 and 2, are apparently in the AT&T Long Lines or other Interexchange carrier domain. However, the EO's, tandem switches, and digital PABX's of strata 3 and 4, seem to be within the BOC realm. Since accurate synchronization may very well call for an integral BSRF operation over a variety of territories, a simple separation between common carriers and BOC's may be disputable here.

3.4 Automated Intercept System

The Automated Intercept System (AIS) provides operator assistance to subscribers and occasionally to other operators. Most everyone has had experience with the local directory assistance (411) or the long distance directory assistance (NPA-555-1212) operators, where NPA stands for the Numbering Plan Area. Beyond that, there are several other operator categories in the Bell System. The general situation is illustrated in Figure 17. One sees that the highest level operators are associated with the Class 3 Primary Centers. They are the remote directory assistance operators. Somewhat below Class 3 and nearer to Class 4 at the Toll Centers, there are the CAMA-ONI and the rate-and-route operators. When automatic number identification (ANI) fails for one reason or other, operator number identification (ONI) is undertaken to assist CAMA. The rate-and-route

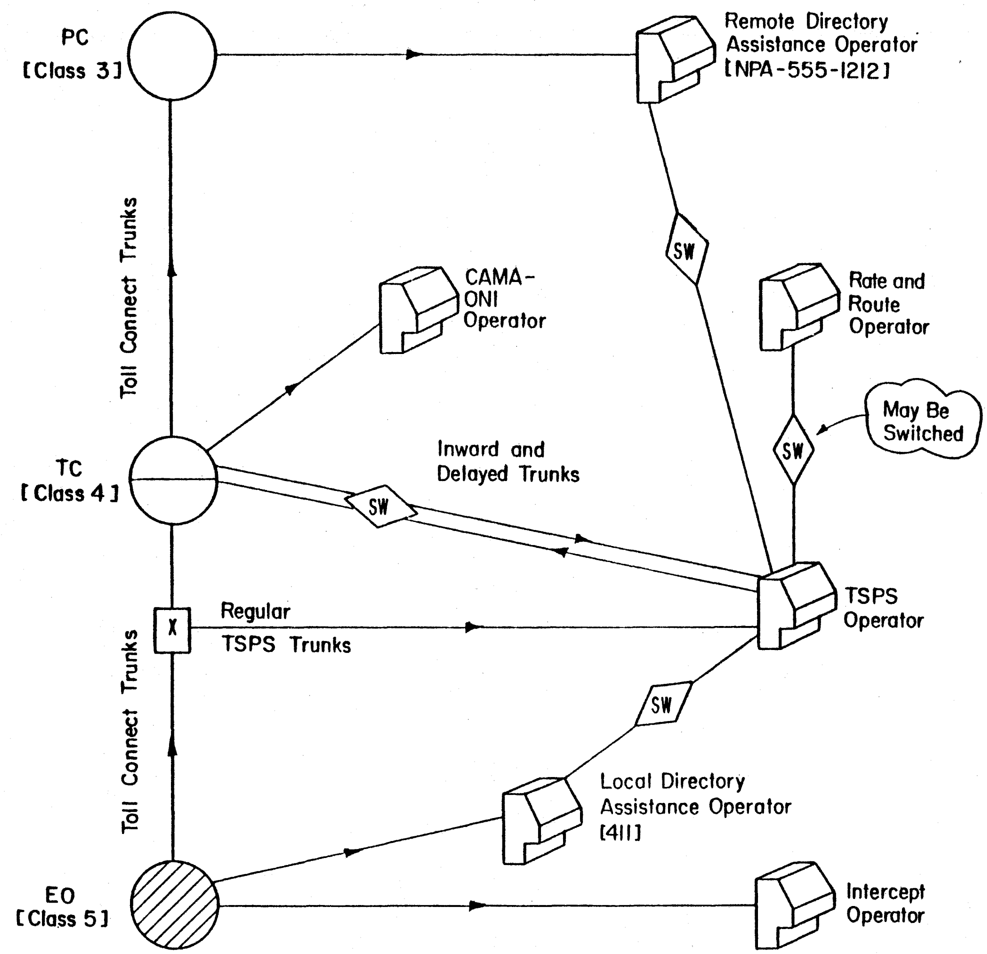


Figure 17. The topology of the AIS.

operators try to resolve origination/destination conflicts by talking to terminal subscribers and consulting data base ID's.

The Traffic Service Position System (TSPS) operators provide assistance on coin operated, credit card, hotel/motel, and related calls. It is an extensive automated system that has switched access to Class 4 Toll Centers, as well as to toll connecting trunks via regular TSPS trunks. In the next section, TSPS will be used as an illustration and described in more detail. Finally, near the Class 5 EO level one finds the local directory assistance and intercept operators. Their objective is to aid call attempts that either cannot get started or that require attention through interruption.

As a whole, the AIS system extends from Class 3 to Class 5. It bridges the long line and the exchange domains with an assortment of automated and human service aids.

3.5 Traffic Service Position System

To illustrate the role of the AIS further, this section discusses the TSPS. TSPS is an extensive system consisting of approximately 150 operator sites, also called TSP's. One such installation is outlined in Figure 18. The service area of one TSP can be quite large. The TSP base remote trunks can range up to 1000 miles and may serve up to 8 remote trunk accesses (RTA).

The broken horizontal line near the middle of Figure 18 separates the actual operator position system (lower half) from the RTA (upper half). The TSP contains a TSPS switching network run by an SPC processor. It is triggered by signaling data received from the EO/TC toll connecting trunks and relies extensively on the TSP resident station signaling and mass announcements subsystem. Special concentrated carrier trunks carry the operator's voice to the remote trunk and either to the calling party at the EO, or to the called party (or another TSP) via the Direct Distance Dialing (DDD) network.

The range of the TSPS network extends over several exchange areas (different toll centers), as well as several area codes (NPA's). Whether an individual TSP can serve several BOC's is not clear, but the TSPS network as a whole extends over all BOC's plus the AT&T Long Lines territory.

3.6 Signaling

While most of the two hundred million subscriber loops implement the BORSCHT, including the implied loop signaling, this section is not concerned with that.

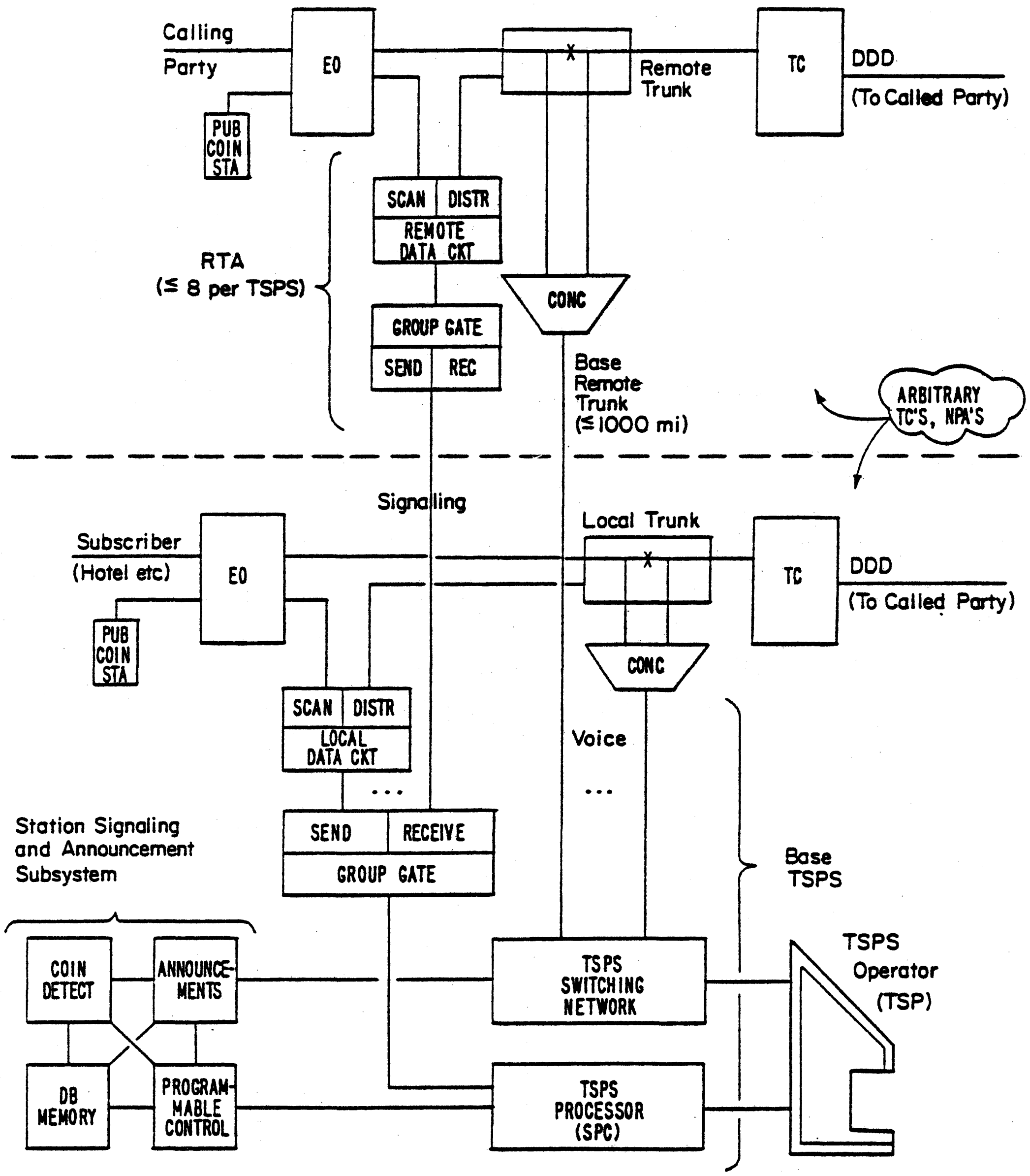


Figure 18. Outline of a TSPS installation.

Instead it describes the interoffice signaling network. Switches of all classes, 1 to 5, exchange signaling (addressing, supervision, status, etc.) messages to set up, to maintain, and to disengage call talking paths and to manage a long list of network functions, which are elaborated elsewhere. Signaling messages are inherently digital. Because of the size and the activity of the AT&T's LL signaling network, it has been described as the single largest digital packet switched network in the world.

