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Command Post/Signal Center Bus Distribution System Concept Design

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Preface

The study, whose results are presented in this report, was supported by the U. S. Army Communications-Electronics Engineering Installation Agency, Fort Huachuca, Arizona on Project Order Number CCC-PO-15-78. Administration of the program was performed by the agency by Mr. Howard R. Smith of the Systems Engineering Office (SEO); Mr. R. E. Brackett and Mr. J. Smith of the SEO served as technical monitors of the program.

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The authors wish to thank LTC Frensted of the 3rd Corps, Fort Hood, Texas, and Captain Bryd of the 11th Signal Battalion, Fort Huachuca, Arizona. It is from them and members of their teams of specialists that we obtained valuable insight into what a real tactical situation is like and what the Army Field Commander's operational communications needs really are.

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COMMAND POST/SIGNAL CENTER
BUS DISTRIBUTION SYSTEM CONCEPT DESIGN

Robert F. Linfield, Martin Nesenbergs and Peter M. McManamon*

The communications network structures currently used to interconnect terminal clusters and switching nodes within an Army tactical command post and area signal center are reviewed. With this background, five alternative structures are defined in terms of their functional requirements. These candidate alternatives are evaluated and a preferred structure is selected based on a number of critical issues including deployment time, flexibility, performance, and survivability. The preferred alternative is a transparent bus-type distribution system incorporating analog-to-digital conversion for analog sources, time division multiplexing, and digital transmission facilities. A three-phase improvement plan is also outlined. The three phases are 1) imbedding the transparent link into the existing network structure, 2) merging these links with digital switches, and 3) changing the topology by adding switches to enhance survivability.

1. OBJECTIVE AND SCOPE

This report presents bus distribution network concept alternatives to the present network structure for the U. S. Army Command Post/Signal Center field installations. The overall objective has been to conceive different network alternatives which lend themselves to small installation and removal times while retaining or enhancing the survivability features of the existing networks. This program was conducted by the Institute for Telecommunication Sciences (ITS) for the U. S. Army Communications-Electronics Engineering Installation Agency (CEEIA) in Fort Huachuca, Arizona, on Project Order Number CCC-PO-15-78.

The following introductory paragraphs provide background information, a brief statement of study objectives, the ITS approach towards these objectives, an outline of this report, and a summary of the conclusions and recommendations.

1.1. Background Information

The tactical nature of transportable Army Command Posts and Signal Centers (CP/SC) poses many real operational problems to the Army Field Commanders. This appears particularly true for the internal CP/SC communications distribution systems. Such a system must often be installed, modified, or transported rapidly.

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The system must be survivable, movable, and flexible. Its telecommunications performance must meet all operational requirements faced by the transportable CP/SC scenarios. In addition, new distribution system concepts must be adaptive to changing technologies.

In the study reported here, we are concerned with the operational and technical system requirements for a system capable of replacing the individual wire/cable lines currently used to interconnect the various shelters, tents, vehicles, etc., within a command post at Army, Army group echelon, and an area signal center typical of corps or higher echelon.

A typical CP/SC consists of several functional elements dispersed over an area 3 km to 5 km in diameter. Basic functional elements include command headquarters, operations center, communications center, signaling center, radio park, helipad, and life support areas. The command post utilizes communications facilities extensively both for internal and external transfer of information. The information may be analog (e.g., voice) or digital (e.g., teletype) in nature.

Field wire and cable systems are used by tactical signal units to:

- Provide telephone service within the posts and major headquarters.
- Provide trunk circuits between unit switchboards at various levels of command (e.g., division, brigade, and below).
- Extend telephone circuits from multichannel terminal equipment to subscribers and switchboards within and between units in assembly areas.
- Provide the primary means of communication when radio silence is necessary and for interconnecting preselected defensive sites.

Figure 1 illustrates the current connectors and cables used to interconnect functional elements in the field. The photograph shows a connection panel on one of the mobile shelters used in a signaling center. This particular shelter contains patch panels for distributing information between telephone subscribers, switching centers, data terminals, radio receive and transmit sites, and the like. The shelter may also contain technical control equipment. It serves as a large "junction box", centrally located and star-connected to all of the functional elements in the area.

Most of the cables shown in Figure 1 contain 26 wire pairs. Reels containing 250 feet of this cable are deployed manually by two-man teams. These reels can be seen below the shelter. Each cable is terminated with a special quick connect and release connector. These are joined to the shelter via connectors called hocks.

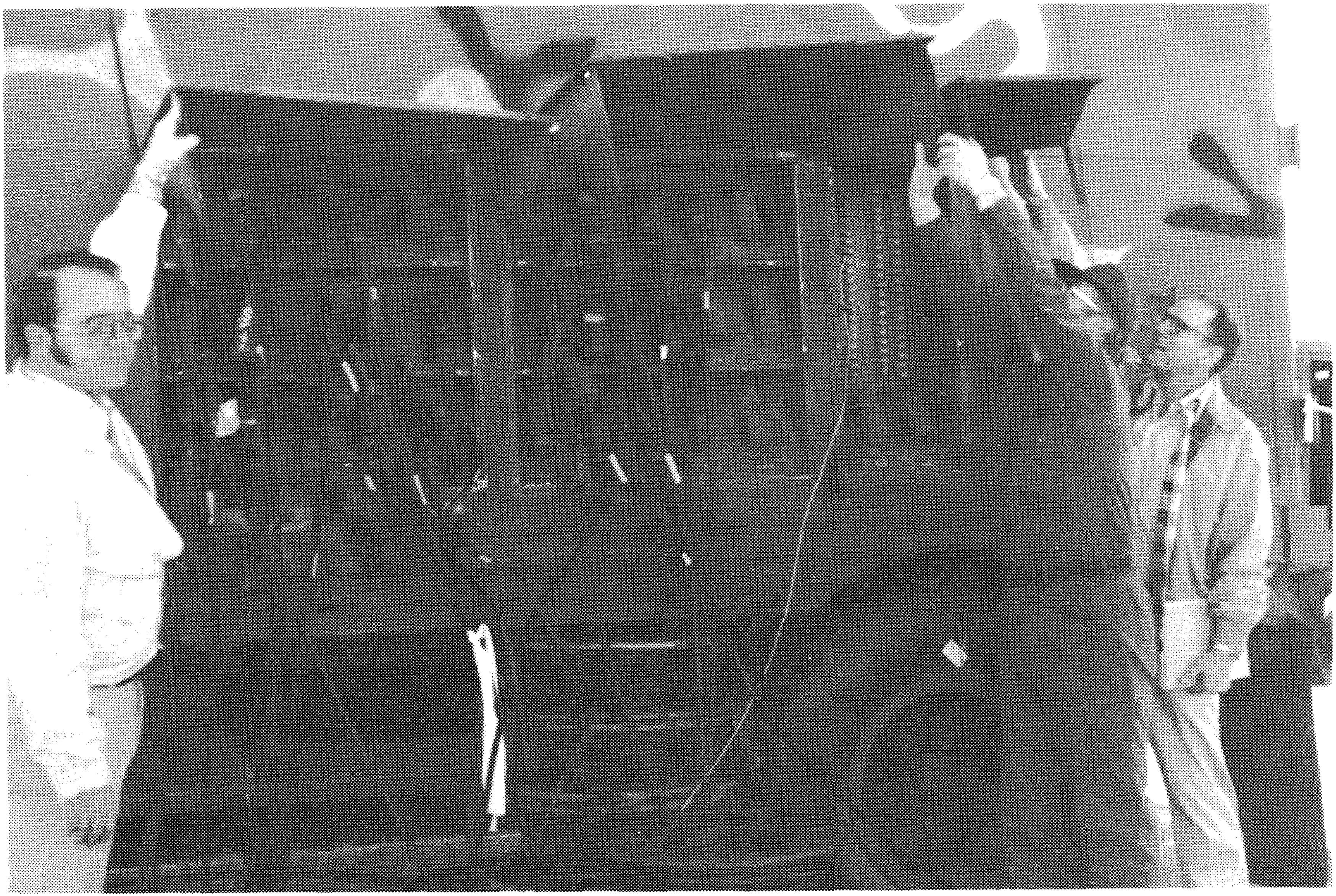


Figure 1. Photograph of cables and connectors currently used for CP/SC distribution system.

Single twisted wire pairs and coaxial cables also are used and connected to the panels like the one on the right in the photograph.

The time required to install a CP/SC varies considerably depending on the size, the terrain and the cabling procedure (e.g., buried vs overhead vs on the ground). Currently, a complete setup, excluding planning and transport time, could require two or three days with 20 percent to 30 percent of this time required for interconnections. A principal objective of this program is to reduce this deployment time to 1 day or less. Thus, the interconnect time should be on the order of 6 to 8 hours. However, reduction of the deployment and interconnect times should not be achieved at the expense of other essential performance characteristics. This applies, in particular, to survivability. Network survivability must be maintained at least at present CP/SC levels.

To achieve this objective, a functional design and specification of a bus-type distribution system is needed. The principal study effort reported here seeks to determine what the CP/SC internal communications network should do. Therefore the emphasis is on operational requirements and design functions, and to a much lesser degree on physical structures and implementations.

1.2. Problem Statement

The ultimate objective of this program is to develop and implement a bus-type distribution system which could be used to replace the existing wire pair and cable distribution systems in transportable Army command posts and signal centers. The goal is to provide a means whereby the CP/SC deployment time can be substantially decreased and, at the same time, maintain performance at current levels.

Another primary purpose of the study program reported here is to develop new network topologies which are applicable to the functional design and specification for a bus-type distribution system. To do that, one must consider various candidate network and bus alternatives. A subsequent program phase would involve an engineering test model development based on the functional design and specification.

The critical issues addressed in the current study include the following.

Installation Speed Improvement. The time and manpower saved by the use of bus techniques to install the internal CP/SC distribution compared to currently used wire pairs and cables.

Flexibility. The flexibility of bus techniques in making the transition from analog to digital and mixes of services, i.e., voice and data.

Service and Performance. The practical limitations of bus capacity in terms of bandwidth, number of subscribers, physical length, signal design, and media used. Performance aspects involve the quality of service, i.e., access time, grade of service and delivery delay. For voice signals the intelligibility and recognizability of the speakers may be most essential.

Survivability. This is an essential command post network objective. Survivability is closely related to vulnerability, nondestructibility, robustness, and reliability.

The above issues are recognized as basic measures of effectiveness (MOE's) and are considered in some detail in Section 8 of this report. Note that the installation speed improvement and survivability tend to be conflicting requirements if not properly recognized in the functional design.

Additional MOE's are introduced in Section 11 for selecting and evaluating alternative bus-type link structures. These MOE's are security, modularity, range, capacity, development risk, cost, and power distribution.

1.3. Technical Approach

An in-depth look at new and evolving technologies is needed to ascertain whether and how new system concepts, such as a bus distribution system could beneficially replace existing facilities.

The project was divided into three basic tasks. Task I, Determination of Requirements, was concerned with identifying, collecting and interpreting the actual operational requirements of the transportable CP/SC. In performing this task, a considerable amount of information on tactical communications requirements and the field commander's needs was collected. This was accomplished by a literature search, discussions with cognizant persons, and visits to tactical field exercises. The latter included one practice CP/SC deployment exercise conducted by the 11th Signal Battalion at Fort Huachuca, Arizona, and another full-scale tactical maneuver called BRAVESHIELD at Fort Hood, Texas. The results of this task are summarized in various sections of this report.

Task II, Definition and Evaluation of Preferred Alternatives, dealt with communications distribution system solutions to the CP/SC requirements developed in Task I. There are a number of bus-type systems which have been tried on a small-scale basis. Examples include ETHERNET, SPIDER and MITRIX. These and other bus architectures were reviewed under this task to determine the service they provide (e.g., data, voice, or both), the transmission technique (analog or digital) employed, the transmission media used (wire, coaxial cable, radio, fiber optical), the bus access concept (polled, multiple access, or dedicated), the method of multiplexing or concentrating (time division or frequency division), and other pertinent characteristics.

With this background information and given the operational requirements from Task I, overall network topologies were examined using state-of-the-art transmission media to determine alternative bus configurations which might meet the unique requirements of a CP/SC.

Included in this evaluation of design alternatives for network topology was an evaluation of system capacity (e.g., bandwidth, data rate, integrated voice/data, traffic intensity, and priorities) and control protocols. Measures of effectiveness were defined for the distribution system so that preferred alternatives could be selected.

Task III, Summary Assessment, determined one or two preferred system alternatives after evaluating and summarizing the results of Tasks I and II.

Preliminary analysis of these alternatives emphasized comparisions with existing systems, projections of critical tactical operational advantages and disadvantages in the field, and bus concept versatility for the anticipated future transition from all analog, to part-analog and -digital, to an all-digital network.

1.4. Report Organization

This report is organized into two major parts as indicated in Figure 2. The first part includes Sections 1 through 7 and is concerned with CP/SC operational requirements and the existing facilities used to meet these requirements. The second part includes Sections 8 through 13. Here the emphasis is on new technologies with potential applications for improving the existing facilities.

Section 2 describes the environment in which tactical communications systems must operate from the user's viewpoint. It is here that the CP/SC bus distribution application area is defined by giving an overview of the currently envisioned tactical army structure and its communications needs. This tactical environment must be considered in any tactical system implementation. It is necessary background material for the five subsequent sections as indicated by Figure 2.

The user's needs are described in Section 3. Here the user is the tactical field commander, his staff and support elements. The kinds of services which might be provided to meet this user's operational requirements are classified in

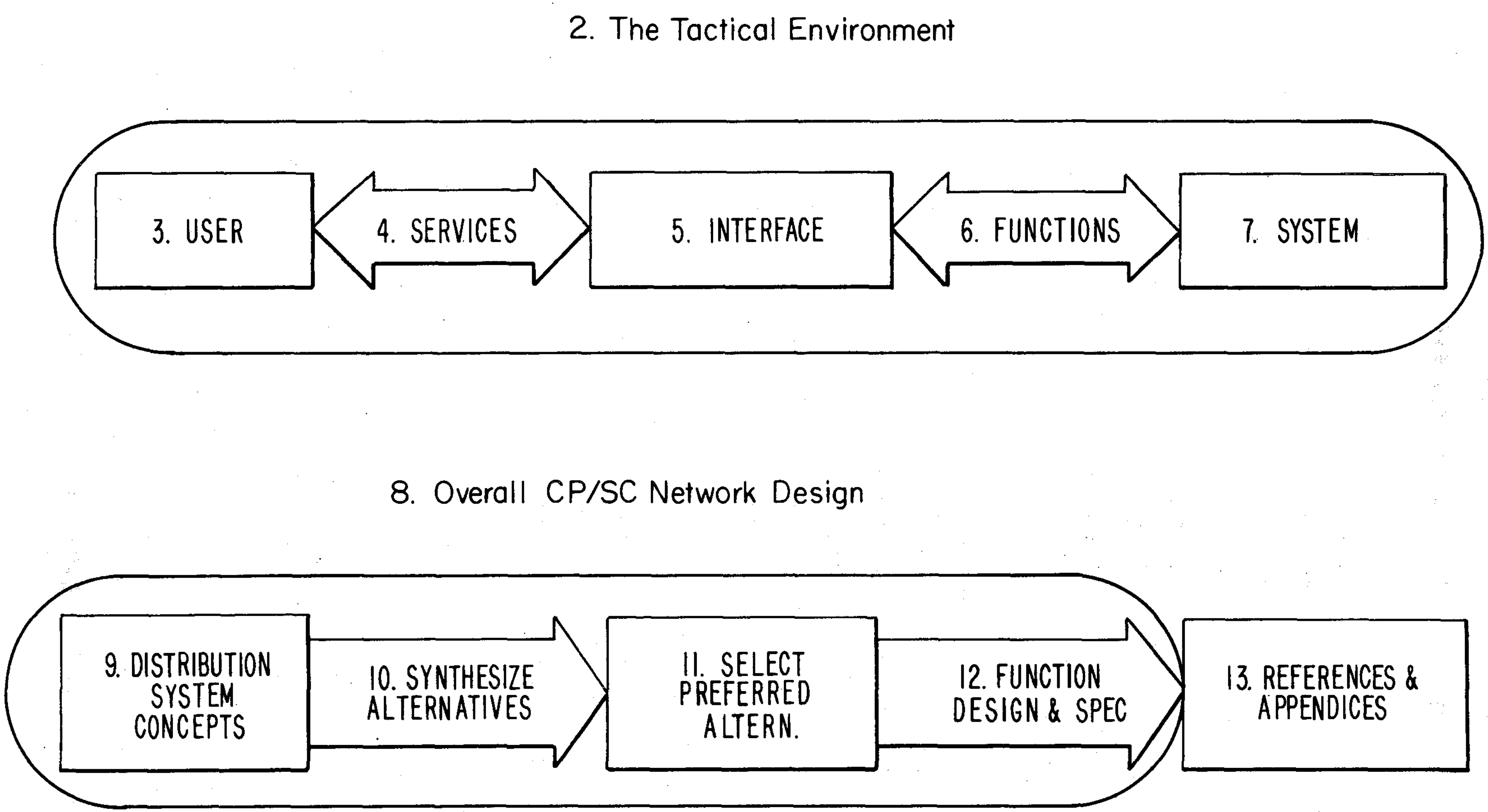


Figure 2. Report organization.

Section 4. Providing any service class involves an interface between the user and the system. For telecommunications systems the interface usually involves some form of media conversion (e.g., acoustic to electrical). Interface terminals which have potential application in a CP/SC are discussed in Section 5. The types of terminals along with their densities and distribution are considered along with the traffic generation in the tactical environment. In order to transfer this traffic certain functions must be performed. These functions define what a system must do, but not how it is accomplished. Functional aspects are considered in Section 6. Finally, Section 7 addresses the basic system elements used in current CP/SC networks. In this section the existing concepts used in switching, signaling, concentrating, multiplexing, and transmission are introduced. Some aspects of network deployment and system implementation also are covered.

In summary, Sections 2 through 7 introduce the basic concepts needed to understand the second part of the report, i.e., Sections 8 through 12.

In this second part, the emphasis is on more specific aspects of internal CP/SC networks, their basic concepts and distribution system subelements. Section 8 covers the overall aspects of CP/SC network design. This is of major importance to the sections that follow. It is in Section 8 that the general network objectives are defined. It also presents fundamental measures of merit - namely installation speed, survivability, service quality, performance, and upgradability.

The concept of hierarchal structuring is introduced. In the relatively small command post network application this hierarchal level approach breaks up the design problem into manageable size. This is followed by a subsection on network design and topology where it is shown how the capacity assigned to various levels impacts on the survivability. This leads to structured network configurations which appear to be suitable for CP/SC applications. Methods for quantifying the survivability of these structure configurations are then presented.

In Section 9 some important concepts for distribution system design are reviewed. A three-phased improvement plan is described for evaluations of the bus-type system. Only by considering the impact of later stages can an optimum system be developed for phase one.

Using the assumed evolutionary process some functional tradeoffs are described in Section 10. Preferred alternatives are described in Section 11 so that a functional design and specification can be outlined in Section 12. Conclusions and recommendations are summarized below. A selected bibliography for major topics is listed in Section 13.

1.5. Summary of Conclusions and Recommendations

Our review of tactical communications systems currently used in Army command posts and area signal centers resulted in the following general conclusions.

1. There may be no such thing as a typical CP/SC. Each installation varies in size, equipment used, configuration, cabling technique and deployment, time depending on the tactical situation, the terrain, and the commander's needs.

2. Telephone and teletypewriter terminals are presently the major source of traffic. This analog and digital traffic mix is primarily carried on 4-wire circuits using multiple wire pair cables.

3. At corps level, and echelons above corps, the number of terminals on a post ranges from a few hundred to one thousand or more. These are geographically dispersed in small clusters over an area whose largest dimension is 5 km.

4. Terminal clusters are star-connected to switching and distribution centers using twisted wire pairs and 26-pair cables. Interconnecting cables is a major logistics problem. A 300 meter spool of 26-pair cable weighs over 100 kilograms and several kilometers of such cable are required.

5. The time required to move a CP/SC is highly dependent on the time required to dismantle, transport, and reinstall the cabling system. This deployment time could be reduced by replacing the multiplicity of wire pairs with a transparent bus-type distribution system.

6. Network topologies, different from the star-network currently used, could improve survivability and deployment time if properly configured. This is feasible as switches, terminals, and transmission facilities are in a transition to all-digital networks using large scale integrated circuitry.

Based on these conclusions and the result of our near- and far-term forecasts concerning future tactical terminals and switching equipments, we recommend a three-phase improvement program to be conducted at approximately 5-year intervals. The three phases involve: 1) imbedding transparent bus-type links into the existing network structure, 2) merging these links with digital switches, and 3) changing the network topology by adding switch nodes to produce an all-digital structured configuration.

The initial improvement phase requires a development program whose major activities are concept development, validation, system development, system implementation and system operation. The later sections of this report are concerned with the concept development activity. Five alternative link configurations are defined in terms of the major functions to be performed. The major functional classifications are signal conversion, media matching and transfer mode. The five candidate alternatives selected for further evaluation are listed below for analog sources. The inverse functions are not listed but are implied.

Alternative	Signal Conversion	Multiplexing	Media Matching	Transfer Mode
I	Discrete Time Sampling	Time Division	Pulse Amplitude Modulation	Analog Over Dual-Wire Pair
II	Narrowband Frequency Modulation	Frequency Division	Frequency Modulation	Analog Over Single Coaxial Cable
III	Pulse Code Or Continuously Variable Slope Delta	Time Division	Bipolar Or Unipolar Binary Waveform	Digital Over Coaxial Or Fiber Optical Cable
IV	Pulse Code Or Continuously Slope Delta	Frequency Division	Frequency Modulation	Quasi-Analog Over Coaxial Cable
V	Linear or Adaptive Prediction Coding	Time Division	Unipolar Pulse Modulation	Digital Pulses Over Fiber Optical Cable

These five alternatives are evaluated using ten selection criteria, namely, deployment time and manpower, flexibility to the transitional environment, channel capacity, range, security, performance, development risk, cost, power distribution, and modularity. Based on our subjective grading, Alternative III has been selected as the preferred system.

In order to complete the concept development and validation the following research and development activities are recommended.

1. Development of "Proof of Principal" hardware for capacity, cost, risk and field adaptability evaluation.

2. Finalize concept design quantitatively based on the initial evaluation.

3. Produce limited quantity of bus distribution systems for field test validation.

2. THE TACTICAL COMMUNICATIONS ENVIRONMENT

In this section the environment in which tactical communications systems must operate is characterized. The first subsection summarizes the physical aspects of the environment. The second subsection describes the Army theater of operations, the communications concept for the corps area, the corps signal brigade, and the functional elements involved in a CP/SC from the communicator's standpoint. The subsection also defines the CP/SC external and internal communications traffic requirements in general terms and thereby provides background for subsequent sections.

2.1. Physical Aspects

Tactical communication systems introduce unique requirements for mobility, transportability and size, weight, and power restrictions. Tactical communications systems are more demanding than commercial and public systems regarding operational capability under adverse physical conditions. This physical environment involves transport via land, sea and air facilities. Restrictive environmental standards, therefore, must involve the following:

- bounce, shock, and vibration exposure;
- desert, rain, and arctic climates; and
- dust, sand, moisture, salt, and altitude changes.

In addition, provisions must be made for reasonable human comfort control for operating personnel.

Tactical system standards quantify these physical environment requirements. These can be found in the appropriate series of military standards documents. These standards must be kept in mind when reviewing commercial systems for applicability to the CP/SC area.

2.2. Communicator's Standpoint

Today the Army's theater of operations is typically divided by the theater commander into two zones - a combat zone and a communications zone (COMMZ). Figure 3 represents such a theater of operations. The COMMZ is a large geographic area containing the various combat support and service units for the theater army. Typical sizes range from 0.6 M km^2 to 1 M km^2. Theater forces may vary from three to five corps deployed on the line. A U. S. Army Corps consists of one infantry division, two mechanized divisions and two armored divisions. The corps also

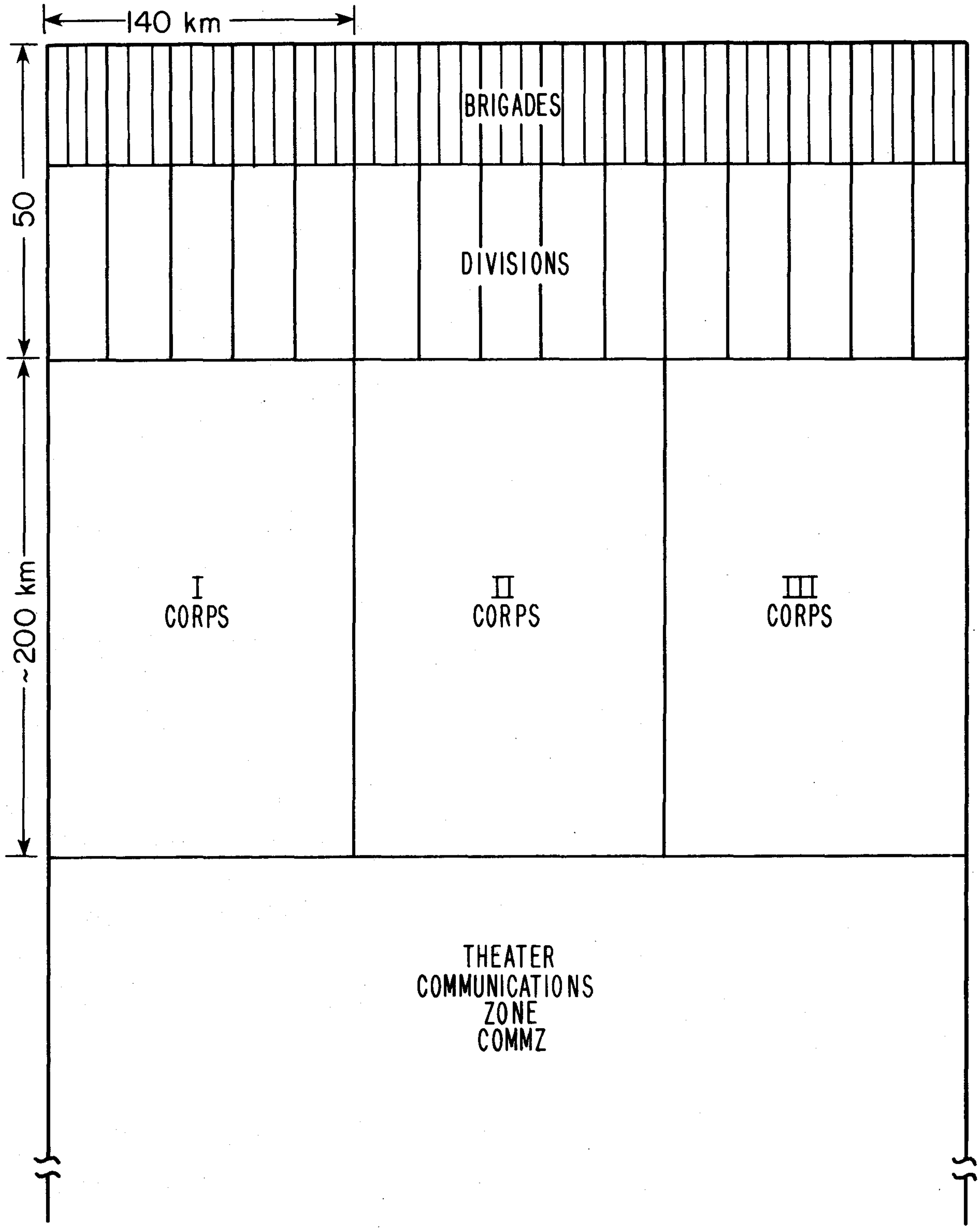


Figure 3. Typical theater.

includes a separate signal brigade and an armored cavalry regiment. The signal brigade is of principal concern here.

Corps boundaries encompass an area about 140 km x 250 km. The number of nondivisional troops in this area may approximate 120,000.

The corps signal brigade provides the communications for the diverse units in this large area. This corps signal brigade may have 5,000 personnel, 1,300 vehicles, 500 shelter contained assemblages, and over 2,600 km (1,600 miles) of wire and cable. It provides communications to corps of up to six divisions. The signal brigade contains the following organization elements:

1. Headquarters and Headquarters Company,
2. Command Operation Battalion,
3. Cable and Wire Battalion,
4. Radio Battalion, and
5. Four Area Signal Battalions.

At full strength each Corps Area Signal Battalion contains four area signal companies. Each company is capable of establishing an area signal center. The signal center includes multichannel systems and terminal facilities, extension links, messenger service, communications system control elements, and equipment maintenance facilities. The missions, capabilities and other major characteristics of the signal brigade's organizational units are covered in detail in the Army Field Manual FM 11-92, dated November 1978.

An example of the network organization of transmission links and switching nodes in the corps area is shown in Figure 4. Each node may correspond to a CP/SC for various organizational units from corps to division to brigade level. Transmission facilities to the COMMZ usually involve large distances and require troposcatter links. In the corps area line-of-sight (LOS) microwave links provide connectivity over shorter ranges. At the division and brigade level VHF radio links are normally used. The different means available to electronically transmit messages are multichannel radio, cable, radio teletypewriter (RATT), AM and FM single channel radio, and radio wire (RWI) facilities.

Future corps multichannel communications systems may employ tactical satellite terminals (TACSAT) and automatic switchboards. The TACSAT terminals will be used to establish communications until LOS links are installed.

The backbone grid network of the corps communications system conceptually illustrated in Figure 4 is primarily multichannel radio augmented by cable as

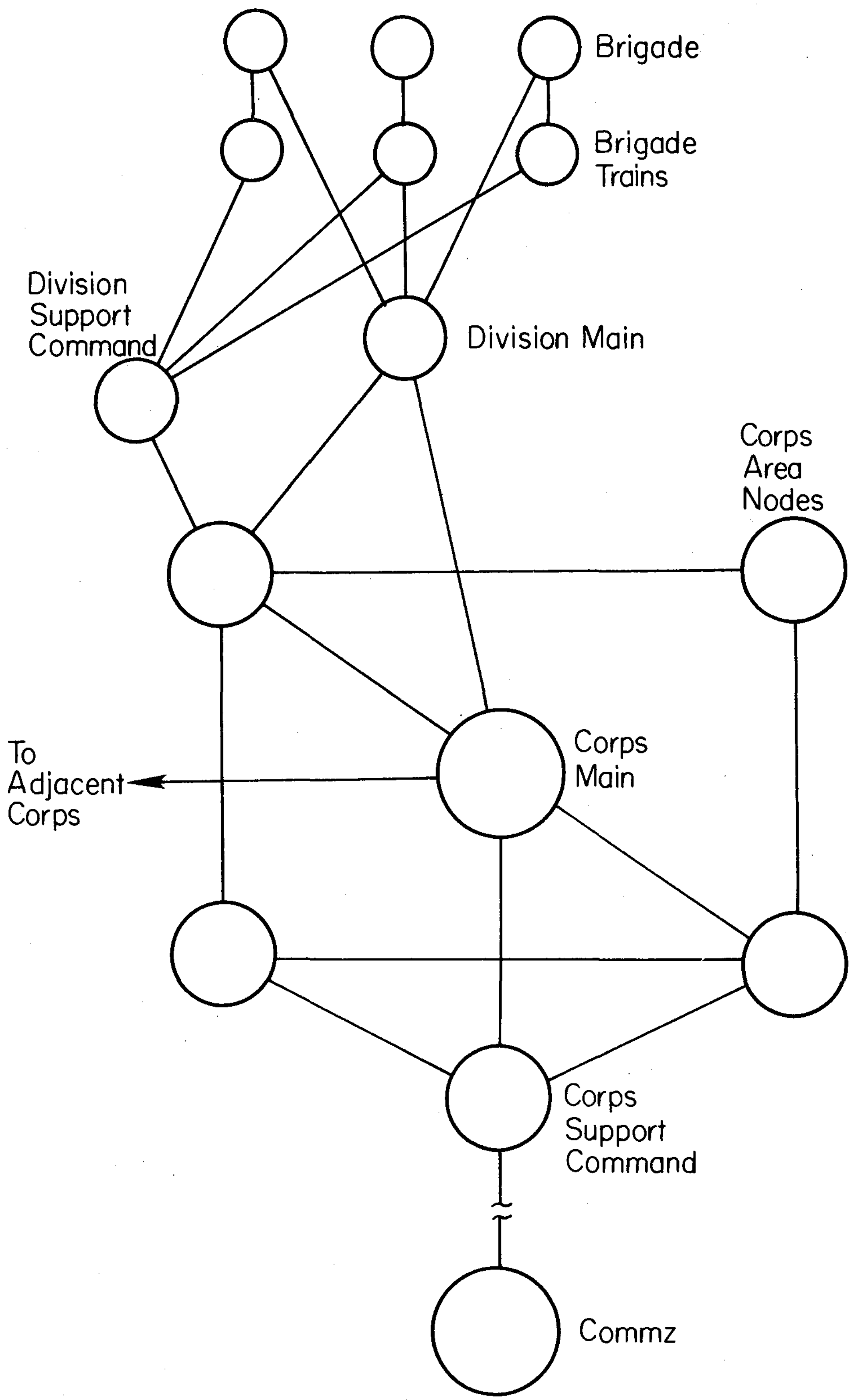


Figure 4. Corps area network organization.

required. Multiplexing equipment combines multiple circuits into one carrier signal for transmission over a single radio or cable link. The multichannel circuit can be a voice (telephone), data, facsimile, or teletypewriter circuit.

In this report the communications traffic requirements within and to each node are the main interest. External communications systems are only of interest because of their impact on the internal traffic and the local distribution systems. This is because traffic generated by a node and traffic terminating at a node must be carried by the internal network. The nodes also serve as relay points and for routing purposes. This traffic may or may not be carried on internal links. The corps main node in Figure 4 includes a main command post, operations center and signal center with associated terminal equipment. Another node is the rear CP, usually collocated with the corps support command (COSCOM). Still another node serves as a tactical command post (TAC-CP). It provides a forward command point and may serve as an alternate command post if required. Other area nodes provide links to division main command posts and division support commands (DISCOM). Alternate communications circuits are provided via DISCOM nodes and the brigade trains to the brigade commanders. Figure 5 illustrates the functional elements of one corps main node. The functional elements are interconnected using a star-connected network as indicated. The main patch panel serves as a distribution center and usually includes the technical control facility. The telephone switch center (manual or automatic) provides telephone service throughout the area. This includes life support areas, military police, helipad, and the like.

All functional elements are located in mobile shelters, tents or even buildings. They are dispersed over a 5-km area and covered for concealment from the air. Usually the radio transmitters and receivers are located some distance away on a hilltop or roof of a building. This so-called "radio park" provides the main links for long-distance circuits to and from the command post. Multichannel cables carry multiplexed PCM signals to and from the radio park. These and other land lines are installed according to the field commander's requirements. They are sometimes carried on poles or strung in trees, sometimes completely or partially buried, and sometimes just laid on the ground. The current tactical situation is usually the controlling deployment factor.

External links to a node, both radio and land lines, determine most of the traffic. An example of the external links used at one node visited is shown in Figure 6. This site was installed at Fort Hood, Texas, during the tactical exercise denoted BRAVESHIELD 19. The entire command post, including the radio park, covered

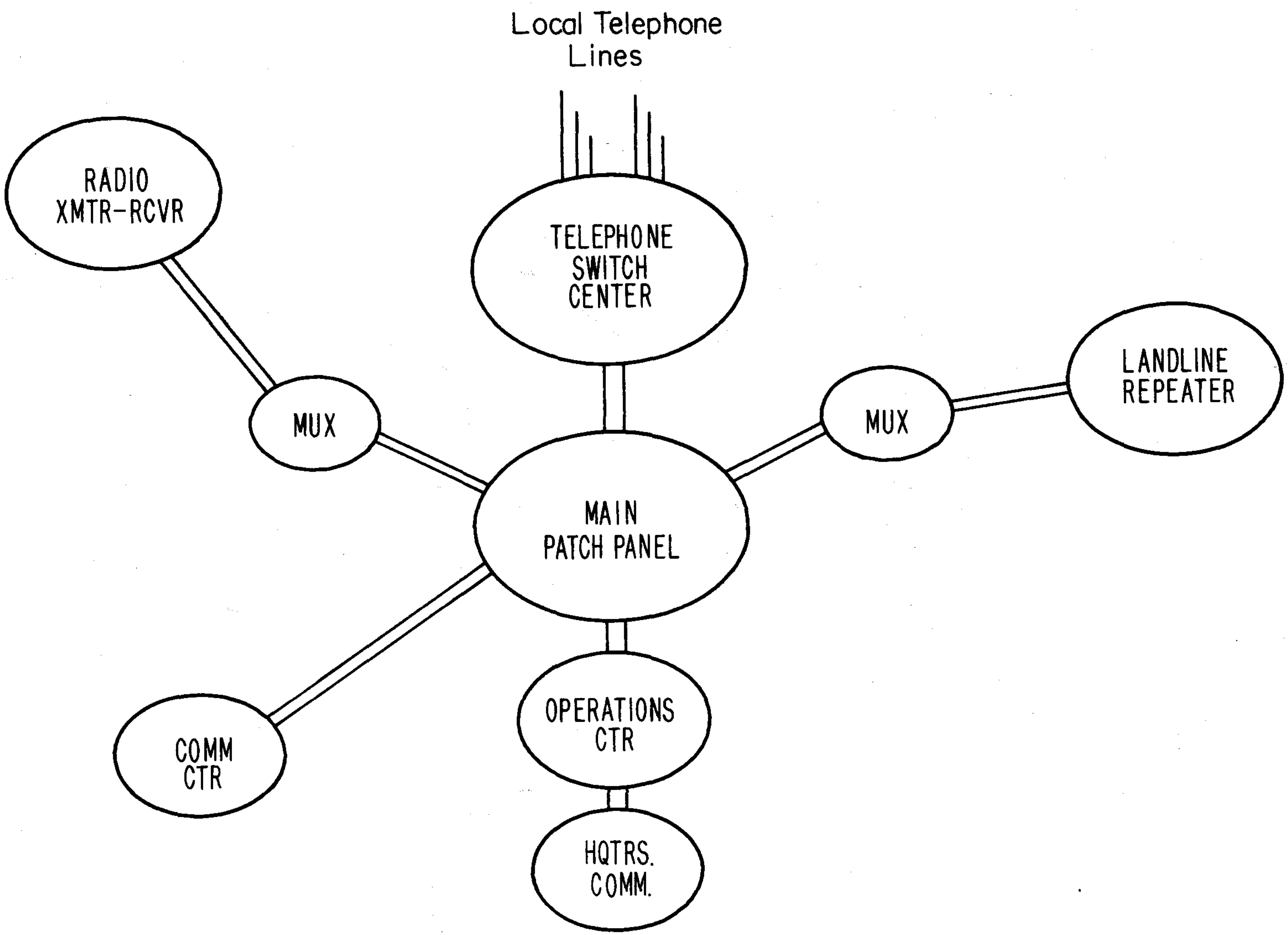


Figure 5. Interconnection of functional units for a typical area signal center.

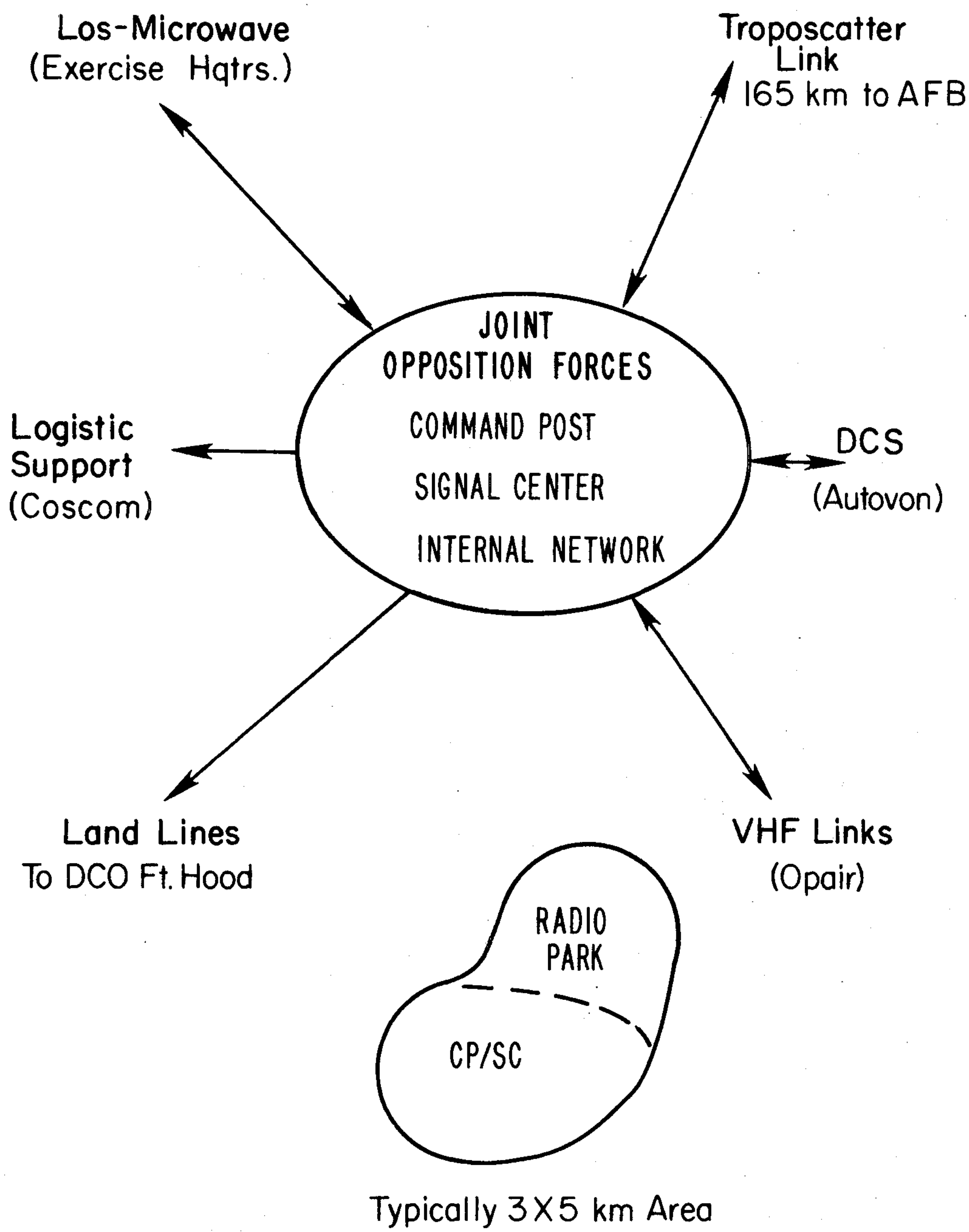


Figure 6. External traffic links to command post used for operation Braveshield exercise.

an area estimated to be 3 km by 5 km as shown by the inset in the figure. This post was the main corps headquarters for the Joint Opposition Forces (JOPPFORS) during the exercise. LOS microwave links, troposcatter links and VHF links terminated in the radio park on a nearby hill. Other land-line links provided connectivity to Fort Hood, to the corps support area, and to the Defense Communications Systems Automatic Voice Network (AUTOVON).

A rough estimate of traffic categories at this post was obtained from the operating personnel. This is shown in Figure 7. Note that for this post the largest percentage of traffic was relayed traffic. Only 10 percent was local traffic. This includes the circuit switched telephone traffic and private line field telephone services.

Information on the mobility of the corps and division level command posts was also obtained during the visit to Fort Hood. A corps command post may be required to move 50 to 100 km every 5 to 10 days. The moves for a division command post are highly dependent on the tactical situation, i.e., 1 day for high intensity situations 3 days for medium intensity situations and 10 days for low intensity situations. Relocation distances are of course much shorter for division CP's than corps CP's and typically are less than 25 km.

This review of the tactical communications environment provides background for sections that follow. First the field commander's communications needs are examined so that the various classes of communications service can be defined. Then specific terminal equipment used now, and planned for the future, are characterized so the command post traffic handling capabilities can be determined.

3. CP/SC USER'S OPERATIONAL REQUIREMENTS

A major difference between commercial communications networks and the military networks is the user population they serve. Helping to achieve the Army's mission is an ultimate goal for designers of military networks. Cost is therefore not always the primary concern as it is for commercial systems designers. Commanders must have communications that are responsive to their needs. Here we review those needs, summarize important measures of effectiveness for military networks, and address certain problems that exist in the CP/SC communications environment.

Figure 8 depicts the information flow to and from a command post. These inputs and outputs are required by the tactical field commander so he can perform his command, control, and intelligence functions.

		TRAFFIC FROM CP	
		OUTSIDE	INSIDE
TRAFFIC TO CP	OUTSIDE	40% RELAYED	20% ORIG.
	INSIDE	30% TERMINATING	10% INTERNAL

Figure 7. Traffic categories estimated for corps main during operation Braveshield exercise.