As noted previously, the interoffice signaling system is currently experiencing a major upgrading. The earlier over-the-trunk or in-band signaling arrangements (and there are virtually tens if not hundreds of ac and even dc signaling schemes) are rapidly being replaced in the USA by CCIS. This replacement accompanies the widespread digitization of the national network and is expected to continue for the next 10 years (BSTJ, 1978). Around 1990, one may speculate that all Class 1 to 4 toll, plus tandem, switches will have CCIS terminals and will use the disassociated CCIS network. But to what extent the Class 5 End Offices (EO) and their subordinate machines (e.g., RSU, PABX) will benefit from the CCIS is not too certain. Both short-term economic and legislative boundaries may be in the way.

For the present, however, one must face the coexistence issues of the old and new signaling plant. As time passes, the interoperability requirements must face an environment that ranges from a completely over-the-trunk, to a mix of per-trunk with CCIS, to a predominantly CCIS system. The evolution of these signaling networks is the topic of Figures 19 to 22. All four figures concentrate on the EO to TC trunking which normally could be viewed as the intra-exchange or intra-BOC domain. However, at the loop side of the local exchange one must eventually encounter the sophisticated data customer and his premises equipment; and at the toll switch somewhere may be the BOC versus LL boundary.

At both switches there are signaling control units, implemented in one, two, or more modules, that process the signals. First, signals are extracted from incoming lines and trunks either in or near the D channel banks, or at the digital trunk frames of the TDM switch. See also Figure 8. These extracted signals are the main input to the signal control. Other inputs come from the traffic service position (operator console), clock, and secondary sensors or status monitors from the TDM switch. The signals are processed, translated into formats appropriate for output lines and trunks, and inserted into the lines and trunks in question. Single frequency (SF), multi-frequency (MF), or many other schemes are used on

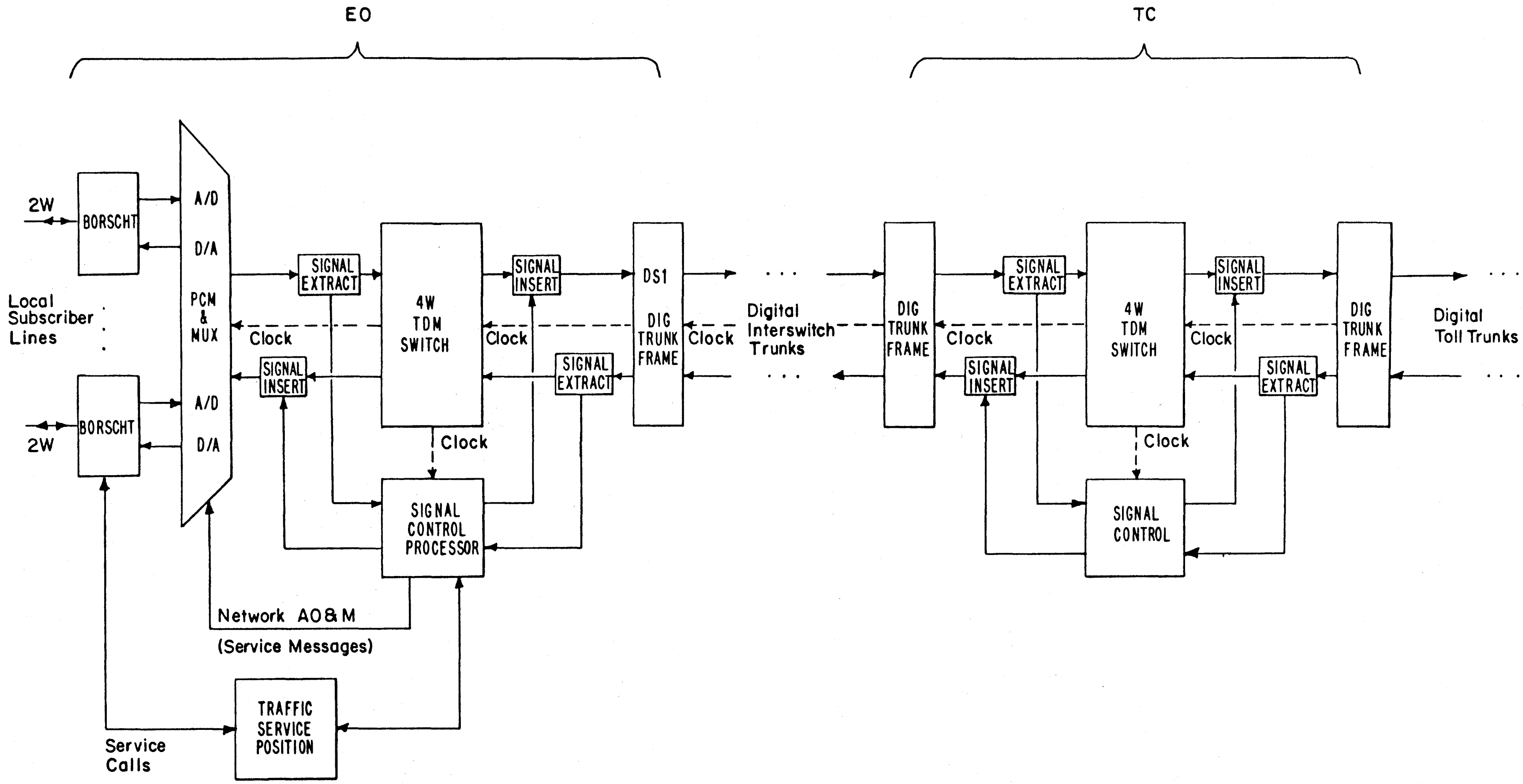


Figure 19. In-band or over-the-trunk signaling through a digital EO to TC network.

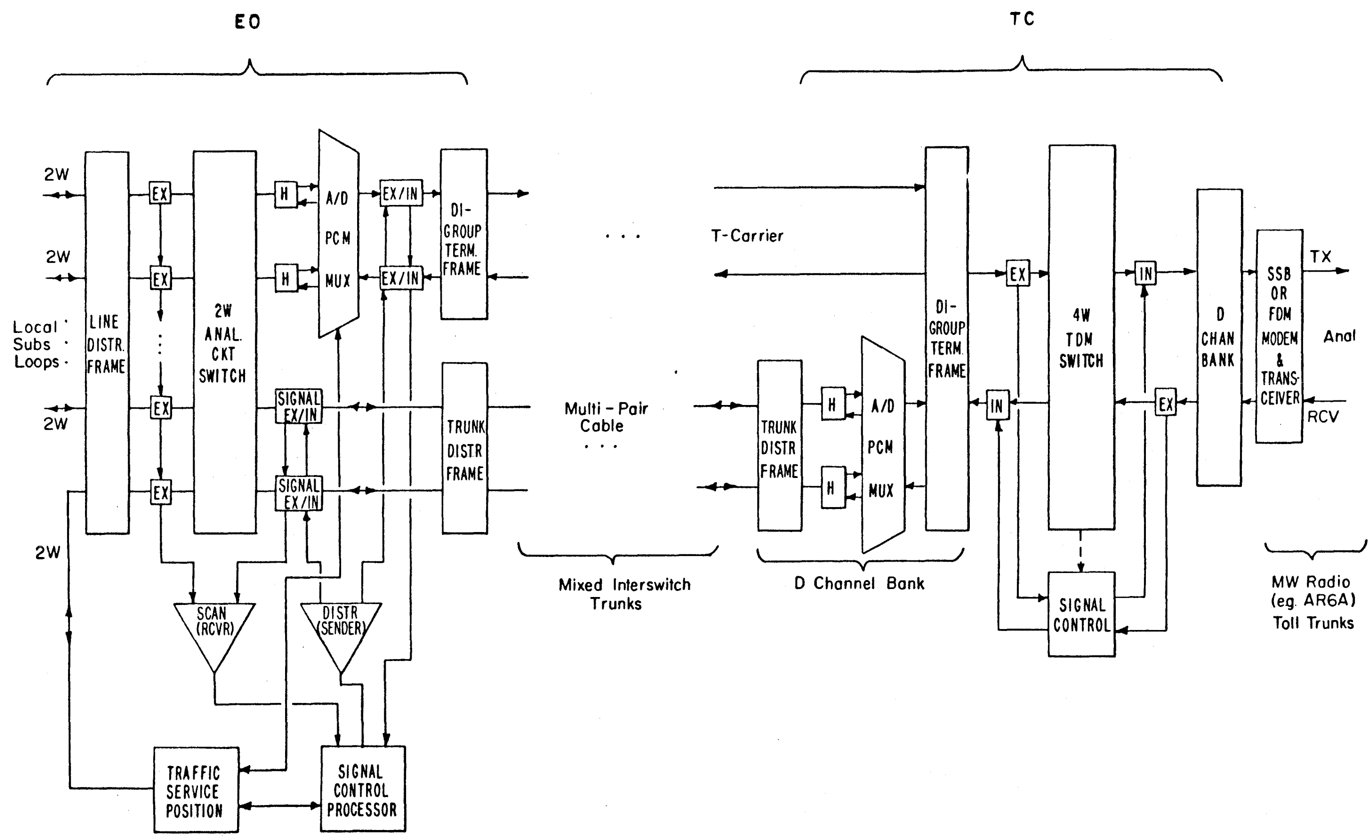


Figure 20. In-band signaling in a typical mix of analog and digital facilities.