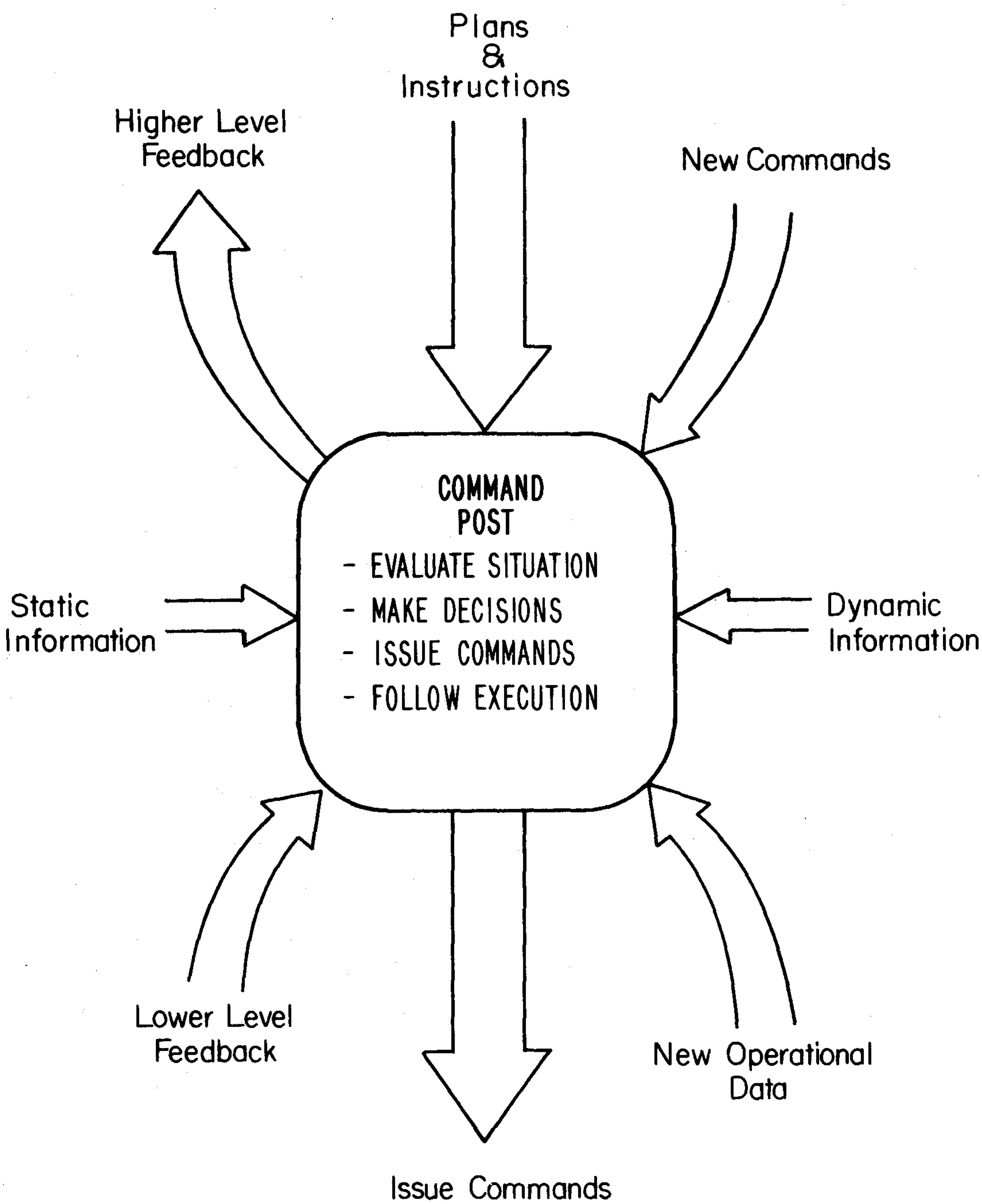


Figure 8. Information flow to command post.

There are a number of tools for providing the information flow depicted in Figure 8. These include FM voice radios; hardwired, switched, and private telephones; hard copy messages (includes radio, teletype, facsimile, and courier-delivered written messages); and telemetry data from various sensors. From the tactical user's standpoint there are a number of factors to consider in the design and implementation of these systems. Pertinent factors include:

1. Inclusion of operational features which enhance the commander's effectiveness,
2. The commander's demand for timely response to tactical events, and
3. The background and training of CP/SC operating and maintenance personnel.

The effectiveness of any system after implementation depends on how well it meets the user's needs. Measures of effectiveness (MOE) for military communications systems have been developed by the Army's Training and Doctrine Command (TRADOC) using panels of combat officers with command experience. The resulting MOE's are listed in Table 1. Most are self-explanatory. The MOE "upgradability" has been added to the original list to account for subsystem designs which encompass periods of transition from "old" to "new" systems.

Each MOE can be assigned a relative weight and used to evaluate the effectiveness of a tactical system. In this table a subjective evaluation has been made to determine the impact of each MOE on major design aspects of a CP/SC distribution system. The major design aspects are the distribution network's topology, method of control, signaling techniques, and the transmission media. Note that some aspect of the distribution network has high impact on at least two or more of the MOE's listed in the table.

Network topology, for example, has a high impact on survivability, service quality, upgradability and mobility. We include installation speed under mobility. The impact of these MOE's on overall network design is considered in Section 8. Another major concern in Section 8 is quantifying the network survivability. Other MOE's are considered in appropriate sections of the report.

In the past, and even today, many tactical systems in operation have serious deficiencies when evaluated against certain MOE's shown in Table 1. Existing systems are often too vulnerable, too big, too hard to move, require too much power, and are too easily detected both visually and by electronic and thermal signatures.

Bus-type distribution systems which may evolve from this program should reduce most of these deficiencies. They also should not introduce new ones.

Table 1. Impact of CP/SC Distribution System on Measures of Effectiveness

Measures of Effectiveness	Network Topology	Network Control	Comm. Technique	Transmission Media
Survivability	High	Medium	Low	Medium
Operability	Low	High	Medium	Low
Security	Medium	Medium	Low	High
Reliability	Medium	Medium	High	Medium
Flexibility	Medium	High	Low	Medium
Transportability	Medium	Low	Low	High
EM Signature	Medium	Low	Medium	High
Maintainability	Medium	High	Low	Medium
Service Quality (Performance)	High	High	High	Medium
Availability	Medium	High	Medium	Medium
Upgradability	High	High	Medium	Medium
Mobility (Installation Speed)	High	Low	Low	Medium

In subsequent sections we examine existing CP/SC communications systems in more detail in order to establish a baseline architecture for such systems. This baseline architecture provides the basis for comparing alternate system configurations. Since our interest is limited to the distribution network portion only, the number of MOE's used for comparison purposes is limited to those which have the greatest impact.

4. CP/SC SERVICE REQUIREMENTS

In order to indicate the CP/SC service requirements, it is useful to examine a general service classification scheme and then to determine which service classes are used in a CP/SC environment. Figure 9 illustrates one such scheme for classifying telecommunication services. This scheme uses five major bases for division:

1. The nature of the information communicated between end users (analog or digital).
2. The type of user information source (voice, sensor or image for analog services; operator, device medium or application program for digital services).
3. The number of users participating in an individual transaction (two or more).
4. The operating requirement with respect to communications security (secure or nonsecure).
5. The nature of user application (strategic, tactical or administrative).

There are, of course, other bases of division which could be considered such as the simultaneity of user information flow (simplex, half duplex or full duplex), the quantity of information transferred, the terminal compatibility, the switching technique (circuit, message or packet), the control signaling scheme (common channel or perchannel), and many others. The method used depends on the viewpoint. In Figure 9 emphasis is user oriented - not technology oriented.

In nearly all service classification schemes the specific application (i.e., administrative, tactical or strategic) determines the quality of service or performance. For the CP/SC the tactical user application is the prime concern.

Referring to Figure 9 the primary tactical services currently provided fall under two classes: 1) analog, voice, 2-point, nonsecure systems primarily are used for telephone service; 2) digital, operator, 2-point, nonsecure systems primarily are used for teletype service. There are a few secure systems, however, in each class. In the future it is expected that nearly all services will be secure, that multipoint connections will be used, and that all types of information sources shown on the figure will be needed.

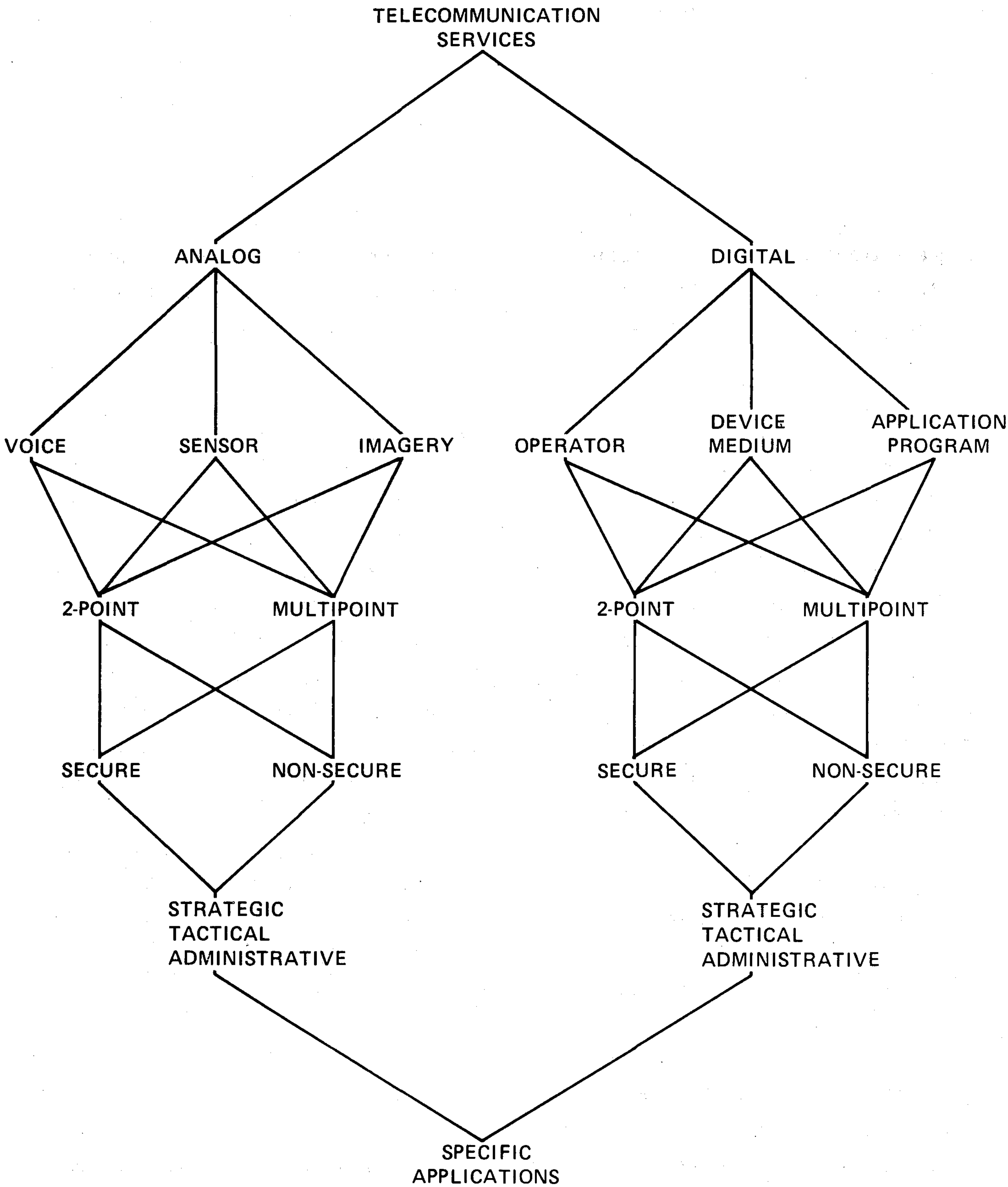


Figure 9. General service classification scheme.

Specific terminals and associated equipment currently being used for CP/SC installation are listed in the following section. Some transitional equipment and future TRI-TAC systems also are listed. These provide the bases for projection of CP/SC traffic requirements.

5. CP/SC TERMINALS AND TRAFFIC

The user desiring telecommunications services must interface with the system at some point. This interface provides the means for media conversions and subsequent transmission of information. In this section we describe the interfaces or terminals used at a CP/SC installation. This leads directly to estimates of the internal traffic intensity and traffic types carried by this node.

5.1. Types of Terminals

There are numerous types of communications equipments used by the tactical forces and numerous ways in which this equipment is deployed. Individual command preferences at all levels - division, corps and echelons above corps - and requirements result in numerous types of command post installations.

Table 2 lists various equipment available in the current army tactical (ATAC's) equipment inventory. The table also contains a transitional equipment column listing new equipment which is expected to be used in the 1980's. During this period many of the tactical systems will be undergoing change. This is principally because of a transition from all-analog to all-digital switching and transmission systems. By the 1990's a new class of digital equipment developed under the TRI-TAC program is expected to be in use. This terminal and switching equipment is listed in the third column.

The summary listings in Table 2 include voice terminals, message terminals, switches, multiplexing terminals, technical control systems, and operations centers. The type designator is given in the type column using the AN nomenclature. The AN nomenclature consists of the name followed by the type indicator letters. A brief description of equipment characteristics follows the AN designator.

5.2. Distributions and Densities

USACEEIA has prepared Tables of Organization and Equipment (TOE's) for transition planning strategy. These tables determine equipment inventories at typical installations. The TOE and equipment characteristics (bandwidth, number of channels, etc.) provides an upper bound to the capacity requirements for the local

Table 2. Command Post Equipment Summary

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
VOICE TERMINALS	TA-1				TA-( )	DSVT, DIGITAL SUBSCRIBER VOICE TERMINAL CVSD, 16/32 KB/S 4W
	TA-236	2W, Rotary Dial, DC				
	TA-312	2W, Ringdown, DC				
	TA-341	4W, 3x4 Push Button, MTDF				
	TA-720					
	TA-838	4W, 4x4 Push Button, (Field), MTDF				
	TA-938	4W, 4x4 Push Button, (Office), MTDF				
MESSAGE TERMINAL	GSQ-80	MESSAGE CENTER	TGC-40	TTY CENTRAL, 2FD paper tape s & rec & printer 5 or 7 level code, replaced MGC-17, 2FD BRIG-DISCOM-DIV		
	TSC-58	TELEGRAPH TERMINAL replaces MSC-29, 3FD				
	MGC-19	TTY OPERATIONS CENTRAL CORPS, 5FD	TGC-41	TTY CENTRAL, 4FD paper tape s & rec. CORPS & DIV. MAIN SC's		
	MGC-22	TTY TERMINAL TAC LEVEL CORPS HDQ, 4FD				
	MGC-23	TTY RELAY CENTRAL TAC tape, 6FD	TGC-42	TTY RELAY CENTRAL, 6FD 6/TH-22 TELEGRAPH 12/KW-7 KEY GENERATOR 6/TRANSMIT TTY, UGC-72 16/UGC-73 REPERF 2/UGC-74/75 TTY CORPS AREAS - NODES SC's		
	MGC-32	TTY OPERATIONS CENTRAL THEATER				

Table 2. (Continued)

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
MULTIPLEXER/ TELEPHONE TERMINALS	Medium capacity- Corps & Area SC's		TD-982	Pulse Form Restorer Unattended repeater in 96 ch PCM in CX-11230 Cable	TD-1023	LSCDM Low Speed Cable Driver on CX-11230 2048 KB/S
	TCC-60	TELEPHONE TERMINAL 2,TD-204 CABLE MUX 2,TD-352 MUX 2,CV-1548 CONVERTER 2,TSEC -/KG-27 KEY GEN. Groups: 2/12 or 1/24 ch			TD-1218	LSPR Low Speed Pulse Restorer on CX-11230 Max 2304 KB/S
					TD-1237	MGM, Master Grp MUX 15 Switched rates 72 KB/S - 4.9 MB/S
	TCC-61	TELEPHONE TERMINAL 8,TD-352 MUX 8,TD-204 CABLE COMBINER 8,CV-1548 CONVERTER, 12 ch 8,TSEC/KG-27 KEY GEN. 8 Groups of 12 or 4/24 ch			TD-1236	TGM, Trunk Grp MUX 12 Switched rates 72 - 2304 KB/S 4 Groups in Super out 128-4608 KB/S
	TCC-69	TELEPHONE TERMINAL 2 of TD-352, TD-204, CV-1548 & TSEC/KG-27 2 Groups of 12 or 1/24 ch			TD-1235	LGM, Loop Grp MUX WF-16 input 7,8,15 or 17 input of 16/32 KB/S +1 over-head ch 256-576 KB/S out
	TCC-72	TELEPHONE TERMINAL (Secure) 2,TD-754 CABLE COMB. 2,TD-660 MUX 2,CV-1548 CONVERTER 2,TSEC/KG-27 KEY GEN. DUAL 12 ch PCM			MD-1026	GM, Group Modem Diphase 15/72-4608 KB/S rates Dipulse 4/288-2304 KB/S rates Bipolar 1/1536.2 KB/S rate
MULTIPLEXER/ TELEPHONE TERMINALS	High capacity- Area SC's					
	TCC-73	TELEPHONE TERMINAL 4,TD-204/TD-754 CABLE C. 8,TD-660 MUX 8,CV-1548 CONVERTER 8,TSEC/KG-27 KEY GEN. 2,TD-976 ASYNC-DIGITAL ((V) 1 only) COMBINER 2-48 or 1-96 ch PCM			TD-1219	HSPR Hi Speed Pulse Restore 19.2 MB/S
	C-6709	CONVERTER - Radio/Wire Integ. "phone patch"				

Table 2. (Continued)

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
SWITCHES	MTC-1	MAN., 196 CKT-20T, 3-SB249	TTC-38	AUTO., 300/600 CKT	TTC-39	AUTO., 300/600 CKT 4W
	MTC-3	MAN., 119 CKT, 2-SB86	SB-3614	AUTO., 30 CKT, 2W	TTC-42	AUTO., 75/150 CKT 4W
	MTC-7	MAN., 60 CKT, SB86	TTC-41	AUTO., 30/60/90 CKT SHELTER SB-3614	TYC-39	AUTO., 25/50 MSG line, w CNCE & TTC-39
	MTC-9	MAN., 596 CKT-60TK				
	TTC-23	MAN., 98 CKT-20TK, 2-SB1398			SB-3865 ULS	AUTO., 30/60/90 CKT
	TTC-25	AUTO., 344/620 VF/WB 50 KB/S PER TDM SLOT				
	TTC-28	AUTO., 600 VF				
	TTC-29	MAN., 60 CKT, SB248				
	TTC-35	MAN., 50/100 CKT, SB3082				
	TTC-38	AUTO., 300/600 VF/WB				
	SB-22	MAN., 12 CKT				
	SB-86	MAN., 60 CKT				
	TTC-30	AUTO., 378 lines cross-bar mech.				
MULTIPLEXER/ TELEPHONE TERMINALS	Low Capacity- Division		TD-1065	HSSDB, Hi Speed Serial Data Buffer 16/32 KB/S to 576 KB/S	TD-1233/ TTC	RLGM 4 channels Digital 16/32 KB/S or 144 KB/S
	TCC-65	TELEPHONE TERMINAL 4,TD-660A MUX (DIPULSE) 4,TD-204/TD 754 CABLE 4,CV-1548 CONVERTER, 12 ch 4, TSEC/KG-27 KEY GEN. QUAD. 12 ch PCM			TD-1025	RLGM/CD 2 ch Cable Driver 2-72 KB/S or 144 KB/S
			TD-976	ADC, Asyne Digital Combiner replace TD-353 & TD-203/ TD-206 (BiPolar) 8 of 576 KB/S into 4.9 MB/S	TD-1234	RMC Remote MUX/Combiner 1-digital group or 8 ch. 72, 128, 144, 256 or 288 KB/S of 16/32 KB/S CVSD

Table 2. (Continued)

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
RADIO (LOS)	GRC-144	4.4-5 GHZ, 30 mile 48/96 PCM FM 3/TRC-138, TCC-73/TCC-62	GRC-103	220-404.5 MHZ 394.5-705 MHZ 695-1000 MHZ 1350.5-1849.5 MHZ TRC-151, TD-1069, TD-1065 SINGLE/DUAL 12/24 ch TRC-152 RPTR	GRC-144	4.4-5.0 GHZ 14.5-15.35 GHZ 3/TRC-138, MD-1026/ MD-1024 1152 KB/S to 4.9 MB 96 ch PCM TAC 36/72/144 @ 32 KB/S SAC 32/64/128
	GRC-103	220-404.5 MHZ 394.5-705 MHZ 695-1000 MHZ 1350.5-1849.5 MHZ 6/12/24 ch PCM @ 288,576,1152 KB/S 2/TRC-145 TD-660, CV1548, KG27 DUAL 12 ch 3/TRC-113, TD-204/754 12 ch				
	GRC-50	601.5-999.5 MHZ 1350.5-1849.5 MHZ 4/12/24 FDM or 12/24 PCM @ 576, 1152 KB/S 3/TRC-110, TD-202/204 12/24 ch 2/TRC-117, TD-352, TD-202/ 204, CV-1548, KG-27 DUAL 12 or single 24 ch 2/TRC-151, TD-660, TD-202, TD-754, CV-1548, KG-27 RPTR 12/24 ch 3/TRC-152, TD-660, TD-202, TD-754, TTC-65 or TTC-72				
RADIO (TROPO)	GRC-143	4.4-5 GHZ, 100 mile, 1 KW-FM 12 ch PCM @ 250 KHZ BW 24 ch PCM @ 500 KHZ BW 1/TRC-112, CV-425, TD-352/ TD-660, 24 ch 2/TRC-121, CV-425, 48 ch			GRC-143	1/TRC-112, TD-352, TD-660 12/24 ch or 18/36 ch TRC-170 2 KW to 10 KW QPSK .65 KW 1.85 KW 6.6 KW @ 100/150/200 miles 60-32 KB/S or 120-16 KB/S 2.084 MB/S @ $< 10^{-5}$ BER

Table 2. (Continued)

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
TECH. CONTROL/ PATCH PANEL	TSQ-84 rc	TECH. CONTROL FACILITY replaces SB-675 MSC 4W, 432 CKTS 2/CV-1548 Converter, 24 ch 2/CV-2636 Converter, 24 ch 12/TH-22 TELEGRAPH TERM.	TYC-5A	DATA COMM. TERMINAL Interface & Control Mode I AUTODIN	TSQ-111 (V)	CNCE, COMM NODE CONTROL ELEMENT
			TSQ-84(A)	TECH. CONTROL FAC. UPDATE Mini computer-display-keyboard		
	TSQ-85	VIDEO TECH. CONTROL FAC. forms up to 96, 6/12 channel PCM video groups to TRC-138 or TCC-73(V)1 96 ch				
	TSC-76	PATCH PANEL DIVISION				
	MSQ-73	TECH. CONTROL FACILITY 240 VF & 120 TTY CKTS				
	SB-675	COMM. PATCH PANELS 2W, 468 CKTS				
COMMUNICATION OPERATIONS CENTER	MSC-25	TACTICAL SC OPERATIONS & ENGINEERING				
	MSC-31A	AREA SC OPERATIONS & ENGINEERING				
	MSC-32A	OPERATIONS CENTRAL 1/SB-22, 2/TT-98, 3/TH-22 4/TA-312, (used with MSC-31A)				

Table 2. (Continued)

EQUIPMENT	ATACS (CURRENT)		TRANSITIONAL (1980-90)		TRI-TAC	
NAME	TYPE AN/	DESCRIPTION	MODEL	DESCRIPTION	MODEL	DESCRIPTION
COMMUNICATION SATELLITE TERMINALS	PSC-1				PSC-1	UHF MANPACK LOS or SATCOM VINSON voice or burst mode
					MSC-65	UHF Mobile TAT SATCOM TERM. Various modems & DAMA
					TSCVT	TACTICAL VEHICLE (INTACS) Single channel voice or record Brigate up to Theater "Command Post Vehicle"
					MSC-64	UHF Mobile SATCOM TERMINAL 100 W with omni or directional antenna 75 B/S and/or FM voice half duplex

distribution area under ideal conditions. The results obtained from the TOE for a large headquarters signal operating company at the echelons above corps (EAC) level are shown in Table 3.

Referring to Table 3, the telephone switching centers, switchboards, telephone and teletypewriter terminals, and telephone and teletypewriters sets, etc., through which the traffic flows or originates help to define an upper bound on the traffic that can be handled in the CP/SC. The number of channels that each unit is designed to carry and the bit rate associated with each channel can be used to calculate the maximum traffic possible. The two columns on the right side of the table indicate this maximum traffic for all the assigned units of that type. Note there are two TTC-38 telephone switching centers, two TSQ-84 technical control centers, four TRC-138's, five TCC-62 telephone terminals, and two TCC-69 cable telephone terminals through which the telephone traffic flows. There are 1150 telephone sets that originate or receive the traffic. The same division of the message handlers and message originators can be made for the telegraph and teletypewriter equipment. The four GSQ-80 message centers, the TGC-30 teletypewriter central and MGC-23 teletypewriter relay central would be handlers and the GGC-3, PGC-1 and KW-7 teletypewriters would be originators of record traffic.

Table 4 summarizes telephone (voice) and teletypewriter (message) terminals which might be found in various size units. The voice switch commonly used by each unit also is indicated. The number in parentheses following the switch type indicates switch capacity by number of lines it can handle.

The TTY terminals may operate full-duplex (FDX) or half-duplex (HDX). Two half-duplex circuits are equivalent to 1 FDX. Note that the corps headquarters MGC-22 has 4 FDX or 8 HDX circuits available. The SC contains a total of 6 FDX. This also may be divided to handle some HDX circuits.

The distribution and density of the equipments at a CP/SC is highly variable. In general, however, units tend to be clustered in several groups in the command post area. The telephone terminals probably are the most widely dispersed although here, too, the pattern shows clusters with lower density. Teletypewriter terminals usually are collocated in shelters, tents, or buildings in a small area called the communications center. Switches, patch panels, and technical control centers are separated some distance away but also are clustered together. Radio terminals may be still farther away at some high point known as the radio park.

Table 3. Equipment List of Large Headquarters Command Post

NOMENCLATURE	DESCRIPTION	NO. OF UNITS	CHANNELS/ UNIT	BANDWIDTH/ CHANNEL	TOTAL CHANNELS	TOTAL BANDWIDTH
TTC-38(V)2	Auto. Telephone Central Office Sw. (4 W.)	2	600 terminals	4 kHz 300 Hz-108 kHz	1200	4.8 MHz
TSFC/KL-7	Cipher Machine	2				
TSQ-84	Communication Tech. Control Center (4 W.)	2	432 4W. circuits 48 FDM TTY 1 Intercom	4 kHz 74.2 BPS 4 kHz	864 96	3.456 MHz 7.12 KBPS
CV-2/TX	Data Signal Converter	2				
TSFC/KW-7	Electronic Secure Teletypewriter	83				
TXC-1	Facsimile Set	2				
GSQ-80	Message Center	4				
MCS-32	Operations Central (Local Tel. & TTY)	1	4 Telephones 4 TTY 1 Intercom	4 kHz 74.2 BPS 4 kHz	4 4 1	16 kHz 296.8 BPS 4 kHz
MRR-8	Radio Receiving Set	3/2				

Table 3. (Continued)

NOMENCLATURE	DESCRIPTION	NO. OF UNITS	CHANNELS/ UNITS	BANDWIDTH/ CHANNEL	TOTAL	
					CHANNELS	BANDWIDTH
VRC-46	Radio Set	6				
TRC-138	Repeater Radio Set (3 GRC-144)	4	288 ch PCM 3 (Local) Voice 1 Intercom	48 BPS 4 kHz 4 kHz	1152 PCM 12 4	55.3 KBPS 48 kHz 16 kHz
TSFC/BL-1	Tape Reader	2	2	74.2 BPS	4	296.8 BPS
TH-22/TG	Telegraph Terminal	16				
SB-22/PT	Telephone Manual Switchboard	1	12 Voice	4 kHz	12	48 kHz
TA-312/PT	Telephone Set (DC Pulse)	10	1	4 kHz	10	40 kHz
TA-341/TT	Telephone Set (DTMF)	1140	1	4 kHz	1140	4.56 MHz
CV-1919/G	Telephone Signal Converter (2 to 4 wire, DTMF)	1	3	4 kHz	3	12 kHz
TCC-62	Telephone Terminal	5	96 PCM	48 BPS	480	23.04 KBPS
TCC-69	Telephone Terminal (TDM MUX Cable or Radio)	2	24 PCM 1 (Local) Voice 1 Intercom	48 BPS 4 kHz 4 kHz	48 PCM 2 2	1.3 KBPS 8 kHz 8 kHz

Table 3. (Continued)

NOMENCLATURE	DESCRIPTION	NO. OF UNITS	CHANNELS/ UNITS	BANDWIDTH/ CHANNEL	TOTAL	
					CHANNELS	BANDWIDTH
MGC-22	Teletype Terminal Central	4	4	74.2 BPS	16	1.19 KBPS
TGC-30	Teletypewriter Central Office	1				
MGC-23	Teletypewriter Relay Central (tape)	3				
GGC-3	Teletypewriter Set (tape-reperforator)	16	1	74.2 BPS	16	1.19 KBPS
PGC-1	Teletypewriter Set (page printer)	16	1	74.2 BPS	16	1.19 KBPS

Table 4. ATACS Equipment and Channels for Unit Sizes

Size Unit	Voice Terminal/Wire	Voice Switch (Lines)	Message Terminal (CKTS)
Squad	TA-1/WD-1	-----	-----
Platoon	TA-1/WD-1	SB-993 ( )	-----
Company	TZ-312/WD-1	SB-22 (12)	-----
Battalion	TA-312/WD-1 & WF-16	SB-3082 (50)	RTTY VSC-2 or GRC-142
Brigade	TA-312/WD-1 & WF 16	TCC-35V1 (50) or TTC-29 (60) or MTC-7	RTTY GRC-122 (1FDX) or GRC-142 (1FDX)
Division	TA-341/CX-4566 TA-312/WD-1	TCC-35V2 (100) or MTC-3 or TTC-23 (100)	RTTY, GRC-122 (1FDX) & MGC-17 (2FDX) or TGC-30 (1FDX)
Corp HDQ/CP	TA-341/GX-4566	TTC-38V1 (300) or TCC-25V2 (600) or MTC-9 (600)	MGC-22 (4FDX) & MGC-23 RELAY
SC	TA-341/CX-4566	TTC-38V2 (600) or TTC-25V1 (300) or MTC-1	RTT, GRC-122 (1FDX) & MGC-19 (5FDX)

FDX - Full Duplex

HDX - Half Duplex

5.3. Traffic Generated

The characteristics of traffic generated by various types of terminals are summarized in Table 5. Traffic rate data are plotted in Figure 10 to show the rate ranges one might expect from various types of terminals. Typical speeds of computer peripherals and various computer memory devices are summarized in Table 6. Although computer terminals do not currently appear in the TOE listing, they undoubtedly will in the future. Card readers and data processing equipment already are being adapted for tactical use from commercial sources. Such equipment is particularly useful by the corps support command (COSCOM) located in rear areas. It is used as a data bank for ordering equipment spare parts, or replacement units.

5.4. Traffic Statistics

Traffic data from the Communications Systems Requirements study known as COMSR were furnished by the USACEEIA/SEO for evaluating the traffic load on a large command post. These traffic data correspond to a large headquarters using the equipment listed in Table 3. Evaluation results are summarized in Tables 7 through 10 for voice, TTY, message, and facsimile traffic, respectively. An adjustment factor of 0.111 was used to convert the daily average traffic load to busy hour traffic in each case.

The traffic load in Table 7 (voice) and Table 8 (message) is shown in Erlangs (call-hour/hour). For the voice circuits the average holding time per call was found to be 3.33 minutes and about 0.1 Erlangs for the CP. These values are similar to those found for many civilian telephone calling habits.

The average message traffic load of 0.035 Erlangs is based on sending 1 page of text at 100 words per minute. It assumes there are 10 words per line and 10 lines per page.

This also can be derived from the traffic volume data given in Table 5. For alpha coded text the volume is 3×10^4 bits per page. The number of words per page is derived as follows:

$$3 \times 10^4 \text{ (bits/page)} \times 1/5 \text{ (char./bit)} \times 1/6 \text{ (words/char.)} = 100 \text{ (words/page)}.$$

The average traffic load in Erlangs per circuit is obtained from:

$$\text{BHCA/circuit} \times \text{(No. of pages)} \times 100 \text{ (words/page)} \times 1/100 \text{ (No./word)} \times 1/60 \text{ (hours/min)} = \text{Erlangs (call-hour/hour/circuit)}$$

where BHCA is busy hour call attempts.

Table 5. Characteristics of Traffic Generated by Various Types of Terminals

	Volume	Digital Rate (one-way)	Call Duration	Delivery Delay
Voice				
PCM (Pulse Code Modulation)	continuous bits	64 kb/s	minutes	<200 ms
LPC (Linear Predictive Coding)	continuous bits	2.4 kb/s	minutes	<200 ms
Data				
Data Base Update	10^2 bits/message	2.4-16 kb/s	seconds	seconds to minutes
Interactive	10^3 bits/message	150 b/s-9.6 kb/s	hours-holding time (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 kb/s	minutes to hours	minutes to hours
Narrative				
Alpha Coded Text	$3\mathrm{x}10^4$ 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	$3\mathrm{x}10^5$ bits/page	4.8 kb/s	minutes	minutes to hours
Half Tone Photo	$3\mathrm{x}10^6$ 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

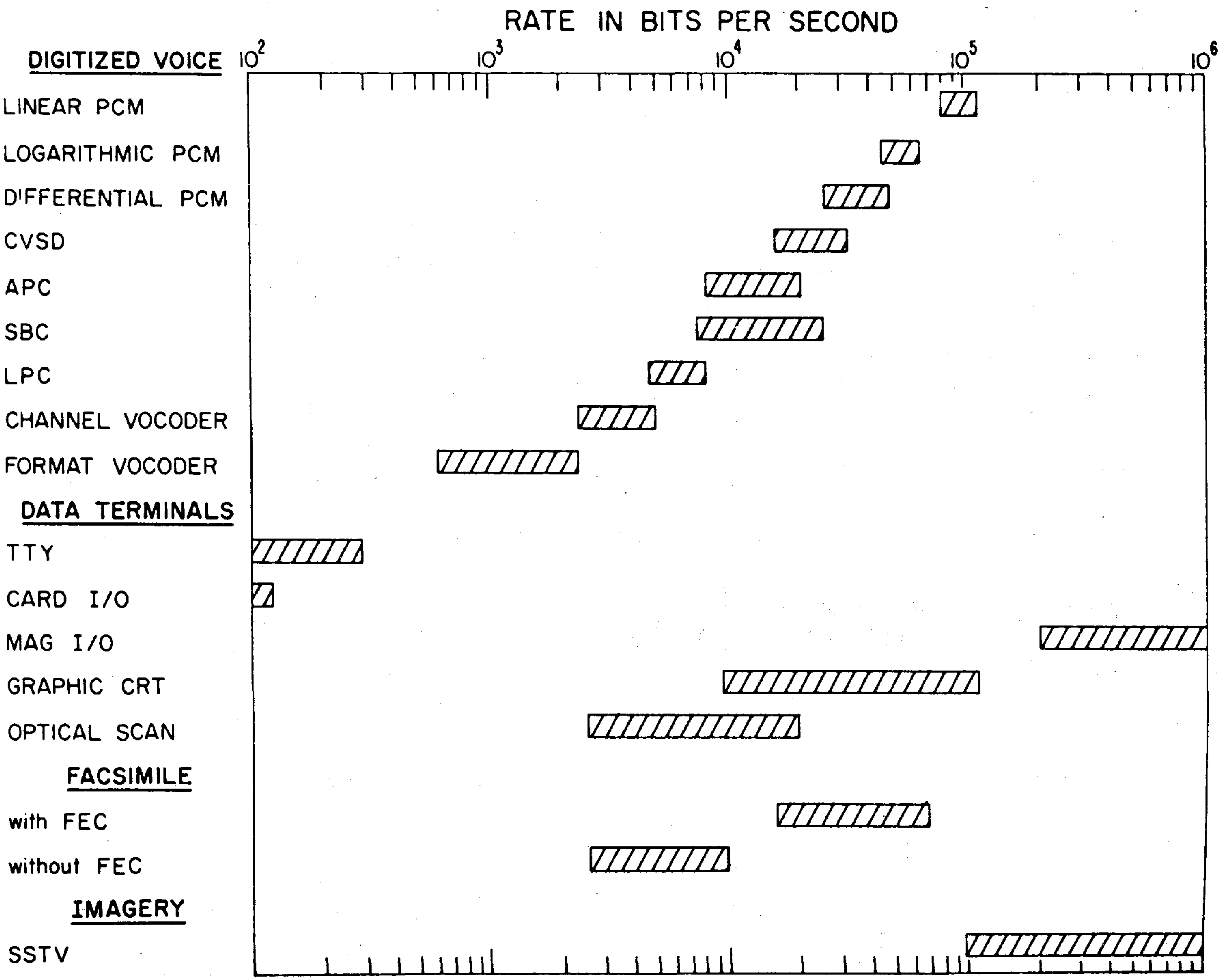


Figure 10. Traffic rates generated by various types of terminals.

Table 6. Typical Speeds of Computer Peripherals and Memory

Type	Words/Minute	Characters/Second	Bits/Second	Character Period Microsecond
Memory				
CCD	7.5 M	625 K	5 M	1.6
CORE	6 M	500 K	4 M	2
DISC (Rigid)	6 M	500 K	4 M	2
DISC (Floppy)	3 M	250 K	2 M	4
DRUM	24 M	2 M	16 M	0.5
Magnetic bubble	4.5 M	375 K	3 M	2.67
Magnetic tape	300 K	25 K	200 K	40
Semiconductor	15 M	1.25 M	10 M	0.8
Peripherals				
Line printer	15 K	1250	10 K	800
Card reader	15 K	1250	10 K	800
Card punch	6 K	500	1500	2000
Paper tape reader (hi speed)	6 K	500	1500	2000
Paper tape punch (hi speed)	1200	100	800	10 K
Paper tape punch (lo speed)	100	8	64	125 K
CRT terminal	57 K	4750	38 K	210
Teletypewriter	120	10	120	100 K

Table 7. Busy Hour Voice Traffic Load

Level of Priority	Originated % of Total Traffic	Originated Load, Erlangs	Received % of Total Traffic	Received Load, Erlangs
Routine	80.0	0.076	76.3	0.0627
Priority	14.8	0.014	16.4	0.0134
Immediate	2.8	0.0027	4.7	0.0039
Flash	1.6	0.0015	2.6	0.0022
Flash Override	0.0	0.0	0.0	0.0
Orig/Rec. Avg.	100	0.094	100	0.082
Overall Avg.		0.088		

Table 8. Busy Hour TTY Traffic Load

Level of Priority	Originated % of Total Traffic	Originated Load, Erlangs	Received % of Total Traffic	Received Load, Erlangs
Routine	57.7	0.020	77.9	0.038
Priority	39.1	0.015	20.7	0.009
Immediate	38.8	0.002	1.59	0.001
Flash	0.0	0.0	0.0	0.0
Flash Override	0.0	0.0	0.0	0.0
Orig/Rev. Avg.	100	0.037	100	0.048
Overall Avg.		0.042		

Table 9. Busy Hour Data Traffic

Level of Priority	Originated		Received	
	Number of Characters	Messages	Number of Characters	Messages
Routine	3.02×10^5	91	None Originated	
Priority	1×10^3	21		
Immediate	8×10^2	2		
Flash	0	0		
Flash Override	0	0		

Table 10. Busy Hour Facsimile Traffic

Level of Priority	Originated		Received	
	Number of Pages	Messages	Number of Pages	Messages
Routine	65	17	2	8
Priority	3	4	0	0
Immediate	0	0	0	0
Flash	0	0	0	0
Flash Override	0	0	0	0

Table 9 indicates the number of characters and messages transmitted from the large headquarters during a busy hour using optical character readers. Usually these are data requested from the headquarters for the support command data processing equipment. No processing equipment is located at the headquarters so no data are received.

Table 10 shows the number of pages and the number of messages of facsimile transmitted and received over a one day period.

Table 11, summarizes TTY traffic data obtained during the visit to the BRAVESHIELD exercise at Fort Hood, Texas. The table indicates the TTY message statistics for the Joint Opposition Army Headquarters gathered over the six previous days of the exercise. Note that the number of messages transmitted and received continually increased as the exercise progressed. There were nearly 2.5 times more incoming messages than outgoing messages. This is partly because in the tactical environment outgoing transmissions can be harmful if detected and pinpointed by opposition forces.

It appears that, for this exercise, priority P is used most often, closely followed by O. The average message duration, shown as holding time in the table, varies somewhat between priorities and days of operation. A typical holding time is about 1 minute corresponding to 100 word messages. This is less than half the message holding time used to obtain TTY traffic loads in Table 8.

No traffic statistics were available for the voice circuits used at the BRAVESHIELD exercise. However, because of staff relocations and telephone changes, there was a need for operator-assisted calls at the corps headquarters. All other calls were routed automatically by an electronic switching system. On the second day of the Fort Hood maneuvers, there were approximately 150 operator-assisted calls over a twelve hour period at the JOPPFOR command post. The total number of automatically switched telephones at this post was 116. These operator-assisted calls probably were less than 1 percent of the total number of switched calls.

At the division headquarters two manual switchboards were used. These handled 200 to 300 calls per busy hour for 100 line terminations. The 300 calls per busy hour correspond to 0.175 Erlangs per line, assuming 3.5 minutes average holding time per call.

5.5. Terminal and Traffic Projection Summary

In the previous subsections we have developed a basis for projecting the number of terminals and the traffic load they generate as a function of the CP/SC

Table 11. TTY Message Traffic Levels

Priority	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Priority Totals
			Received				
Z (Flash)	0	0	0	1	0	0	1
O (Immediate)	4	22	28	41	75	122	292
P (Priority)	7	29	66	61	56	95	314
R (Routine)	1	8	15	14	12	16	66
Total	12	59	109	117	143	233	673
Cum-Total	12	71	180	297	440	673	673
			Transmitted				
Z (Flash)	0	1	0	0	3	0	4
O (Immediate)	0	4	2	7	40	39	92
P (Priority)	0	8	14	25	34	40	121
R (Routine)	0	4	3	5	10	14	36
Total	0	17	19	37	87	93	253
Cum-Total	0	17	36	73	160	253	253
			Average Holding Time (s)				
Z (Flash)	0	20	0	0	21.6	0	NA
O (Immediate)	0	53	13.5	13.3	73.8	30.1	
P (Priority)	0	62	42.6	24.7	74.8	42.5	
R (Routine)	0	67	69.5	29.7	78.6	35.4	

size. This sizing relationship is summarized in Figures 11 through 14 for telephone and teletype terminals and the traffic load they generate.

Figure 11 relates the total call attempts per hour to the total number of telephones. This assumes an average holding time per call of 3 minutes and an average traffic load per telephone of 0.1 Erlangs. Two curves are drawn. One curve assumes all calls originate to, or are received from, stations external to the CP/SC. The other, lower, curve assumes all calls are local calls, i.e., they originate and are received on the CP/SC. In a real tactical environment the true curve must be somewhere between the two.

Also on Figure 11 we have estimated the CP/SC size in terms of the number of telephone terminals existent on the post. These sizes are divided into five categories: very small (<100 telephones), small (100 to 200 telephones), medium (200 to 500 telephones), large (500 to 1000 telephones), and very large (>1000 telephones). Generally small and very-small size posts may be found at echelons below corps level. Medium and large posts are found at corps level and very large posts are found at echelons above corps level. The number of call attempts per hour expected for each category also is indicated on the figure.

Figure 12 shows the size relationship as a function of the estimated maximum telephone traffic load. The maximum load is given in Erlangs, E, and is obtained from:

$$E = \lambda \times \tau$$

where λ is the maximum number of call attempts per hour assuming all calls are external, and τ is the average holding time per call in hours. The CP/SC size relationships also are indicated on this figure.

A similar sizing relationship is given for teletype terminals in Figures 13 and 14. In Figure 13 holding time per message is assumed to be 1.5 minutes and the average traffic load per terminal is 0.04 Erlangs. All messages originate from, or are received from, external stations.

It is apparent from Figures 12 and 14 that the maximum traffic load for a given size CP/SC is primarily caused by telephone usage. Teletype terminals generate only about 5 percent of the total traffic.

These projections are useful for determining the maximum load carrying capacity of local bus-type distribution systems. Such systems are described later in this report.

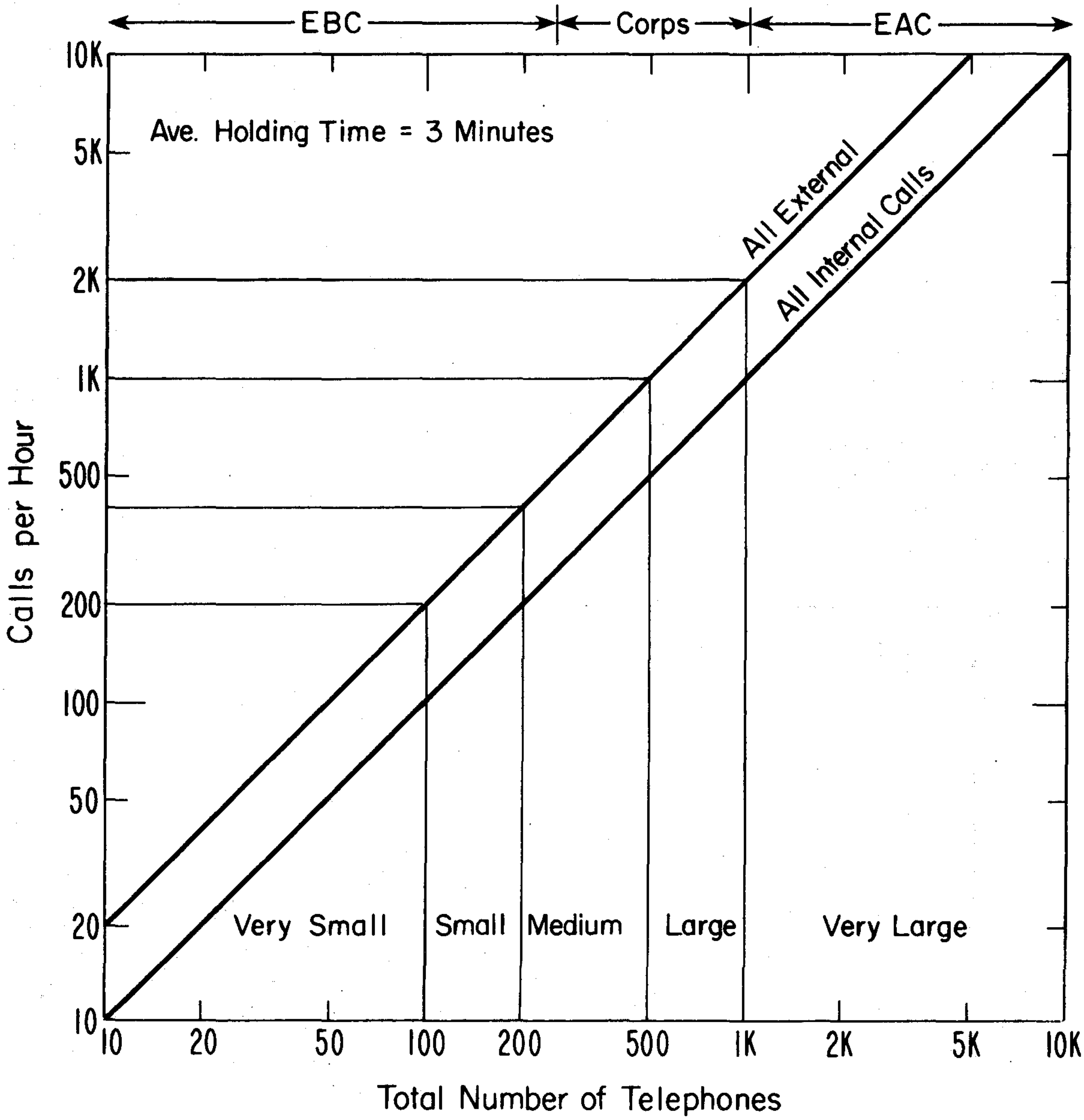


Figure 11. CP/SC size relationships in terms of number of telephone calls per hour.