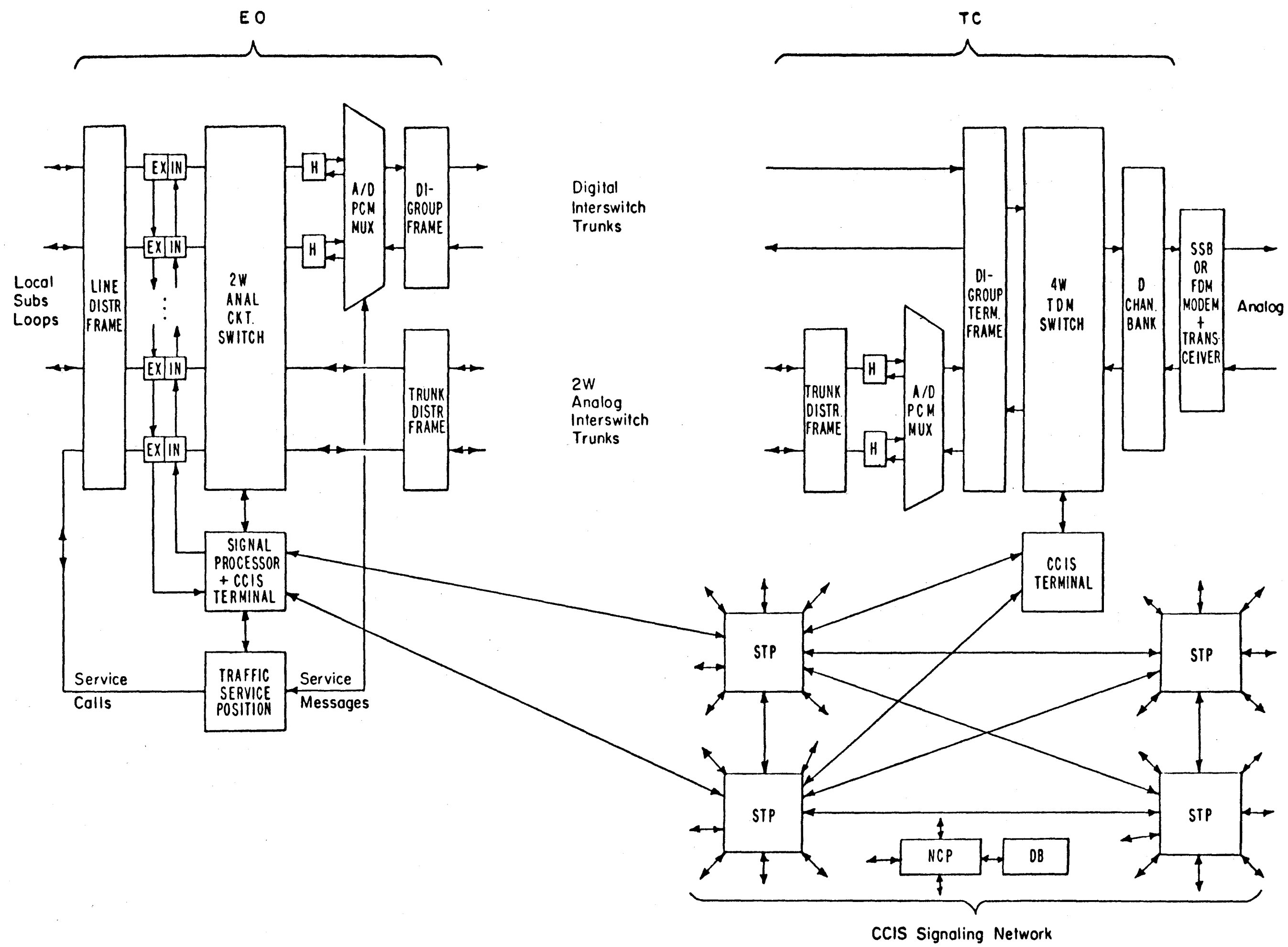


Figure 21. CCIS for a typical mix of analog and digital facilities.

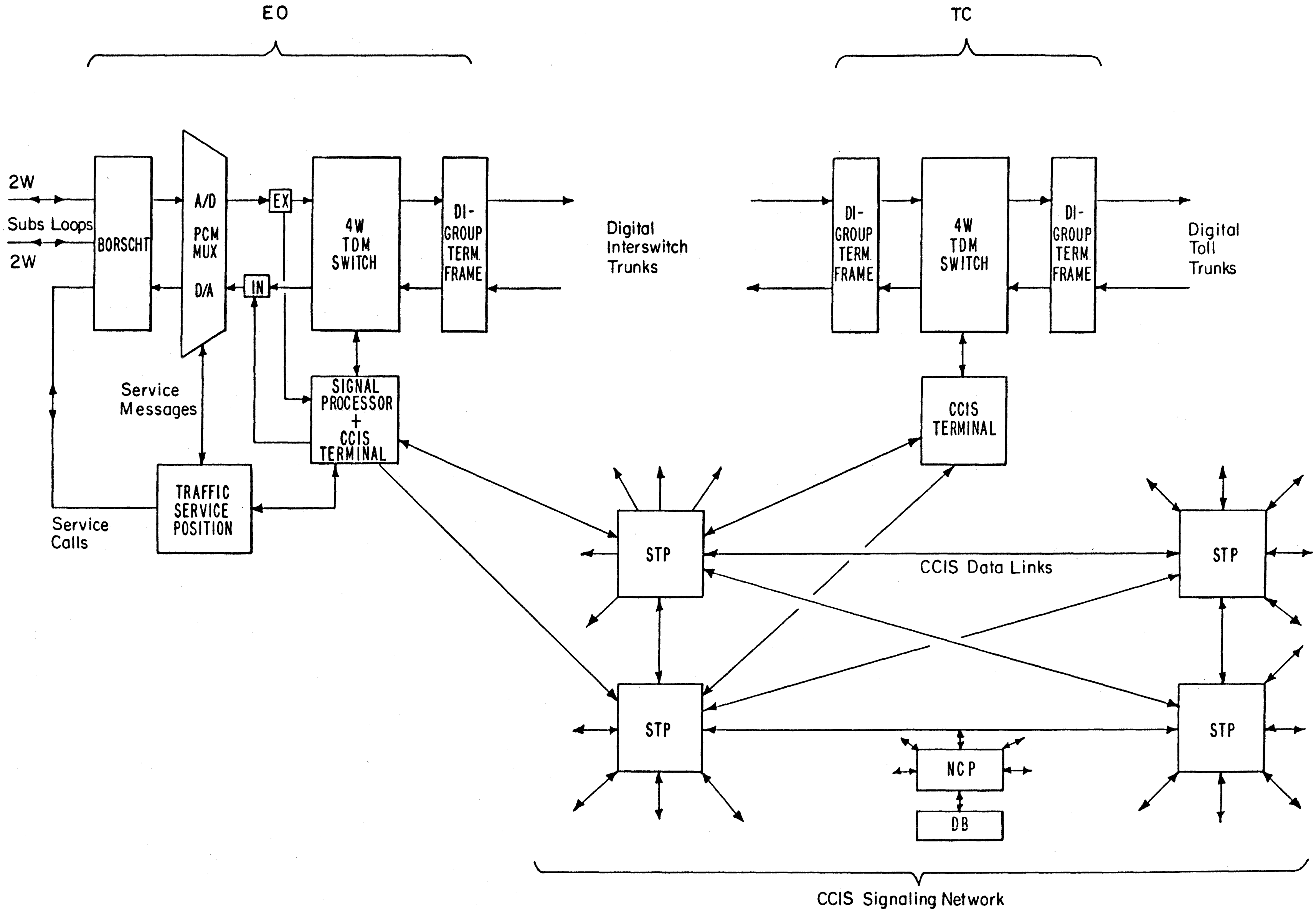


Figure 22. CCIS for digital EO-to-TC trunks.

analog lines. For the digital interswitch trunks of Figure 19, signaling bits are inserted in the PCM frame. This method appears relatively straightforward, but it has several drawbacks. First, the signal insert/extract circuits are per line items and as a group of thousands they demand a significant investment. Second, the passing of addressing and status information sequentially from switch to switch ties up network resources, especially during heavy traffic periods, making the overall system more expensive. And third, call establishment and disengagement consumes more time during the sequence of signaling passages than it would if a one-shot direct signaling path were available. The third drawback is quite stressful to subscribers who require short access delays.

A more frequently encountered signaling situation is shown in Figure 20. Signaling is still in-band, but both the switches and the transmissions are mixes of analog and digital. The greatest variety of signal extractors and inserters occurs for the analog lines/trunks and digital trunks at the 2W analog circuit switch. Various scanners (signal receivers) and distributors (signal senders) exist in the field: for different switches, different trunks, and different vintages of manufacture. At the 4W digital toll switch things are simpler, especially if, as shown, the extract/insert functions are performed on the switch side of the D channel banks. In addition to the network mix complexity, the in-band signaling arrangement in Figure 20 possesses all the other drawbacks discussed in connection with Figure 19. To overcome the disadvantages and to foster in the age of the total digital network, the Bell system is turning to CCIS.

Figure 21 demonstrates the application of CCIS to the same hybrid analog and digital network environment discussed in Figure 20. Two things stand out. Except for the local loop (i.e., line) side of the analog EO, the signal extract/insert circuits have disappeared. And the signals have now an independent network to reach the required nodes, or more precisely their CCIS terminals. No signals travel on the interswitch trunks, be they 2W, 4W, analog, or digital. The transmission medium thus has become a more transparent message pipeline than in the previous implementations of POTS. This freedom is bought for the price of the CCIS network.

The CCIS network is disassociated from the normal message network. Its nodes (they are called Signal Transfer Points or STP's) and its links are not colocated with the rest of the Bell network. There are 20 STP's in the CONUS, two per each switching region. The 10 regions and the 20 STP's are illustrated in Figure 23. The regions correspond, one for one, to the regional centers listed earlier in

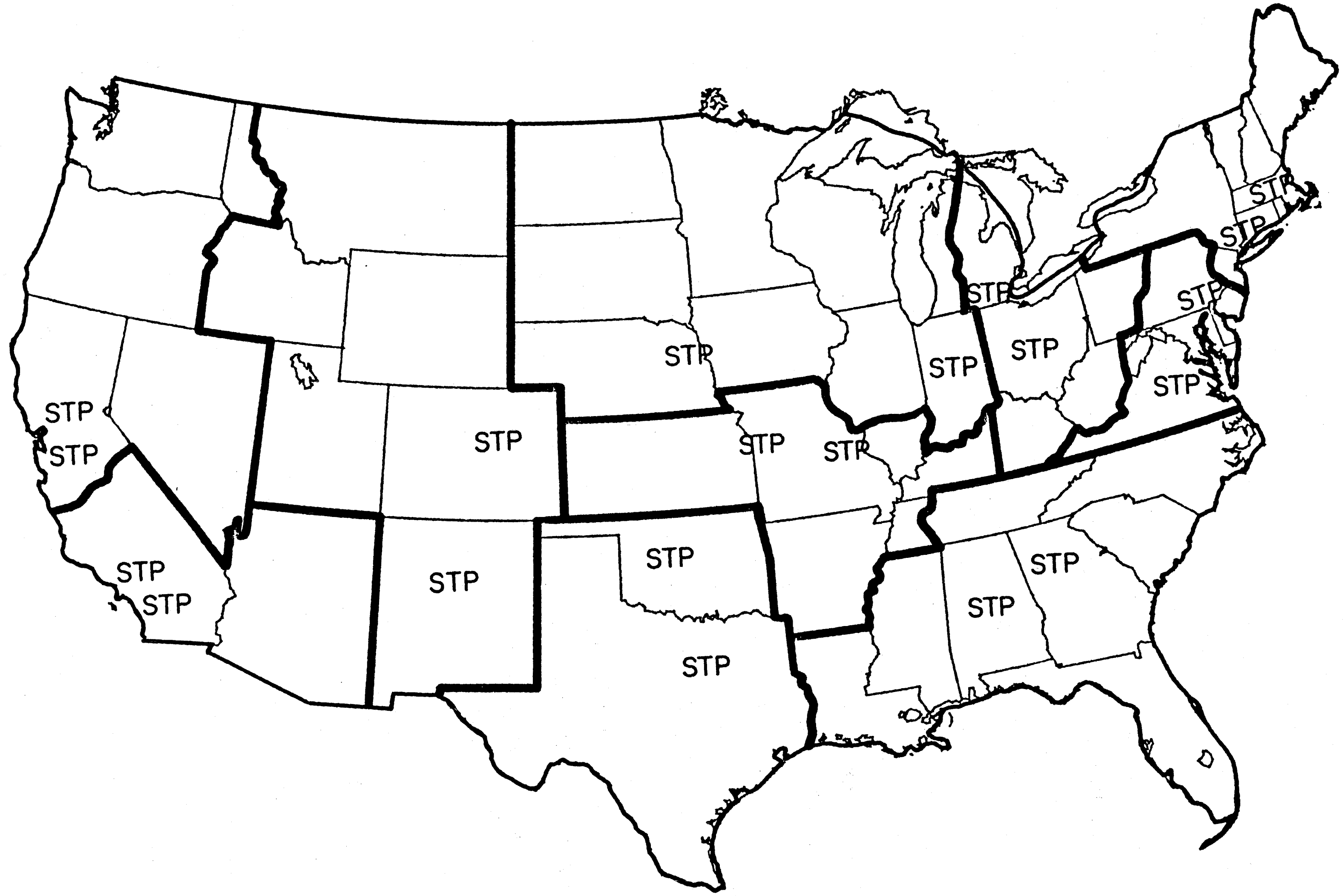


Figure 23. The 20 STP's and the 10 switching regions.

Table 3. The coordination of inter-STP operation and resolution of various problems, such as signal rerouting, is in the hands of the Network Control Point (NCP) and its associated NCP data base (DB).

As a final comment on Figure 23, one should note that the Bell System switching regions correspond to neither BOC nor political state boundaries.

A CCIS terminal of a given switch homes to both STP's in its region. These STP's are connected to each other, to all other STP's, and to the NCP. The signaling messages sent over the CCIS are encoded for error protection. The STP's carry messages back and forth between both end CCIS terminals to ascertain the state of subscriber terminals, address validity, and to establish least cost routing (LCR) through the network. The CCIS also carries additional signaling messages to enhance subscriber services, to provide for unique features, and to aid various subnetwork functions discussed elsewhere in this section. Experience has shown that the CCIS network enables much faster and more efficient call access and related tasks over the toll network.

For a relatively typical long distance call, the CCIS network activity extends across exchange, state, BOC, and switching region boundaries. It involves intelligence and operating routines stored somewhere in AT&T Long Lines data bases.

Figure 22 shows the CCIS network in the fully digitized switch and trunk environment of the future. (The only things that are left analog in Figure 22 are the 2W subscriber loops.) One notes the strong independence and separation of the two networks: CCIS and the switched circuit/message network. This arrangement is proving out to be faster by a factor of 2-10 over the existing in-band signaling networks, implying operational and cost efficiencies to the users.

3.7 Switch Operations Support Systems

While modern, especially large switching systems -- such as the ESS -- take on the appearance of stand alone machines, that is far from truth. Switches with stored program control (SPC), see Figures 14 and 15, rely on extensive software support to operate reliably and without service interruption. The support systems can be down loaded and distributed to many locations. However, that all involves costs and a variety of budgetary issues.

An example of a network-wide long lines system is the family of switch operations support systems, shown in Figure 24. It can be remotely accessed from any SPC switch, Classes 4/5 and above. The functions of the support system acronyms are listed in Table 8. Note that these support systems interact with each other

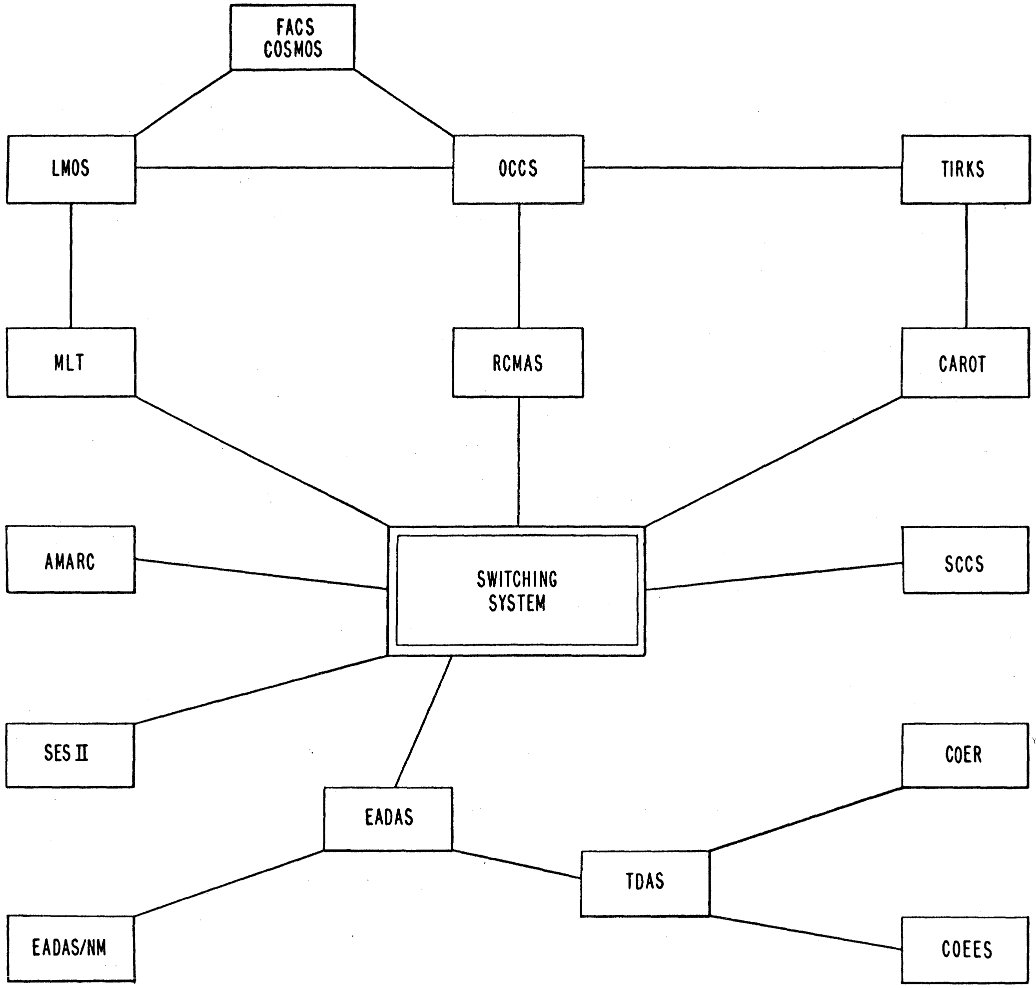


Figure 24. Switch operations support systems.

Table 8. The Functions of the Switch Operations Support Systems

Acronym	Function
AMARC	Automatic Message Accounting Recording Center System
CAROT	Centralized Automatic Reporting on Trunks
COEES	Central Office Equipment Engineering System
COER	Central Office Equipment Reports
COSMOS	Computer System for Mainframe Operations
EADAS	Engineering and Administrative Data Acquisition System
FACS	Facility Assignment and Control System
LMOS	Loop Maintenance Operations System
MLT	Mechanized Loop Testing System
NM	Network Management
OCCS	Other Common Carrier (Centralized Ordering) System
RCMAS	Remotely Controlled Memory Administration System
SCCS	Switching Control Center System (Data Base)
SES II	No. 2 Service Evaluation System
TDAS	Traffic Data Administration System
TIRKS	Trunks Integrated Record Keeping System

as shown in the figure. The features, applications, and limitations are to be found in Bell System technical literature (BSTJ, 1977; McKay, 1980; IEEE, 1982). It may suffice to elaborate here on the network management (NM) role of the EADAS. A three-level hierarchy of network-wide centers is employed. As shown in Figure 25, at the top of NM hierarchy is a single Network Operations Center (NOC). At the second level are 10 Regional Operations Centers (ROC). And at the lowest level, there are 27 Network Management Centers (NMC). The centers employ interfaces, denoted as EADAS/NM, to interchange and to collect traffic data via an intermediate computer based Traffic Data Collection System (TDCS). Data is collected from all major toll switches and international gateways (Hester, 1982). Traffic data, of course, is needed to manage the network via another automated system, the TDAS (see Table 8).

3.8 Inward WATS

The Inward WATS (for Wide Area Telecommunications Service) is a Switched Digital Capability (SDC) enhanced service wherein any subscriber dials his own NPA (area code) number to reach a typically corporate enterprise anywhere in the country. It is also known as the 800 service. There is no charge to the call originating party, as the corporate service subscriber is billed. Tens of thousands of Inward WATS exist in the CONUS at any one time. Enterprises, such as hotels, motels, credit organizations, insurance companies, airlines, travel agencies, telecommunications for disabled, and various interstate businesses that find it in their interest, either seasonally or permanently subscribe to the 800 service.