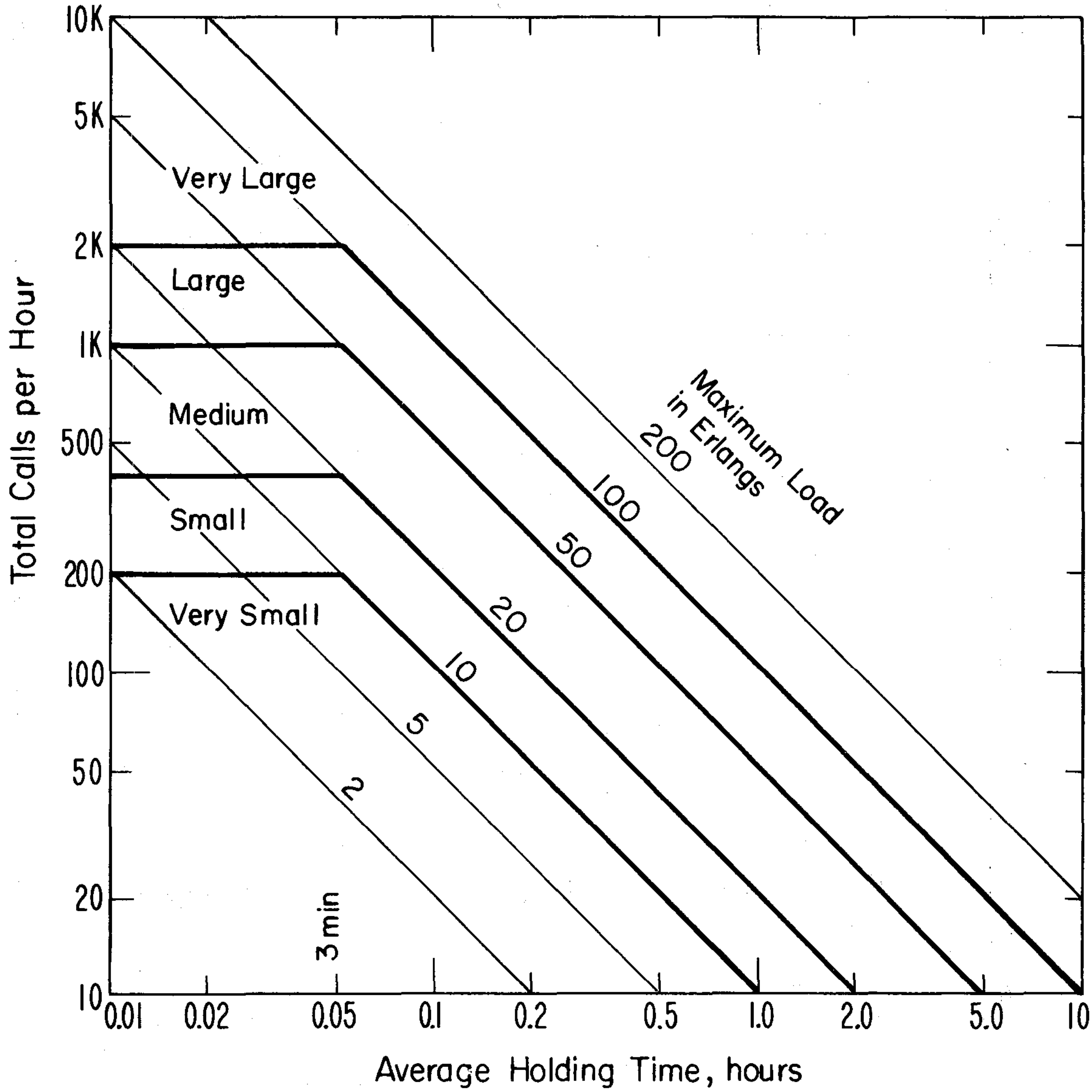


Figure 12. CP/SC size relationships in terms of maximum telephone traffic load.

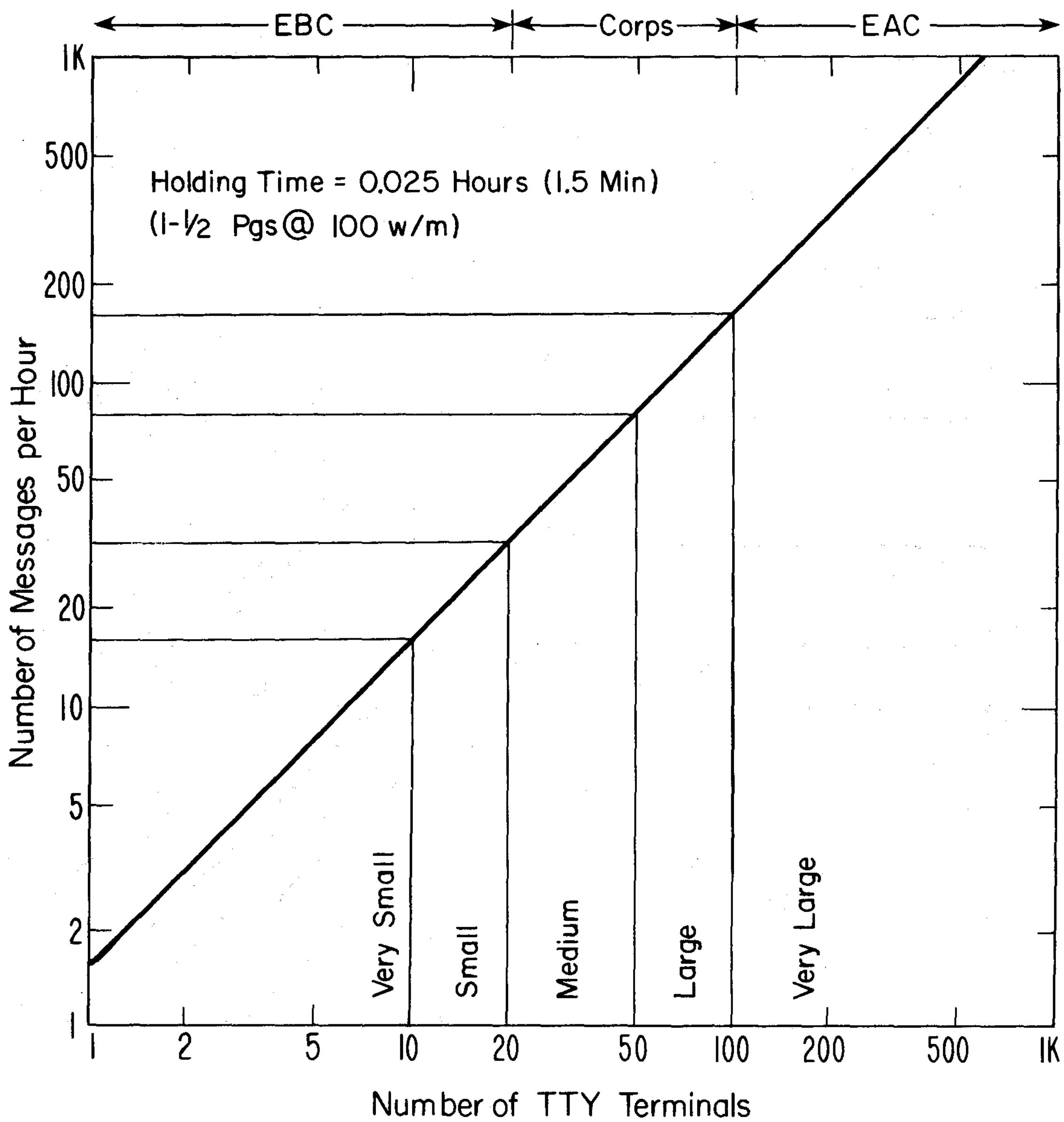


Figure 13. CP/SC size relationships for teletype terminals and message/hour.

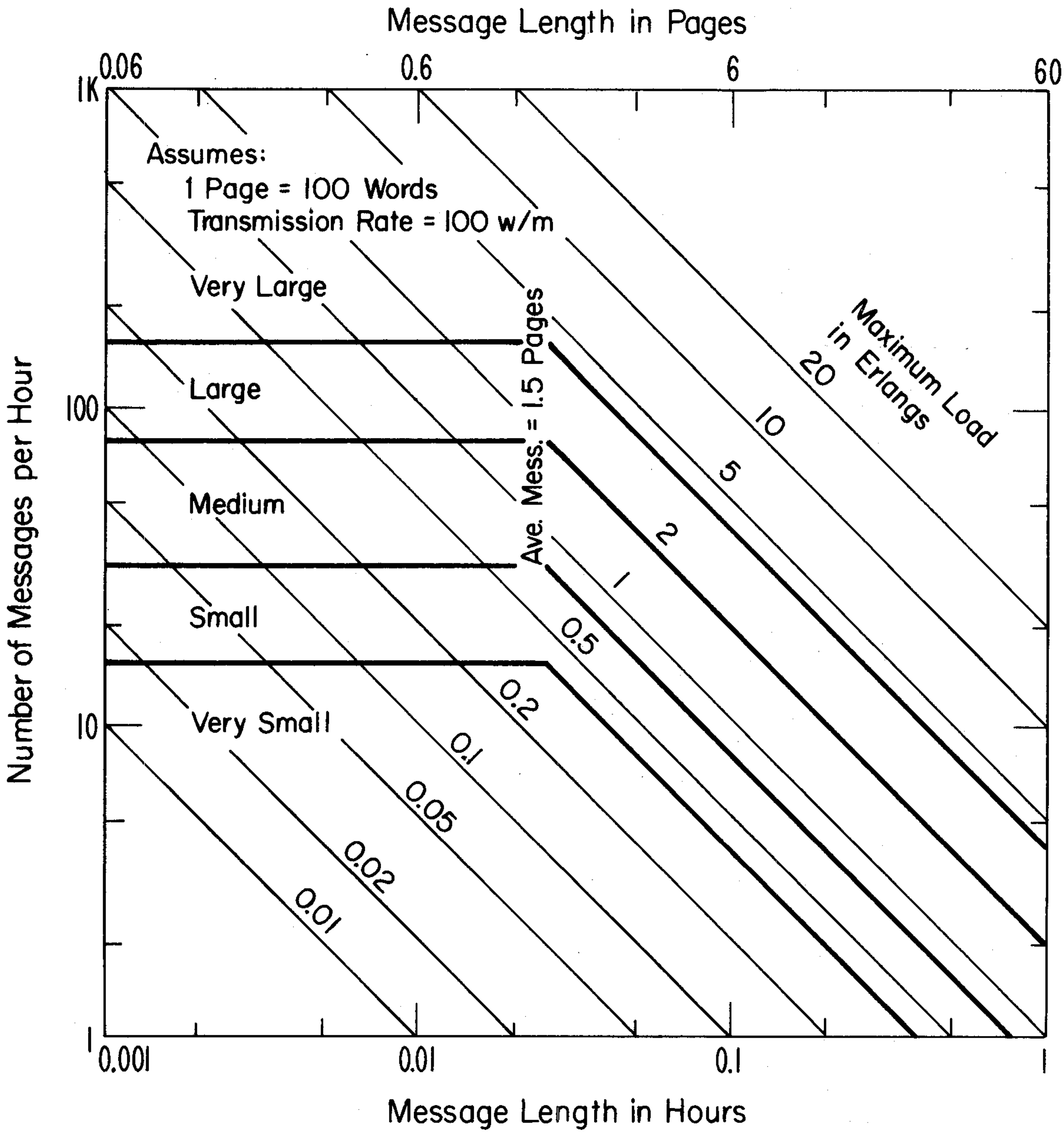


Figure 14. CP/SC sizing based on maximum teletype traffic.

6. FUNCTIONS AND OPERATIONS FOR CP/SC NODE

In the previous sections we have summarized the tactical environmental, the tactical commander's communications needs, services available to meet these needs, and the interface terminal equipment he may use. In this section we examine the functions and operations that a communication system must provide at a CP/SC node. Emphasis is on the internal distribution systems consisting of terminals, transmission, and switching systems.

In order to provide a particular service a system must have certain functional capabilities or attributes. A complete set of attributes specifies the terminal, transmission, and switching system.

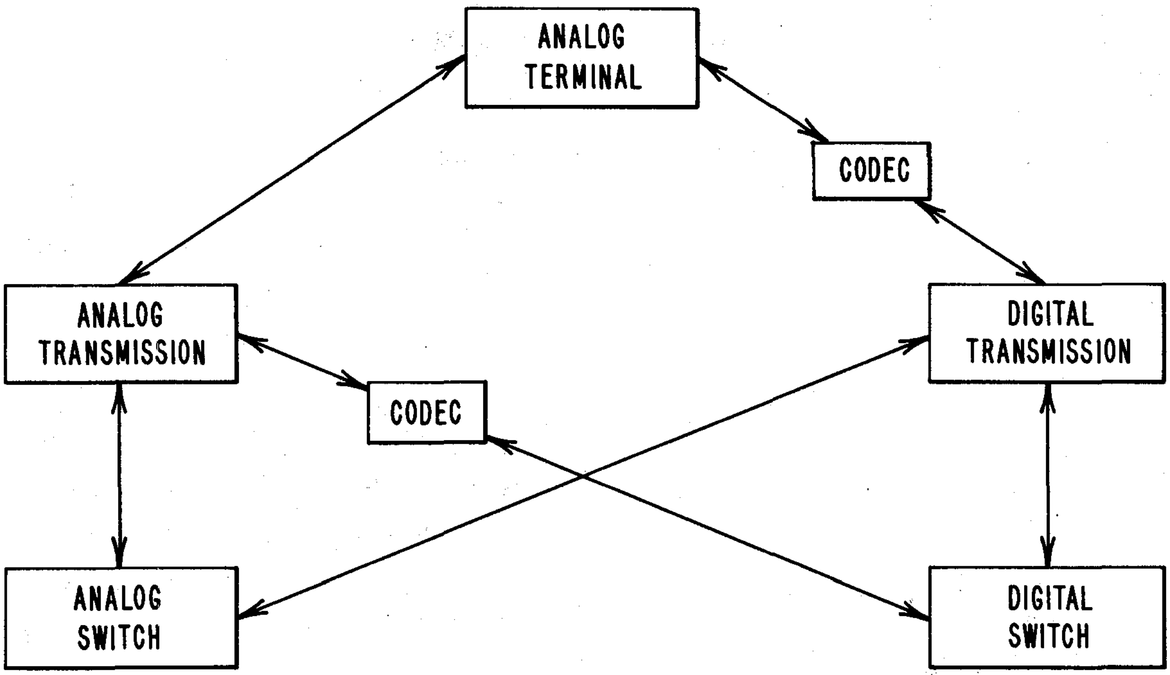
Figure 15 summarizes these basic functions. At the same time this figure indicates basic modes of operations which are performed to provide information transfer. The operating mode depends on the class of service (analog or digital) which is used and the type of facilities available to provide that service. Thus an analog terminal using digital transmission and switching facilities requires a codec for analog to digital conversion and vice versa. Note that in this figure no looping is permissible, i.e., the terminal-to-switch path must follow the same path back to the terminal since it depicts a single terminal's connection to the nearest switch.

In addition to the basic functions of the terminal, the transmission link, and the switch, there are other functions which must be performed or which may be added to increase efficiency or reduce cost. For example, control signals are needed in addition to the information signals so the terminal can access the network. This includes addressing, alerting, and supervisory signals. Multipliers or concentrators may be inserted to permit sharing the transmission resources.

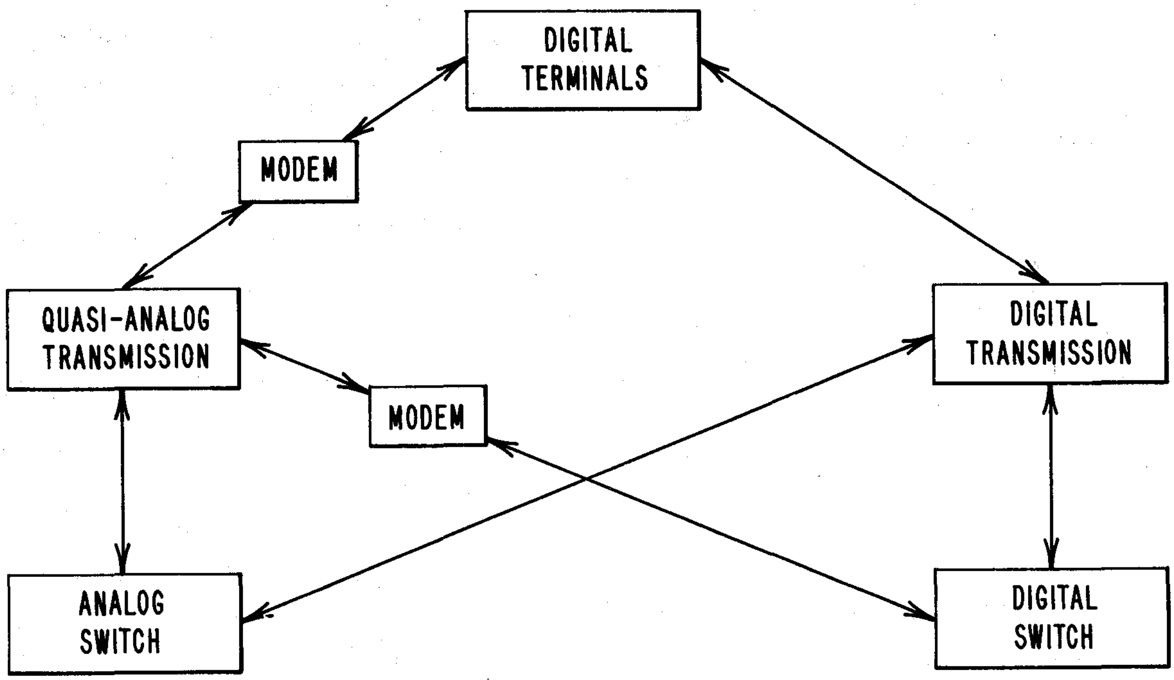
In the following subsections we review the basic and auxiliary functions in more detail.

6.1. Interface Functions

The primary function of the interface terminal is media conversion. The telephone, for example, converts the acoustic speech signal into an electrical analog signal. The teletypewriter converts mechanical pressure on the keyboard to a binary key stream. An additional function involves matching the converted signals to the transmission media. The TTY binary key stream, for example, modulates a carrier for transmission via wire or cable. A digital source may be converted to light pulses for transmission on a fiber optical cable. Analog



a) Analog Service



b) Digital Service

Figure 15. Basic functions and operating modes for digital and analog services.

sources can be converted to digital sources or vice versa using coders and decoders (codecs) for both transmission and switching. Digital sources may be converted to analog sources and vice versa using modulators and demodulators (modems).

The terminals on a switched network also provide the control signals for destination addressing service requests and alerting desired users. Special overhead signals may be used to check circuit status, monitor faults, and provide overall network management. For transmission of both the control signals and users information check bits may be added for error detection and correction.

6.2. Multiplexers and Concentrators

Multiplexers and concentrators provide functions for increasing the volume of data transmitted. This is accomplished by sharing the same transmission path with a number of sources. This sharing of paths may occur on a time or frequency basis. Efficient sharing methods reduce the cost per information bit transmitted since fewer transmission facilities are required. Fewer transmission facilities in a CP/SC application can also reduce deployment time. Thus multiplexing or concentrating CP/SC communications onto a minimum number of bus type paths is desirable.

The distinction between multiplexing and concentrating is primarily their impact on grade of service. Paths through concentrators may be blocked or delayed. Paths through multiplexers cannot be blocked. This is because multiplexers permit traffic from several terminals to share the transmission facility by fixing the allocation of circuits. Concentrators, on the other hand, allocate circuits dynamically and the transmission facilities are shared randomly as needed.

The bandwidth required at the common output of a multiplexer is the same as the sum of the bandwidth of the input channels. The bandwidth of the common output of a concentrator is less than the sum of the bandwidths of the input channels.

As noted previously, multiplexers and concentrators may be of different types. Frequency Division Multiplexers (FDM's) modulate high frequency carriers from several sources and these modulated carriers are transmitted in parallel over some transmission medium. Such an FDM multiplexer is shown by the block diagram in Figure 16. FDM's are readily cascadable. Synchronous Time Division Multiplexers (STDM) operate by interspersing information signals in a synchronous time relationship. Specific time slots in the output channel are dedicated to each input channel. STDM's are more expensive to cascade because a complete STDM unit is required at intermediate points. A means of clocking the time slots is essential.

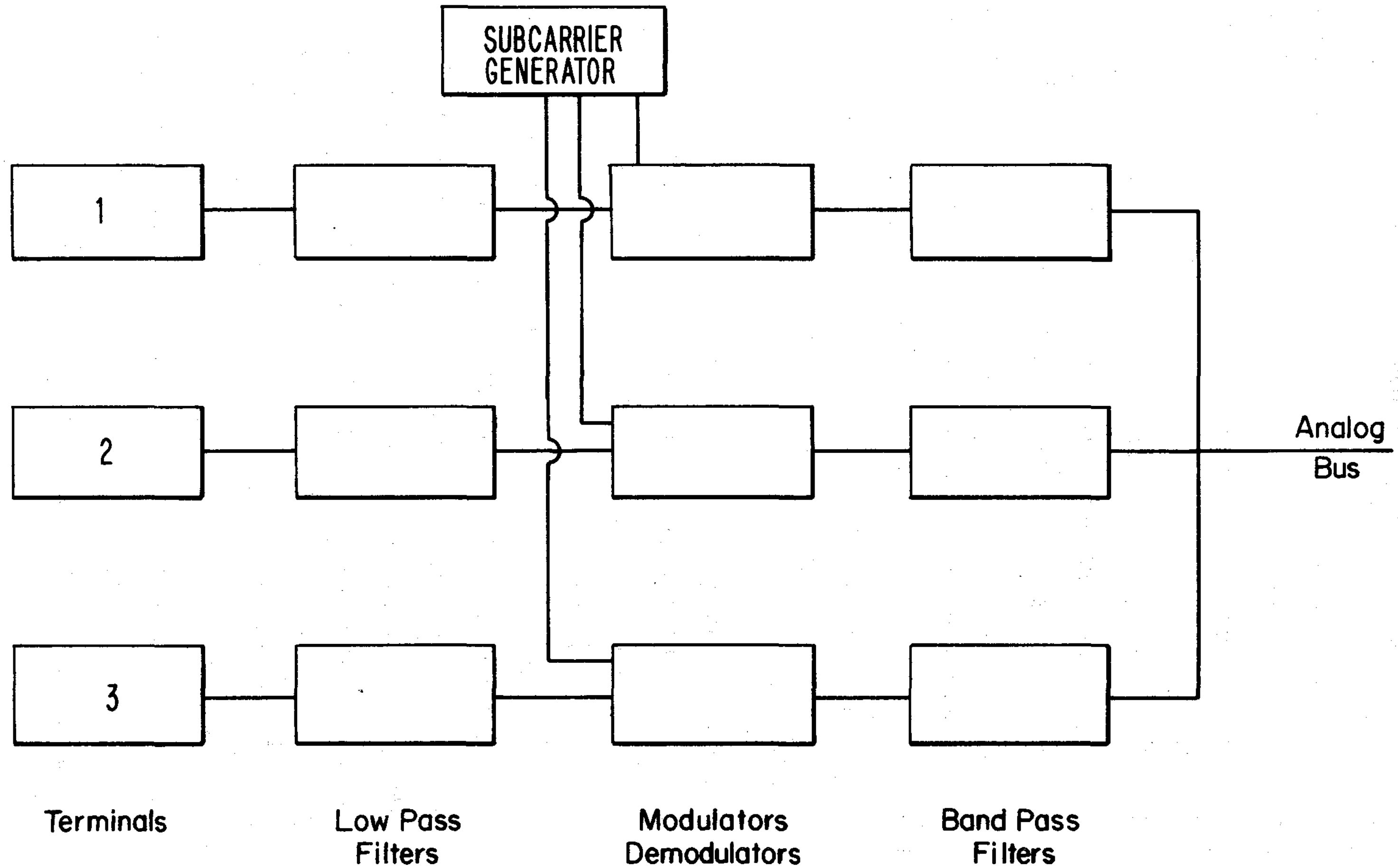


Figure 16. Frequency division multiplexer.

Asynchronous time division multiplexers (ATDM's) are actually concentrators. Time slots are assigned on a dynamic "as available" basis. An ATDM block diagram is shown in Figure 17. Delays may occur and if adequate buffering is not provided then some sources may be blocked. The ATDMs are more complex and therefore more costly but utilize the transmission facilities more efficiently.

6.3. Switching Functions

Switching provides the means for time sharing transmission facilities among a number of users. There are two basic types of switches, circuit switches and store-and-forward switches. Circuit switches generally provide a continuous bi-directional path with essentially no delay during information transfer. An initial delay for setup time is required. Store-and-forward switches are unidirectional and substantial delays may be encountered. Figure 18 illustrates one method of classifying switch types. The store-and-forward switch may be either a packet or message type.

The type of switching function desired depends on the user and the traffic generated. Usually circuit switches are more efficient for continuous traffic (speech), message switches for interruptable traffic (TTY), and packet switches for interactive traffic (computer terminals).

Switches may also be categorized by the technology used to control the switch. Those used for circuit switches are illustrated in Figure 19. Finally, switches are distinguished by the method used to control the switch remotely. This is shown in Figure 20.

In a tactical CP/SC the circuit switch is commonly used. Current technology is analog, space division with metallic crosspoints. Both manual and automatic switches are used. A hybrid circuit switch and store-and-forward switch is being developed for future use on the TRI-TAC program. These switches are designated TTC-39 and TYC-39, respectively. The TTC-39 circuit switch uses merged (analog and digital) technology in the switching matrix. Detailed characteristics of an ATACS and the TRI-TAC switch are given in Section 7.

Since the circuit switch is commonly used its call processing functions are of interest. These functions are summarized in Table 12 for each major element of the switch. The per-line functions are required on a continuous basis. Per-call functions are required only during the information transfer time while per-setup functions are required only during the access and disengagement time.

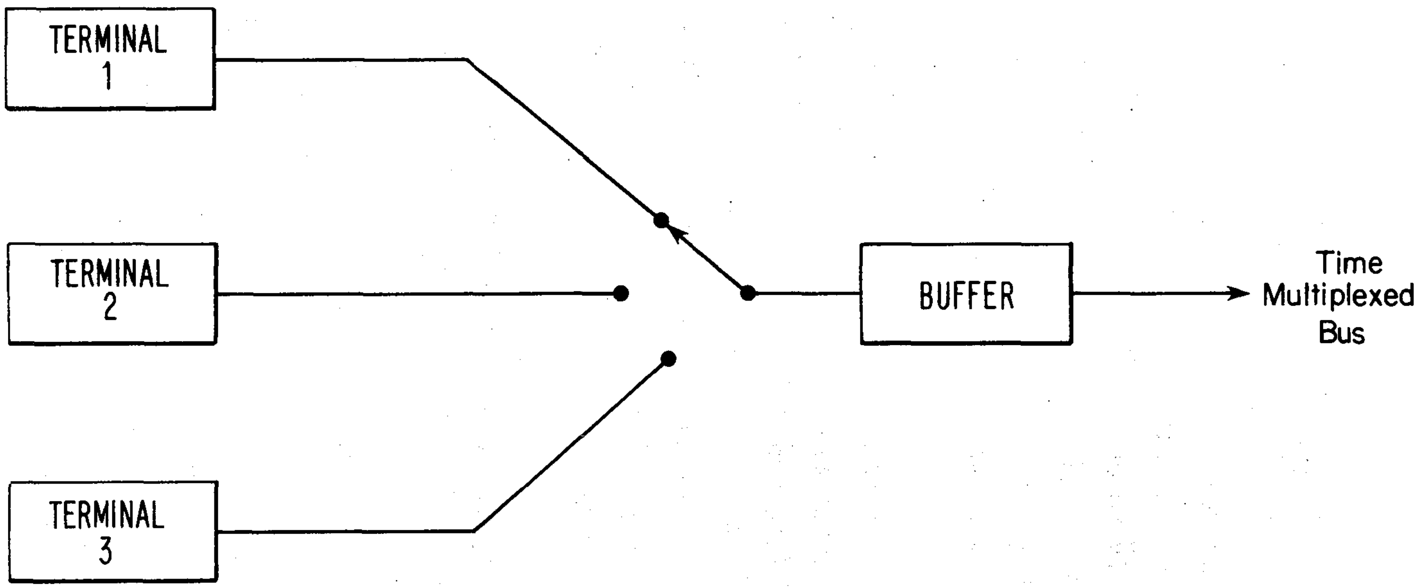


Figure 17. Synchronous time division multiplexer.

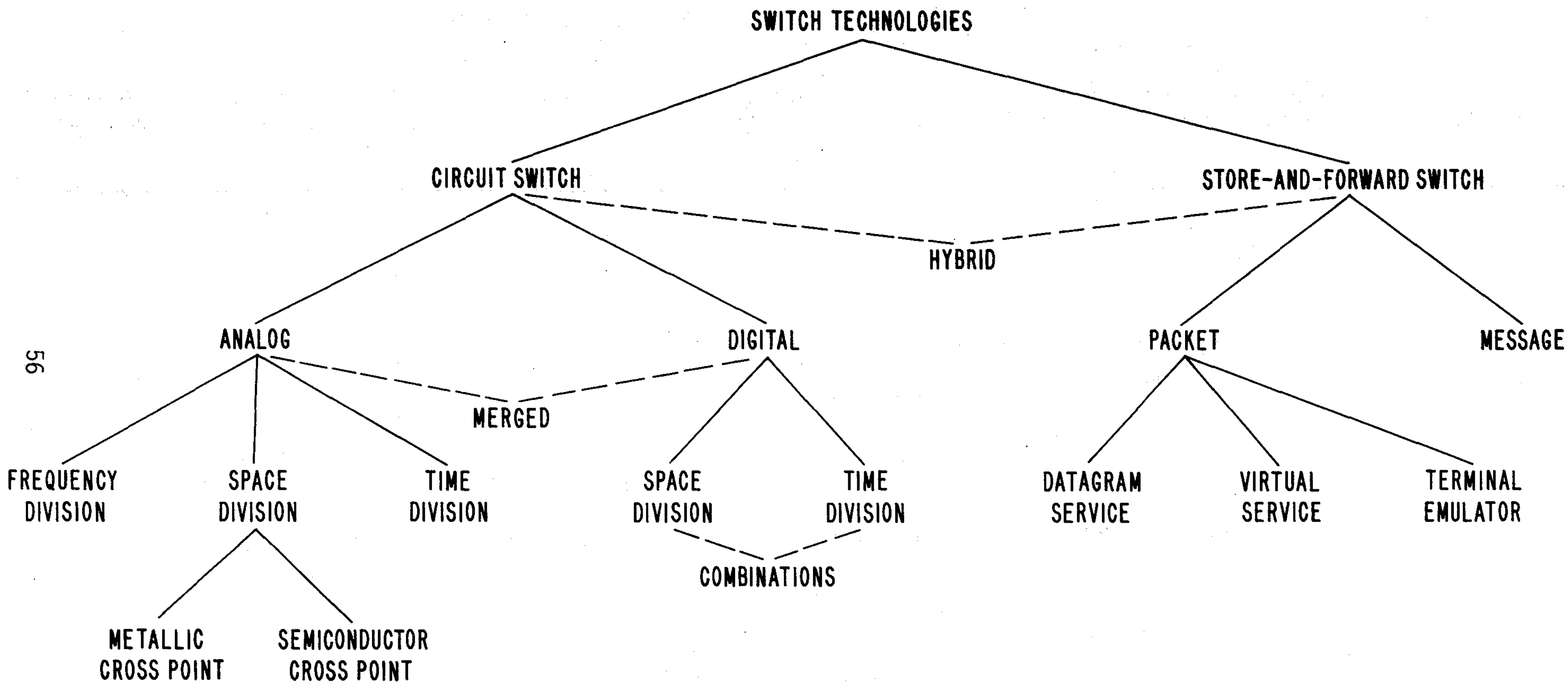


Figure 18. Switch technology classifications.

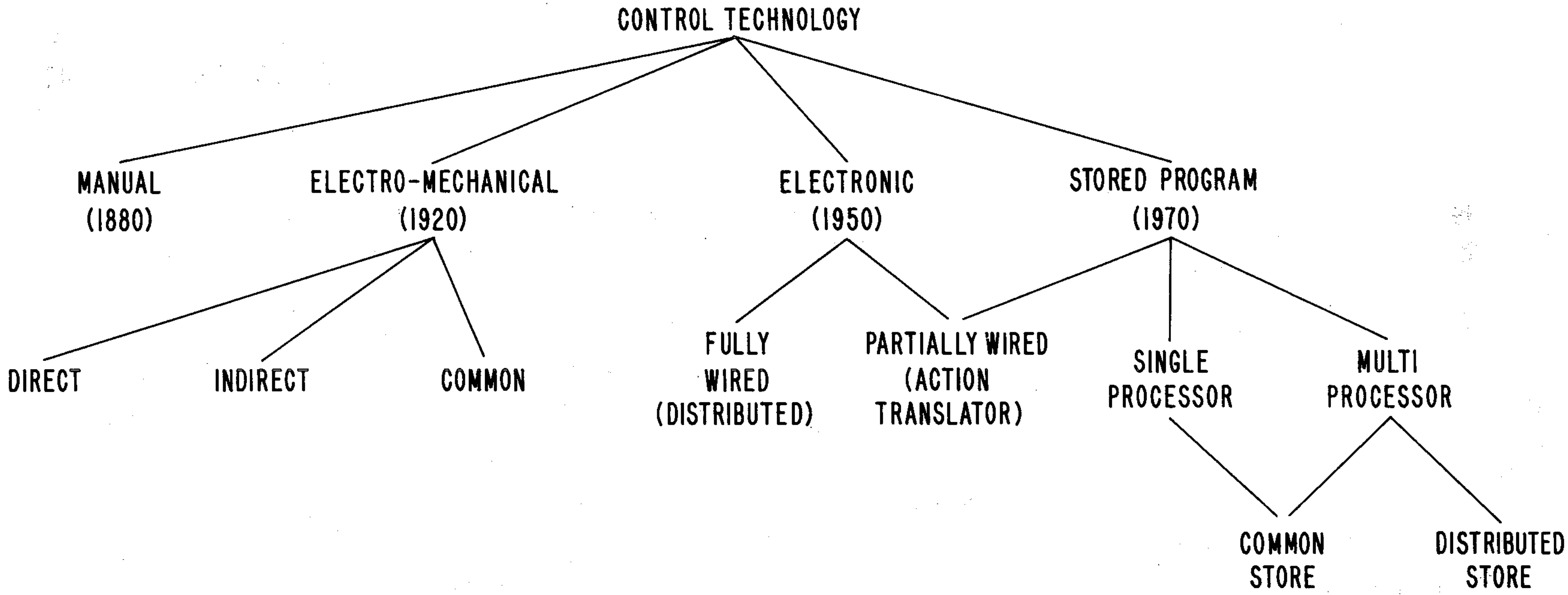


Figure 19. Control technologies used in circuit switching systems.

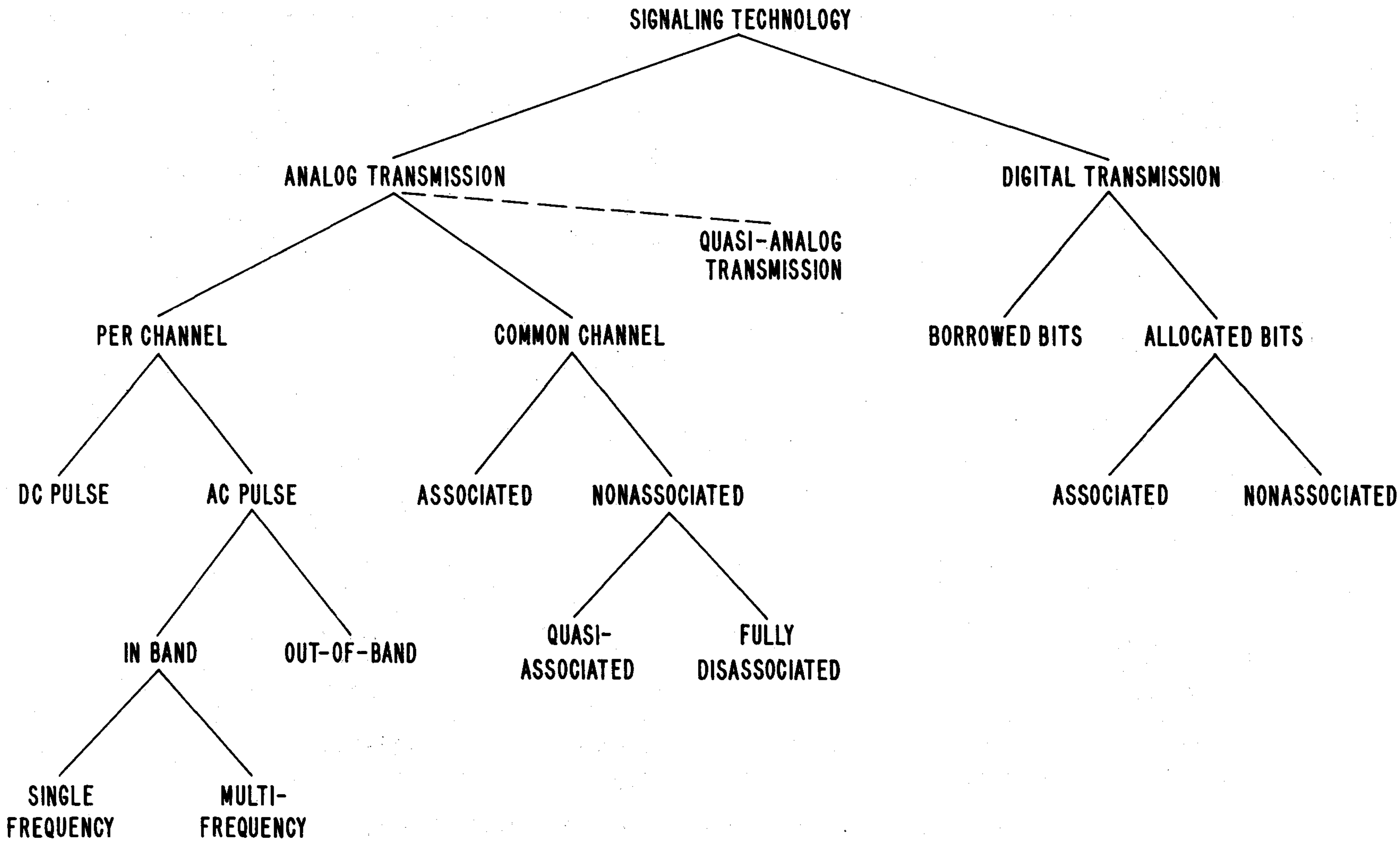


Figure 20. Signaling technologies for remote switch control.

Table 12. Call Processing Functions Performed by Circuit Switch Elements

	Signaling	Control Unit	Switching Matrix	Interface
Per-Line Functions (Continuous)	Attending (Service Request Detection)	Input Scanning		Battery Feed Overload Protection Hybrid
Per-Call Functions	Supervising (Call Completion Detection)		Interconnection	Codec Supervision (Answer and clear)
Per-Setup Functions	Addressing (Sending and Receiving Alerting (Dial Tone, Ringing, Busy, etc.)	Registration Translation Output Distri-buting Path Selecting Routing Busy Text Establish Connection Release Connection	Establish Connection Release Connection	Ringer Access Test Access

7. CP/SC SYSTEM STRUCTURE AND IMPLEMENTATION

Previously, in Section 5, Table 2 listed the Army Tactical Communication Systems (ATAC's) current equipment inventory, new transitional equipment to be fielded in the 1980's and a new class of digital equipment being developed under the TRI-TAC program. In this section specific characteristics of some of this equipment are defined in more detail. Emphasis is on those units which could have specific application in a CP/SC bus-type architecture or units which interface with this architecture.

7.1. Switching Systems

Manual Telephone Switches under ATACS include the AN/MTC-1, 3, 9 and AN/TTC-23, 29, and 35. Automatic switches include the AN/TTC-25, 28 and 38. The TRI-TAC equipment includes the AN/TTC-39 and AN/TTC-42 circuit switch, AN/TYC-39 message switch and SB-3965 unit level switch.

Tables 13 and 14 characterized the AN/TTC-38 and AN/TTC-39 switches, repectively, in terms of the major switch elements.

In addition to these manual and automatic switches the Army occasionally uses commercial switches. At two of the field exercises which were observed an automatic switch manufactured by Western Electric Corporation, the WECO 400, was deployed. This switch samples the voice signals 8000 times/second and switching is accomplished by time slot interchange of the pulse amplitude modulated (PAM) samples. The racks containing the switch elements are shock mounted in a semi-trailer for transportability. Maximum capacity of the WECO 400 is 368 lines and 32 trunks.

7.2. Concentrators and Multiplexers

The Army Tactical Communication Systems (ATACS) in the field today are in the process of being upgraded to allow integration with TRI-TAC equipment. The following equipment is of interest here because it could have application in a bus-type CP/SC architecture.

<u>Time Division Digital Multiplexer (TDDM), TD-1069/G</u>

This TDDM is designed to multiplex several low rate bit streams into a 16 or 32 kb/s channel.

<u>High Speed Serial Data Buffer, TD-1065/G</u>

This buffer is designed to interface TRI-TAC 16 and 36 kb/s digital subscribers into a ATAC's 48 kb/s PCM system. Twelve digital subscribers can replace twelve PCM subscribers.

Table 13. AN/TTC-38 Switching System Characteristics

General		
Model	:	AN/TTC-38
Introduced	:	1975
Application	:	Tandem/End office (Tactical)
Interface		
Min. Terminations	:	320
Max. Terminations	:	640
Load/Line (Erlangs)	:	
Adapter	:	2- or 4-wire
Multiplexer/Concentrator	:	
Signaling		
Lines	:	SF/DC supervision, DC pulse or DTMF addressing
Trunks	:	SF/DC supervision, DC pulse or DTMF addressing
Switch/Matrix		
Technology	:	Analog space division, 4 stage
Crosspoints	:	Semiconductor (see note 1)
Carried Load (Erlangs)	:	180
Control		
Technology	:	SPC
Architecture	:	Central
Max. Capacity (BHCA)	:	2700 (600 lines)

Note

1. Crosspoints are normally PNPN diodes which switch 12 channel group level FDM, 4-wire, wideband (80 kHz channel) information.

Table 13. (cont.)

Processor(s)

Number and type	:	Custom (See note 2)
Number of Registers	:	
Word Length (Bits)	:	24
Instruction Length (Bits)	:	24+1 parity
Data Bus (Bits)	:	
Address Bus (Bits)	:	
Clock Rate (MHz)	:	12.5 MHz
Cycle Time (μs)	:	5.6
Access Time (μs)	:	5.6
Storage	:	Ferrite Core
o Semipermanent	:	65 K (48 K implemented)
o Permanent	:	
o Off-line	:	Paper tape
Instruction Set	:	
Call Processing Inst.	:	47 K
Maint. & Adm. Inst.	:	
Peripherals	:	Remote page printer

Note

2. A second processor/memory unit provides backup. Transfer interrupt period is approximately 100 ms.

Table 14. AN/TTC-39 Switching System Characteristics

General		
Model	:	AN/TTC-39
Introduced	:	198?
Application	:	Tandem/End office
Interface		
Min. Terminations	:	150
Max. Terminations	:	750
Load/Line (Erlangs)	:	
Digitizer	:	CVSD @ 16 or 32 kb/s
Multiplexer/Concentrator	:	
Signaling		
Lines	:	DC pulse or DTMF addressing plus others
Trunks	:	SF/DC supervision, MF addressing plus others
Switch/Matrix		
Technology	:	Digital and analog
Crosspoints	:	Time divided and space divided
Carried Load (Erlangs)	:	180 (600 lines)
Control		
Technology	:	SPC
Architecture	:	Centralized
Max. Capacity (BHCA)	:	3300 (600 lines)

Table 14. (cont.)

Processor(s)

Number and Type	:	Custom L3050
Number of Registers	:	
Word Length (Bits)	:	32
Instruction Length (Bits)	:	32
Data Bus (Bits)	:	
Address Bus (Bits)	:	
Clock Rate (MHz)	:	
Cycle Time (μs)	:	
Access Time (μs)	:	
Storage (words)	:	524 K (max.), 262 K (min.)
o Semipermanent	:	
o Permanent	:	
o Off-line	:	Magnetic tape
Instruction Set	:	
Call Processing Inst.	:	195 K
Maint. & Adm. Inst.	:	30 K
Peripherals	:	

Asynchronous Digital Combiner, TD-976/G

Combines up to eight 576 kb/s group bit streams into a 4.9152 Mb/s bit stream for radio or cable transmission.

TRI-TAC equipments being developed for fielding in the 1980 to 1990 era also could have CP/SC applications in a bus-type architecture. Of particular interest is the series of digital multiplex and combining equipment known as the Digital Group Multiplex (DPM) equipment. The following are included in this group.

Remote Loop-Group Multiplexer (RLGM), TD-1233

The RLGM multiplexes four 32 kb/s or 16 kb/s channels and the control signals into a 144 kb/s or 72 kb/s channel group.

Remote Multiplexer Combiner (RMC), TD-1234

The RMC can accept one digital group input plus up to eight single digital channels. The group input can range from 72 kb/s to 288 kb/s depending on the source. Two RMC's can be operated in tandem.

Master Group Multiplexer (MGM), TD-1237

The MGM will handle up to 12 digital groups with switchable bit rates from 72 kb/s to 4.9152 Mb/s. Output rates are 9.36 Mb/s or 18.72 Mb/s.

The Defense Communication System (DCS) may have sites in the COMMZ area at principal nodes to provide access to the DCS strategic backbone. Digital systems, either installed or planned, include AN/FRC-162, 165 and 169 radios which use 3-level partial response transmission systems. The Digital European Backbone (DEB) will use a new Digital Radio and Multiplex Acquisition System (DRAMA). The first level multiplexer of DRAMA, the AN/FCC-98), performs analog-to-digital conversion and time division multiplexing for 3, 6, 12 and 24 voice channels. The digitization process for 24 channels is essentially the same as for T-carrier used in North America, i.e., 24-channel, 8-bit PCM at 1.544 Mb/s. The 3-, 6-, and 12-channel modes are used for the Defense Satellite Communications System and the 24-channel mode for the DCS. The output ports of several first-level DRAMA multiplexers can be combined in a second-level multiplexer (TD-1193) as follows:

Number of 1.544 Mb/s Ports	Number of Voice Channels	Date Rate (Mb/s)
2	48	3.168
4	96	6.336
6	144	9.504
8	192	12.672

Digital data can be interleaved by replacing voice channel cards in the first-level multiplexer. Data rates specified are 0 to 20 kb/s and 50 kb/s asynchronous and 56 kb/s, 64 kb/s, and 128 kb/s synchronous.

The basic process used for voice digitization within the ATACS, TRI-TAC and DCS are compared below.

	ATACS	DGM	DCS
Digitization Process	PCM	CVSD	PCM
Code Bits Per Channel	6	N/A	8
Number of Channels	12	18	24
Channel Rate	48 kb/s	16 or 32 kb/s	64 kb/s
Group Rate	576 kb/s	576 kb/s	1.544 Mb/s
Signaling Format	Unbalanced/NRZ	Balanced/NRZ	Balanced/NRZ

Table 15 lists the ATAC's PCM specifications for digital voice systems currently in the field.

7.3. Transmission Links

The transmission links provide the access path between end users. Tactical command posts use various types of transmission media to provide this access path.

The internal CP/SC distribution system is primarily hardwire. Examples of Army tactical wire and cable are listed and characterized in Table 16.

Types WD-1, WD-14, and WD-36 are a single twisted-pair for a single channel (circuit) that can be easily reeled out and may be abandoned when moving on. They are used to connect field telephones which are installed to take over communications from mobile radios and thereby minimize EM signatures. They are used mainly by the battalions, companies, and platoons near the forward battle area. VHF/FM radio is used in conjunction with the twisted pairs to form an integrated radio and wire system using phone patches.

Four-wire circuits include the WD-16 and spiral four, WD-8. These field wire cables may be used for an overload backup system in the division level nodes and corps level nodes. The main interconnection wire in a main CP/SC in the CX-4566, a 26-wire pair cable. Several 75 m sections of CX-4566 may be paralleled for carrying the heavy loads of traffic between the message center switch patch panel. Several lengths in tandem may be used to extend connections to remote sites.

Coaxial cables are used where PCM signals and/or multiplexers are required to carry 12-, 24-, and 48-channel traffic to the Radio Park, toward the rear echelons, to the helipad and forward artillery post.

The CX-11230 twin coaxial cable is designed for use with new digital equipment and eventually is expected to replace the older CX-4245 cables. With a pulse

Table 15. Army Tactical PCM Specification (from ATACS, 1974)

Characteristics common to all systems:

General

Type of Multiplexing	Time Division
Type of Coding	Pulse Code
Channel Sampling Rate	8000 per Second
Digits per Sample	6
Primary Power, Medium and High Traffic	109-121 volts 47-63 Hz
Primary Power, Low Traffic	109-121 volts 47-420 Hz

Audio

Input Level for Full Modulation	-4 dBm
Output Level for Full Modulation	-4 dBm or +1 dBm
Input and Output Impedance	600 ohms floating
Bandwidth	300 to 3500 Hz
Signal-to-Noise Ratio FIA	55 dB min.
Signal-to-Noise Pulse Crosstalk Ratio FIA	53 dB min.
Total Distortion	3.2% max.
Delay Distortion	200 μs max.

Systems

	Low Traffic	Medium Traffic		High Traffic	
Number of Channels	6 or 12	12	24	48	96
Volume, cu m (radio terminal)	.07	0.16	0.27	0.28	0.51
Weight, kilograms (radio terminal)	50	100	170	190	712
Power Consumption, watts (radio terminal)	80	187	344	278	526
Bit Rate, kb/s (radio system)	288 or 576	576	1152	2304	4608
3-dB Bandwidth (radio system)	240	240	240	935	935
Pulse Type (ratio system)	binary	binary	biternary	binary	biternary
Bit Bate, kb/s (cable system)	2304	2304	2304	2304	2340*
Pulse Type (cable system)	dipulse	dipulse	dipulse	dipulse	dipulse

*Two cable systems required for 96 channels.

Table 16. Characteristics of Field Wire and Field Cable

COMMON TERM	BASIC CABLE OR WIRE	ASSEMBLIES	LENGTH	ATTN PER km	WEIGHT	TENSILE STRENGTH IN kg	LOADING	ADDITIONAL INFORMATION
Field Wire	WD-1/TT (Std A) WD-14/TT (Std B)		0.4 km 0.8 km 1.6 km 4 km	1.5 Wet 1.0 Dry	20 kg/km	90	None	Extruded nylon outer cover (WD-1/TT) Braided nylon outer cover (WD-14/TT) Stranded conductors, 4 copper 3 steel
Cable, Tel (Assault Wie)	WD-36/TT (Std A)	MX-6894/TT MX-6895/TT	0.4 km 1.8 km	3.7 Wet 2.2 Dry	3 kg/km	12	None	Solid Aluminum Conductor #23 AWG FSN MX-6894 3895-089-7278 MX-6895 3895-089-7279
Cable, Tel (Four-Wire, Field Wire)	WF-16/U (LP)		1.6 km	1.6 Wet 1.2 Dry	20 kg/km	90	None	7 conductors are copper-cadmium alloy, stranded
Spiral Four	WF-8/G (Std A)	CX-1606/G CX-1512/U	0.4 km 30 m 4 m	0.8 unloaded 0.45 loaded	130 kg/km	315	1320-6 (use Coil CU-260 4 CH CXR only)	Conductors are all copper, stranded, #19 AWG
Inter-Area Coaxial Cable		CX-4245/G (Std B)	0.4 km	24 @ 2.304 MHz	160 kg/km	200	None	Two coaxial conductors (twisted)
Inter-Area Coaxial Cable		CX-11230/G (Std A)	0.4 km 30 m	24 @ 2.304 MHz	100 kg/km	340	None	Two coaxial conductors, improved connector, improved shielding
Twenty-Six Pair Cable	WM-130/G (Std A)	CX-4566/G CX-4760/G	75 m or 7.5 m 5 m	1.5	250 kg/km	315	None	Stranded conductors, 6 copper, 1 steel - #24 AWG

restorer (Type TD-982) at 0.8 kilometer intervals the CX-11230 can provide a 96 digital voice channel capacity at 4.9252 Mb/s. With the high-speed pulse restorer (TD-1219) located at 0.4 kilometer intervals this capacity can be increased to 18.72 Mb/s.

The spiral four cable is a portable four-conductor field communication cable used for voice and carrier frequencies up to approximately 12.5 kHz. Approximately half kilometer lengths of this cable are terminated with a molded connector containing a 6 mh loading coil for decreasing transmission losses.

The U. S. Air Force uses a 100 pair cable (not shown in Table 16), Type 407 L, for multichannel use. This cable is spooled in 300 meter lengths with connectors assembled.

Two types of fiber optical cables (not shown in the table) are under consideration for tactical use. A 2-fiber version is intended ultimately to replace the WF-16 field wire for digital voice subscribers. A 6-fiber cable ultimately would replace several 26-pair cables.

7.4. Deployment

Representative deployments of the mobile shelters housing communication equipment for various tactical CP/SC situations are given in the Army training circular TC 101-5. Three configurations are illustrated in Figure 21 for a tactical command post, Figure 22 for a main command post, and Figure 23 for the operations center within the main command post.

The actual deployment in the field may vary considerably from that depicted in the figures, because of terrain, tactical situations, and individual commander's preferences.

Two separate visits to tactical field exercises were made during the course of this program. One visit was made to observe a practice CP/SC deployment exercise conducted by the 11th Signal Battalion at Ft. Huachuca, AZ. The other, to observe the CP/SC operations in a tactical field maneuver conducted at Ft. Hood, Texas. The purpose of both visits was to obtain background information on current procedures on current deployment configurations and operational procedures and on potential constraints to deployment time in a realistic tactical environment.

The equipment layout for the deployment exercise at Ft. Huachuca is depicted in Figure 24. A commercial 400 line switch was employed for local telephone switching and for interfacing with a nearby dial central office on the base. The various equipments in addition to this switch included the technical control center, two LOS microwave radio links and a variety of terminal equipments. A total of

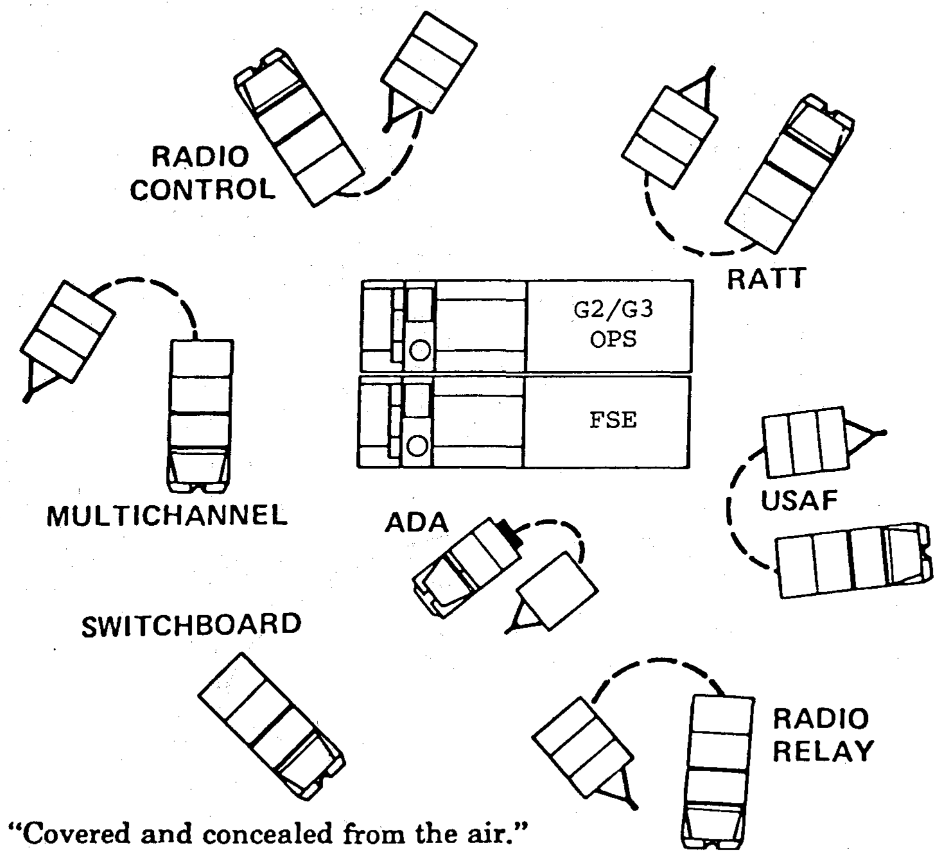


Figure 21. Tactical command post configuration.

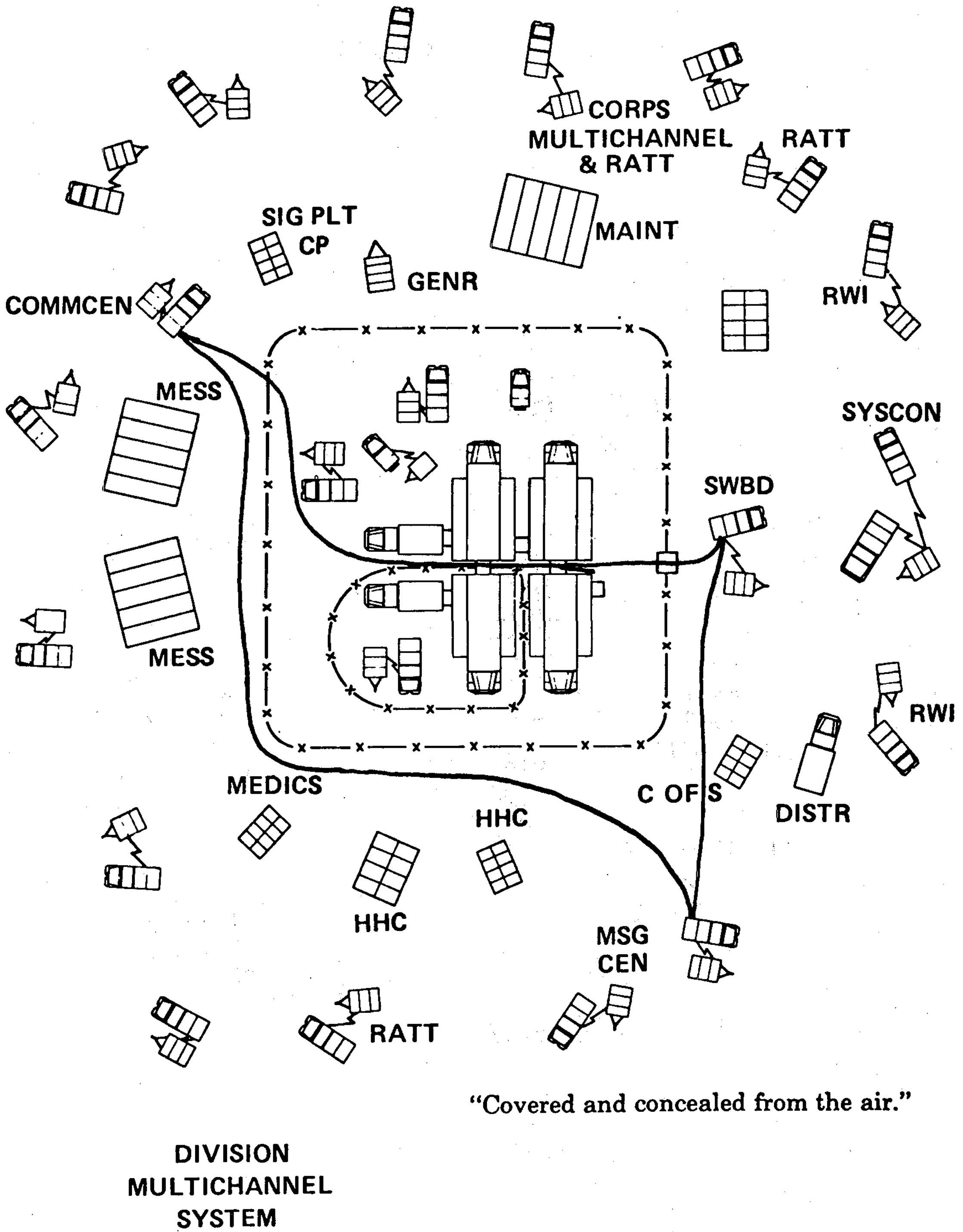


Figure 22. Main command post configuration.

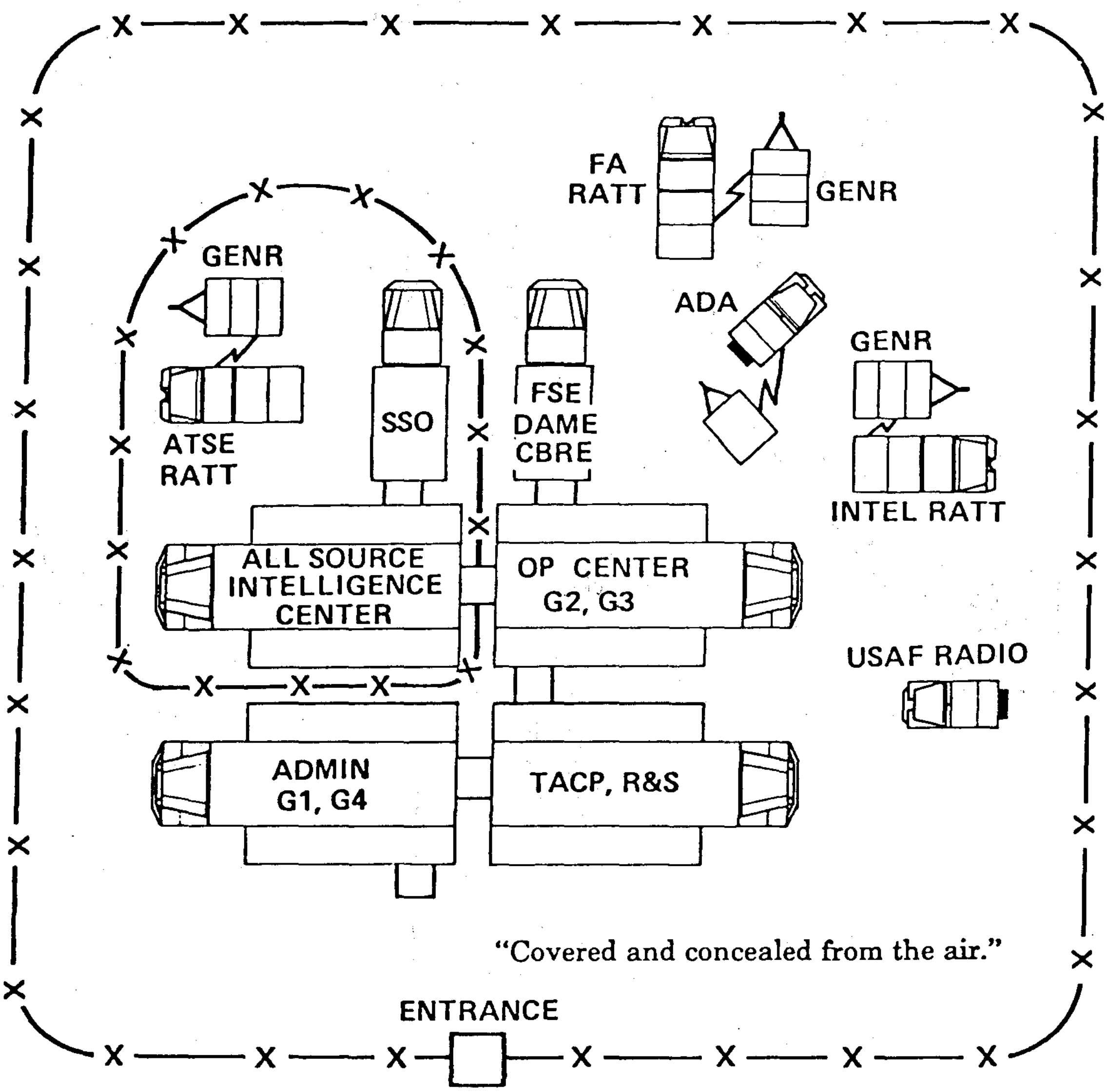


Figure 23. Tactical operations center, main CP.

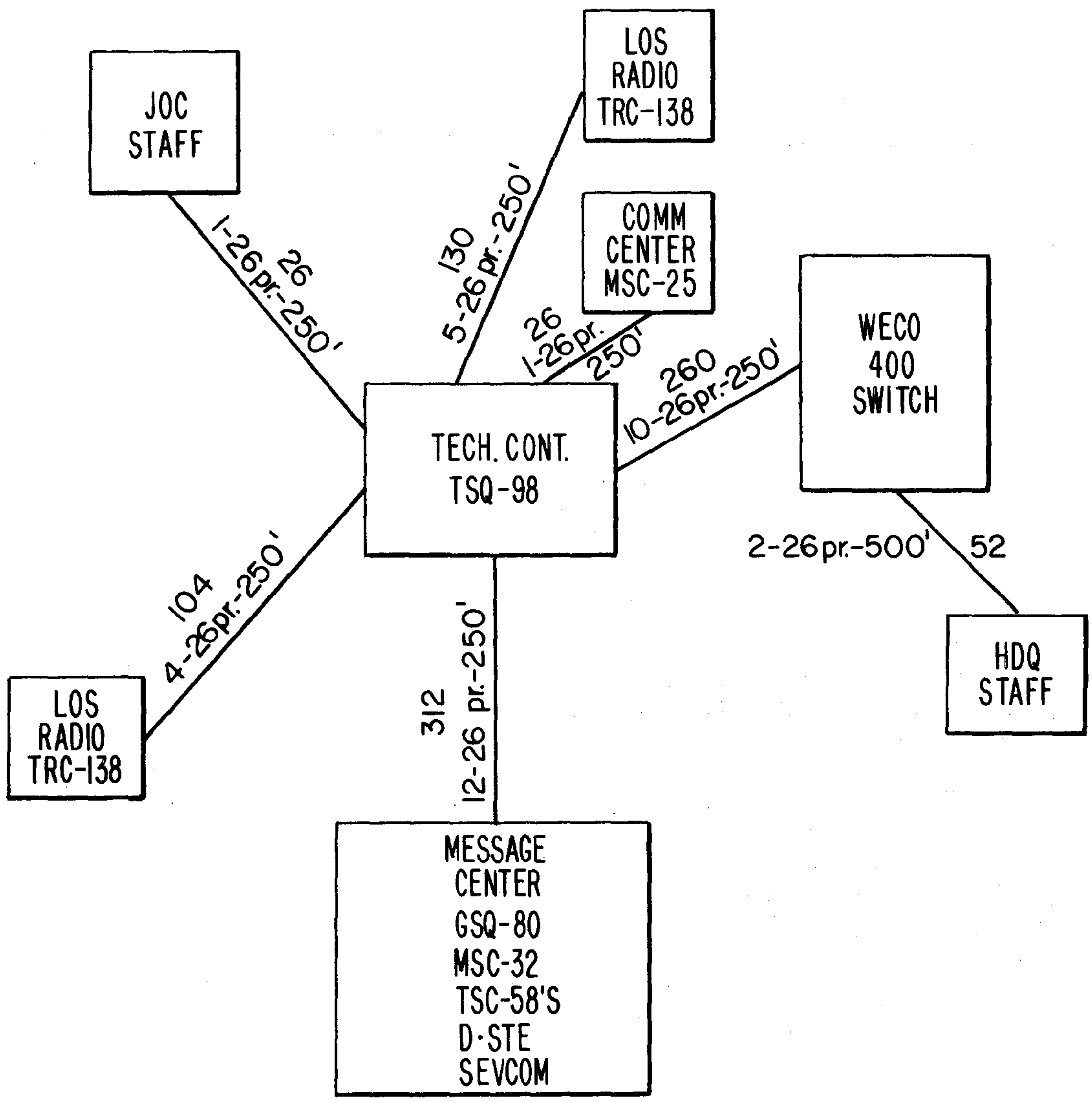


Figure 24. Fort Huachuca deployment exercise equipment layout.

20 trailer mounted shelters containing these elements and associated power units were deployed over an area about 300 meters in diameter. The terminal equipment included radio teletypewriters (RATT) and conventional teletypewriters (TTY), digital subscriber terminal equipment (DSTE), torn-tape senders and receivers, secure voice, and secure data terminals. Mobile shelters for all of these terminals were collocated in a physically secured area compound, i.e., the message center. This message center contained 15 vans alined back to back. The major equipment elements were star connected to the technical control center outside the compound using groups of 26 wire pair cables (CX 4546) as indicated in Figure 24. These cables were laid on the ground and deployed manually from reels containing either 7.6 m or 76 m of cable. Connections were made to each shelter on panels containing standard 26-wire connectors (hocks). See Figure 1. A total of 26 reels of cable was used at this particular site.

The installation of a CP/SC including the internal cabling is accomplished by command post personnel who check out and operate the systems. Remote cables from the signaling center to the radio park, the dial central office and other longer hauls are usually installed by a special cable platoon. A typical cable platoon consists of approximately 40 men who are specially equipped for this purpose.

The time required to install a CP/SC varies considerably depending on size, terrain, and cabling procedure (e.g., buried vs. overhead vs. on the ground). Typically a complete installation excluding planning and transport time could require two or three days with 20% to 30% of this time required for the interconnections.

The tactical deployment and operations of a Communications-Electronic (C-E) network used for exercise Braveshield 19 were observed at Ft. Hood. The primary site of interest was the Joint Opposition Forces (JOPPFOR) headquarters and associated communications facilities. This headquarters included a joint operations center (JOC) opposition Army headquarters (OPP-AR), communications center, signaling center, life support area (LSA), radio site, military police (MP) sites and a helipad. These were interconnected as shown in Figure 25. This installation was unique in that C-E equipment was collocated for both corps and division level operations. Normally these facilities would be separated by 50 km to 100 km or more.

The geographic area which included all the facilities shown in Figure 25 was about 3 km by 5 km.

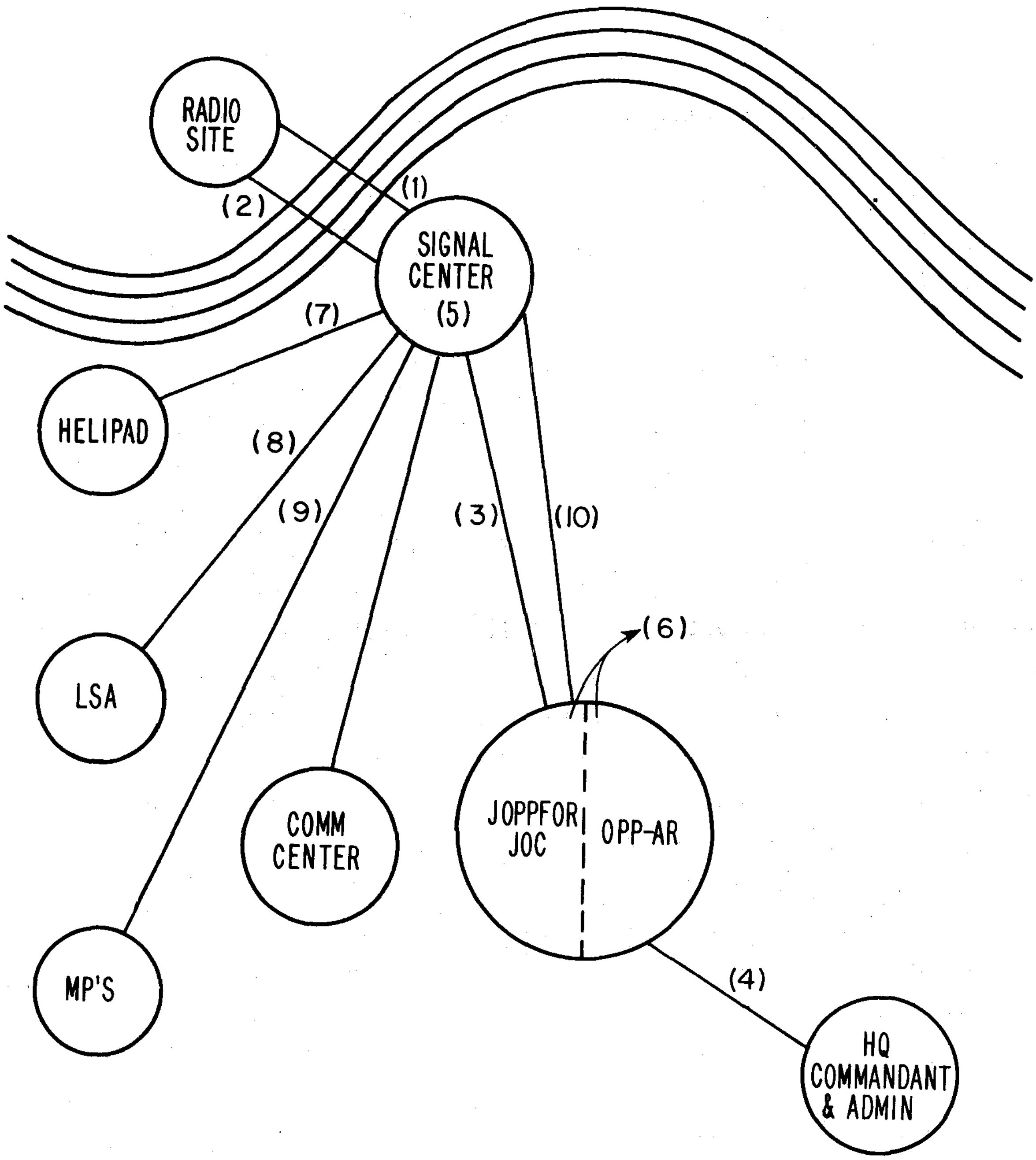


Figure 25. CP/SC facilities and interconnections during Braveshield exercise.

Cabling to each JOPPFÖRS site is summarized below. The numbers in parentheses refer to the links shown on Figure 25.

(1) Two 0.4 km runs of PCM cable

(2) Four 400 meter runs of 407 L cable

(3) One 500 meter, 100-pair cable

(4) One 26-pair cable

(5)(6) In-house wire and 26-pair cable for intra-signal and center connections

(7)(8)(9) Spiral four cable

(10) Two runs of 26-pair cable

At this location most of these cables for the longer runs were buried underground by special cable teams prior to the start of the exercise. The 20 ma and 60 ma teletype circuits sometimes caused crosstalk problems when collocated in trenches over distances of several hundred feet.

Each separate area had its own power generating plant so that 60-cycle power cables were not buried in the same trenches as the communication cables.

Approximately 200 telephones were scattered throughout the area. Of these, approximately half were switched automatically using the WECO 400 switch. The rest were switched from manual switchboards.

8. OVERALL CP/SC NETWORK DESIGN

8.1. General Network Objectives

The CP/SC communications plant consists of three parts: the user terminals, the network links, and the network nodes. The majority of user terminals are field telephone sets. Teletypes and other data equipment comprise a lesser part. The present network links are single or multiple twisted wire pairs. Rather typically, one finds 26 such pairs in one multi-wire cable. The network nodes can be small automatic switches, such as PABX's, manual switchboards, multiplexers (MUX), concentrators, radio transmitters or receivers, and so forth.

The basic objective of the command post network is to provide required communications services during the service time part of the CP/SC life cycle. Part (A) of Figure 26 illustrates the four parts of that life cycle. The cycle commences at a given site with the arrival of the equipment. This is the initial transport phase. It is followed by deployment and installation of the network. Once installed and working, the network provides its intended service to the military

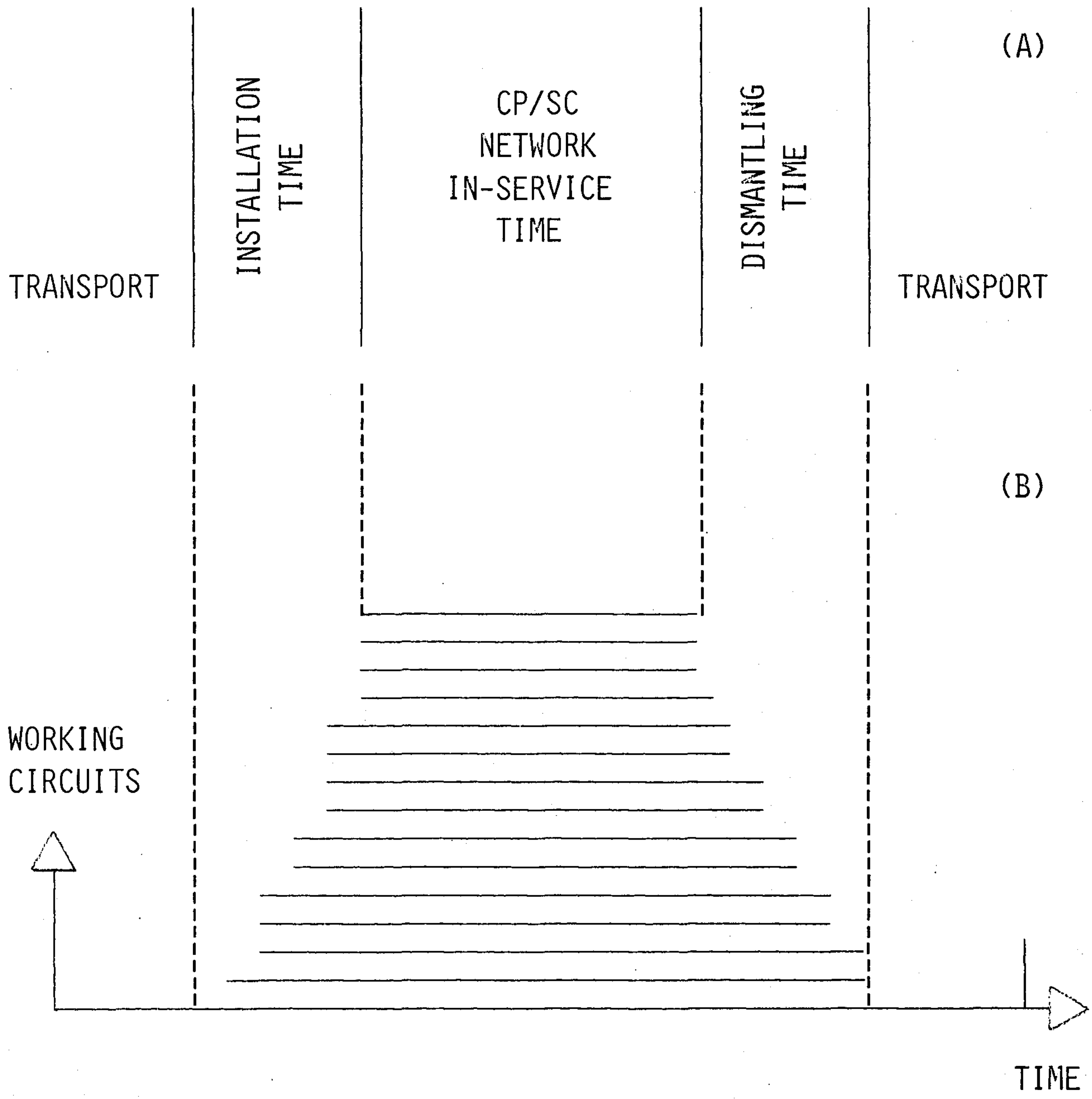


Figure 26. Typical life cycle of the command post network.

command post. At the conclusion of the CP mission, the service time gives way to dismantling and securing all movable gear into transport vehicles. Finally, of course, the removal turns into another transport phase. A new cycle of the CP network can now begin at a different staging area.

This section is concerned with three of the phases: the installation time, the in-service time, and the dismantling or removal time. As shown in Figure 26, part (B), the full capacity of the working circuits is only available during the established in-service time. Various fragments of the network may be functional and working during the installation and dismantling times.

In providing the needed communications services to its tactical users, the network must meet many functional objectives. They include transportability for rapid arrival and departure. They call for fast and trouble-free installation of the system. They also encompass initial troubleshooting, turn-on, modification, normal maintenance, as well as emergency operational measures. The emergency measures can seldom be fully anticipated, as they occur in response to destructive field events of varied magnitude.

This section reviews the general CP/SC objectives. It also presents functional measures of merit. The latter are design yardsticks to check how specified requirements and objectives are met. To do that, the three network parts, terminals, links and nodes are viewed as a joint mechanism throughout the three-part life cycle of the network. This approach is emphasized in Table 17.

Table 17 presents 16 conventional network objectives. In alphabetical order they are: availability, connectivity, ..., transportability, upgradability. There tends to be considerable overlap, or mutual impact, or cross-correlation between these parametric descriptors. This cross-correlation is indicated in Table 17 by the numbers, scaled 1 to 10, at the intersection of two parametric objectives. For instance, service availability has a relatively low cross-correlation to system performance (score 2), but a high correlation to grade of service, i.e., probability of blocking (score 9). The numbers in Table 17 are to be interpreted as approximate and very vague indicators only. The given numbers reflect the authors' subjective judgement only. They are apt to vary among individual designers, because of non-uniform interpretations of the parameter definitions, time varying importance of certain objectives, as well as the mission-oriented nature of certain command posts and their military significance.

In what follows, installation speed, survivability, service quality, performance and upgradability are recognized as most basic. Service and performance are combined into one, because of their relatively similar cross-correlation properties.

Table 17. Qualitative Cross-Correlation Between Conventional Network Objectives

	Upgradability	Transportability	Survivability	Service Quality	Security	Reliability	Performance	Operability	Modularity	Maintainability	Installation Speed	Grade of Service	Flexibility	EM Signature	Connectivity
Availability			6	7		7	2	4				9			5
Connectivity		4	8			3			3		5	6	2	1	
EM Signature		6	6		6						4				
Flexibility	7	1				1		2	3	4	2				
Grade of Service			5	6		4	2			3					
Installation Speed		7	4		5				8						
Maintain-bility	1		2	5		9	3	5	7						
Modularity	6	5	1			1		3							
Operability				6		5	4								
Performance				8		6									
Reliability			3	7											
Security		2													
Service Quality			1												
Surviv-ability		3													
Transport-ability															

The summary definitions and descriptions of these main network design objectives are given next.

8.1.1. Installation speed

It is often imperative that at new command post sites the communications plant be installed and working in a short time. This includes the deployment or dispersement of terminals to their assigned locations; the placement of nodes in shelters (e.g., vans or tents); and their interconnection with the required capacity lines or links. The total installation is, of course, not complete until the system works. To this end, initial diagnostics and installation repairs are often needed.

Field reports indicate that at present most time and man-machine effort is consumed in link (e.g., multi-pair cable) installation, such as burial of the cable a one-third meter or so below the ground. Together with other time-consuming installation jobs, it tends to take more than one day to set up a modest command post.

A key objective therefore is to reduce the network, and particuarly the cable, installation time. This cabling requirement is alleged to be more critical than installation times for all other CP elements. It is deemed more urgent than the removal or dismantling times required later by the various equipments. There also appears to be far more merit in reducing installation time than, for instance, in minimizing in-service repair or maintenance efforts.

8.1.2. Survivability

Survivability is essential to the command post and its network objective. It is stressed throughout the network design section.

The definition of survivability is closely related to invulnerability, non-destructibility, robustness, and even reliability in the larger sense.

Network reliability refers to the probability, or percent of time, that a network will work satisfactorily under normal conditions, or to the user's confidence in the network is satisfactorily working. Survivability and invulnerability, on the other hand, address network performance under adverse, damaging, and specially debilitating circumstances. If said circumstances are caused by nature, such as floods, storms, extreme temperatures, or even by human oversights - not to mention man-made accidents - one may talk of system vulnerability or invulnerability. When the conditions are substantially caused by actions by enemies or potential hostile forces, one tends to use the term survivability.

The above definitions, unfortunately, are neither precise nor widely accepted. Survivability will be used in the present context to depict the network ability to work or the probability of its working satisfactorily in the tactical command post environment. One should stress that the phrase "working satisfactorily" can be subject to many interpretations. Such interpretations, see Table 17, are related to service availability, grade of service, operability, performance, service quality, etc. They are discussed next.

8.1.3. Service and performance

A circuit switching network provides communications circuits or paths between terminals so that communication can occur. At the military command post level, at least to the authors' knowledge, it is an unresolved tactical requirement whether all terminals should be able to reach all other idle terminals. And whether this should be so at all times and under all tactical scenarios. Without going into further detail, we stipulate here that as a network service requirement "all essential CP connectivity" shall be provided.

Another issue concerns the quality aspects of the service. Here one encounters the probability of network blocking (i.e., the grade of service) and the associated statistics of delay, such as mean delay and variance thereof. Once the connection is established, the signal quality is affected by the transmission path. Signal-to-noise ratios, phase and amplitude distortions, crosstalk, and other effects, become apparent. For data messages, there may be too many errors or deletions to suit the recipient. For voice signals, the intelligibility, the clarity, or the recognizability of the speakers may be essential.

It is realistic to require that, in addition to providing terminal interconnection, the CP network be engineered to provide signal quality performance measures that satisfy the military standards for data and voice communications.

8.1.4. Flexibility/Upgradability

Telecommunications and related technologies have developed rapidly over the last ten to twenty years. More advanced developments may be predicted for the future. The design must be flexible in order to adapt to changing technology. No matter how expedient or firmly established a CP network design may appear now, there is a strong possibility that it may be upgraded within the next five to ten years. This upgrading compatibility represents a significant, albeit a somewhat long term, network design objective.

The network design must combine present utility with realistic future upgradability. There should be a minimum of technical constraints, so that at some unforeseen future date the CP/SC communications network can be modified, either partly or fully, to take advantage of advanced engineering developments.

8.1.5. Other measures of effectiveness

Elsewhere in this report, various measures of system effectiveness (MOE's) are introduced. Some of them, such as availability, EM signature, flexibility, maintainability, operability, removability, security, and transportability were partly listed in Table 17. They are not explicitly analyzed in this network design section. However, this does not imply that they have no impact or significance in command post network design. Additional studies may be needed to establish and document the CP/SC roles of these and other network objectives.

8.2. Hierarchies

This section introduces hierarchal structuring to command post network design. Hierarchal structures have been employed with considerable success in the engineering of numerous large telecommunication networks. In the relatively small command post network application, the hierarchal approach may be justified for several reasons.

8.2.1. Reasons for hierarchal levels

To start, a properly chosen hierarchy breaks up the design problem into smaller, more manageable elements. It identifies difficult subsystems and isolates trouble spots from the rest of the system.

Second, the hierarchal model promotes engineering in response to modified design objectives. This happens, for instance, when different numbers are tried for the previously emphasized objectives of installation speed, survivability, service, performance, and so forth.

Third, the good hierarchal levels tend to help themselves. That is, they suggest improvements in the level makeup. Usually this occurs through separation into independent subsystem functions. Identification of their unique parameters and their optimal numerical values are important to hierarchal level design.

Consider the general problem illustrated in Figure 27. Given user terminal statistics and external gateways, a network is to be specified. Typically, the

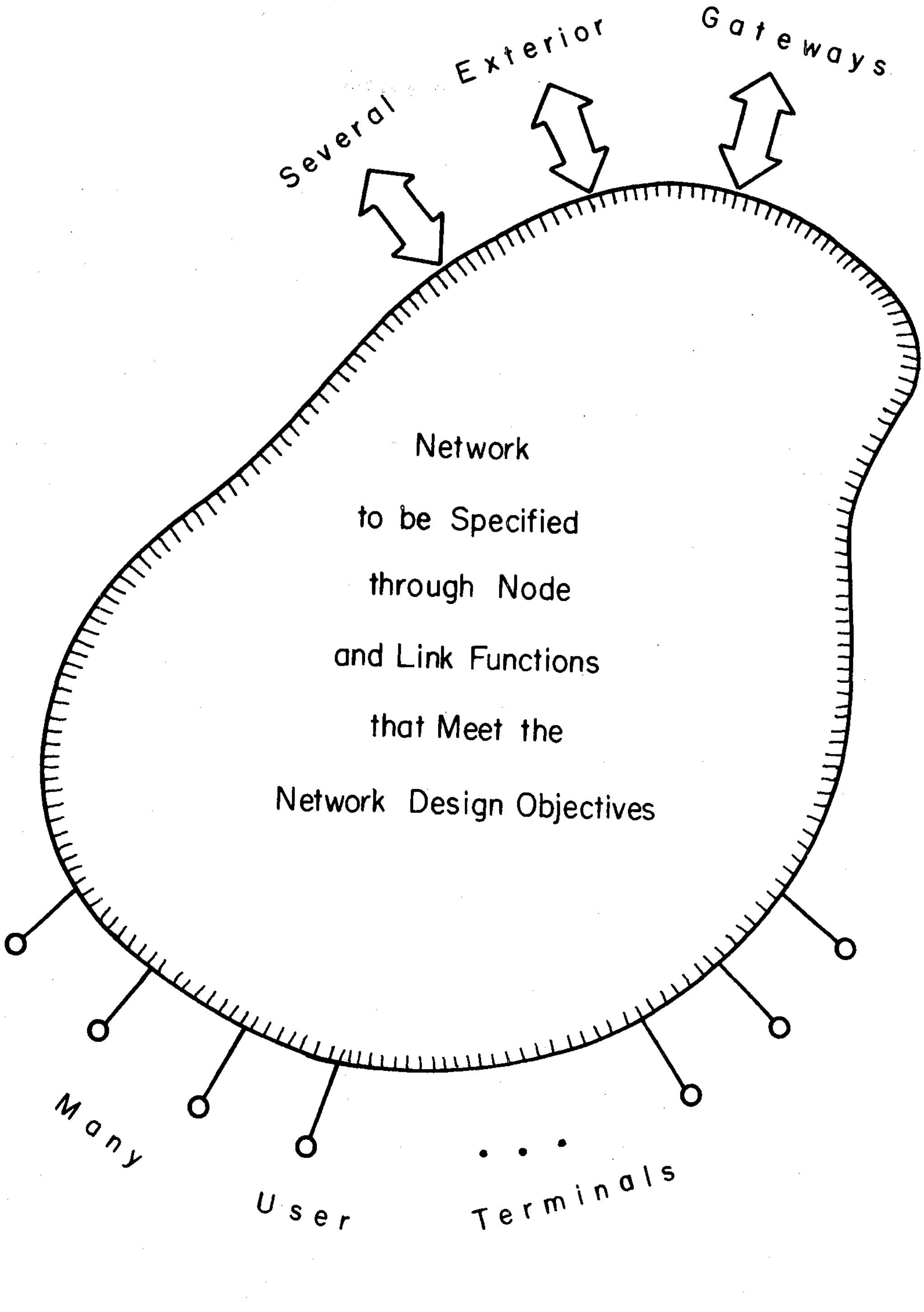


Figure 27. Conceptual definition of the command post network.

initial specification is functional in nature. Later specification is more quantitative. It defines the functions in terms of parameters and their numerical values.