Figure 26 presents the latest enhanced version of the 800 or Inward WATS service. It is based on the premise of the nationwide SDC (Dorros and Horing, 1980). As seen in the figure, the calling and called stations can be nearly anywhere in the USA. The calling party accesses the Inward WATS service at the nearest Network Access Point (NAP), which could well reside in the same exchange area or the same BOC. The NAP could be a Class 5 EO, or a higher class switch, perhaps of the ESS family.

Upon receipt of calling and called addresses, the NAP instructs CAMA of the applicable billing arrangement and the serving Inward WATS Action Point (ACP), which is typically a CCIS equipped toll switch (e.g., a #4 ESS). From this point on, CCIS signaling runs the show. It consults the centralized nationwide 800 service data base for the validity and routing instructions of the call. This data

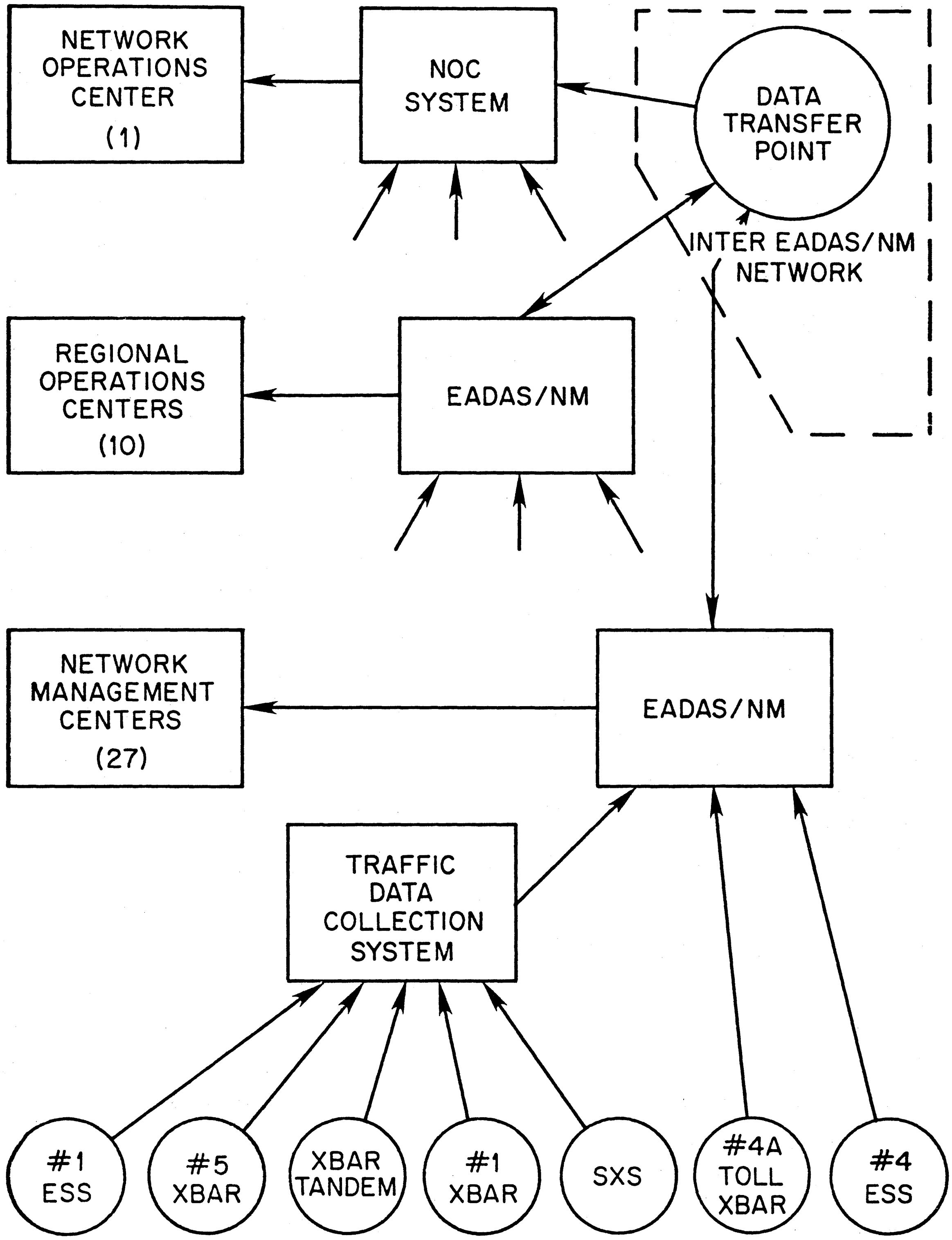


Figure 25. Network management hierarchy and data collection through EADAS/NM interfaces.

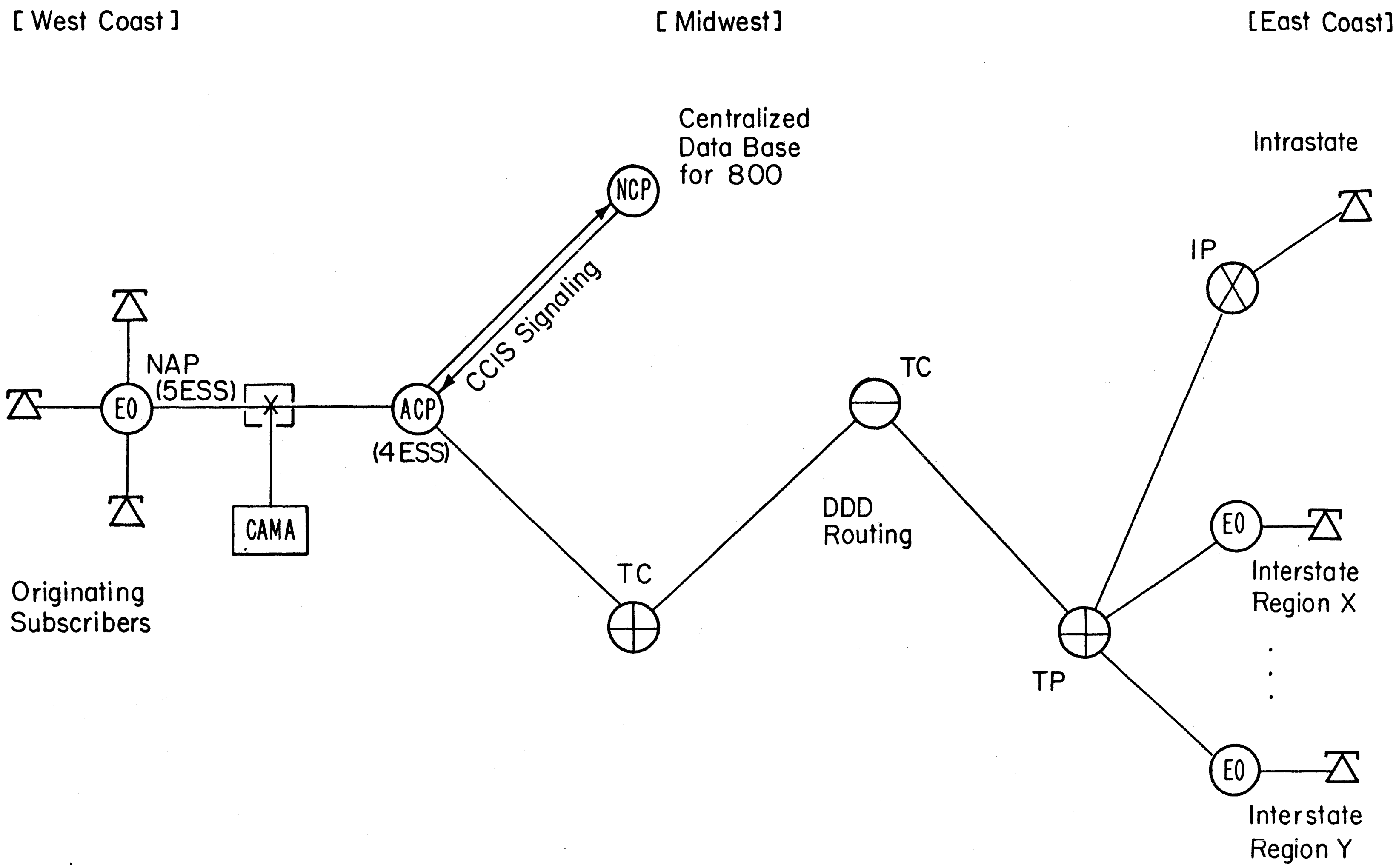


Figure 26. The enhanced 800 or inward WATS service.

base is found at one or more NCP's, perhaps in a completely different BOC area from the calling and called stations. If everything is correct, the 800 call is routed via the DDD toll network to its destination. Several toll switches and EO's can be involved, as shown.

There are three main features to be noted about this enhanced service. First, the virtual Inward WATS network for a given 800 number extends over the entire multi-BOC plus AT&T Long Lines serving domain. Second, the service networks are continually added, deleted, and modified as requested by customers. And third, no real physical Inward WATS network exists. What exists is a software package in the 800 data base. In as much as this software can be variously processed, copied, transferred, and so on, this concept is quite versatile and technically serviceable.

3.9 Private Line Networks

A substantial fraction of AT&T's revenue is due to private line networks, Common Control Switching Arrangements (CCSA), plus various Inward and Outward WATS. Thousands of such private arrangements exist in response to business, government, and other institutional needs. The private line network structuring is undergoing modernization that is currently transforming, among others, older Switched Service Network (SSN) concepts into innovative Enhanced Private Switched Communication Service (EPSCS) networks. Since all the above arrangements must coexist at present and in the near future, a brief discussion of SSN and EPSCS is given next.

Figure 27 shows the existing SSN structure. The hierarchy is centered around three classes of switches. At the top one finds the Class SS-1 switches that provide the final route trunks, for on-net and off-net traffic, as well as switching, and employ four wire equipment. At the next lower level, Class SS-2 switches are largely involved with high-usage trunking. These switches can be either 2W or 4W. They are typically end offices or local tandems. At the lowest level there are the Class SS-3 machines. In implementation and off-net traffic routing, Classes SS-2 and SS-3 are quite similar. One exception might be the higher incidence of PABX and PBX tie-lines to Class SS-3.