The hierarchal approach taken here assigns both nodes and links to different system parts, called hierarchal levels, or sometimes hierarchies. Each part has some unique identifying features. Usually, the number of hierarchy levels does not exceed six or so.

8.2.2. Hierarchal example

One elementary and quite practical approach to hierarchy assignment is shown in Figure 28. The figure illustrates four hierarchy levels with relatively straightforward functions.

The first and lowest level consists of user terminals, such as telephone handsets, and their station loops. A station loop is usually a twisted-wire pair. In the exceptional cases of four-wire operation, as might occur for data or secure voice, more than one pair may be deployed. The network functions performed at this hierarchal level number 1 are the familiar local telephone loop functions.

The second hierarchy level in Figure 28 contains loop or line concentrators and multiplexers (MUX'es), as well as the concentrated tie lines (or buses or trunks), that tie the MUX units to the higher level switches. Note: To distinguish between the two, a MUX may be visualized as an unintelligent, pre-wired, multi-terminal patch-board. A concentrator, on the other hand, may possess various degrees of intelligence. It may select any of several channel routes for a requesting terminal. Neither concentrators, nor MUX'es, perform any circuit switching.

At the third hierarchy level, the switching, processing and control functions take place. At this level, Figure 28 shows three switches, plus a pair of operator consoles. There are also various trunks and tie-lines included in level three. The switches could be small PBX's, or PABX's, or manual switch boards. The switches are heavily interconnected to provide redundant backup paths in case of bus or even switch outages.

The fourth and highest level in Figure 28 is shown to consist of a satellite earth station, plus a radio center, and the associated tie trunks to the switch level. In the notation of Figure 27, the satellite and terrestrial radio facilities serve as exterior gateways for the relatively localized command post network.

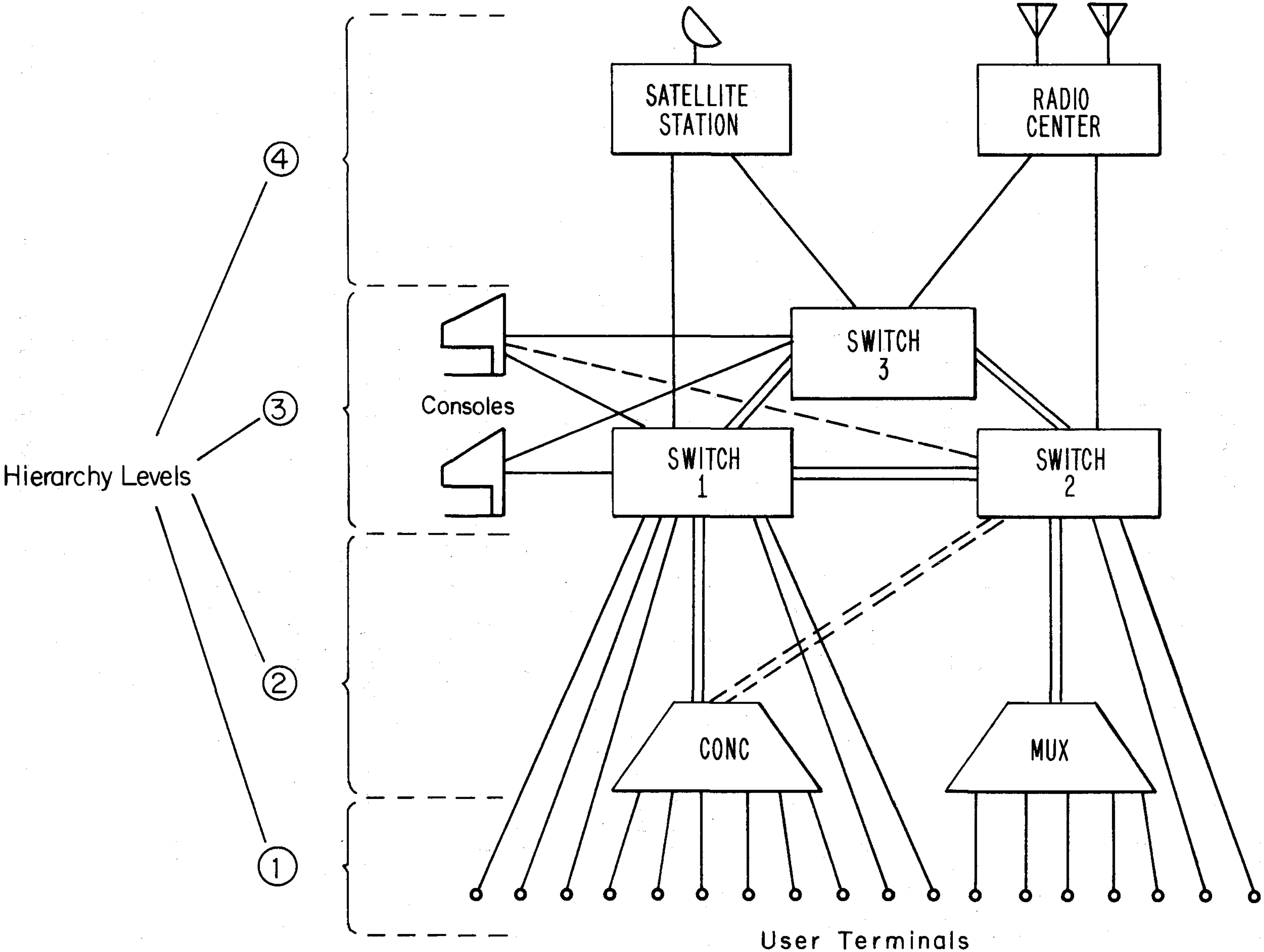


Figure 28. A four-level hierarchy network.

The general objectives of Section 8.1 must be addressed from the vantage point of a given hierarchy. Thus, installation speed, survivability, performance, and potential for updating are projections (viz., like coordinate axes) of the corresponding functions performed at the hierarchy levels of Figure 28.

Clearly, installation time is reduced when the sum total of cable spans and distances is reduced. In the four levels of Figure 28 this has different implications. At level 1, the matter is perhaps the simplest. Each user terminal has nominally one path to the network. As long as that remains so, and no nodes are added, deleted, or reconfigured, the line distances of level 1 can be minimized only by connecting the user stations via a star configuration to their nearest concentrator, multiplexer, or to a switch.

At the second hierarchy level, there are more options. First, one must select the appropriate number and types of concentrators or MUX units. Second, one must assign them to suitable locations, so as to reduce the overall cable and line distances. This topological problem extends outside level 2 proper. It depends on the geographic scattering of user terminals, as well as on the nodal constraints.

At the third level, most communications traffic is further concentrated, switched, and otherwise controlled. The switching centers may often, but not always, be in relatively central locations, not too distant from each other. Therefore, the total cable distance is not dramatically increased by redundant interconnection of the switches. At the same time, the enhanced connectivity between switches aids the broad survivability objectives of the network.

The fourth level has the radio gateways. This so called radio park is ordinarily quite remote from the hub of the command post. The actual placement is dictated by the terrain, the EM emission, hazards and command decisions. At this level the networking options are somewhat limited. A single link to each of the radio transmitter/receiver vans may lessen the cable length. However, to increase the CP tactical survivability, some backup circuits may be worthwhile. Figure 28 shows two paths to both the satellite station and to the radio center, respectively, at the hierarchy level 4.

8.2.3. Levels and distance objective

A quantitative summary of typical link distances for the main network elements is given in Figure 29. It is seen that all communication units of a command post are distributed within roughly 3 km$\cong$2 mi of the central switches of the post. By

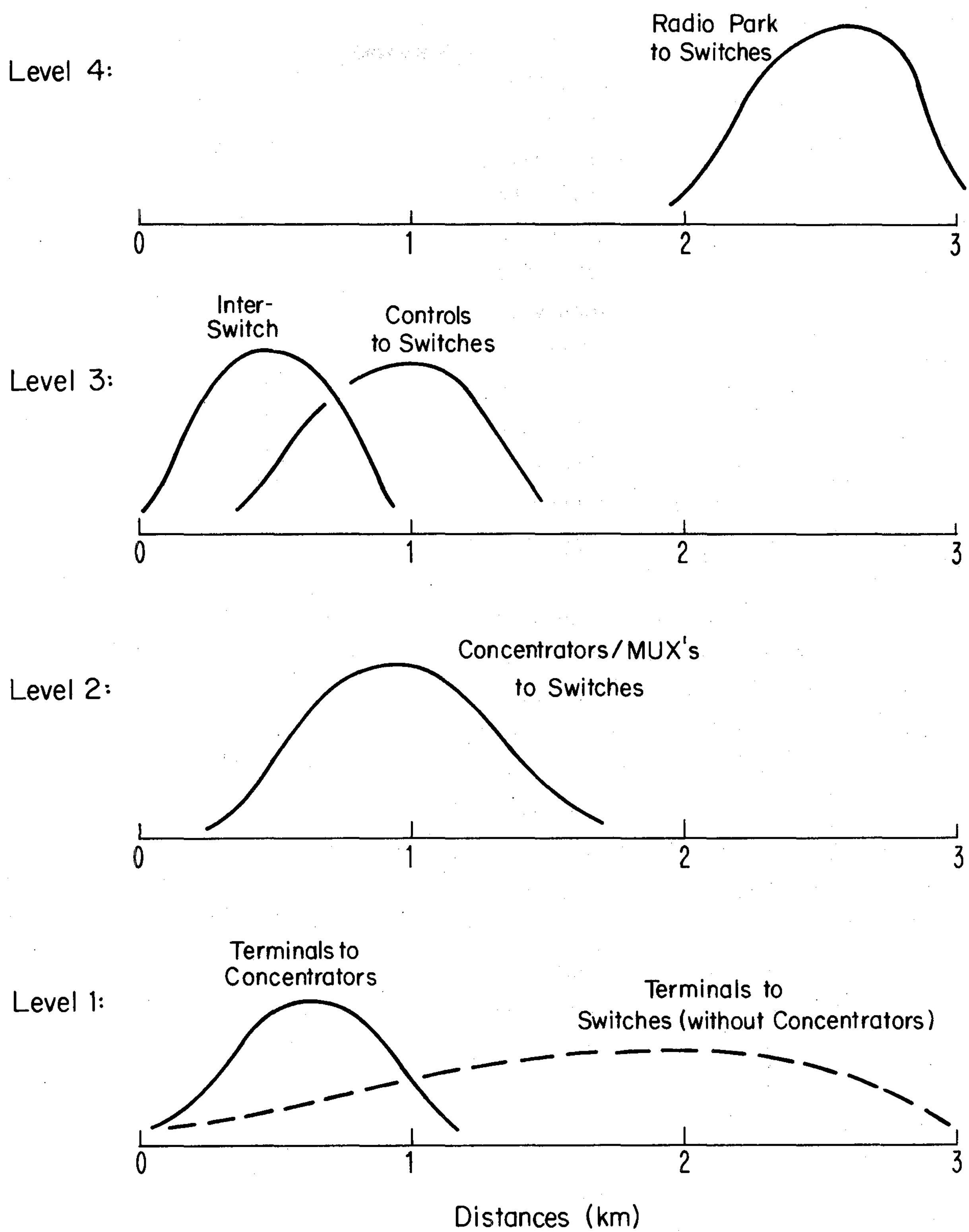


Figure 29. Typical CP/SC link distance distributions.

definition, closest to the center may be the switches themselves. They, plus the nearby controls, comprise hierarchy level 3. The distribution of distances to the radio park (level 4) appears to have the largest mean, namely 2 to 3 km.

If there were no concentrators or multiplexers, that is, if level 2 were removed, the distances to individual terminals could be widely dispersed. This is shown with the broken curve in Figure 29, level 1. Without concentration, the user terminals could be located anywhere from 0 to 3 km from the switches. The introduction of level 2 concentrators serves to reduce the station loop lengths to the order of 1 km or less. To achieve that, however, the concentrator to switch distances must be taken into account. Figure 29, level 2, shows these concentration/MUX distances to average around 1 km.

8.2.4. Levels and other objectives

Different network design objectives are differently affected by hierarchy level modifications. One has already seen how the level 2 introduction reduces station loops at a cost of concentrators and their higher capacity cables. The net effect could be a reduction in overall installation time. There is, however, a problem of contrary objectives. To enhance survivability or connectivity of entire user groups, redundant concentrator cables may be desirable. Survivability measures that add extra cable spans counteract the objective of minimizing the installation effort.

Survivability enforcing cable redundancy seems more effective at the higher hierarchy levels, such as levels 3 and 4 in Figure 28. Other objectives, such as those discussed in Section 8.1, also appear to be somewhat level selective or sensitive. This sensitivity of objectives at the suggested hierarchy levels is summarized qualitatively in Table 18. Three descriptors, low, medium and high, are used to reflect the bearing that a certain hierarchy level has on the assumed objectives. Thus, for example, level 2 is alleged to have a higher impact on installation speed.

As a preliminary design tool, Table 18 can be used as follows. At the first pass, all highs should be addressed. That is, level 2 should be designed to minimize installation speed. Level 3 should be tailored for improved survivability, performance and upgradability. And for the final high, level 4 should stress survivability.

The second pass may concern medium impacts, and so forth. Conflicts between different objectives and level pairs are resolved through cost-benefit tradeoffs.

Table 18. Hierarchy Level Impact on General Network Objectives

		GENERAL NETWORK OBJECTIVES			
		INSTALLATION SPEED	SURVIVABILITY	PERFORMANCE	UPGRADABILITY
HIERARCHY LEVEL	4	MEDIUM	HIGH	MEDIUM	MEDIUM
	3	MEDIUM	HIGH	HIGH	HIGH
	2	HIGH	MEDIUM	LOW	MEDIUM
	1	LOW	LOW	MEDIUM	MEDIUM

8.3. Network Design and Topology

The overall design of a network has four parts:

(1) Identifications of nodes and terminals.

(2) Assignments of links or connections.

(3) Capacity assignment.

(4) Flow control specification: switching, routing, management, and so forth.

The first two parts are inherently topological. The last two parts are strongly dependent on topologies used.

For the command posts, the number of nodes and terminals are relatively small: there may be 1 to 6 switching nodes and from 100 to 500 user terminals. Their locations are often determined by terrain conditions, field commander decisions, and other nontechnical factors. The first topological part (1) is thus removed from the technical design arena.

In this section we review the remaining parts (2) and (3) of the network design. Because of program constraints, part (4) is not included in this study. Part (2) discusses the connectivity issues. It presents most of the topological material contained in this study.

8.3.1. Linking of nodes

In the real operational world, with its uncertainties and day-to-day changes, precise optimal algorithms may not be superior to common sense and quickly impleented rules of thumb. In what follows, we review the connectivity problem based on the premise of overall utility. Emphasis is placed on the key objectives introduced earlier in Section 8.1.

The CP/SC networks may contain several node types (e.g., multiplexers, concentrators, automatic switches, manual switchboards, etc.) and at least two kinds of user terminals (i.e., ordinary field telephones and teletypes). When one talks of nodes and terminals in the general context, one presumes that the entities mentioned could be any of the above.

Consider the four-level network hierarchy discussed earlier in Section 8.2. Network design must, among others, specify the topological connectivity between levels and within each level. For example, at the level 1 of user terminals, the station loops are nominally strung without backup - in a star configuration - to the nearest network node. This star topology appears as a leading alternative for level 1 connectivity.

At higher hierarchy levels, such as at level 3 of the switches, there may be far more connectivity and the appropriate network may contain several loops. Note that in Figure 28, the three-switch net at level 3 is fully interconnected by the single loop shown. The inclusion of the two consoles makes this a five-node network. That version has more loops, but is not fully interconnected.

Consider the situation of Figure 27, where the set of user terminals and exterior gateways is specified. To have something concrete to talk about, let there be 300 terminals, 3 gateways, and assume that only one switching node is available. Then the first network topology alternative is the familiar star, see Figure 30.

The star configuration has three hierarchy levels. Level 1 has the 300 terminals and their respective station loops. These are the previously mentioned twisted-wire pairs. Level 2 consists of the central switch hub. It contains all network controls either automatic or manual. Level 3 has the three exterior gateways. Depending on the amount of distant vs. local traffic, the links to the gateways must be appropriately sized multichannel cables.

The three-level star network of Figure 30 must be assessed in terms of the general network objectives of Section 8.1. One finds, of course, that the installation time objective boils down on just how fast the 300 plus 3 lines can be deployed. The total line distances (see Figure 29) are estimated to be:

Single twisted pair, not buried	-	450 km.
Multipair cable, buried	-	8 km.

Thus, a grand total of roughly 460 km lines must be laid.

The burial or trenching distance is reducible when groups of terminals are clustered (as in a HQ's complex or a message distribution tent). One merely gathers as many lines as possible into a common trench (see Figure 31).

A simple extension of this spatial combining (sometimes called space division multiplexing or SDM) assembles clustered users onto multipair cables. In typical division or even corps-level installations, the 26-pair cable is quite adequate. Often the cable may be only partly, such as half, wired. In rare instances at corps level, the 100-pair cable is really needed.

The SDM cables extend from the switch outward. They terminate in individual junction boxes, wherefrom station loops are fanned out in their own directions.

Return briefly to the trench distances for Figure 31. Realistically, let 50% or 150 of the 300 terminals share common 26-pair cables. Then (see Figure 29 for typical distances) the line distances are on the order of:

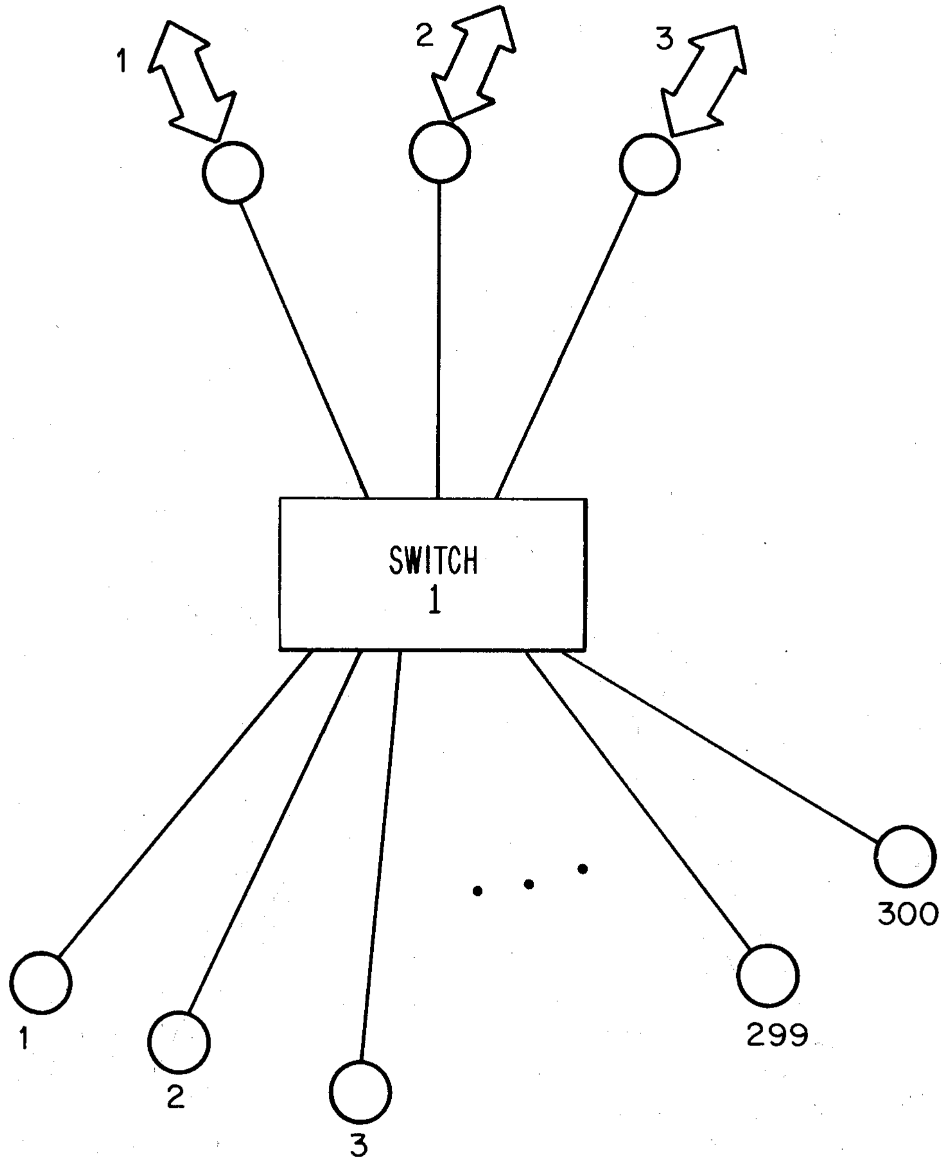


Figure 30. The star network.

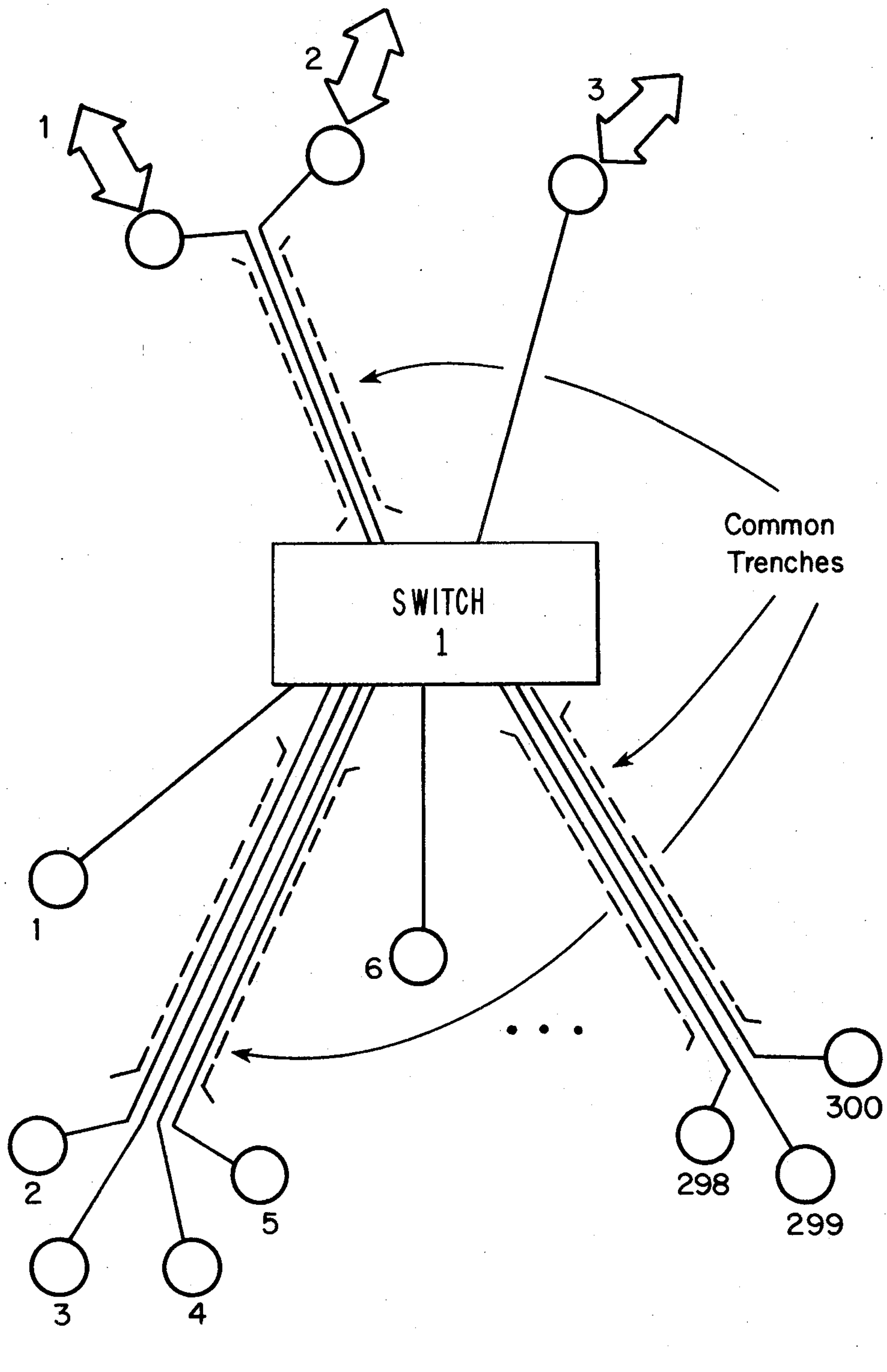


Figure 31. Space-division-multiplexing (SDM) or common trenches for the star network.

Single twisted pair, not buried	-	300 km.
Multipair cable, buried,	-	20 km.

Now, a grand total of 320 km lines must be laid. The approach illustrated in Figure 31 thus compares favorably with the pure star of Figure 30.

The three-level hierarchy of star, as shown in both Figures 30 and 31, has apparent survivability shortcomings. After all, the failure of a single node, the centralized switch, brings the entire network to a halt. Individual line cuts affect only a single terminal, if they occur on the user terminal side. On the other hand, if they occur on the gateway side, they tend to cause serious exterior connectivity problems.

The other network objectives of service, performance, future updates, and so forth, seem to offer no particular difficulties to the star configuration.

The three-level hierarchy can be extended in several ways to higher level hierarchies. A simple extension is shown in Figure 32. The new hierarchy consists of the previously mentioned four levels. An additional level of concentrators and multiplexers is added on the user terminal side of the switch. And, the exterior gateways are mutually interconnected to enhance their survivability against link outages. By the way, the links between gateways, the links between gateways and the switch, and the links between the concentrators/multiplexers and the switch are assumed in Figure 32 to be higher circuit capacity multichannel buses. These could be the previously mentioned space division multiplexed (SDM), frequency division multiplexed (FDM), time division multiplexed (TDM), or any other transmission mode or medium with sufficient capacity. The buses, be they cables or optical fibers, should be buried for field survivability.

Basically, the single switch in Figure 32 still occupies the same vulnerable spot as in Figures 30 and 31. The outage of the switch node has catastrophic consequences on the entire network.

To improve the network survivability, additional switching nodes should be provided. It is intuitively clear, that, depending on the number of switch nodes and their connectivity, the individual node and link outage consequences can be variously suppressed. This enhances survivability. However, it also requires more installation time for both the added cable spans and for the setting up of the switches. This is particularly true, whenever all the switches are fully interconnected among themselves.

Figure 33 shows the fully interconnected versions of the switch hierarchy level only. This would correspond to level 3 in Figure 28. The four parts of

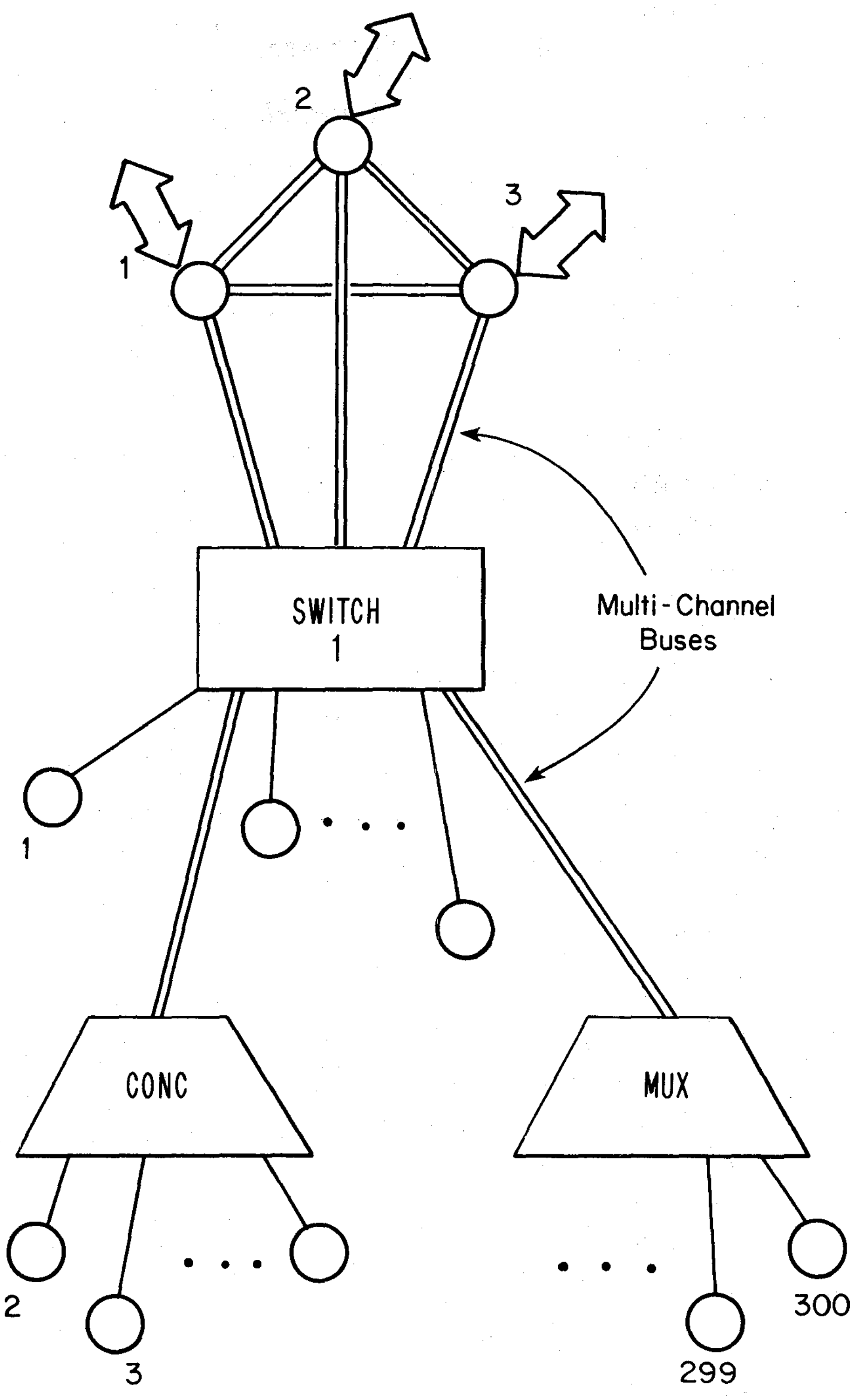


Figure 32. A four-level hierarchy with centralized switching.

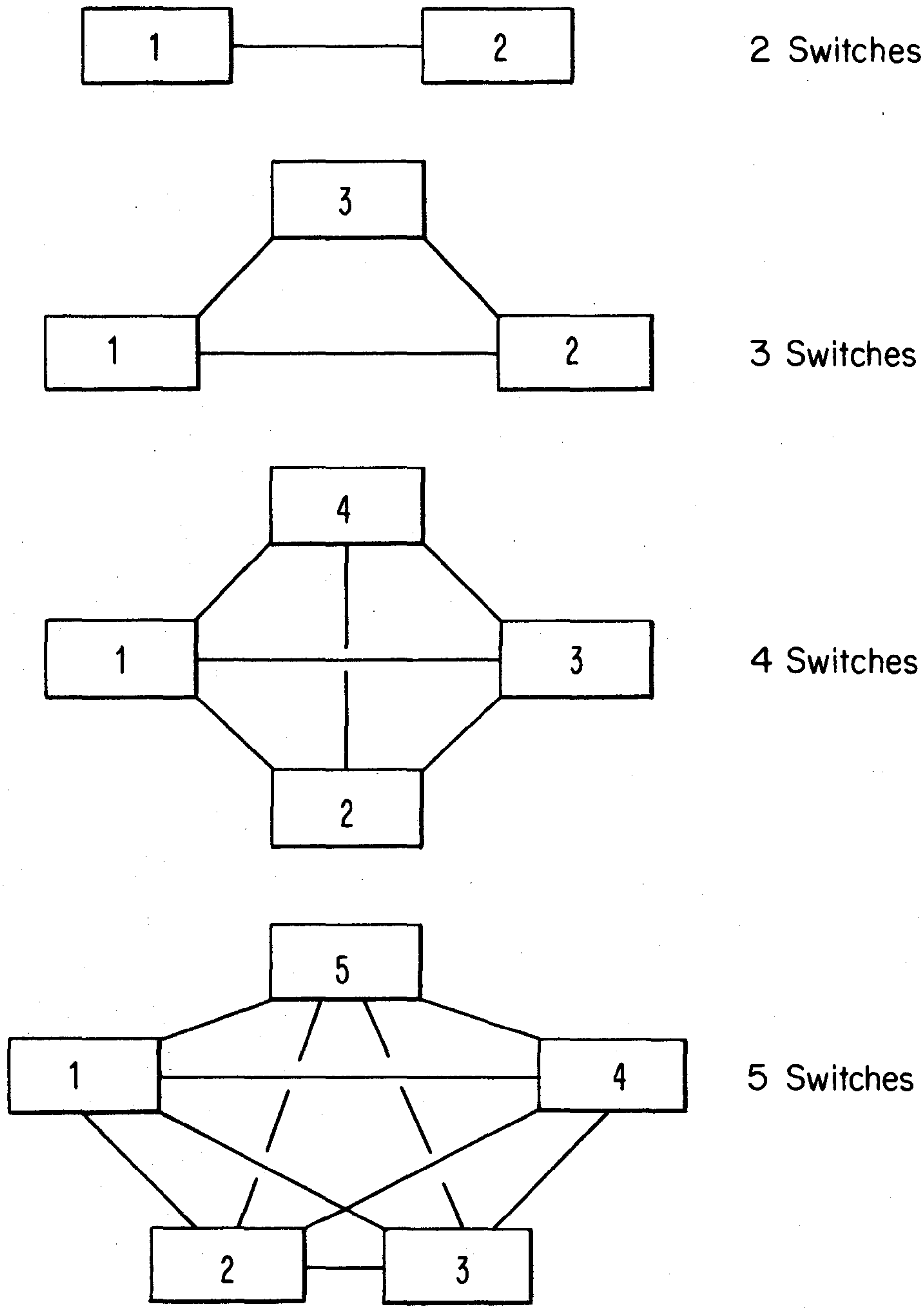


Figure 33. Fully interconnected, distributed switch hierarchy level.

Figure 33 show the fully connected topologies for 2, 3, 4 and 5 switches. The network elements on other hierarchy levels, such as user terminals, external gateways, or multiplexers, are purposely not shown in Figure 33.

There is no question, that the high switch network survivability inherent in the large number of fully interconnected nodes is bought at the expense of expanded cable plants. Roughly, for such configurations, the total cable distance grows in proportion to the square of the number of switches. The installation time grows proportionally. This contradicts the first design objective, namely that of minimal installation time. Some configurational compromise appears needed. Various compromise networks are introduced in the next sections.

8.3.2. Capacity assignment

Both links and nodal elements can generally be engineered to carry varied amounts of telecommunications traffic. In circuit switched applications for command post networks, this boils down to specifying the number of calls (or busy terminals) that can be served at the sundry levels of the network. The specification usually is only valid for a time period of interest, such as the worst case or busy hour of the day. It is also based on the realization of a desired grade of service for the community of users.

Insufficient switch and/or line capacity results in calls not getting through when the other (called) party is idle (on hook). The probability of such call blocking is normally referred to as the grade of service. A typical design objective in the commercial telephone world is a busy hour 1% grade of service. Then, on the average, one out of a hundred calls is likely to be blocked. If blocked, a service request could be dropped (lost) or allowed to wait (queued).

In the CP environment, the priority classes (i.e., P, R, O, Z) may preempt each other according to specified rules. This reduces the probability of blocking for the higher classes to essentially zero. And, since the number of high-classification terminals is small, it increases the blocking of the lower classes only by a very slight amount.

The following ideal grade-of-service situation will be assumed here. In its fully implemented operational state, with no link or node outages, it is assumed that the network is fully nonblocking. That means that any pair of idle terminals can promptly communicate with each other. Grade of service impairments then occur only when some nodes or links, or both, are disabled.

To protect against such grade of service degradations, i.e., to reduce the network vulnerability to subsystem outages, one may supplement and reinforce the network in various ways. For a fixed node arrangement, one can add more links (viz., increase the connectivity) or one can add link capacities, or both.

A two-step capacity assignment is illustrated in Figure 34. Both parts (A) and (B) display the same concentrator and switch hierarchy levels of a potential installation. Three switches and two concentrators are shown. Each of them is a hub (i.e., collection point) for a number of user lines. That number of terminals is indicated adjacent to the nodes of Figure 34. Thus, switch 1 serves 48 stations, switch 2 has 36, and switch 3 is the homing point for 24 station loops. The two concentrators are assumed to have 12 and 6 terminals, respectively.

Part (A) may be viewed as the first step of network design at this hierarchy level. Part (A) proposes a star configuration which centers at the largest node (i.e., at switch 1). The capacities of links are assigned to concur with the number of stations at the lesser of the two end nodes. For instance, between switch 1 and switch 3, which have 48 and 24 terminals, respectively, one installs 24 channels. Then, given enough switching capacity, all idle users at switch 3 can be served. This assignment ensures total absence of blocking in part (A).

Trouble occurs when either switch 1 or any of the links in part (A) of Figure 34 is disabled. In the first case nearly all nodes are disconnected from each other. In the second case, one node is separated from the network.

To enhance the survivability of this network, one proceeds to the second step of the design. This is shown in part (B) of Figure 34. Here one adds new links to increase survivability for all nodes. The procedure is simple. One constructs a secondary star around the second largest node. That is, one adds new links from switch 2 to all those other nodes, that previously had no direct path to switch 2. This secondary network is drawn with broken lines in part (B) of Figure 34.

The new individual link capacities may again be picked to be the lowest number of terminals at the two end points.

If any one of the nodes is deleted from (B) the rest of the network remains intact. By that one means that the remaining network is still connected and nonblocking. When a single link is severed, the network does remain connected. However, it may or may not exhibit some blocking. For instance, if the largest link between switches 1 and 2 is cut, some nonzero probability of blocking might occur. On the other hand, if either of the 6 circuit links from concentrator 2 is cut, the blocking probability is still zero throughout the network.

The second step of part (B) has made the first step network of part (A) more survivable. But, it does represent added cables, trenches, and more sophistication at the switches and concentrators. The extra distance (see Figure 29) is on the

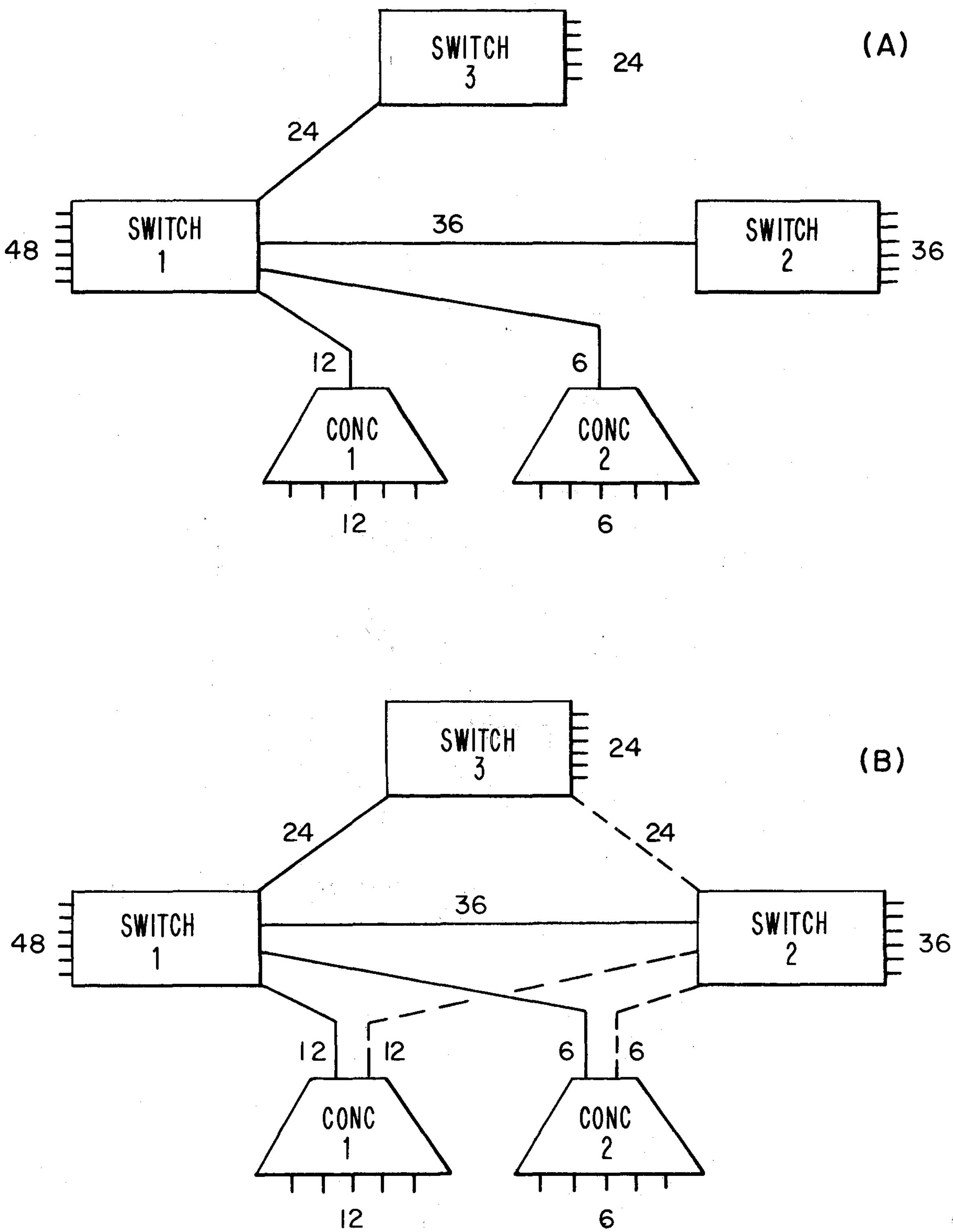


Figure 34. Link and capacity assignment.

order of 3 km, which is perhaps 75% of the total distance in step 1, part (A), of Figure 34. The additional installation time is expected to be commensurate.

The star configuration of part (A) represents a minimum capacity nonblocking topology. Part (B) enlarges the capacity by nearly 54% over the minimum.

The procedure can be variously generalized. Third, fourth, and so on, sub-stars may be added. Or, the individual link capacities can be increased to the point where connectivity implies nonblocking. Usually, one-half of the total number of terminals is a safe upper bound for the link capacity throughout the network. From Figure 34, adding the terminals yields,

$$\frac{48+36+24+12+6}{2} = 63$$

This suggests that part (B) with all links increased to 63 channels must be non-blocking in the presence of a single link outage. This is a relative increase of some 465% over part (A)! It is safe, but far more than is necessary.

There do exist capacity efficient network design algorithms. Unfortunately, they are rather complex. For the command post network design, simpler methods appear desirable. In addition to the multistep star approach of Figure 34, the structured configuration of the next section should not be overlooked.

8.3.3. The structured configuration

The previous sections on link topologies and capacities should be viewed as simple working introductions to a complex design problem. No complete solutions have been offered here. In fact, no problem has been defined with the necessary generality in mind. The general topic is quite theoretical and only tractable with numerical algorithms. It calls for completeness and depth beyond the scope of this short study.

The examples given here demonstrate what can be done with simple tools. The list of topologies can be expanded into tree networks, loops, grids (meshes), and numerous hybrids thereof. We shall skip that, as most of such networks and their rudimentary properties must be familiar to the readers.

Instead, it appears more meaningful to consider a sequence of structured network configurations, that seem suitable for the concentrator and switch levels of the command post networks. The simple concept is introduced graphically in Figure 35 for 2, 3, 4, and 5 switching nodes. For an arbitrary number of N nodes, the structured configuration network is defined in Figure 36.

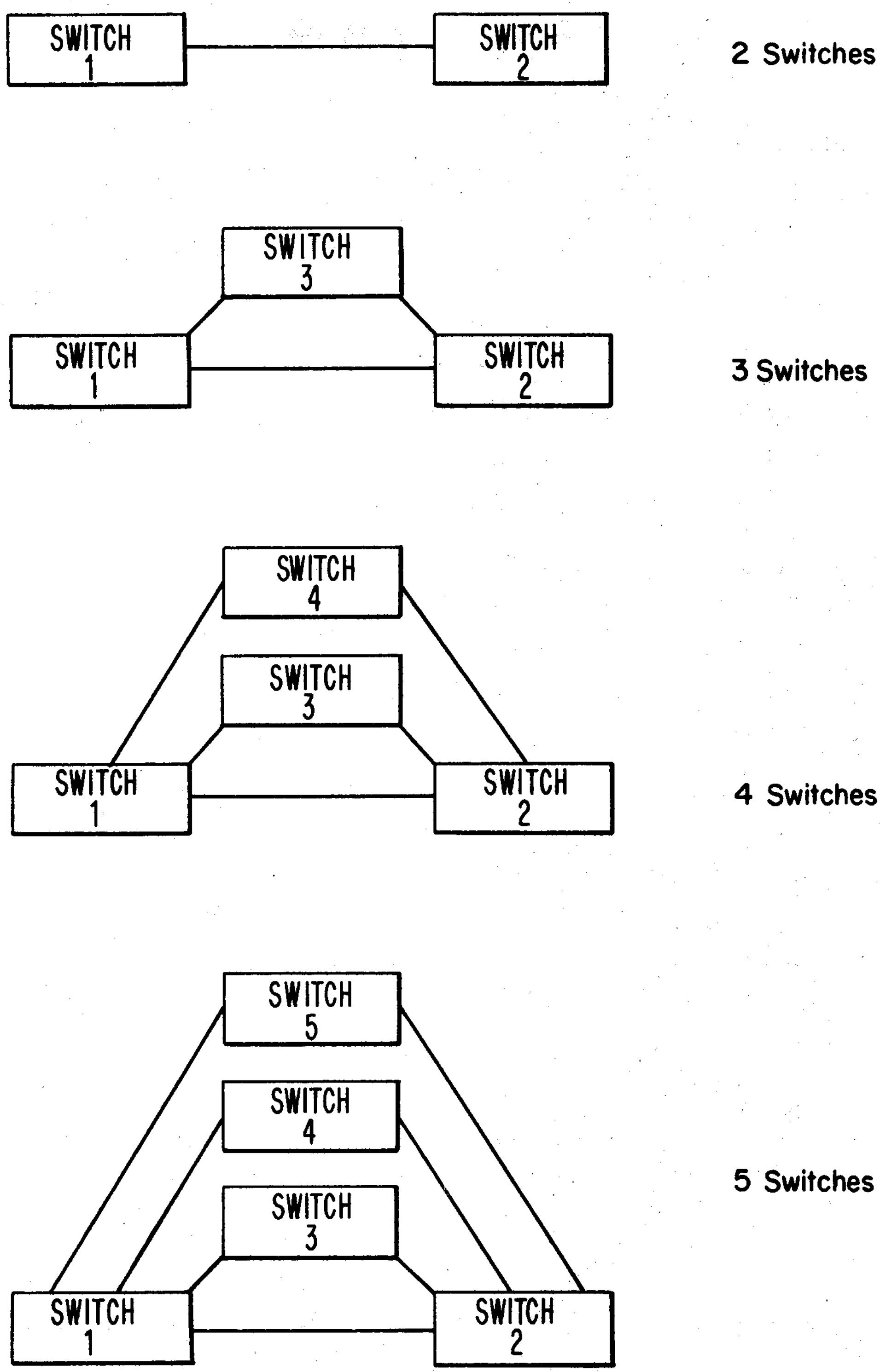


Figure 35. The structured configuration networks for two to five switches.

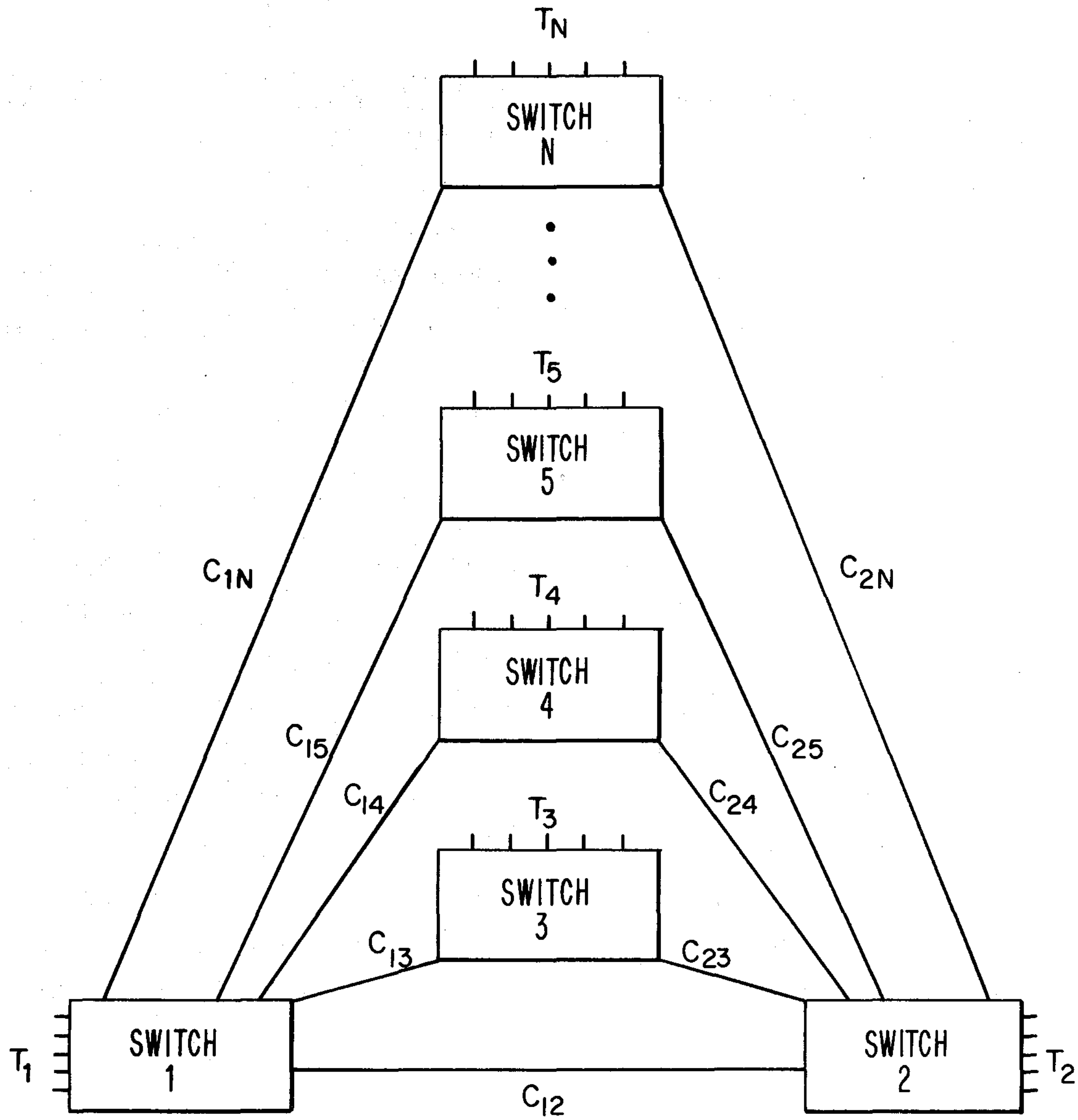


Figure 36. The general structured configuration.

To start, order the nodes 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

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

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 two upper networks in Figure 35. 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 multi-loop structure with 2N-3 links for $N \geq 2$ nodes. For larger N, this number is nearly double that for minimum spanning tree (such as the star network). But, it is noticeably less than for fully connected networks with the same number of nodes.

Figure 37 compares the number of links necessary to implement the more common network types.

The notation for the structured configuration was introduced above in Figure 36. The nodes or switches are identified by n=1, 2, ..., N. Their 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 question that must be answered is how the structured configuration link capacities C_{nm} should be assigned to meet survivability objectives. Effective capacity assignment must be a function of the user terminal set, telecommunications traffic requirements, and other general command post design objectives mentioned earlier.

Note in conclusion of this section, that the second step, part (B), of Figure 34 for N=5 nodes is a special case of this structured topology. It was arrived at from a different point of view, where a secondary star was added on top of a primary star.

8.4. Survivability Aspects

Universal definition of survivability is difficult. The reasons are understandably many. Perhaps the most prevalent reason has to do with the individual systems users and the subjective urgencies that they encounter. System nonperformance in such instances may contribute to losses outside the system itself. The urgency in a tactical environment is certain to vary as a function of time, place, mission, random events, and a series of strenuous circumstances. The survivability of some communications paths may always be essential. Or the opposite may be true, unless some actions happen to reverse the roles. It appears

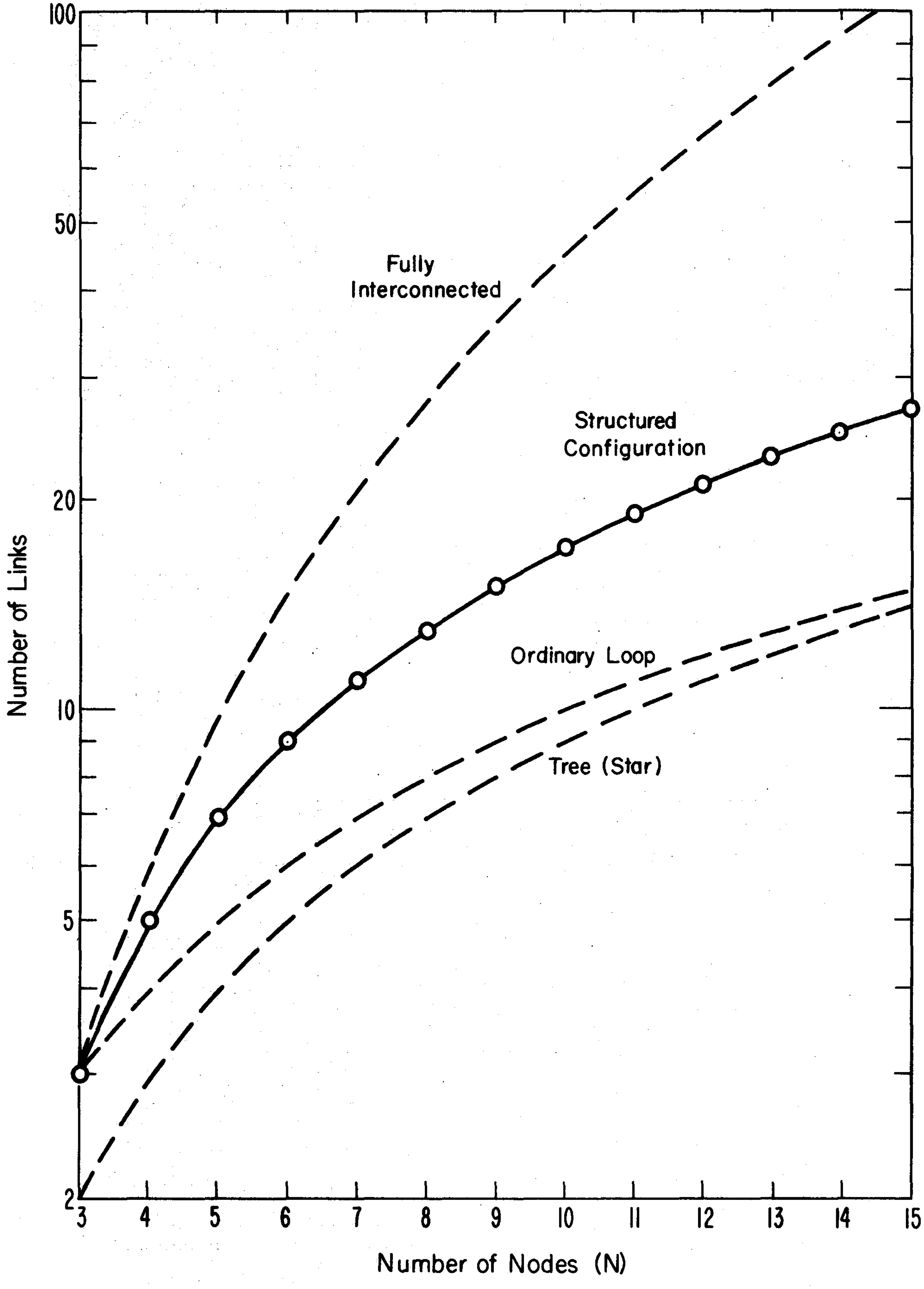


Figure 37. The number of links required by several common topologies.

nearly impossible to find uniformly accepted documented definitions to suit everybody. The definitions, to be attempted next, are intended soley for the tactical command post scenarios.

8.4.1. Two dimensions of survivability

In this section survivability is defined as a two-component entity, (D,P). The first component, D, describes the disconnection or disjointedness resistance of the network. It concerns the connectivity characteristics of a given topology.

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 subnetworks 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 command post 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 command post 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 these 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 38. Figure 38 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 38 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.

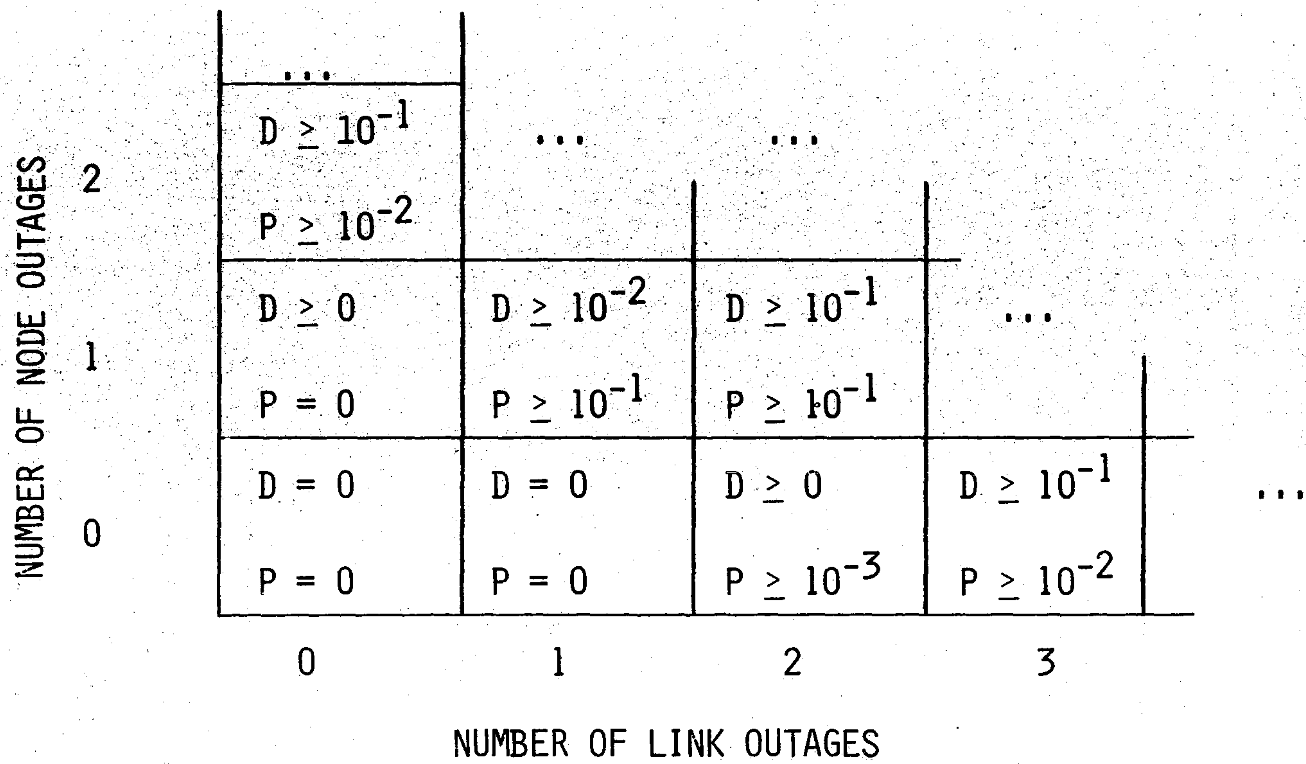


Figure 38. The (D,P) contour as a function of link and node outages.

Let $T=T_1+T_2+...+T_N$ denote the total number of terminals in the command post service area. Let E be the number of exterior gateway or outside lines. Then, as long as the lowest link capacity, C_{min}, satisfies

$$C_{min} \geq 1/2[T+\min(T,E)],$$

network connectivity implies absence of blocking in that network. Then, of course, D=0 implies P=0 and connectivity is tantamount to survivability.

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).

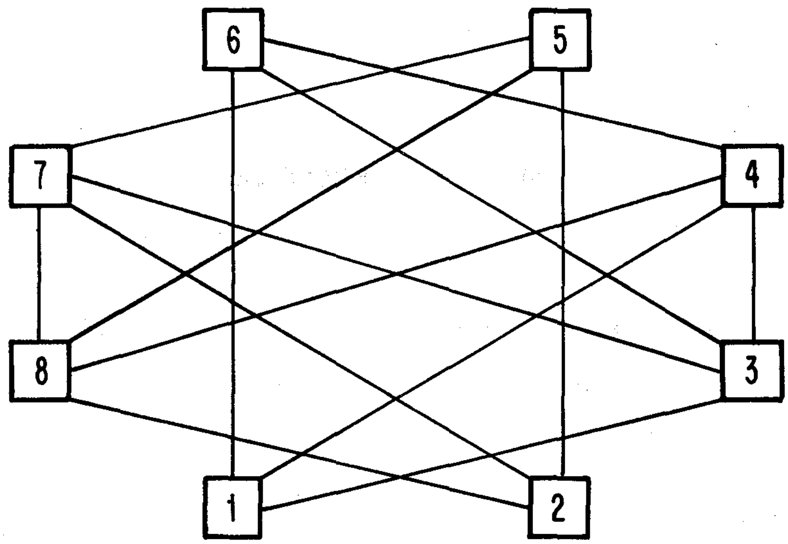
In the extreme case, such as on Christmas Day or Mother's Day, the public switched network may be extremely blocked and yet connected, i.e., P>0 and D=0. Then, in the additional presence of any subnetwork outages, grade of service appears to be the more realistic measure of network survivability.

8.4.2. Determination of D

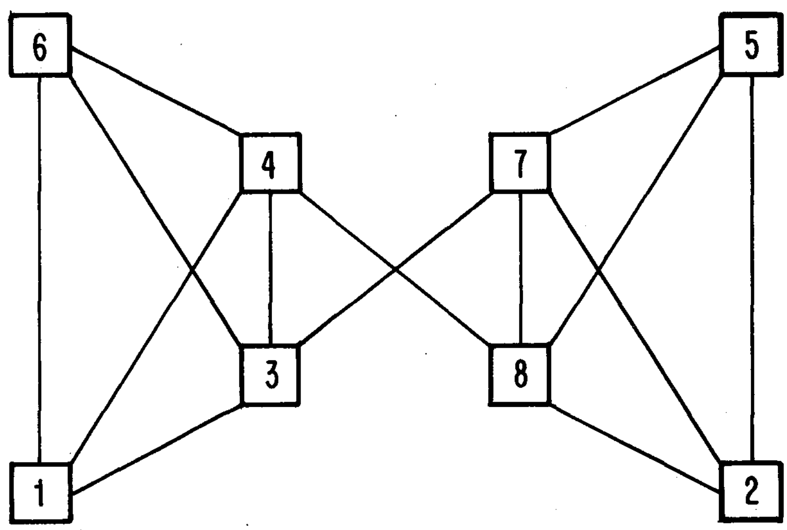
Determination of D involves analysis of topology. Sometimes it is easy, at other times, difficult. Consider a scenario where link cuts comprise the most outages, and examine a network such as shown in Figure 39, part a). What is the least number of link cuts that separate this eight-node apparently connected 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 39.

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 command post situation tends to alleviate these complexities for two reasons. First, the CP networks are relatively small. That is, the number of nodes and higher level links is typically under ten. Quick inspections then may



a) Sample Network



b) Equivalent Topology

Figure 39. A sample network and its equivalent topology.

reveal connectivity flaws and disconnectivity, i.e., $D>0$, possibilities. And second, the command post network layout is under the control of CP/SC commanders. Commanders can purposely adhere to simple and well-connected network architectures.

8.4.3. Determination of P

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

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 present and future CP/SC 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 40. 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 41 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 41.

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 sets $C \geq T/2$, then single-link outages still imply $P=0$.

In Figure 41 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

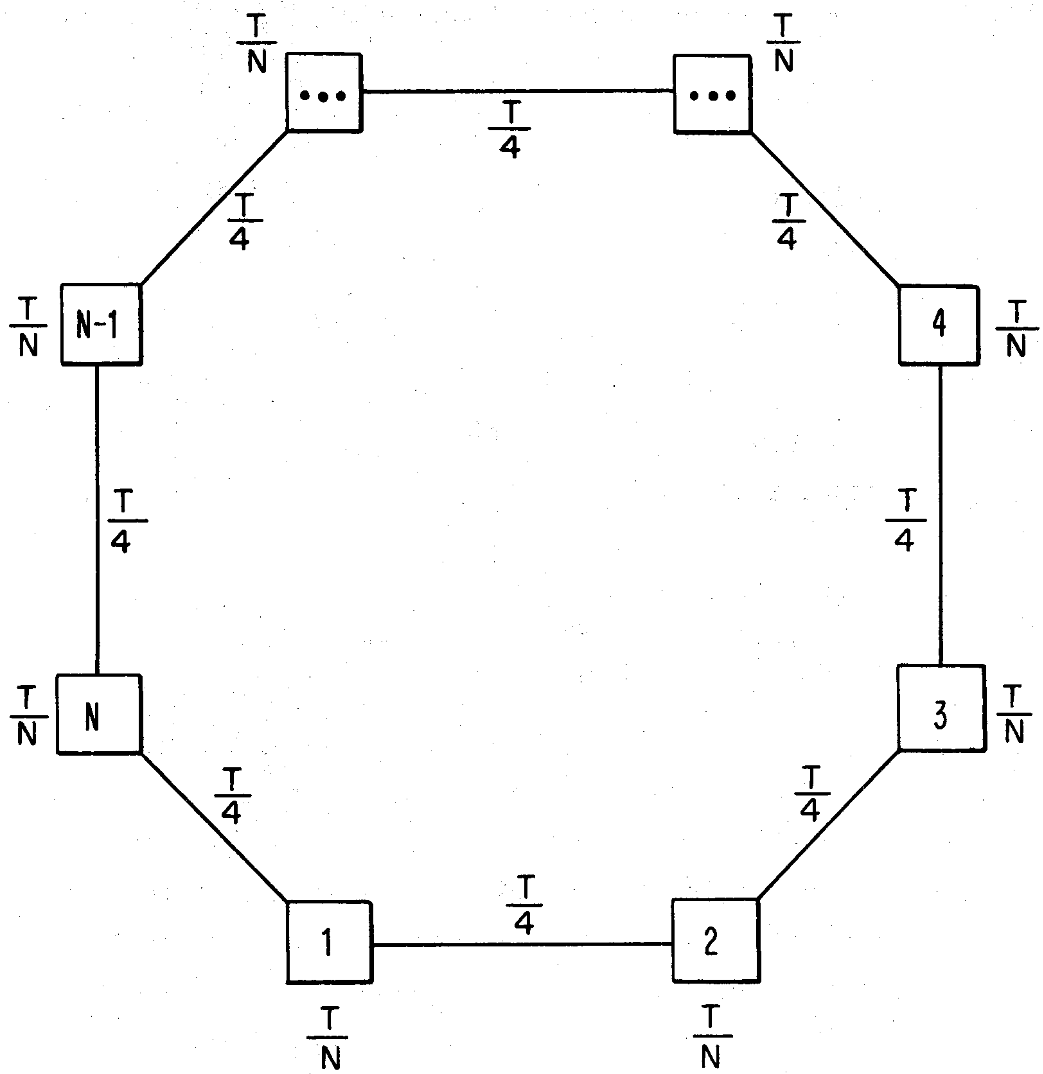


Figure 40. Loop network with uniform links and nodes.

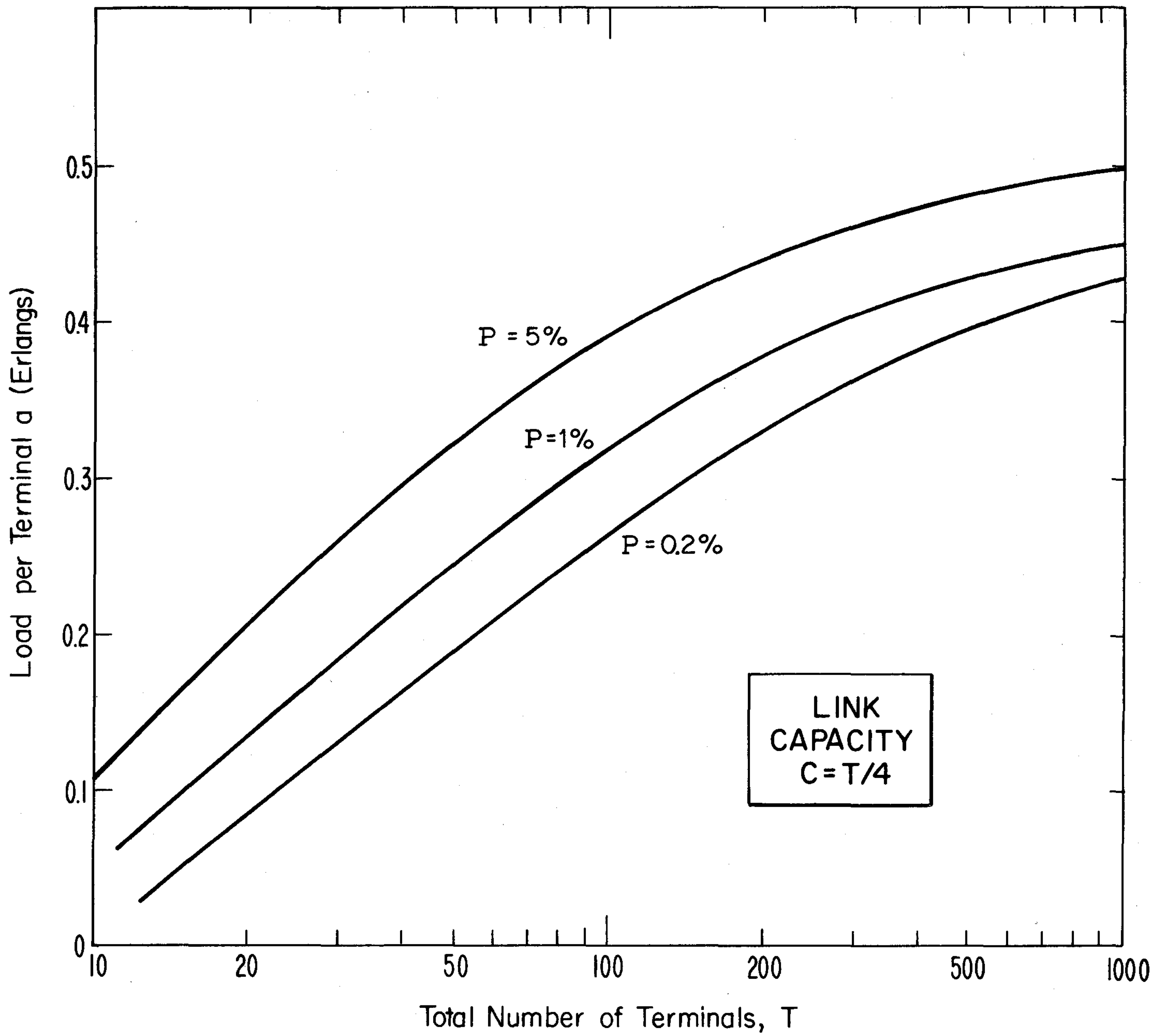


Figure 41. Worst case probability of blocking for the uniform loop network with a single link outage.

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, $aT \cong 2(15.3)$ Erlangs. Hence, $a \cong 30.6/T$. For $T=300$, this yields $a \cong 0.1$, or approximately six minutes of talking activity per individual telephone terminal, per hour. In command post applications, one expects the traffic intensity to be of this order of magnitude.

The characterization of the "worst case" of blocking deserves several comments. The effect of cutting one link in Figure 40 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 non-uniform loop may be the next illustrative example, as shown in part (A) of Figure 42. This is a network of four nodes and

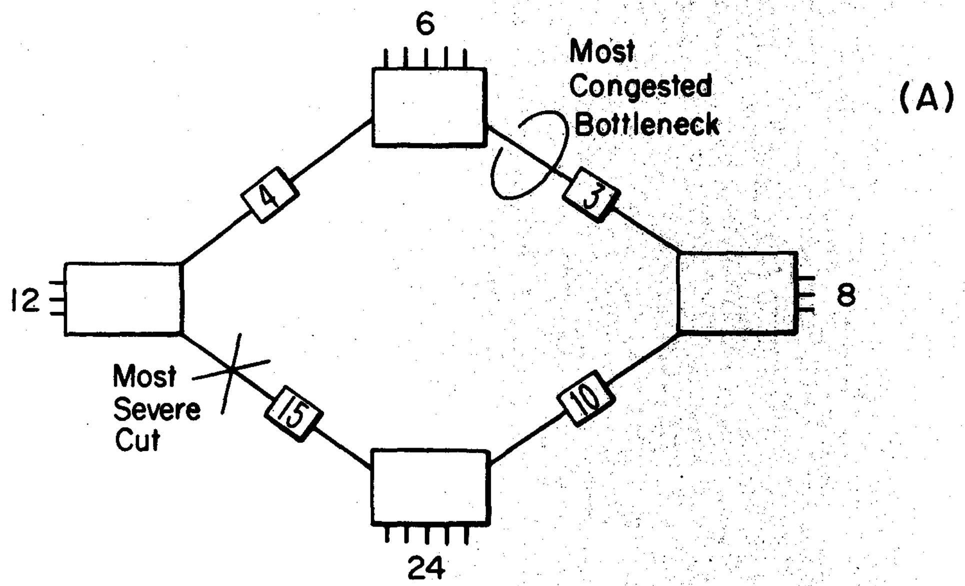
$$T = 24 + 12 + 8 + 6 = 50$$

terminals. The number of channels per each link are indicated in Figure 42 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 42). 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 3 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, then $P \cong 5\%$.

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 42. 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 4. The approximate blocking probability



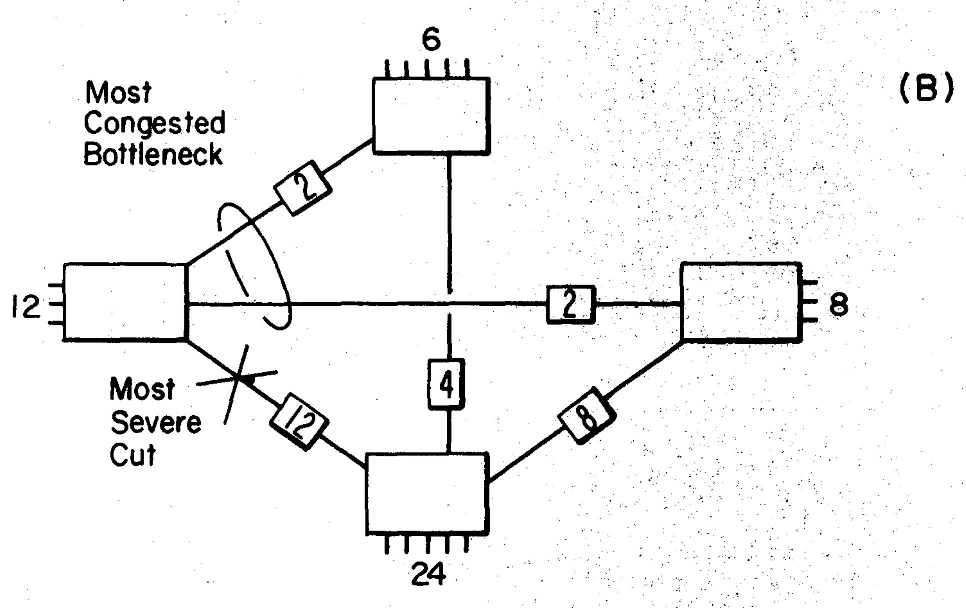


Figure 42. The most severe cuts and bottlenecks in simple networks.

(under the same ground rules as in part (A) of Figure 42) is now $P \cong 2.5\%$. 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.

8.5. Structured Configuration Networks

8.5.1. Disconnect survivability of the structured configuration networks

This section considers the structured configuration, as depicted earlier for an arbitrary number of N nodes in Figure 36. 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} (see Figure 36) would separate node N from the network, causing $D \cong 1/N$. 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} is out.

One concludes that it takes two of any outage kind, nodes or links, to produce D>0 in Figure 36. 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 $P_\ell \ll 1$,

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

is the disconnect probability of the structured configuration network.

8.5.2. 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, user requirements and system economics.

Given no link or node outages, the structured configuration (Figure 36) 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 43. It has N=4 nodes. The number of terminals is structured to obey the inequality

$$T_1 \geq T_2 \geq T_3 \geq T_4.$$

For uniformity, modularity, and speed of installation, Figure 43 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 Sections 8.3.2 and 8.4.1, $C \geq (T_1+T_2+T_3+T_4)/2$ suffices to guarantee nonblocking, i.e., P=0, as long as there is total connectivity, (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 43, 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 19.

Table 19 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 43. 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 19 show the number of link and node outages assumed for that particular row.

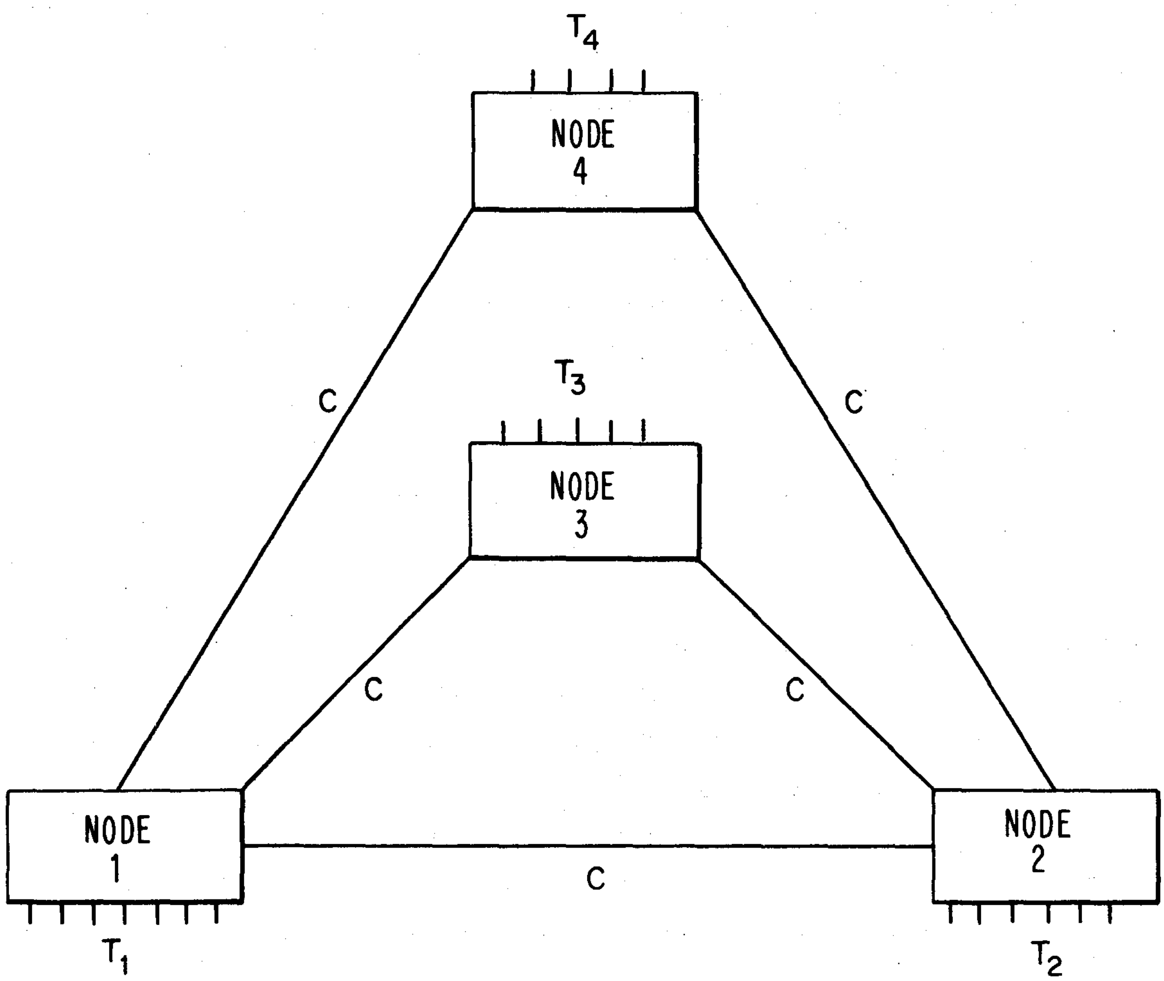


Figure 43. A simplified four-node structured configuration.

Table 19. 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	$\frac{1}{N-2}\max_{I_N}[(N-2)T_3, \min(T_1+\sum_{I_N} T_i, T_2+\sum_{I_N^c} T_i)]$	

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 43, 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 19 presents a simple workable upper bound on the minimum C_0. Being of the form

$$C = (T_2+T_3+...+T_N)/(N-2),$$

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.

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 no outage or single outage cases.

Several explanations may be appropriate for the general N formulas in Table 19. 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, ..., 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 $\{T_1, T_2, ..., T_N\}$ are desirable. The last column, as noted earlier, represents such simplications. Unfortunately, the claimed sufficient capacity for general N is unproved presently.

So far, the emphasis has been on P=0. Realistically, 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 hierarchal levels of interest, a worst-case survivability analysis can and should be performed.

8.5.3. Installation objective

This section reviews the installation objective of the structured configuration network. As discussed in Sections 8.1.1 and 8.2.3, the general objective is to reduce the installation time of the CP/SC network. If the speed of available machines and manpower remain relatively constant, then the installation time must be roughly proportional to the network size. That size consists of link distance in kilometers (1 km=0.62 mi), both buried in trenches and laid on surface, plus all nodal installation. This section concerns the link distances only.

Assume the structured configuration switch network, hierarchy level 3 (Figure 28), with uniform link capacities. For N=4 switches, that network is as shown in Figure 43. We also permit N=1, 2, 3, 4, 5, 6, by including the star configuration for N=1, and by otherwise following the model of Figures 35 and 36.

Beyond the switch hierarchy level, assume the four levels introduced in Figure 28. Let there be T=300 terminals at level 1. Part of these terminals are concentrated at level 2, by multiplexing unto T1 equivalent buses. For practical layout reasons, assume that on the average, 20 out of 24 circuits are active. This may be denoted as a 20/24 channel MUX.

Level 3 consists of the previously elaborated switches. There are N switches. They collect all the MUX loops and direct user loops. Above the switches, at the gateway level (see Figures 27, 28, 30, 31 and 32), assume E=3 exterior access radio nodes.

Higher hierarchy levels above 4, by present assumption, are reserved for higher military echelons and DoD backbone networks.

The number of links depends on the number of switch nodes N used. For the structured switch configuration, plus the four-level hierarchy, the command post link summary is outlined in Table 20.

As the number of switches increases, more terminals are clustered in their proximity. Thus, the number of MUX'es decreases as N increases. More station loops go directly to switches, and less to MUX, at level 1 accordingly. The number of level-2 links (these are multiplexed loops) is assumed to be the same as the MUX'es themselves. Thus, there is one bus per MUX and the MUX'es are configured in star fashion around the switches.

The number of switch level links is, as shown earlier for the structured configuration, 2N-3 for all N=2, 3, ... Note that the total number of intra-command post buses consists of levels 2 and 3. Their total number is nearly constant for all N. A slight minimum of 11 is noted for N=2, 3, 4.

Table 20. Link Summary for Differently Sized Switch Networks and T=300, E=3

# Switch Nodes N	# 20/24 CH MUX	Number of Links: At Terminal Level 1 To MUX	Number of Links: At Terminal Level 1 To Switch	Number of Links: At MUX Level 2	Number of Links: At Switch Level 3	Number of Links: Gateway Level 4
1	12	240	60	12	0	5
2	10	200	100	10	1	6
3	8	160	140	8	3	7
4	6	120	180	6	5	8
5	5	100	200	5	7	9
6	4	80	220	4	9	10

At level 4, which depicts the gateway or radio park links, the numbers in Table 20 are more than the required connectivity minimum. The following rule is used. The three gateway nodes are fully interconnected among themselves. The first, e.g., the largest, switch node is linked to two gateways. This yields the 5 links listed at level 4 for N=1. For every other switch node, a separate path to some gateway node is added.

To assess the network distances of the various N alternatives, the numbers of Table 20 must be combined with typical CP/SC distances. Figure 29 is used here. Thus, one claims the average distances listed in Table 21. Note that the average distance between a terminal and a switch decreases as more switching nodes are distributed in a given service area.

Table 22 lists the total link distances for each of the four hierarchy levels and lists how many kilometers are to be buried in trenches, and how many are to be laid on the surface. The network scenario here is still the same as in Table 20. In particular, the total number of terminals is T=300, and there are E=3 exterior gateways. These gateways are assumed to be interconnected by cables laid on the surface. Their feeds from the CP switches, however, are assumed to be trenched.

The installation time objective is strongly related to the right-most columns of Table 22. If digging trenches and burying cables does consume the bulk of the installation time, then Table 22 has the following usefulness. First, the buried plant (viz., installation time) grows nearly linearly with the number of switches, N. Second, the buried plant (viz., installation time) increment is roughly 10% for each single switch added. This simple rule, of course, is based in large part on the scenario assumed.

The effect of the structured configuration network at level 3 is seen as minor on the installation effort. It amounts to some 15% of the trench digging task. As given in Table 22, most trench mileage is required by MUX loops (especially, when N is small) and by the redundant switch-to-radio park tie lines (when N is larger).

Table 22 also shows that the links laid on the surface, such as wire pairs (WP) or multiwire-pair (MWP) cables, depend but little on N. A maximum amount of surface link distance seems to occur at N=3. It is due to the countereffects of terminal-to-MUX and terminal-to-switch columns in Table 20, primarily. Since surface deployment is apparently a much faster command-post process than cable burial, the latter phenomenon may be an insignificant factor for the installation time objective.

The total distances of various transmission media are also of interest. Table 23 assumes that only two media are used. They are the twisted single-wire pairs

Table 21. Typical Average Command Post Distances

Hierarchy Level	From	To	Valid for N	Average Distance (km)
1	Terminal	MUX	All	0.5
		Switch	1	1.0
			2	0.9
			3	0.8
			4	0.7
			5	0.6
			6	0.5
2	MUX	Switch	All	1.0
3	Switch	Switch	All	0.5
4	Switch	Gateway	All	2.5
	Gateway	Gateway	All	0.7

Table 22. Total Link Distances

N	Total Link Distances (km)						
	Level 1 (Surface)	Level 2 (Buried)	Level 3 (Buried)	Level 4		Total Buried	Total Surface
				(Buried)	(Surface)		
1	180	12	0	5	2	17	182
2	190	10	0.5	7.5	2	18	192
3	192	8	1.5	10	2	19.5	194
4	186	6	2.5	12.5	2	21	188
5	170	5	3.5	15	2	23.5	172
6	150	4	4.5	17.5	2	26	152

Table 23. The Single Wire-Pair (WP) and T1 Bus Totals

N	T_1	Installation Total	
		WP (km)	T1 (km)
1	300	180	21
2	150	190	24
	200	190	23
3	100	192	36
	150	192	32
	200	192	28
4	75	186	35
	100	186	34
	150	186	31
5	60	170	37
	90	170	35
	120	170	33
6	50	150	38
	75	150	37
	100	150	36

(WP) and the 24-channel T1 buses. Both are summarized in the table. One notes that the WP numbers are the same as given for level 1 in Table 22. The total WP distance does not depend on the terminal distribution $\{T_1, T_2, \ldots, T_n\}$. However, the T1 bus mileage does depend on the T_n's.

To estimate the total T1 requirement, one uses the last column of Table 19. According to that column, $C=(T-T_1)/(N-2)$ provides a sufficient uniform capacity assignment. For T=300 and N specified, one needs T_1 to pin down uniquely the T1 bus totals. In Table 23, selected T_1 values are indicated. Since T_1 is restricted to the range, $T/N \leq T_1 \leq T$, there is only one case for N=1.

It is noted that for fixed N the T1 bus total distance decreases as T_1 increases. However, that effect does not appear to be as powerful as the previously mentioned increase with N.

8.6. Remaining Network Issues

This section outlines the dominant outstanding command post network issues. As shown in Section 1, see Figure 2, the general tactical environment imposes broad requirements on the whole command post system and services. We shall comment briefly on these general CP issues. Thereafter, a considerably more thorough discussion will be devoted to the communication network itself.

8.6.1. General and service issues

The general role of the present command post communication system is to provide services in a tactical environment. Any changes in this role, contemplated or imminent, contribute to the issues of future plans and designs. The future issues thus deal with U.S. Army CP/SC deployment and utilization policies. They concern present and future implementation. Service and system growth phases over the next decade are important to know.

From the organizational point of view, the CP roles in the higher echelons affect the service plans. Service interfaces, that are either military, commercial, or others, are key objectives and issues. User-oriented military service standards would be extremely helpful in this area of service issues.

The goal of such a general and service-oriented attack would be to identify first key service features or objectives. They could concern such aspects as availability, reliability, grade of service, security, integrity, connectivity, quality, etc. (see Section 8.1 for other measures of effectiveness). Next, to formulate service requirements, one would have to assign clear definitions and numerical ranges for these descriptors.

The quantification of service parameters is never easy. It depends in a complex way on the entire service scenario. This includes all the service categories (analog, digital, priority, command levels), plus their tactical traffic statistics. Such statistics often tend to have modest means, but huge variances. This seems to be true for service request, or call arrival, or origination intensity distributions that exhibit busy-hour or high-demand peaks. One must also include message-duration or call-holding-time distributions, as the latter determine the loads on the network, plus the ensuing congestion effects.