The management of a private line network is done by the Network Operations and Administration Center (NOAC). The overall control is in the hands of the Network Control Center (NCC). The geographical dispersal of a network illustrated

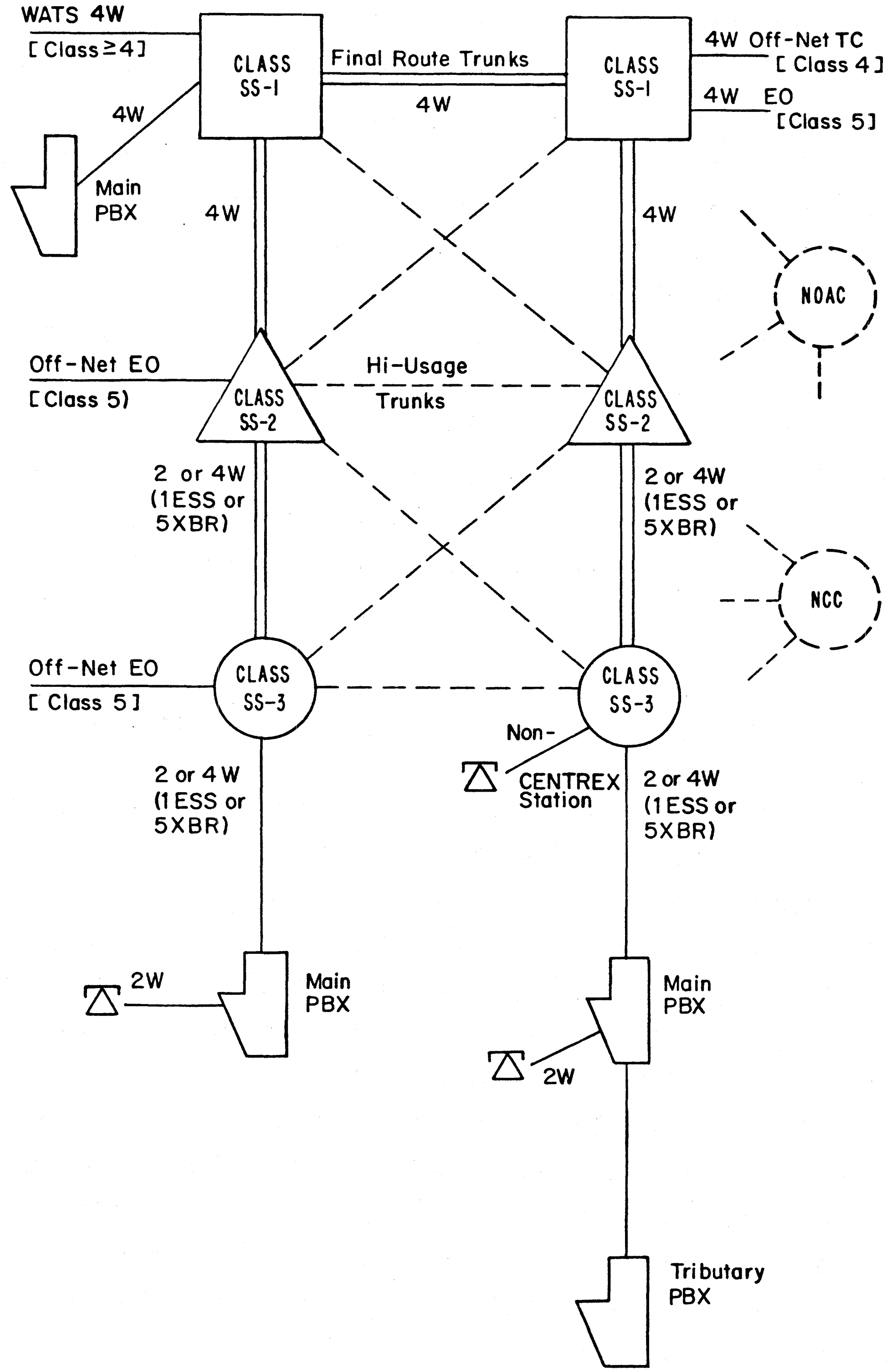


Figure 27. The existing switched service networks hierarchy.

in Figure 27 can be large. It can extend through arbitrary BOC's and throughout the interstate long lines territory.

The enhanced private line network or EPSCS is briefly outlined in Figure 28. Again, thousands of EPSCS arrangements are anticipated to serve the larger user organizations in the decades to come. The layered hierarchy has two levels: Class S-1 at the top and Class S-2 at the bottom. The very lowest family PBX's have 4W access to both S-1 and S-2 levels. All accesses from the main private branch exchanges are 4W. If a tributary PBX has 2W equipment, its tie-lines are nominally homed to the main or CENTREX PBX. Off-net services are liberally provided under software controlled Customer Service Administration Control Center and Customer Network Control Center. CCIS signaling ties Control Centers to each other, as well as to the final-route Class S-1 switches. In some schemes, where Class S-2 has CCIS terminals, the high-usage EPSCS are also under the versatile influence of CCIS and can benefit from the lowered or least cost routing routines. The majority of the nationwide off-net 2W, 4W, WATS, etc., connectivity to toll offices (Classes 4 and above) is provided via the Class S-1 EPSCS hierarchy.

4. THE EXCHANGES AND EXCHANGE AREAS - OPERATING COMPANY TECHNOLOGY BOUNDARIES

A simplified conventional overview of an urban exchange and its coverage area is shown in Figure 29. Note that in the very center one finds the exchange or rate center. By necessity it resides within some central office boundary, but the main point is that the exchange is surrounded by a base rate area (as drawn with the double lines in Figure 29). Any number of central offices or wire centers may constitute the base rate area. Depending on urban and suburban geography, the base rate area may be adjacent to several zones that are all within the same exchange area but subject to different local tariffs. For example, exchanges in larger cities like New York, Chicago, or Los Angeles, have around a dozen zones each. An exchange area is part of a single BOC and usually within the same state.

To show the switch and trunk network within an exchange area in more detail, an area labeled A has been taken from Figure 29 and is enlarged in Figure 30. Any configuration of small and large switching machines are interconnected by trunk groups that are sized to suit offered traffic. For local service the end offices play a major role. However, they need not all be located at separate sites. Rather, as shown in the enlargement of A, several EO's may constitute a wire center. The small sub-switches, such as PABX's and RSU's, are connected via

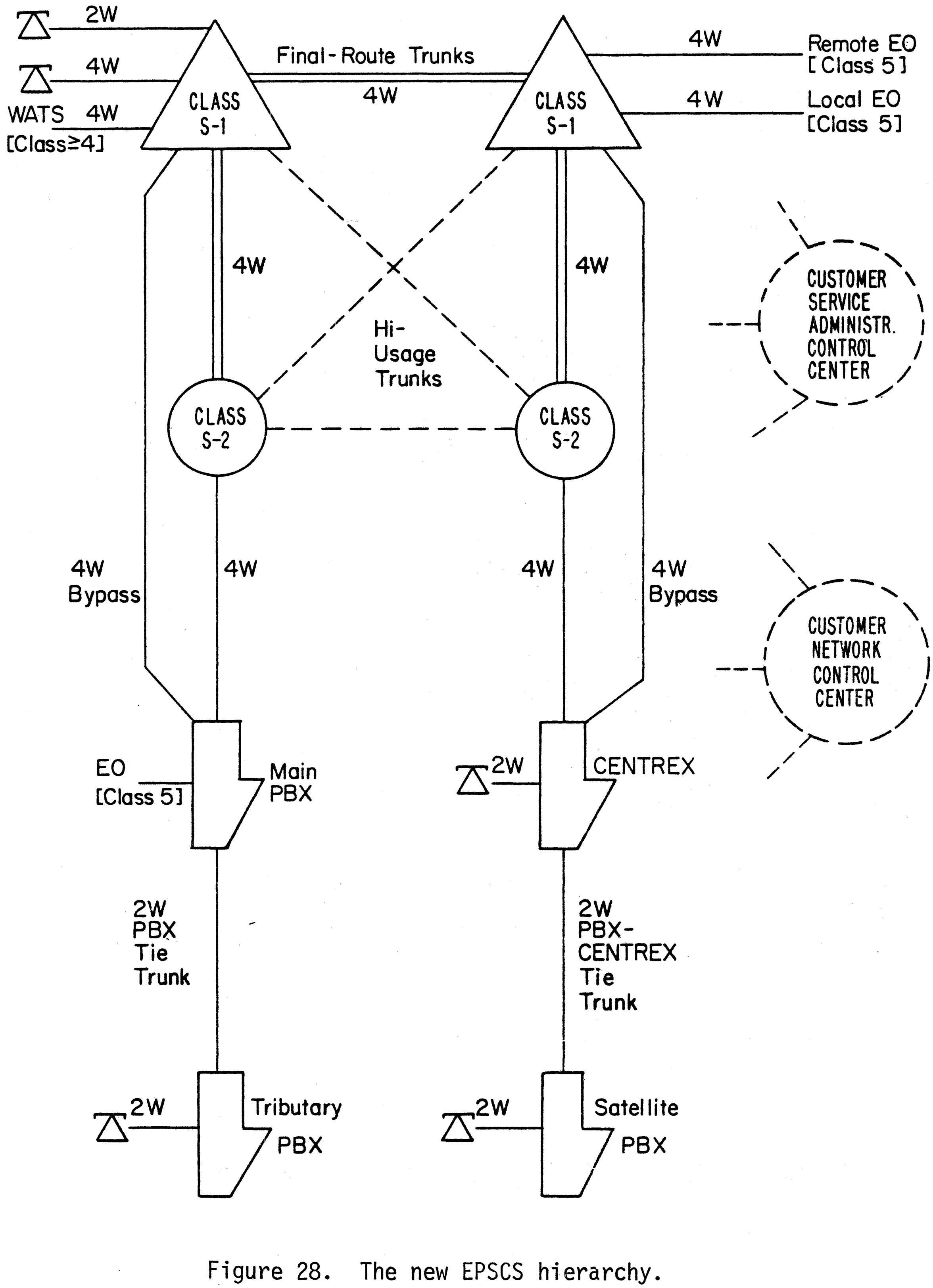


Figure 28. The new EPSCS hierarchy.