The traffic statistics are needed for grade of service determination under realistic line or node outage conditions. This determination pertains to system connectivity, reroutes (message or call detours), probability of blocking, delays, and interrupts or preemptions. It is an issue that arises every time one is faced with the decision of what capacity links or switches to add to (or delete from) the CP network.

8.6.2. Technical network issues

Network issues are typically technical. They interface strongly with other technical issues, such as those dealing with nodal (i.e., switch, console, concentrator) elements and user terminals. Functionally, the networks must provide two flows: (1) control and signaling, and (2) information flow.

Technical compatibility is essential in network design. Existing and future interfaces, such as at the TRI-TAC's new analog and digital TTC-39 switch are basic compatibility requirements. Compatibility issues must be resolved, as they arise in the implementation cycle of various subnetworks. In particular, this concerns establishing and maintaining control, signaling, plus all the functions needed to run communications with other interface systems.

When analog lines serve digital elements, or when digital lines serve analog elements, the AD/DA conversion issues arise. Not only must data rates, formats, and synchronization issues be settled, there are the immediate problems of four-wire (4W) versus two-wire (2W) operation, as well as all types of subtle protocol issues. In the commercial world, as well as for the strategic military nets, digital media are forecast for future generation transmission and switching. A crucial present issue there is the transition period, when new digital elements are required to be integrated with older existing analog elements.

In the tactical CP future, the integration of digital and analog subnetworks may very well become an important future issue. It might arise, for instance, rather soon in the security arena. Encryption and decryption processes, and their controls, are more effectively carried out with digital technology. The automatic key distribution (AKDC) system is an example thereof.

Concentration and multiplexing (MUX), which is a recognized basic prerequisite for higher capacity bus architectures, is also quite amenable with the aid of digital carriers, such as time division multiplexing (TDM) and pulse code modulation (PCM).

The media issue for digital buses must also be thoroughly examined. While either 2W or 4W operation is feasible, their tradeoffs are not at all identical. Moreover, multipair cables may or may not be preferred over more forward looking alternatives, such as coaxial cables, optical fibers, or other media.

A very general networking issue concerns the topological designs and hierarchal function assignments to various levels of the network. Depending on how this is done, other issues may emerge and require resolution. For instance, such general system objectives as installation speed (Section 8.1.1), survivability (Section 8.1.2), service and performance (Section 8.1.3), upgradability (Section 8.1.4), plus other measures of effectiveness, all tend to depend on the topological configuration of the network.

In the body of this report, and notably in Section 8.5, a certain multiloop topology called structured configuration was introduced and examined. One would like to say that it is the preferred configuration for CP networks, at least at some hierarchal levels, but one is hesitant. After all, there remain numerous other topologies that are unexplored. For example, the higher order loops should be examined. Note: If a loop can be defined as a network where every node has exactly two nearest neighbors, then a higher order loop is one where every node has exactly n neighbors, where $n>2$.

The quantification of survivability was attempted in Section 8.4. Network literature abounds with various definitions of survivability, vulnerability and reliability. They differ from the (D,P) definition given in Section 8.4, in several respects. These respects should be examined for the suitability for command-post network survivability uses. Perhaps, a distinction should be made between normal and stress conditions of operation.

It seems that every network analysis requires a numerical data base, or the analysis loses its potency. The command post network is no exception. Many numbers are needed. In what follows, examples are given where the quantitative basis appears most desired.

To start, there is the issue of terminal, gateway, and nodal counts. This section has assumed $T=300$ terminals and $E=3$ external gateways. The number of nodes was left arbitrary in the 1-6 range. What is needed is a range of numbers for all kinds of terminals deployed, their traffic intensity numbers, and their required performance numbers.

Percentages and total numbers are needed for P, R, O, and Z priority phones, as well as for digital and FAX machines. Their clustering around proposed CP nodes needs numerical treatment. Extended to all terminals at all nodes, this would provide more complete link distance data than suggested in Figure 29. This would be particularly needed for the higher hierarchy levels, where cables are prime candidates for burial in trenches. The added installation time for redundant cabling needs quantification, especially at levels 3 and 4 (see Figure 28). The effective installation speeds by men and machines needs numbers for buried cables, as well as for laying of surface wires. Realistic numbers must be known to experienced field commanders. Moreover, it should be important to ascertain how those numbers compare with installation and dismantling time objectives set for various CP scenarios. Numbers are needed.

Realistic numbers are needed for present and future switches. They concern line and trunk capacities, CPU limitations, switch network structures (including full versus percent availability), console characteristics, queue management and limitation numbers, and so forth. Distinction between manual and automatic switches should be made on numerical grounds.

The distant and local call percentages are needed for realistic scenarios. Service requirements should be specified numerically for both. The probability of blocking should be specified in numbers, such as P=0, 0.5, 1, 5%, or other, and under definite network outage conditions. The sizing of link and switch capacities should be done for the selected $P \geq 0$ values. The fact that network blocking can occur in switches, in links, or in some hybrid combination of both, should be quantified and taken into account.

The importance of capacity assignment should be stressed for CP networks. The role of minimum necessary versus arbitrary or any redundant capacity numbers needs clarification. Further, the conjecture of sufficient capacity $(T_2 + \ldots + T_N)/(N-2)$ should be either proved or rejected for structured configuration networks (see Table 19).

Numbers are needed for typical and worst-case disconnection or disjointedness (D>0), as well as for worst-case grade of service (P>0). If pertinent, the probabilities of node and link outages, P_n and P_ℓ, should be reflected in network design. Methods should be developed for studying this for nonuniform capacity structured networks and higher order loops.

In the case of small user classes, grade of service estimates based in Engset (instead of Erlang) formulas should be used.

Control, as a function of topological connectivity, has not been examined at all. It should be done. In fact, the command post network topology should reflect the optimal numerical conclusions drawn from analyzing uses of CPU controls for managing flow under various stress conditions. Flow, connectivity, and control of paths between assumed hierarchy levels should be quantified. The latter would necessarily involve link, connectivity, and capacity, algorithms that may or may not exist in a form needed by tactical networks.

Recognizing that different objectives or measures of effectivenss (MOE) may contradict, a quantitative tradeoff machinery would be quite desirable.

For example, more survivability may call for more installation time. One is good, the other is clearly bad. How does one go about choosing a compromise? More generally, how does one select an optimum tradeoff in the configuration of many variously intertwined objectives? The objectives here are the previously mentioned availability, connectivity, ..., transportability, upgradability (see Table 17). This dilemma has, of course, arisen in the assessment of many systems. It has never been solved with any generality in mind. Only simple rules of thumb have been tailored for individual applications. The tradeoffs for command-post networks may also have to be individually and roughly derived.

9. CP/SC DISTRIBUTION SYSTEM CONCEPTS

In the previous sections we have reviewed the service requirements and some command-post communication system structures which are currently used in the tactical environment. In Section 8 a structured network configuration for the CP/SC local distribution system was described. It was noted that certain general system objectives such as installation speed, survivability, service, performance, upgradability, and other measures of effectiveness depend on the topological configuration used. A number of issues were raised concerning the number of terminals, external gateways, and switching nodes required. Traffic statistics are needed to determine the load carrying capacity for these elements in the structured configuration. These and other problems must be resolved by additional study in order to design and implement an optimum CP/SC distribution system.

Here we can only develop some general networking concepts and conjecture on how the ultimate CP/SC structured network might evolve. This is necessary because the ultimate configuration will, in large measure, determine what improvements can be made, what functions should be performed, and how these functions might be implemented.

Projecting the future is always a difficult exercise at best. However, we already know that changing technologies and usage patterns continue to impact military communications systems. Thus it is essential to forecast these changes so that initial improvements made to these systems are flexible and can be adapted as changes occur.

Our near-term forecasts for bus-type transmission systems are based in part on a review of such systems currently in use on specialized networks primarily for the private sector. Bus distribution networks are found in a number of applications but mainly for digital computer access and intercomputer communications. There are at least a dozen organizations planning to implement local networks this year (1979) alone. Others are already in use, largely for data communication. Some notable examples include: ETHERNET, a broadband broadcast system carrying digital packets between locally distributed computers; MITRIX, a cable-TV network; NBS net, a multi-user coaxial network; and SPIDER, a local packetized virtual circuit switched computer network. The midterm forecasts are based on an evaluation of these and other state-of-the-art of technologies.

Commercial switch manufacturers are currently developing small units for use in the Private Automatic Branch Exchange (PABX) market. The tendency for the design of these PABX's is toward all-electronic digital switches with stored program control using a combination of time division and space division switching matrices. Military versions of these units capable of operating in a tactical environment are sure to come. Their low cost, size and weight, and the specialized features and functions offered make them very suitable for this application.

When connected by digital transmission facilities, digital switches provide a number of advantages to the military user. For example, digital processing in the terminals provides end-to-end security and does not involve the links or nodes. In addition, data and voice services can be integrated on a single network.

In the long-term we forecast an increase in requirements for reliability and survivability in CP/SC networks. This can be achieved by adding redundancy, not only to the transmission links, but to the switching nodes as well. This duplication is feasible because of the lower cost, size, and weights of all equipment involved. A properly implemented network configuration permits a graceful degradation of the grade of service when any node or link becomes inoperative.

In the following subsections these forecasts are considered in more detail. A three-phase improvement plan for the CP/SC distribution system is outlined. This plan leads to the structured network configuration in a logical cost-effective manner. The three phases involve: 1) imbedding transparent bus-type links into the existing network structure, 2) merging these links with digital switches, and 3) changing the network topology and adding switch nodes to produce an all-digital structured configuration.

The improvements planned for each phase are summarized here only qualitatively. Then, in subsequent sections of the report, we explore functional alternatives for the first phase. This initial improvement phase requires implementing bus-type links between the major existing CP/SC nodes.

Functional tradeoffs for the link design are described so that candidate alternatives can be defined (Section 10) and evaluated (Section 11). Functional design specifications for the preferred alternative are then developed (Section 12).

9.1. Existing Configurations

There are basically three principle network topologies which emerge as candidates for local networks, the ring, the star, and the ring/star.

Ring topologies transmit information by moving it along a ring from terminal to terminal or at a higher hierarchical level from node to node. Rings offer simple transmission, are inexpensive but difficult to restore.

The star configuration uses simple point-to-point transmission from a central switching point which also serves as a restoral point.

Star/ring networks are an attempt to utilize the best features of each topology. Nodes that fail on a ring can be bypassed from a central switching point.

The basic star configuration is currently used for command-post communications as typified in Figure 44. This greatly simplified diagram depicts the major centers on the post and the star-connected topology used. The main patch panel provides a centralized control point for the traffic flow. This point also provides technical control facilities for major external links. Traffic distribution is achieved by hardwiring the panel and by manual switching with patch cords. A separate analog switch which may be manual or automatic serves local telephone subscribers on the post and switches calls to distant subscribers via radio links or land lines. Conventional analog signaling on a per-channel basis is used for addressing and routing (e.g., dc pulsing from a rotary dial) with the automatic switch. Multiple-wire-pair cables and twisted-wire pairs are used to connect terminals and adjacent centers. These are shown as lines in Figure 44. Some multiplexed signals on coaxial cable are used to interconnect to the radio park's transmitters and receivers and to land-line repeaters. These are shown as solid arrows on the figure.

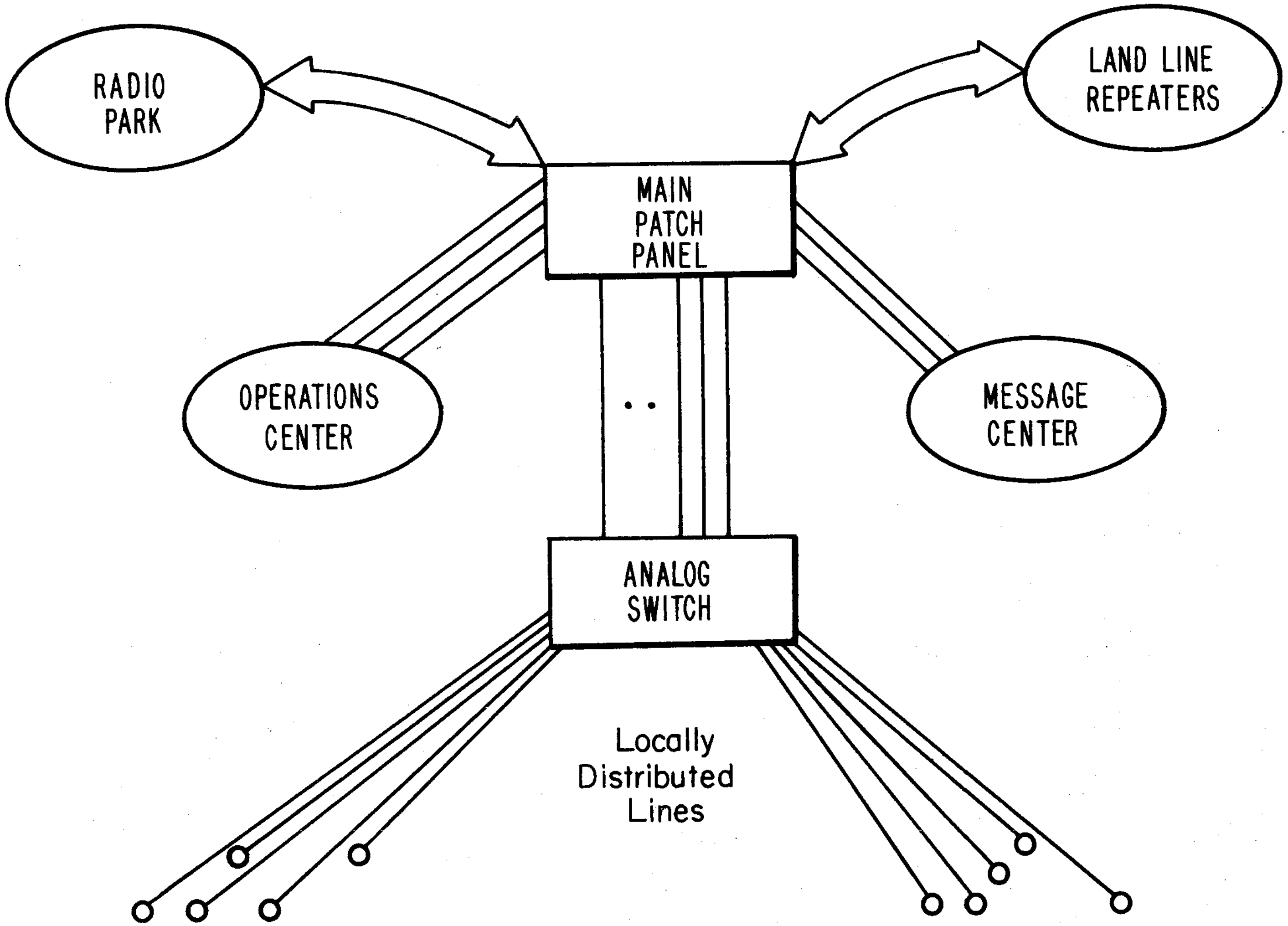


Figure 44. Current CP/SC configuration.

Figure 44, the existing configuration, serves as a benchmark for subsequent improvement to the distribution system.

9.2. Initial Improvement Phase

In the near-term (through 1985) the current inventory of ATACS equipments (i.e., terminals, switches, and network structure) is not expected to change drastically. Gradual changes will occur only as new TRI-TAC equipment is fielded. Initially improvements can be made in the CP/SC connecting links. The primary objective being to decrease deployment time by reducing the number of multiple-pair cables that must be installed. Alternative bus-type structures for these links are considered in Section 10. The preferred alternative must be selected on the basis of subsequent improvement plans.

Figure 45, illustrates the initial improvements that can be made. The basic topology in Figure 44 remains the same. Multiple wire-pair cables are replaced by imbedding transparent buses into this existing structure. This can be accomplished in a number of ways depending on the choice of multiplexing, interfacing and transmission media. It is essential that the chosen alternative be sufficiently flexible so it can serve ATACS as well as TRI-TACS equipments and other new systems which may evolve. Thus a fully transparent link whose output completely reproduces any input is required. The technical feasibility of the selected technique can be demonstrated using engineering models in the field and interconnecting to shelters with existing connectors. The improvements achieved in deployment time would require a more fully implemented system with special connectors installed on the shelters and interface units installed inside.

9.3. Transitional Improvement Phase

By the 1990's the transition from ATAC's to TRI-TAC equipment should be essentially complete. Some new systems using advanced concepts may begin to appear. During these transitional periods (1985 to 1990) the CP/SC network topology is expected to remain star-connected. Digital switching systems capable of handling both voice and data traffic will replace the analog telephone switch and the main patch panel as shown in Figure 46. The network's traffic flow will remain under a centralized control. Digital transmission links will merge with the switch and the digitization of analog sources can in some cases be remoted to new terminals. Under these conditions A/D conversion is no longer required at the link interface. Dispersed telephone lines will, in many locations be concentrated in localized points for subsequent transmission to the switch. New features and functions under software control will be provided from this central node. Examples

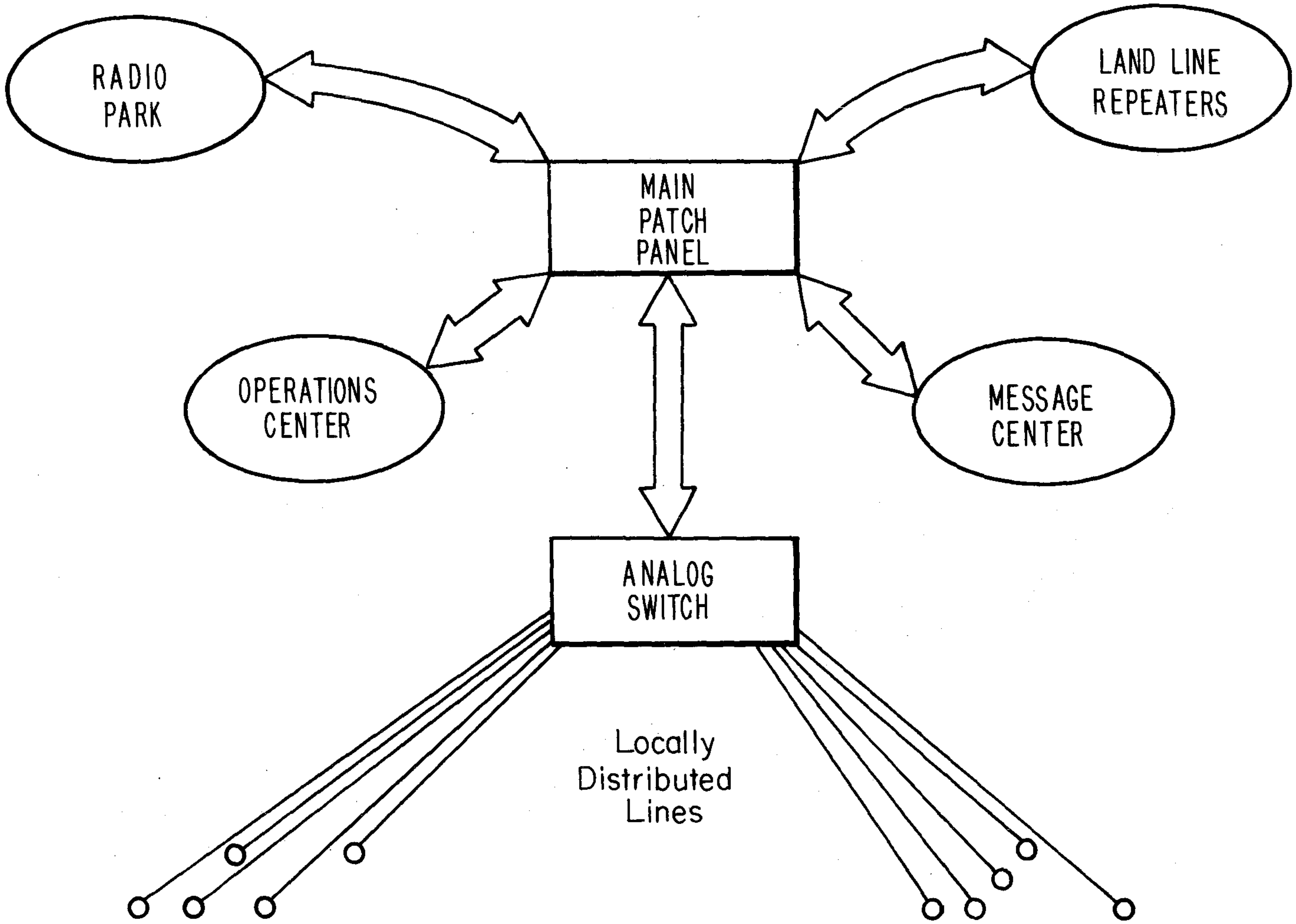


Figure 45. Initial improvement phase.

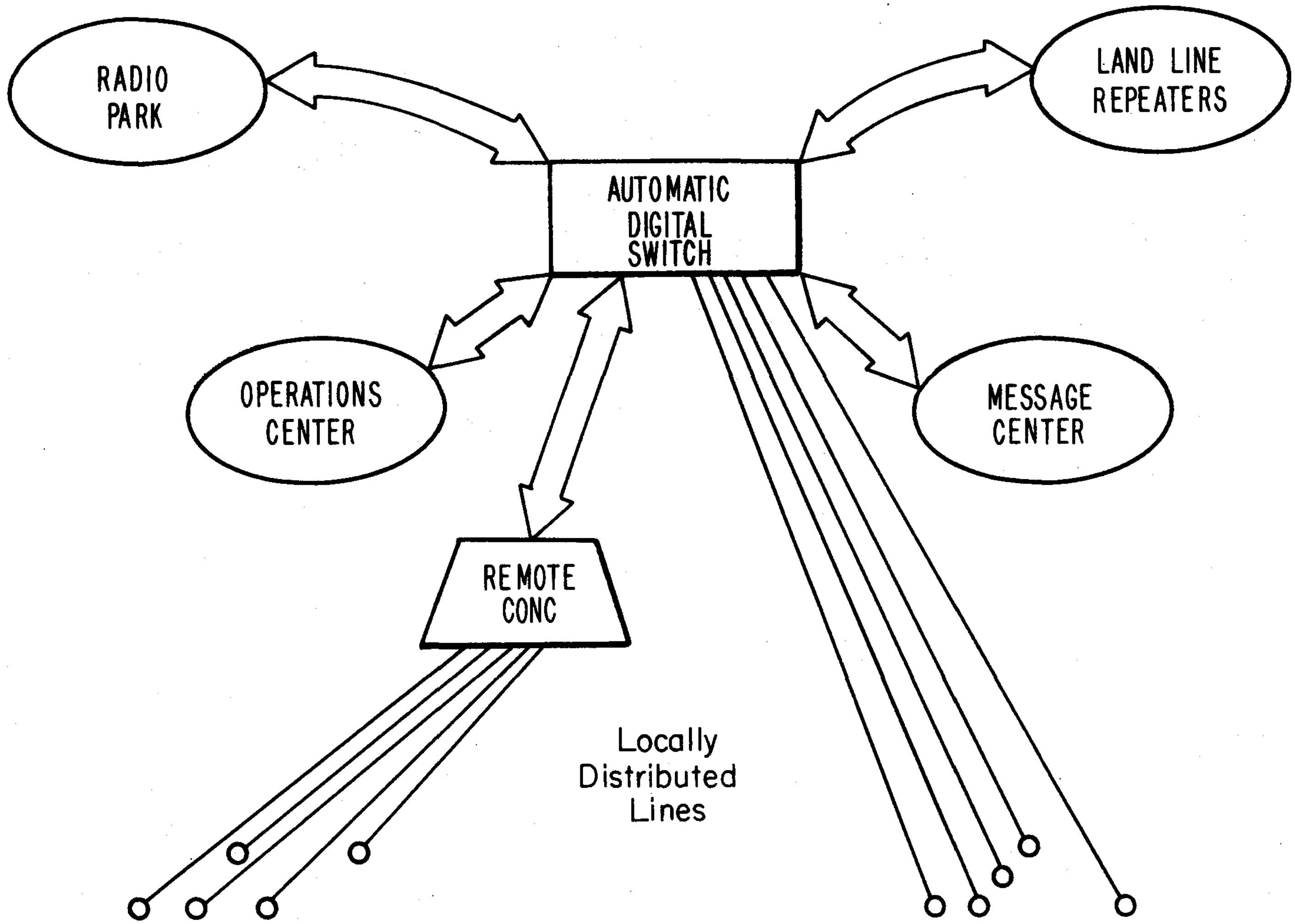


Figure 46. Transitional improvement phase.

of new features offered include priority calling, automatic recall, redirection of calls, multiaddress calling, call back, and conferencing. The control signals for supervision, addressing and routing these calls will be digitally coded and transmitted using borrowed bits on a per-channel basis.

9.4. Final Improvement Phase

Beyond the 1990's further improvements in equipment are expected to appear. The network topology will change toward the star/ring configuration and the command post's functional center will disappear. These changes are expected because of an increased need for reliability and survivability. These can be achieved using a structured network configuration as depicted in Figure 47. The centralized switch of Figure 46 is replaced by two or three switches. Network control becomes decentralized. Each switch can operate independently of the others in case of link failures. More intelligence now resides in the terminals. End-to-end encryption is commonly used between terminals for both voice and data traffic. All of the transmission links and nodal elements are digital. Gateways to remote sites and other networks are the only interfaces where mode, code, speed, and protocol conversion is required.

Control signaling is performed digitally using a common channel between switching nodes and communications centers. Many new features and functions are added to support new electronic office equipment.

Connectivity to widely dispersed terminals is reduced to some extent using remote concentrators with limited switching capabilities. These units will be capable of serving local subscribers on a stand-alone basis if connections to a switch node fail. Equipment breakdowns, including a switch, do not disrupt communications. A graceful degradation in grade of service is effected when nodes or links fail. Critical circuits are maintained using precedence and premption calling with software control under failure conditions.

This decentralized structure enhances survivability but at the expense of some deployment time. This expense is partially overcome by collocating major centers and the switch nodes as indicated in Figure 47. In addition, the weight and size of all equipment elements are reduced considerably using modular construction techniques and LSI circuitry. This improved mobility improves deployment time.

9.5. Summary of Phased Improvement to Distribution System Concept

Table 24 summarizes the basic changes to be made in the CP/SC structure during a projected three-phase improvement plan described in the previous paragraphs.

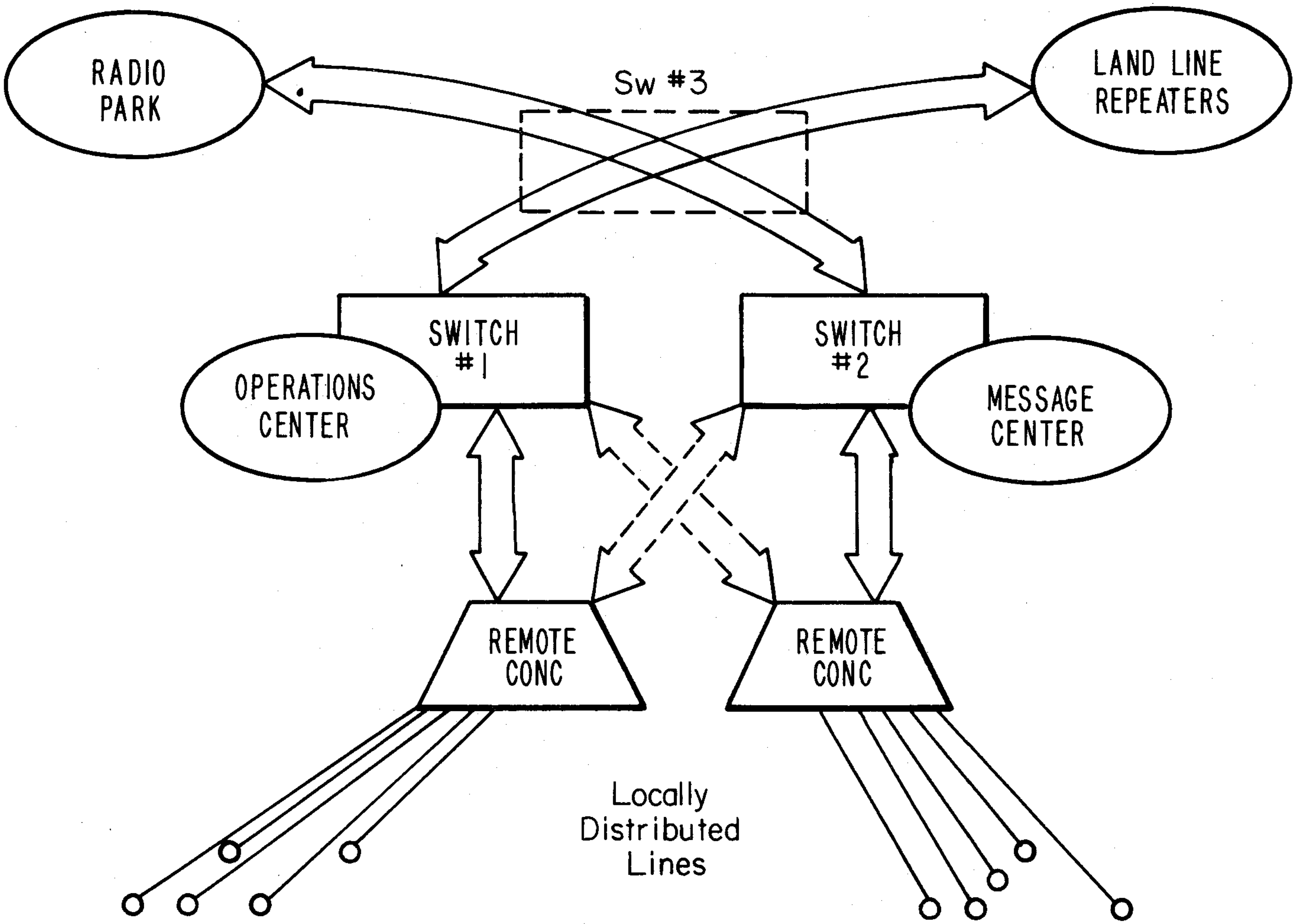


Figure 47. Final improvement phase.

Table 24. Phased Evolution of CP/SC Distribution System Concepts

Phase / Concepts	Current (1979)	Initial Improvements (1980 - 1985)	Transitional Improvements (1985 - 1990)	Final Improvements (Beyond 1990)
Terminals	Mostly analog telephones & low speed teletype-writers.	Analog tele-phones, low speed TTY, some digital termi-nals and facsimile.	A few digital telephones. Mostly high speed termi-nals including computer access terminals.	All digital telephones. Intelligent data & message terminals. Elec-tronic office equipment.
Links	Wire-pair cables, twisted pairs & spiral four. A few coax for remoted links.	Bus-type links imbedded into existing net-work. Some wire pairs to dis-persed stations. SDM & TDM.	A/D conversion imbedded in switch. Digital trans-mission on coax or fiber using TDM.	All digital. A/D conversion in terminals. TDM on coax or fiber optical cables.
Nodes	Manual switch-ing. Some electro-mechanical. Patch cord distribution for flow control.	Automatic with metallic cross points. Some SPC switches with A/D conversion.	Fully automatic digital switch with SPC. Some remote concen-tration for terminal clusters.	Digital switch with SPC. Added features & func-tions. Remote concentrator with limited switching capability.
Control Signals	DC pulse from rotary dial. Some DTMF push-button dialers. Analog trans-mission per channel.	DTMF signals digitized for transmission on per-channel basis.	Digital codes using borrowed bits on digital link on per-channel basis.	Digital codes using common channel inter-switch signaling (CCIS).
Overall Network Control	Star connected under central-ized control.	Star connected under central-ized control.	Star connected under central-ized control.	Structured network under decentralized control from two or three nodes.

The five year improvement phases shown in the table are somewhat arbitrary but are related to the expected schedule for fielding TRI-TAC equipment. The basic structure of the network, the connecting links, the switching nodes, the terminals and the signaling technique are briefly summarized in this table for the initial, (1980-1985) transitional, (1985-1990) and final, (1990-?) configurations.

These projections, although qualitative and admittedly somewhat arbitrary, are needed in order to select a preferred alternative for the bus-type connecting link. The choice to be made is primarily controlled by subsequent plans for improvements. A good example is the multiplexing technique used. A frequency division multiplexed system using a frequency modulated carrier on coaxial cable is one potential choice.

Such a system could prove cost-effective if the only consideration is to replace the wire-pair cables currently used and therby decrease deployment time. However, such a system would likely be changed if, as we project, the analog switches are later replaced with digital switches.

The following sections are devoted to selecting the bus structure for the first phase of improvement.

10. SYNTHESIS OF CP/SC BUS ALTERNATIVES

The first phase for improving the CP/SC structure requires replacing the multiplicity of connecting cables and wires with a much smaller number of bus-type links. This is accomplished using multiplexing techniques to carry the traffic load. The so-called "multiplexed bus" can then be imbedded into an existing network structure. The most critical connections (i.e., those requiring the longest time to deploy) would normally be replaced first.

This initial improvement phase requires three stages of concept development. First, to evaluate a number of bus alternatives and to prepare a functional design for the preferred alternative. This is the purpose of this and subsequent sections of the report. Second, to construct an engineering model for test and evaluation under field conditions. The purpose of this second stage is to determine technical feasibility and to validate the concept. The basic elements of such a model are shown in Figure 48. Field tests would be conducted by connecting the bus elements to suitable nodes using existing connectors. In the third stage of development these connectors would be eliminated by installing the processing and interface units inside the shelter using bus-type connectors. Deployment times would be evaluated during actual field exercises.

In the following subsections we discuss several possible alternative configurations for performing the signal processing, multiplexing, and interfacing functions

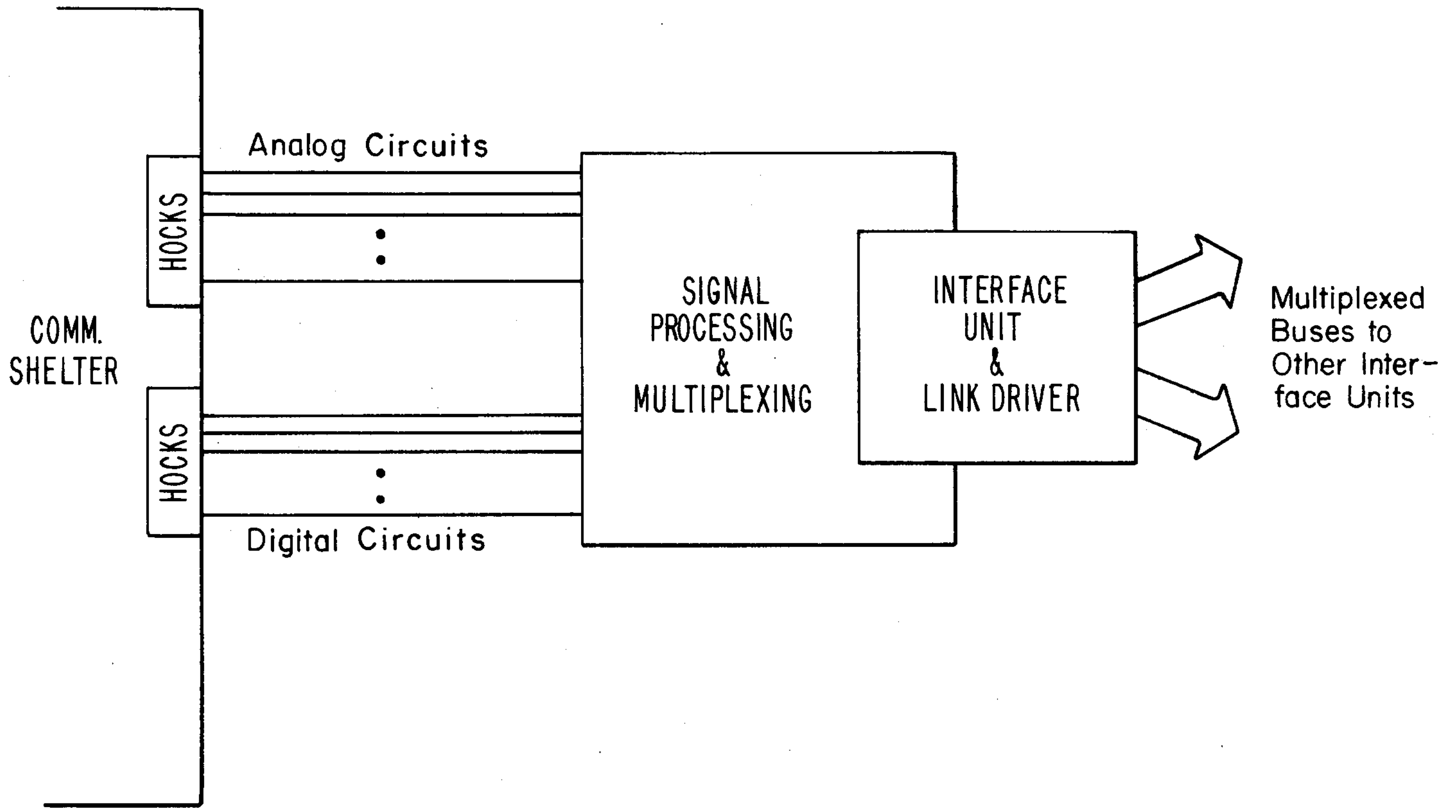


Figure 48. Transparent link structure for demonstrating technical feasibility of bus-type network.

indicated in Figure 48. Then in Section 11 we evaluate a number of candidate alternatives for a bus-type link.

10.1. Major Functions Performed by a Transparent Bus

A number of functions must be performed by any bus-type link. Specific functions depend on the type of source (analog or digital) the signal design (analog, quasi-analog, or digital) and the transmission medium (radio, optical, or guided waves).

Major functions to be performed are indicated in Figure 49. Specific functions are shown by the block diagram across the top of this figure. These are grouped into the major classifications of information conversion, signal conversion, media matching, and physical transfer. Each class is described in the paragraphs below, assuming transfer from source to destination. The inverse of certain functions must be performed by the link at the destination. This includes, for example, demodulation, detection, decoding, digital-to-analog conversion, and finally media conversion from electrical signals to human usable form.

Information Conversion

The conversion process transforms information in human usable form (e.g., printed words and numbers, visual display characters, acoustic speech, holes in tape, etc.) to and from electrical form. For the multiplexed bus it is assumed that these information conversion functions reside in the terminals and nodes and are not performed by the link. Thus, the starting point for the transparent bus structure is an electrical signal which may be analog or digital.

Signal Processing

These functions involve changing the initial electrical form to another form suitable for transfer. The new form would ensure that the information is not inadvertantly or surreptitiously changed. The functions include filtering, A/D conversion, and digital encoding in various combinations. The encoding functions include binary to m-ary code conversion, encryption for security, and error control to enhance reliability.

Media Matching

This ensures successful entry, transmission, and delivery by shaping the signaling waveform and, if necessary, translating these waveforms to other frequencies or modulating carrier frequencies in order to match the transmission media. It includes, for example, signal modulation for carrier system compatibility.

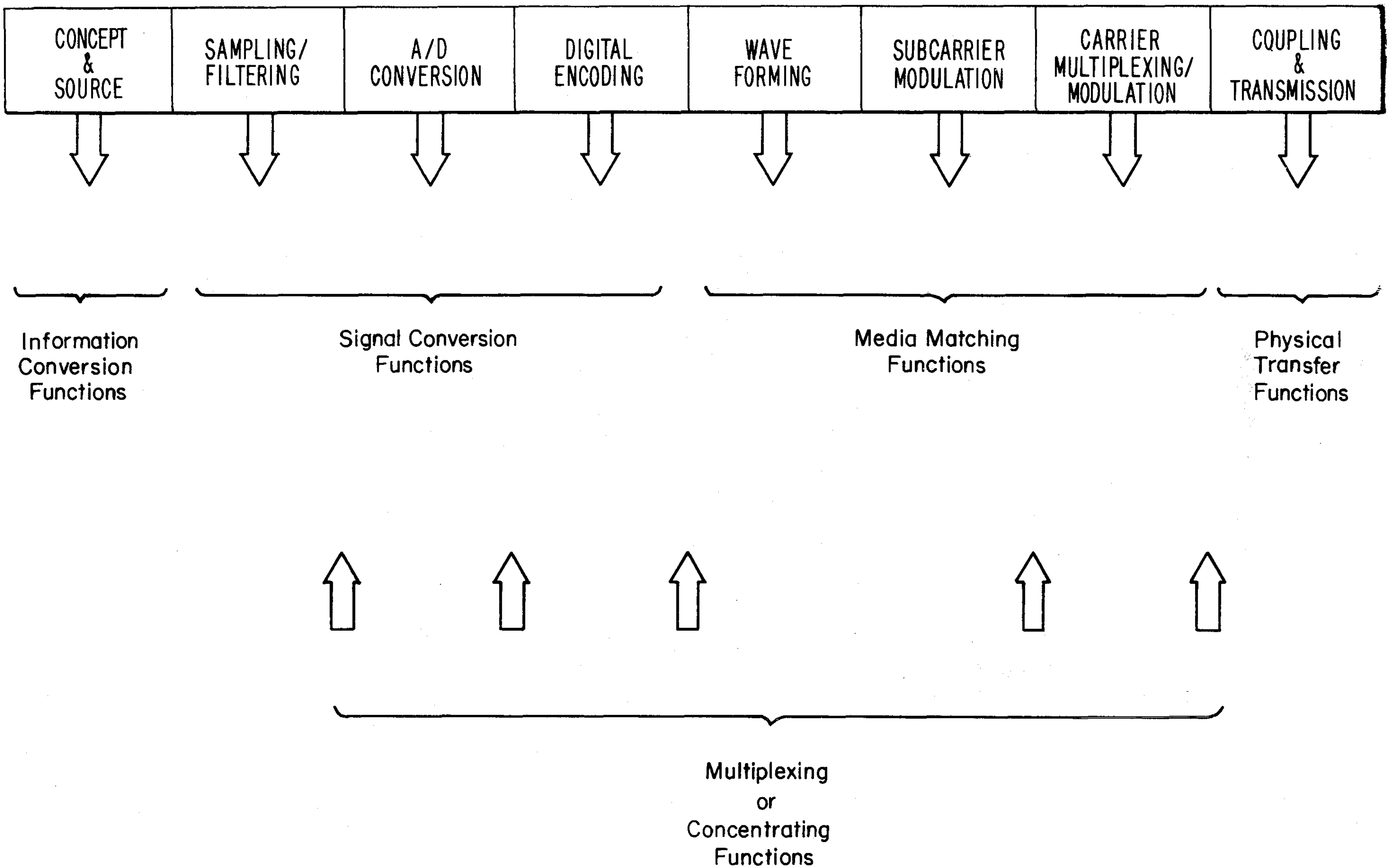


Figure 49. Basic communications functions.

Physical Transfer

The transfer function is performed by some form of transmission medium and the interface to it. The interface includes power amplification (e.g., a transmitter) and coupling to the link (e.g., an antenna). The medium provides the path over which signaling information will pass. Guided wave transmission media include wire lines, coaxial cables, optical fibers, and waveguides. Transmission media could also include radio, optical, or acoustic radiation techniques.

There are three basic transmission modes of operation: analog, quasi-analog, and digital. Analog transmission may be at voice band (e.g., a local telephone loop) or with a modulated carrier (e.g., radio systems) using analog signals. Quasi-analog transmission involves signals in digital form which modulate a carrier and are transmitted in analog mode. Digital modes require transmission of the digital signal directly, i.e., no carrier modulation is involved.

Multiplexing and Concentrating

These functions are the key to bus-type structures. They may occur at various points as indicated in Figure 49. Multiplexing combines a number of signal sources onto a single channel on a fixed allocation basis using frequency or time division techniques. Concentrating allocates the source signals dynamically and may therefore be blocked. Only multiplexing techniques are considered here for CP/SC bus alternatives since no blocking should occur in the transparent link.

10.2. Functional Tradeoffs

The electrical signal representing user information may undergo a number of transformations for transmission purposes. The principal transformations are indicated by the blocks at the top of Figure 49. In this section we indicate a number of possible transformation functions available to the designer of a bus-type link. Some bus structures may not require some of the transformations, some may occur at different points, or they may be combined in unusual ways. For example, voice digitizations may or may not be used. If digitization is included the time division multiplexing may occur after the sampling process or after the analog-to-digital (A/D) conversion process. After conversion, additional digital encoding may or may not be used. A number of other alternative structures are apparent on the figures given in the tradeoff summary at the end of this section.

Functional tradeoffs for each category listed across the top of Figure 49 are described below.

Sampling and Filtering

Sampling converts signals which are continuous in time and amplitude into signals which are discrete in time. The amplitude level is still continously variable. In order to reproduce a waveform completely the samples are obtained at points separated by 1/2B seconds where B is the bandwidth occupied by the signal. Voice signals are normally filtered to a nominal 4 kHz bandwidth and therefore 8000 samples per second are required. Sampling is essential to waveform coded systems.

Sampling may also be used as part of the process of spreading the spectrum of digital signals. These systems are not considered here.

Comb filters and other methods of exploiting the acoustic features of speech production are included in this functional category since they are required prior to the A/D conversion process. Such digitizing processes are known as source coding. Vocoders are one example.

A/D Conversion

This involves converting the continous amplitude variation of analog signals to discrete values. The most common method is pulse code modulation (PCM). Common systems encode each sampled value into a 6 (tactical) or 8 (strategic) bit binary code. Since both systems sample 8000 times per second this yields signaling rates per voice channel of 48 kb/s and 64 kb/s respectively. Other voice digitization techniques provide different rates. Broadband systems operating above about 20 kb/s in addition to PCM include linear delta modulation (LDM), differential PCM, and adaptive versions of delta modulation (ADM). Continously variable slope delta modulation (CVSD) is operational at 16 kb/s and 32 kb/s for tactical systems.