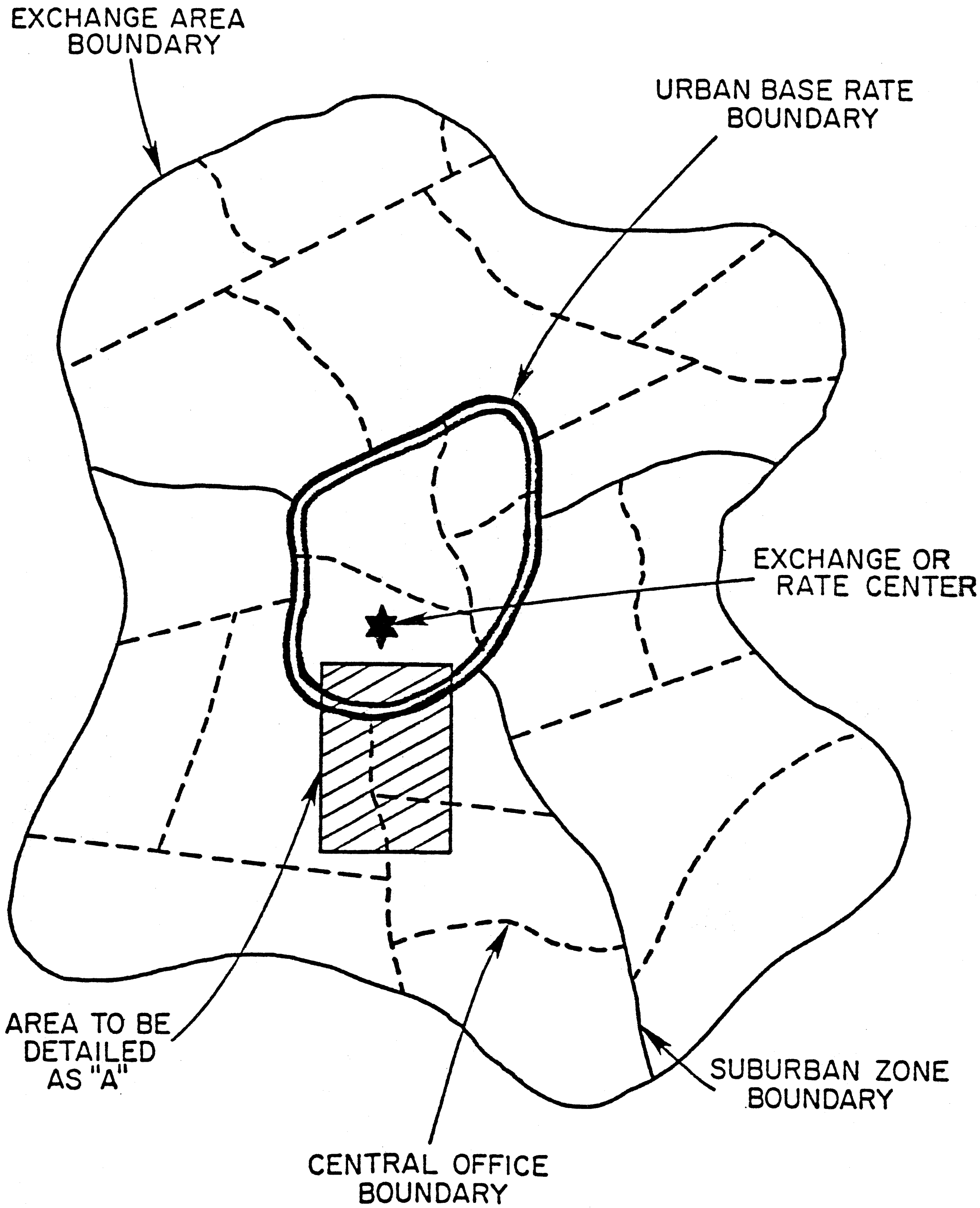


Figure 29. Possible layout of an urban exchange area.

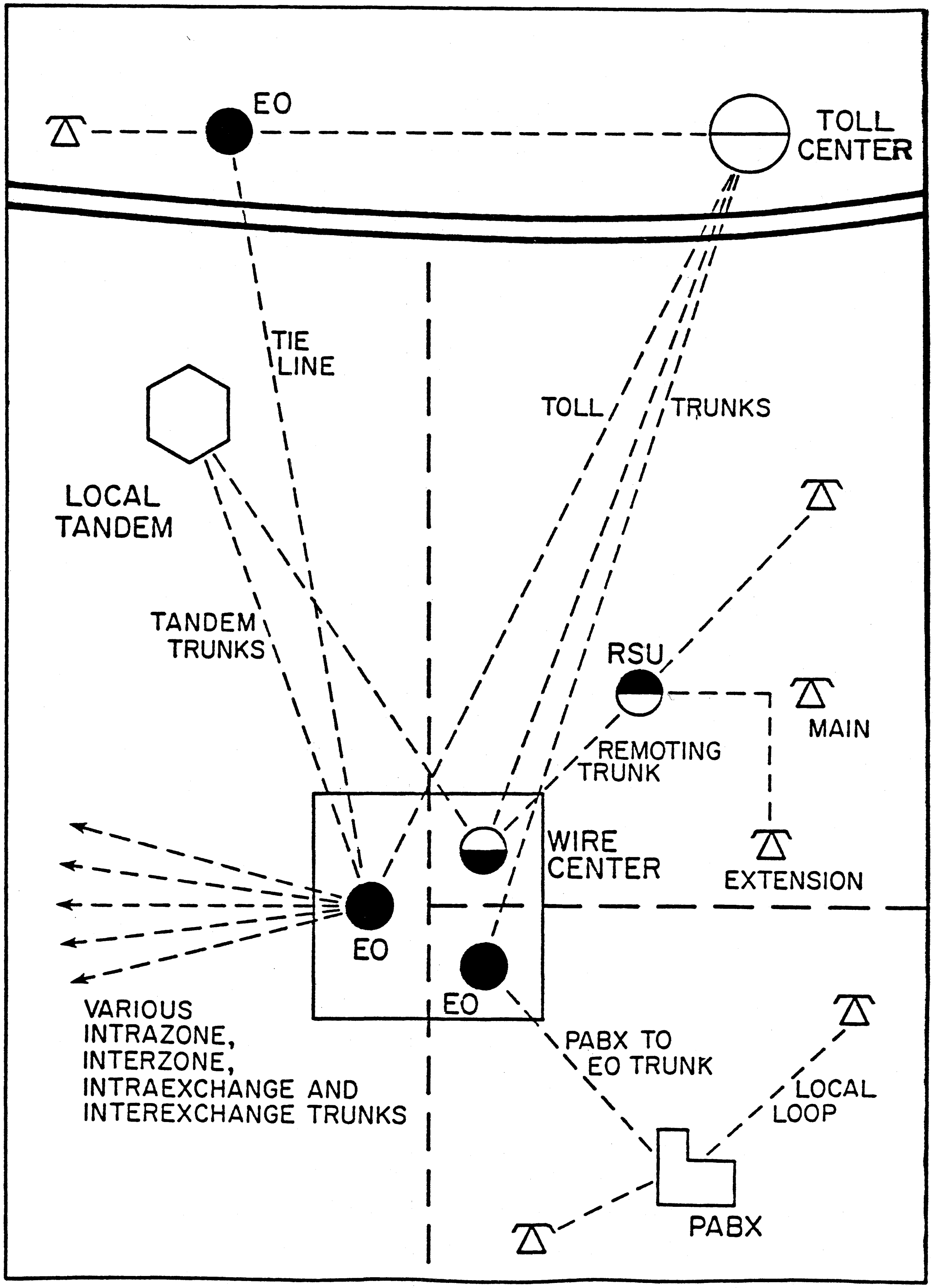


Figure 30. Area detailed as A.

appropriate capacity trunks and auxiliary facilities to their home EO's (Ciesielka et al., 1979).

For billing purposes, the whole of the USA is currently subdivided into approximately 20,000 Bell System and Independents' exchange areas, each with its own rate center (CCMI, 1982a). Of this multitude, around 420 rate centers play a relatively major role and are called Category A rate centers. That means that these selected centers provide within their respective exchange area such services as AT&T Series 2000 (voice) and 3000 (data) private line channels, plus other selective service capabilities (usually specified in rate center directories), or in some cases either Overseas Gateways, Government unique applications, or OCC interfaces.

When a service from one exchange to another is tariffed, the so-called interexchange (IXC) tariff applies. If the IXC mileage is 40 miles or more, the artificial (legal, not geographical) V (vertical) and H (horizontal) coordinates are used to determine the charges. If the distance is less than 40 miles, the V&H system is not used. In these cases, typified by suburbs, multi-zones, and outlying areas, special AT&T tariffs apply.

Within each exchange area the intraexchange services are subject to local or state statutes and tariffs (CCMI, 1982b). This is the BOC territory. There is considerable variation between BOC rate management approaches, even though in recent years there has been an effort to implement a uniformly structured multi-element charging system to telephone customers nationwide.

In summary, Figure 31 shows how the USA is subdivided into BOC's, states, exchange areas and zones. This is an administrative assignment of boundaries. To superpose the technological boundaries right on top of administrative boundaries may be possible in terms of in situ equipment. However, since the functions discussed in Section 3 invariably extend across all local boundaries, such superposition raises many unresolved ownership, responsibility, and accounting questions.

5. THE INTEREXCHANGE AREA COMPETITIVE NETWORKS - TECHNOLOGY AND CONNECTIONS TO EXCHANGE AREAS

The technology described in previous sections of this report forms the working gut of the total telephone network. The union of physical building blocks, their functions, plus operational classifications of all kinds, contribute to the nationwide web. Transmission, switching, signaling, support systems, and last but

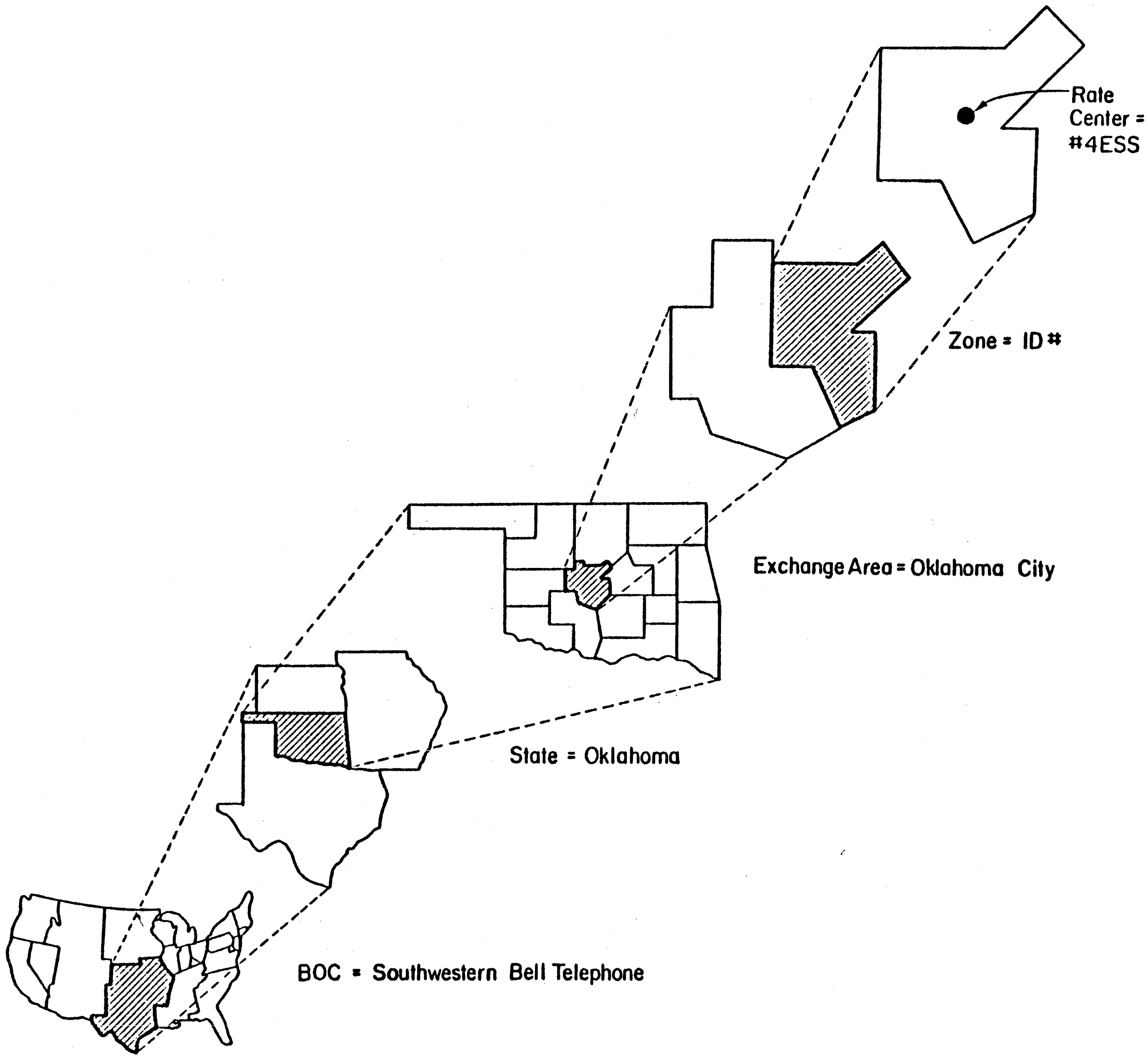


Figure 31. Administrative USA subdivision into BOC's, exchange areas, and rate center zones.

not least, human management are all essential to the system. They also enter in the interexchange area network, which as a whole can be viewed as nearly synonymous or as a slightly modified version of the, so-called, toll network.

The familiar toll switching hierarchy is illustrated in Figure 32. 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).

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 3. 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 by viewed as a method of alleviating trunk group congestion, improving interswitch 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.

Several of the terms associated with the routing through the trunk network of Figure 32 should be noted, as they are essential for the interexchange operations. Such fundamental terms are:

Alternate Routing - A network function that offers an alternate route for a call that encounters the NC condition on its direct route. Either stored tables or algorithms, local or remote, perhaps involving CCIS, can be used for this function.

Final Route - A path that proceeds in Figure 32 from the perimeter to the center of the hierarchy and out again. In an extreme EO-to-EO traffic flow this involves the following class nodes:

5-4X-4-3-2-1-1-2-3-4-4X-5.

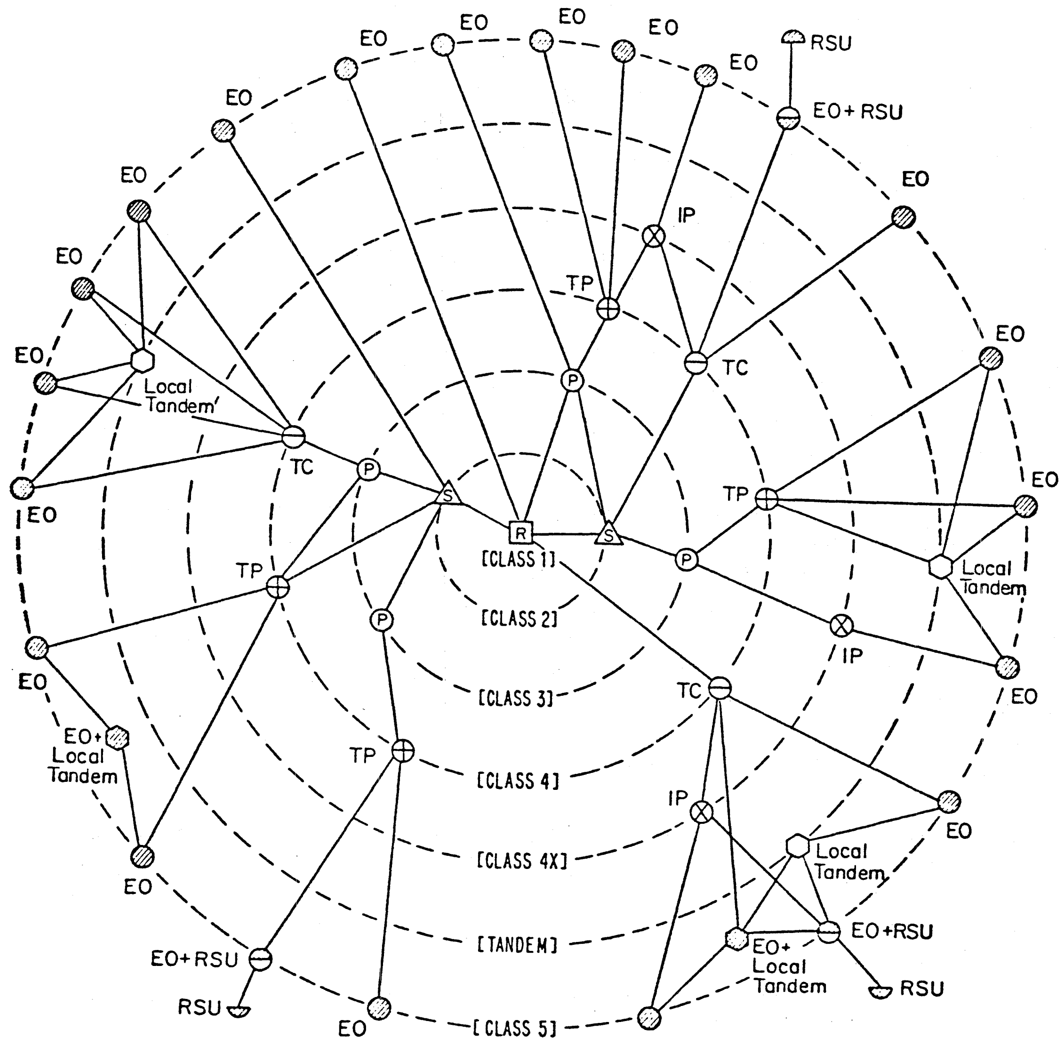


Figure 32. The intra- and interexchange networkwide switch hierarchy and topology.

As seen, such a final route passes through 12 switches and 11 interswitch trunks. The toll network is designed to provide not only acceptable SNR and BER, but also low enough probability of blocking (or GOS) and short enough access delay under a range of high traffic surges in the Busy Hour (BH), when the calls must traverse the 11 final trunk groups in series. Segments of the final route are also utilized as last resort by all traffic, including overflow from HU routes.

High Usage (HU) - High Usage routes or trunk groups are direct ties between nodes that carry considerable traffic. They are engineered for nearly full occupancy during the BH, and are provided with alternate routes.

Least Cost Routing (LCR) - A routing principle or algorithm (there may be several) that strives for cost and traffic efficiency.

Multialternate Route - A sequence of alternate routes to be tried whenever one encounters NC conditions on the first, second, etc., choices of routes. The multialternate route schedule is usually stored in routing tables.

No Circuit (NC) - A condition where a call attempt finds all trunks busy on its preferred route. (It could be the first choice or the next choice in the multialternate route schedule.)

One Level Limit - A rule for implementation of HU trunk groups. It usually means that additional trunks should only be installed between switch classes whose class numbers do not differ by more than one. This limit is always to be interpreted on the basis of traffic and cost, and is subject to a great number of exceptions in practice.

Routing Tables - A stored list of the preferred order in which routes should be tried between nodes A and B. The stored lists can be permanent or programmable. They are used for LCR, as well as for multialternate routing.

Skip-Level Routing - An arrangement of trunk groups that is based on traffic need and by definition violates the One Level Limit. An illustration could be a direct tie from Class 5 EO to the Class 1 Regional Center. See Figure 32.

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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 presents an overview of the 1982 telephone network technology. Many physical facilities constitute the public switched telephone network. Their respective roles in support of voice services and related traffic are reviewed. Essential internal functions, such as accounting, timing, signaling, plus many others, are carried out by cooperative hidden subnetworks that exist within the larger overall public network. Engineering, operation and innovation of these facilities and functions will fall on all sides of exchange area boundaries.

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