For systems with limited channel capacity or limited bandwidth (<20 kHz) more sophisticated source coding techniques are used. This range includes linear predictive coding (LPC) and adaptive predicted coding (APC) as well as a number of vocoding techniques.

Digital Encoding

Given a digital signal or a digitized analog signal the resultant digital waveform may be encoded in many ways. The information content is not changed in this process. This encoding is done to match incompatible terminals, to ensure reliable transmission, or to reduce the channel bandwidth requirements. Digitally encoding a binary sequence into an m-ary sequence is an example of the latter. Parity check bits may also be added for error control. Military systems often use cyclic redundency check (CRC) codes for this purpose. These CRC codes require that additional bits be added to blocks of message bits. Typically 16 or 32 additional bits are required. The use of CRC permits error detection at the expense of throughput.

For secure transmissions, the encryption process would usually follow the digital encoding function.

The steps involved in waveform coding are illustrated in Figure 50. As noted above for voice frequencies of 4 kHz, a sampling rate of 8000 times per second is required for voice. Next, the number of quantizing levels needed to obtain the required resolution is defined. The number of quantizing levels defined is directly related to the number of bits needed. With two bits four levels can be represented, 4 bits--16 levels, 6 bits--64 levels, and 8 bits--256 levels. Six to eight bits are normally used to encode voice signals. The figure shows a waveform digitized with a 4-bit code as a detailed example. Amplitudes are sampled in (b). A digital signal format is assigned in (c) and serialized in time in (d). The resulting binary signal is shown in (e). A parity error detecting check and signal conversion for the particular type of transmission medium used may be added to the bit stream before actual transmission. When the bit stream is received the inverse operations and accuracy checks are made upon detection. The digital code is converted back to analog form and filtered to smooth it. The resulting continuous analog waveform approximates the input waveform.

Many different digital signal forms and codes have been designed. Each has a use or function for which it was designed. Thus, PCM is primarily used for long-haul digital trunks over cable, microwave, and satellite links.

<u>Wave Forming</u>

There are a number of ways to represent the digital encoded sequence of bits. The waveform selected depends on subsequent functions to be performed. For example, a unipolar return-to-zero (RZ) waveform may be used to pulse a light emitting diode for transmission over an optical fiber. A bipolar non-return-to-zero waveform is more suitable for signal modulation on a radio carrier.

These and other common waveforms are shown in Figure 51. All of the waveforms result from the same binary sequence. A synchronous system (clock provided) is envisioned where the receiver samples at the arrows to determine if the amplitude is above or below the threshold dotted line for a binary, 1 or 0.

Waveforms (a) and (b) are two basic formats where (a) has binary levels of one polarity, and (b) was 0 for negative levels and 1 for positive levels. The signal stays at that level for the entire bit period and does not return to zero (NRZ).

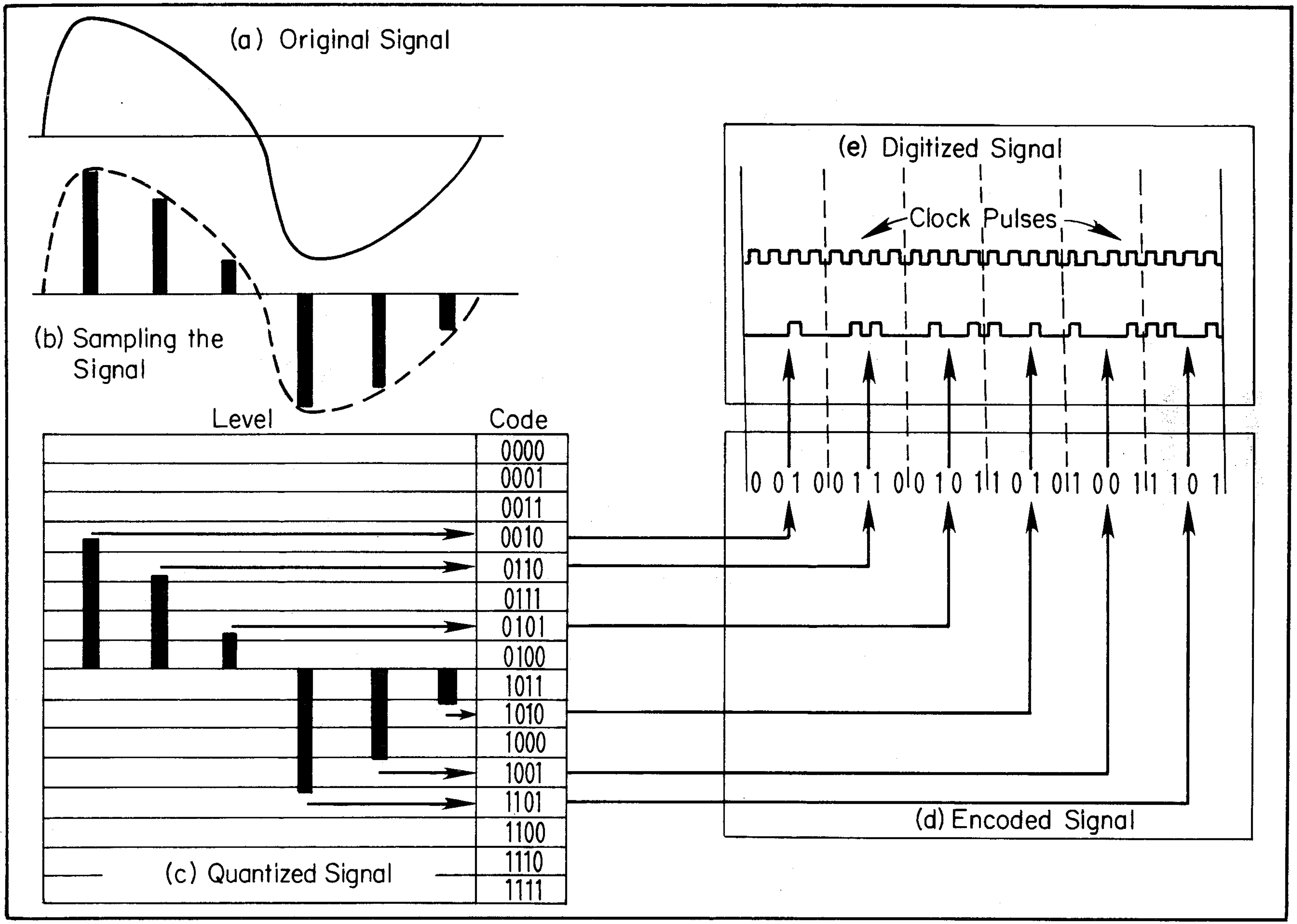


Figure 50. Steps in pulse coding an analog signal.

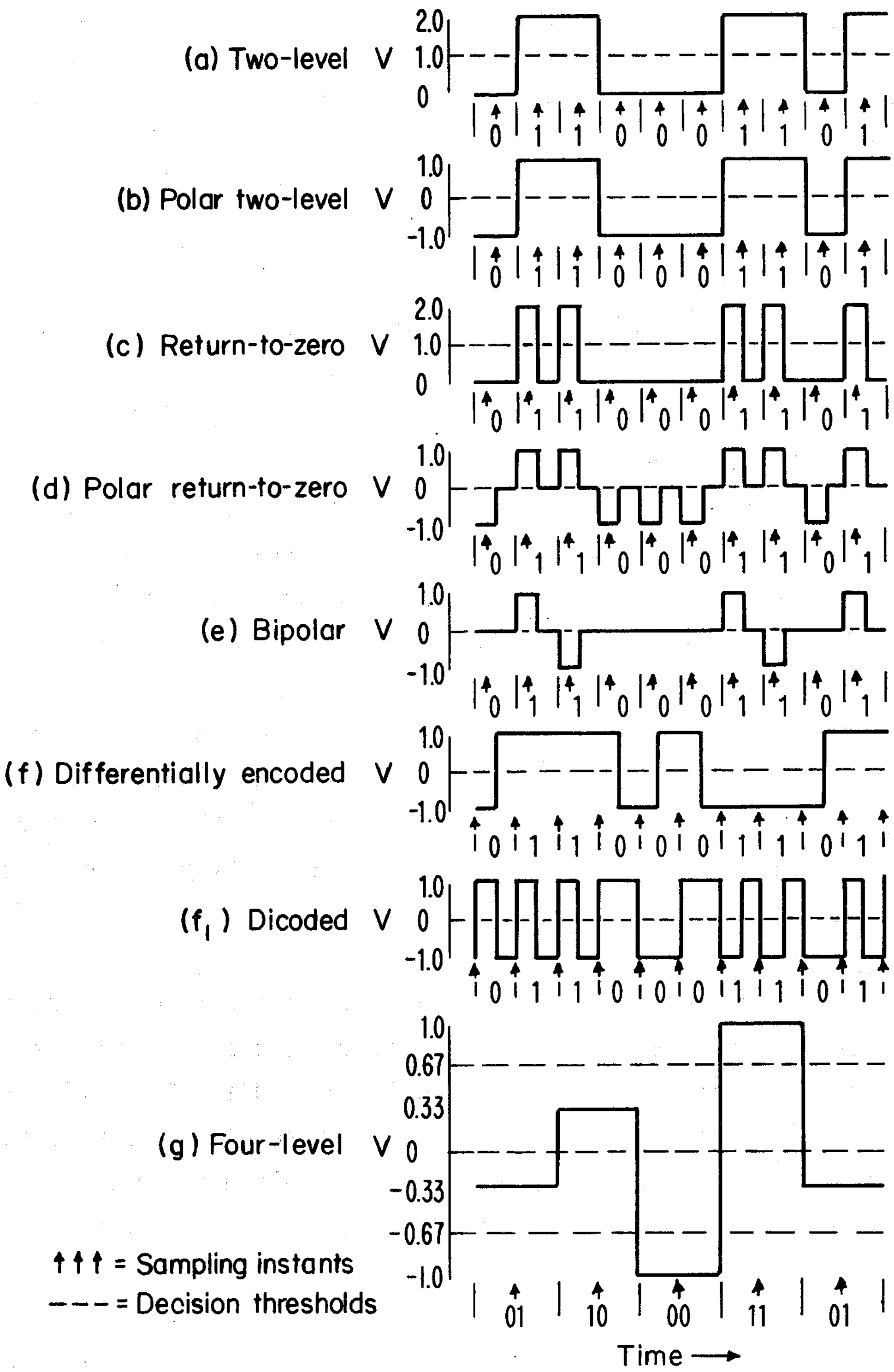


Figure 51. Common digital signal formats for transmission.

Formats (c) and (d) are similar to (a) and (b) except that the attained level is return-to-zero (RZ) before the end of the bit period that indicates less than 100 percent duty cycle. In (d) since a pulse, either 0 or 1, starts at the beginning of each bit period, the synchronization can be derived from information in the signal (self-clocking). Note, (d) and bipolar NRZ (e) are basically three-level signals.

Format (e) is used for T-carrier systems. The 1's are alternating plus and minus from zero, and 0's are the 0 signal. Thus, the dc component is eliminated allowing transformer coupling to the transmission line. The energy is concentrated at the half-baud rate which reduces near-end crosstalk and the bandwidth required. Another useful form not shown is partial response coding. One scheme involves replacing each 1 with the sequence 1, 0, -1.

In (f) the information is coded in terms of the transitions (differences) that occur in the signal. Successive pulse intervals are compared. If they are identical, a 1 is transmitted; if a transition was made, a 0 is transmitted. The (f_1) is the (f) form coded again with 1's coded as a 0-to-1 transition, and 0's coded as a 1-to-0 transition to make a di-code format.

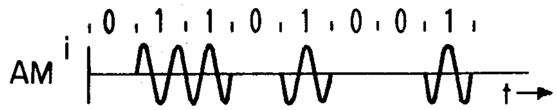
The sequence in (g) is not a binary code but an m-ary code that increases the number of information bits per cycle. It is used when the signal-to-noise ratio is sufficiently high to allow multiple detection levels. It could also be considered as part of the digital encoding process and used directly to modulate a carrier.

Subcarrier Modulation

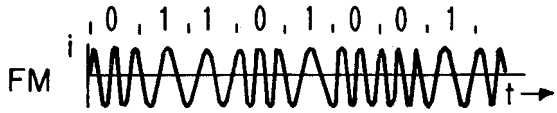
Baseband signal waveforms may be analog or digital depending on the functions previously performed. These waveforms may be transmitted directly or used to modulate a carrier in order to match the transmission media. Subcarrier modulation schemes are another functional category. The signals resulting from subcarrier modulation may be transmitted directly, be used to modulate a higher frequency carrier, or be translated to some other desired frequency. The translation process is used for frequency division multiplexing several signals on a common channel.

Analog baseband signals and digital signals may be used directly to modulate a carrier using amplitude modulation (AM), frequency modulation (FM) or phase modulation (PM). Examples of digitally modulated carriers are shown in Figure 52.

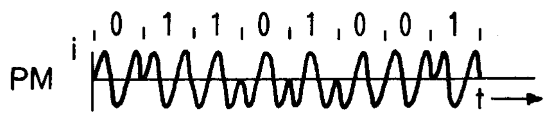
An example of a binary, on-off amplitude modulation (AM) is shown in Figure 52 (a). The amplitude can be varied to represent any of the signals described.



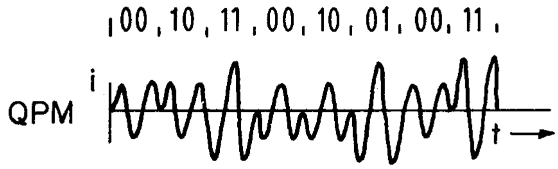
a. On-off amplitude modulation.



b. Binary frequency-modulated carrier wave.



c. Binary phase-modulated carrier wave.



d. Quad amplitude/phase-modulated carrier wave.

Figure 52. Common modulated carrier signals.

Here the carrier is turned on and off corresponding to the 0 and 1 in a binary sequence. This intermittent carrier wave (ICW) was used for sending Morse code in earlier systems. Other amplitude shift keying (ASK) forms were also used.

An example of a binary frequency-modulated carrier, called frequency-shift keying (FSK), is shown in Figure 52 (b).

A binary phase-modulated (0° and 180°) carrier is shown in (c). Where a large signal-to-noise ratio is available, multiple divisions of phase can be used to increase the number of transmitted bits per hertz. A binary phase shift keyed (PSK) signal contains one bit per hertz. Quadrature phase shift keying (QPSK) contains 2 bits/hertz.

Multi-carrier modulations also can be used. The waveform in Figure 52 (d), for example, is a combination of two phase positions and two amplitude levels for a total of 8 logic levels. This combination illustrates how ASK and PSK can be combined. A combination of four AM levels and four PSK phase yields 16 symbol choices and 4 bits per hertz.

Table 25 compares several modulation schemes in terms of their error rate performance in Gaussian noise. The characteristics considered are the bits-per-hertz efficiency and the signal-to-noise ratio (S/N) required at a system bandwidth that will provide a bit error rate of 10^{-4}.

As stated below the table, practical systems may require greater S/N ratio than those calculated. However, this can be considered the limit that can be achieved in this noise environment.

Analog signals may also be translated into a number of pulse modulated forms after sampling. The series of the pulses in Figure 53 indicate ways in which the original continuous waveform is represented. Figure 53 (a) shows an equal interval series of clock pulses used to determine when the original continuous waveform, (b), should be sampled. Pulse series (c) is a pulse amplitude modulated (PAM) representation of, (b), from the reference level slightly below -v, at the clock rate and at equal intervals. The pulse series (d) is the same representation of (b) using a 0 reference level. It is known as bidirectional PAM. Pulse series (e) through (g) have constant amplitude pulses but use the amplitude sampling of the original wave (b) to vary the pulse width (PWM), or pulse duration (PDM), or frequency (PFM). Series (e) shows how the pulse width varies within the limits of the clock cycle periods, as the amplitude samples vary. Series (f) and (g) are equal interval pulses like the rest of the pulse series, but varying in position within the clock interval as in (f) or in repetition rate as in (g).

Table 25. A Comparison of Carrier Modulation Systems

Type	Logic Levels	Nyquist Bits/Hz	Fixed Bandwidth Signal-to-Noise for 10^{-4} BER (Coherent Detection)
Amplitude	2	1	14.4 dB
FSK	2	1	11.7 dB
Partial Response FM	4	2	21.2 dB
Partial Response AM	4	2	23.8 dB
2 PSK	2	1	8.4 dB
4 PSK	4	2	11.4 dB
8 PSK	8	3	16.5 dB
16 PSK	16	4	22.1 dB
QPRS AM	16	4	31.4 dB
QPRS AM + PSK	16	4	28.5 dB

o Practical systems operate at reduced performance based upon filtering, equalization, and transmitted spectrum attenuation

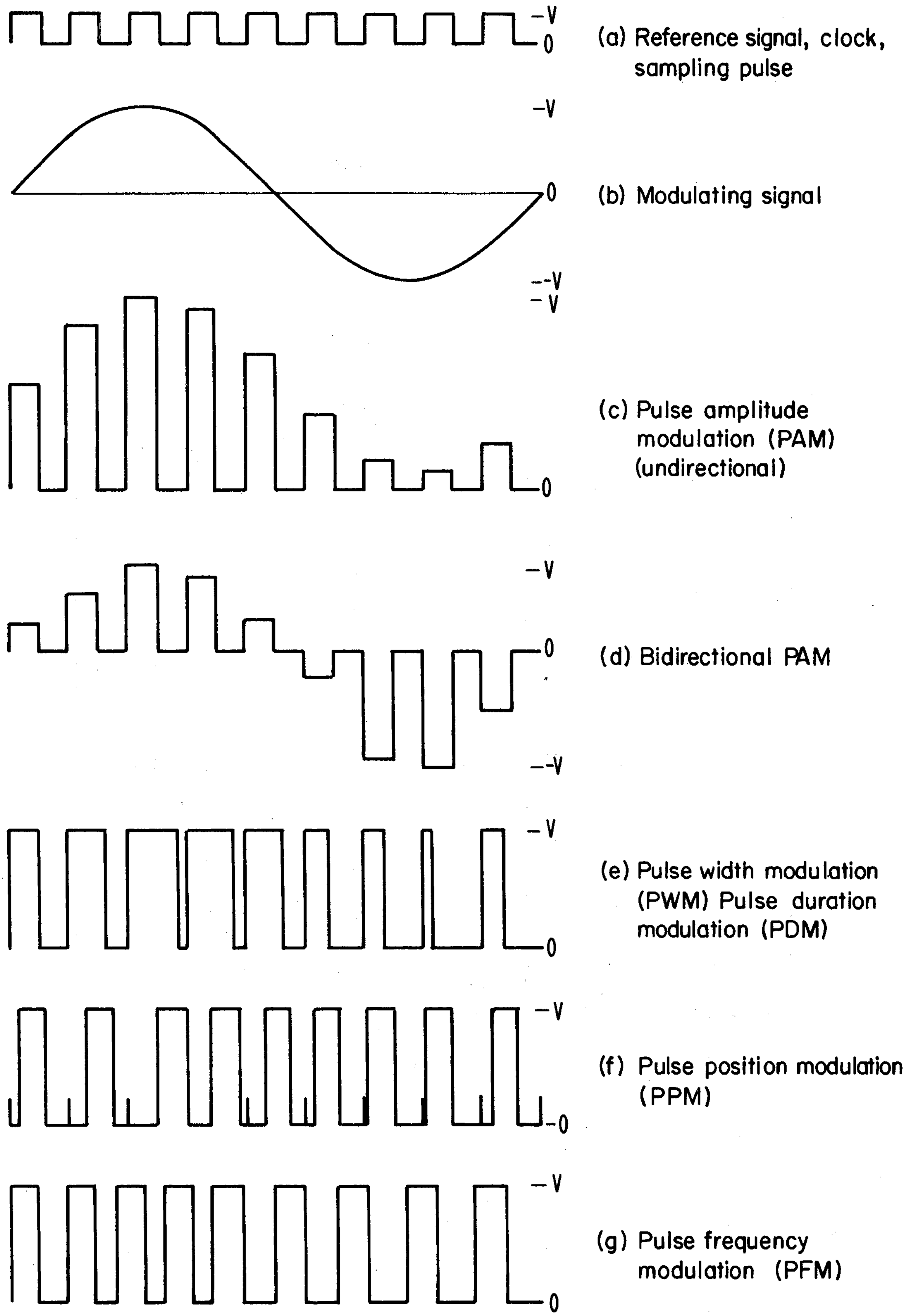


Figure 53. Noncoded pulse waveform representations.

Carrier Multiplexing and Modulation

As noted in Figure 48 there are many points where multiplexing a number of channels onto one channel be accomplished. The multiple wire pairs in a single cable currently used is considered one form known as space division multiplex (SDM).

Alternate forms for replacing this SDM cable with a more manageable bus-type link are frequency division multiplexing (FDM) and time division multiplexing (TDM).

The FDM schemes are suitable for transmission over analog or quasi-analog links. The TDM schemes can be directly coupled to digital links or after using a modulator/demodulator (modem) to a quasi-analog channel.

Common methods for multiplexing analog terminations to analog and digital buses are diagrammed in Figure 54. Methods for multiplexing digital terminations onto an analog bus are shown in Figure 55.

In Figure 56 the TDM method combined with FDM allows geographically separated terminal clusters to access the bus.

Using various levels of multiplexers a high-speed bus structure can be designed to carry traffic from terminations having different source rates. Thus, several low-speed digital sources can be multiplexed onto a medium-speed channel which is multiplexed with medium-speed sources for transmission on the high-speed bus. This multilevel process is depicted in Figure 57.

An example is the frequency hierarchy levels used in the telephone network. In this hierarchy the lowest level of multiplex equipment packs 12 telegraph channels into one 4-kHz voice channel and the second level packs 12 voice channels into 48-kHz groups. Five groups are combined into supergroups of 60 voice channels and 10 supergroups into a master group of 600 voice channels. A master group occupies a bandwidth of approximately 2500 kHz. The L3 coaxial cable system can handle three master groups or 1860 voice channels.

These FDM methods are accomplished by translating subcarrier modulated voice channels to separate carrier frequencies.

Carriers may also be modulated directly using baseband or subcarrier modulated signals. Carrier modulation methods include AM, FM, and PM techniques and variations such as double sideband (DSB) or single sideband (SSB) amplitude modulation and narrowband (NB) or wideband (WB) frequency modulation.

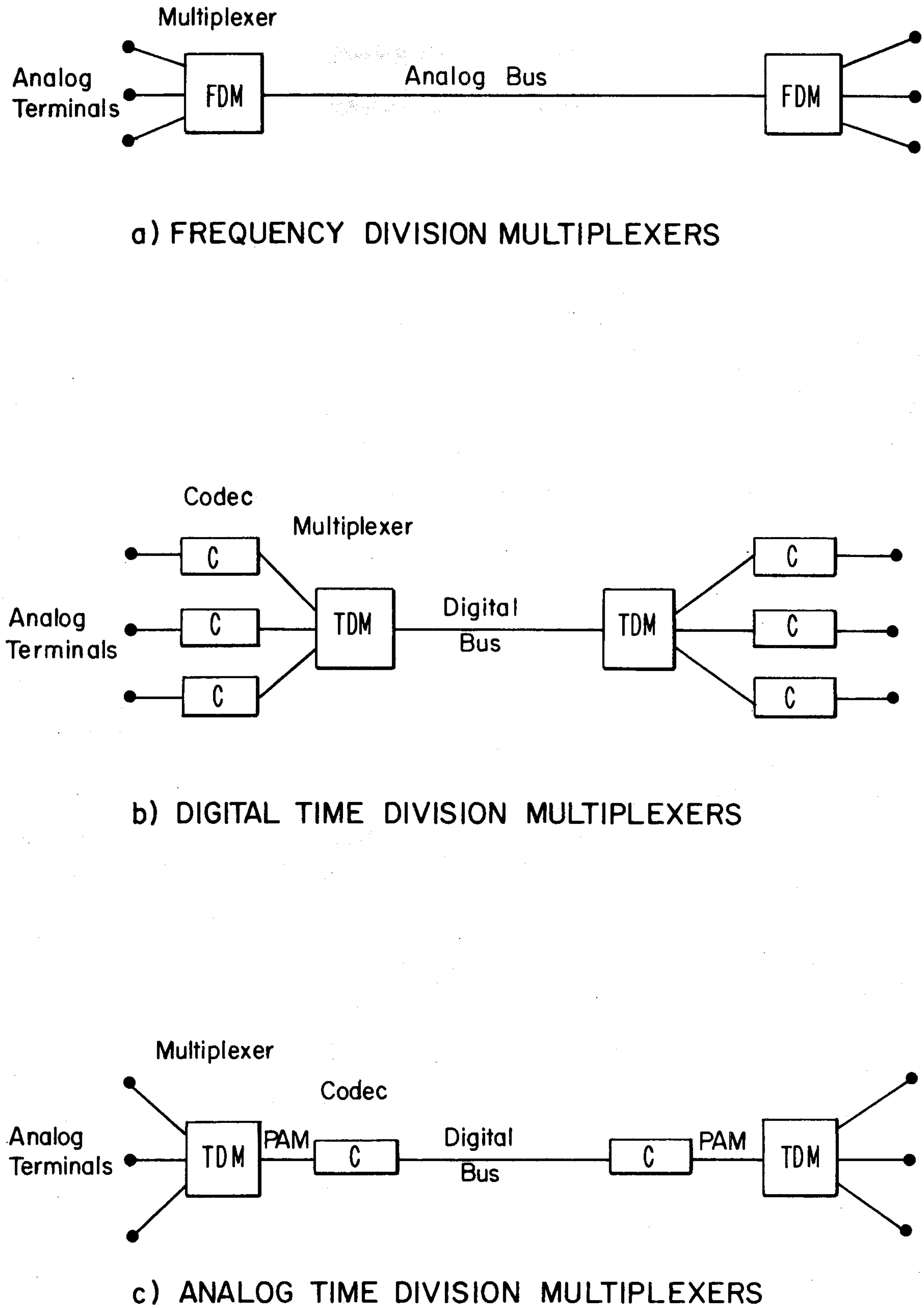
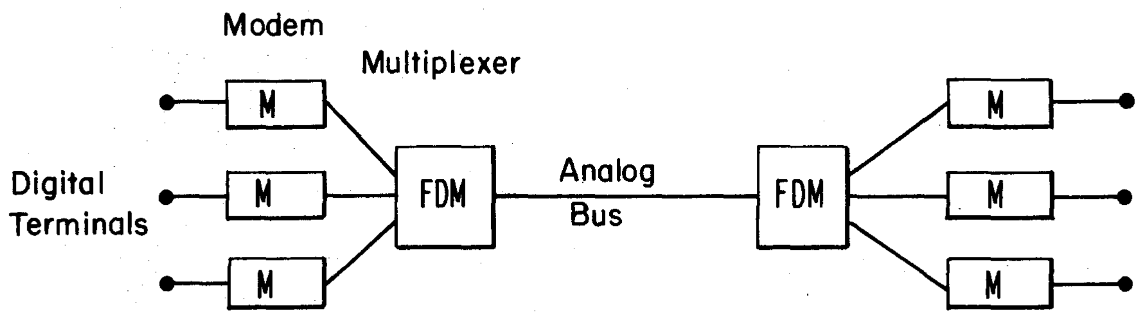


Figure 54. Multiplexing analog terminals on analog and digital buses.



a) FREQUENCY DIVISION MULTIPLEXERS

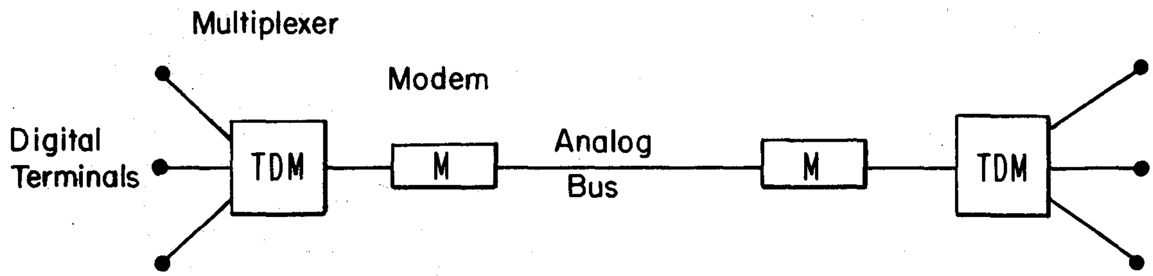


Figure 55. Multiplexing digital terminals on an analog bus.

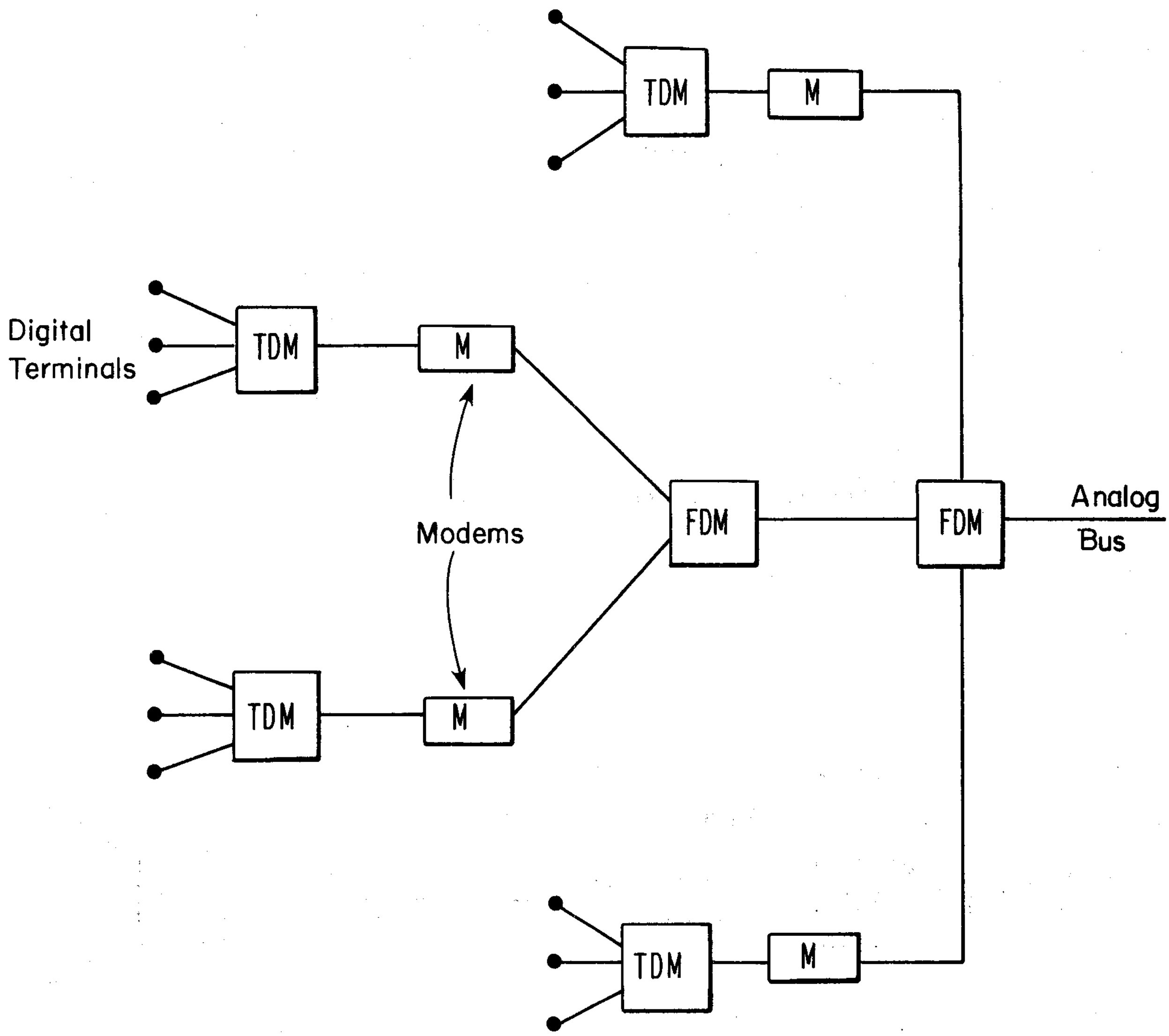


Figure 56. Multiplexing digital terminals on an analog bus with separated access.

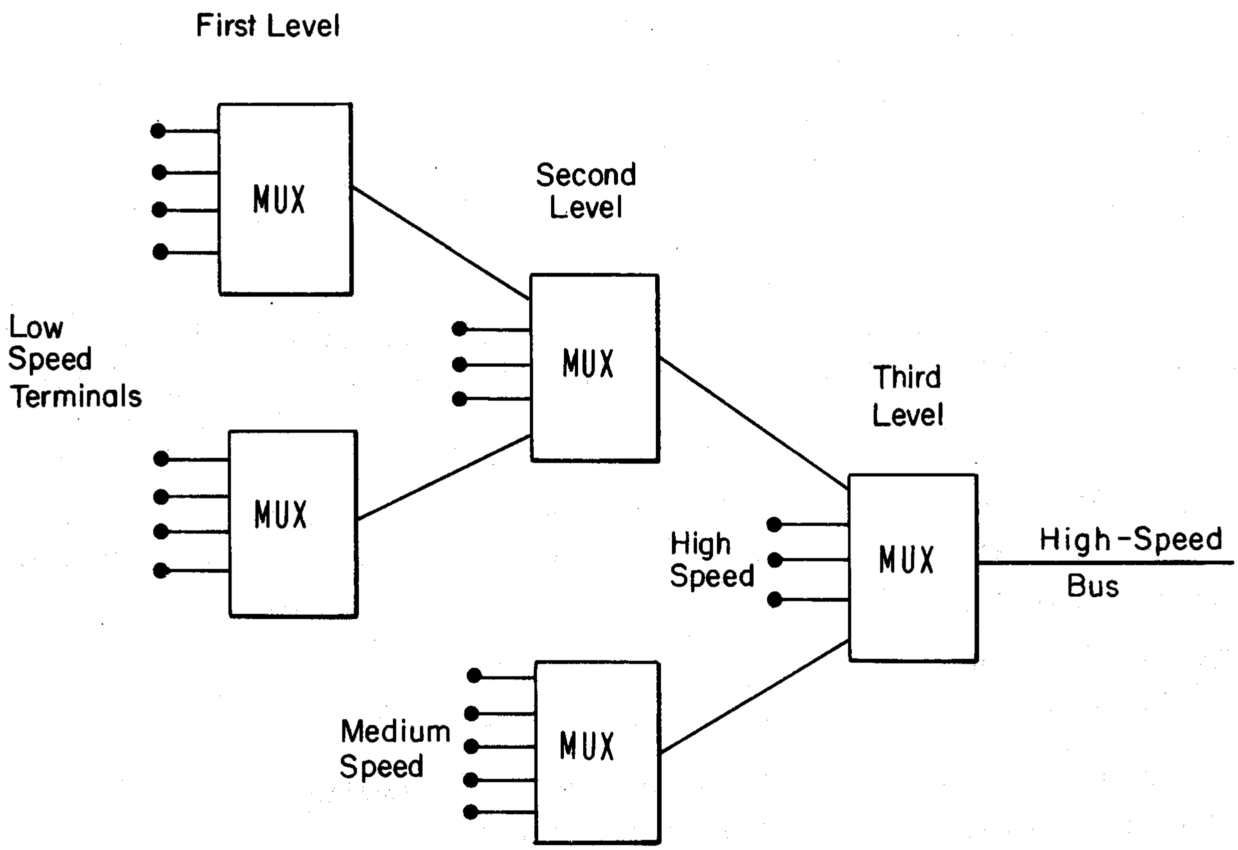


Figure 57. Multiplexing terminal with different source rates.

Coupling and Transmission

Functions in this category include the power amplifications, coupling mechanisms and the transmission media itself. The power and coupling device specifications depend on the medium used and its characteristics. The medium used depends on traffic load to be carried and the cost.

The physical transmission media that can propagate traffic mixes, either separately or jointly, can belong to several categories:

twisted-wire pairs,
multiwire cables,
coaxial cables,
microwave radio,
waveguides,
optical fibers.

The signaling scheme used to transmit over a selected medium may be either analog, quasi-analog or digital. Examples of each are listed below.

Analog	Quasi-Analog	Digital
o voice frequencies at baseband over local wire pair.	o data modem over telephone circuits	o bipolar digital signal on coaxial cable
o FDM/FM carrier on coaxial cable	o Digital modulated carrier on LOS microwave	
o continuously varied light sources over optical fiber.	o Pulse modulated light source over optical fiber.	

These media have different characteristics (Hoth, 1975). One important characteristic, the attenuation in dB/km, is shown in Figure 58. Transmission capabilities, such as data rate and bandwidth, also vary considerably. So do other operational parameters, including cost. See Figure 59.

The power amplifier may be linear or nonlinear. Radio transmitters, for example, must be Class A or B for AM modulation or Class C for FM modulation. The transmission mode for cable drivers may be balanced or unbalanced, and either ac or dc coupled.

The directivity of the transmission mode is an important concern. Transmission may use a simplex (SX) mode which is unidirectional or a duplex (DX) mode

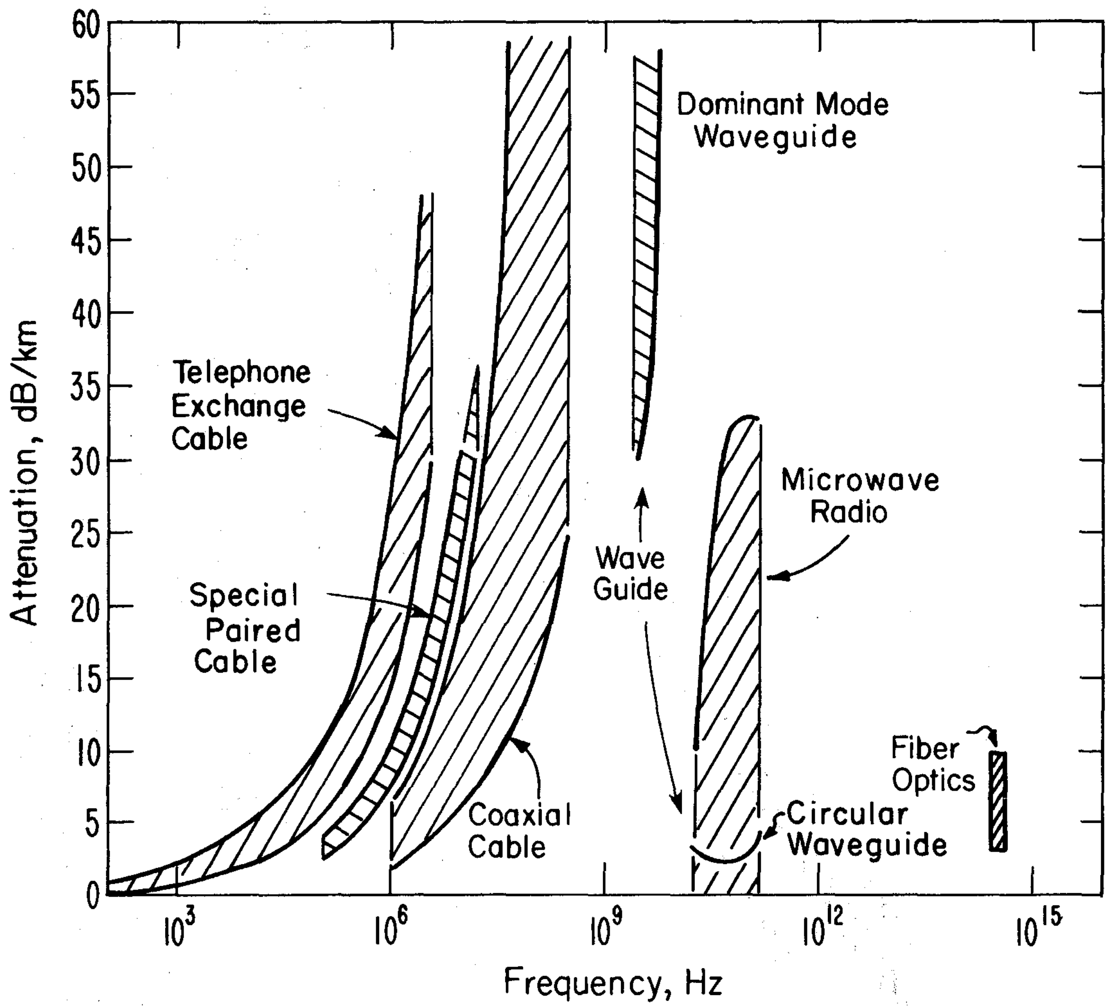


Figure 58. Losses of current telecommunication media.

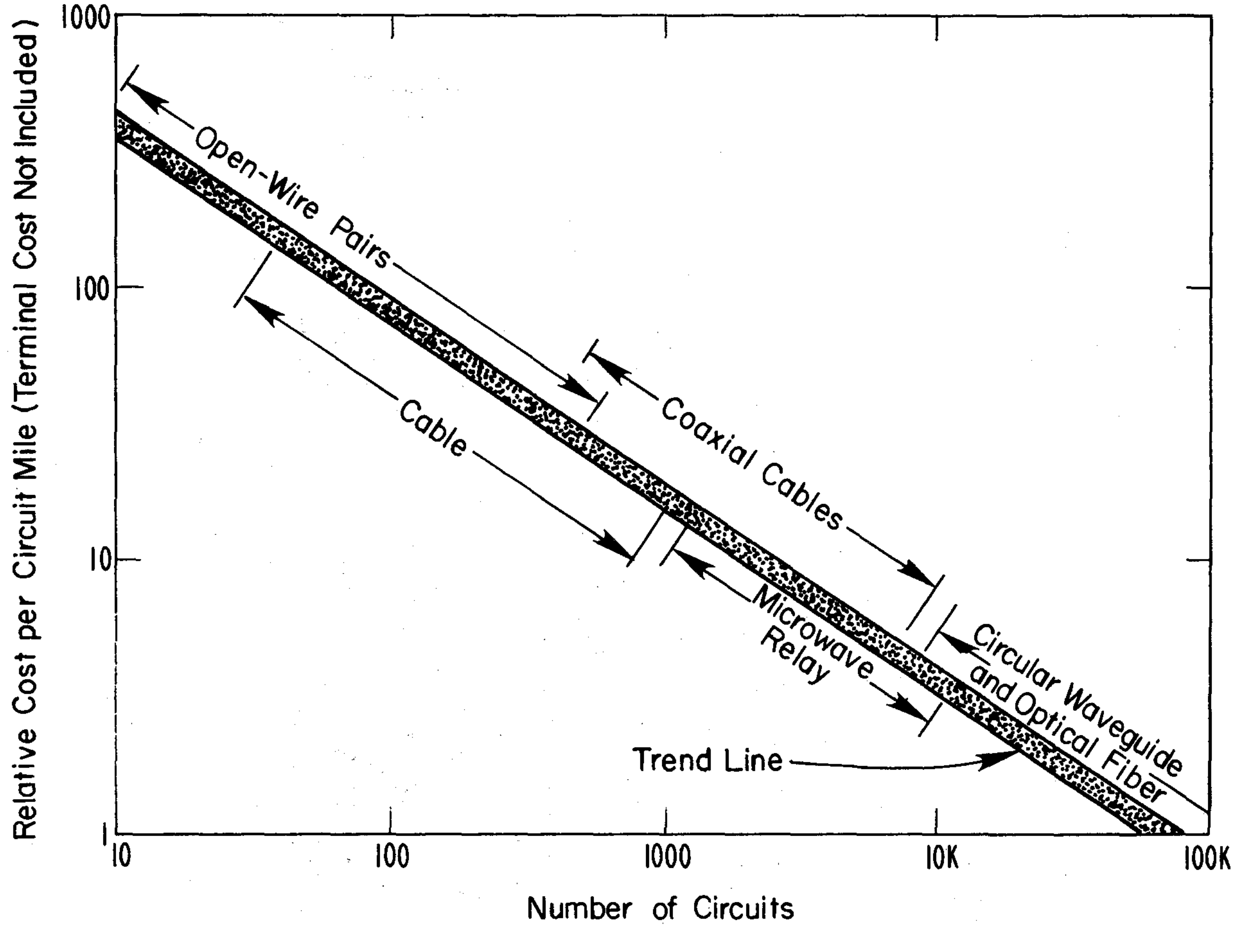


Figure 59. Trend line for relative cost per circuit mile (Abraham, 1960).

which is bidirectional. The DX mode can be either full duplex (FDX) or half duplex (HDX). The FDX mode involves simultaneous transmissions in both directions whereas the HDX mode uses the channel one direction at a time. The FDX circuits normally require two channels using FDM or a 4-wire circuit.

10.3. Bus Synthesis Tradeoff Summary

Figures 60 through 63 are examples of bus type structures which might be used for time-continuous analog signals, time-discrete analog signals, digitized analog signals and digital signals, respectively. Several tradeoff functions defined above are indicated under appropriate elements on these figures. Multiplexing points and methods are also shown. Each basic conceptual structure is identified by a number. Substructures are identified by letters. The current CP/SC links employing multiple wire-pair cable is concept 1b illustrated in Figure 60.

The interface point between the bus distribution system and the existing nodal equipments is assumed to be at the existing 26-pair hocks. This is the line between the source and the sampling/filter function on Figures 60 through 63. This interface point would, of course, change as nodal equipment and terminal equipment change from analog-to-digital in the future since functions such as sampling and A/D conversion would then take place within the node.

This aspect is considered further in Section 11 where candidate alternatives are selected and evaluated.

The bus structures illustrated in Figures 60 through 63 identify the range of choices faced in the selection and evaluation process. There are obviously a number of combinations and permutations which could be selected from the sets given in these figures.

The present CP/SC system is based entirely on the nominal 4 kHz telephone channel for both analog and digital signals. The transition to future switches of the AN/TTC-39 type will introduce 32-kbit/second and 16-kbit/second CVSD as a digital signal. These signals will require digital-to-analog conversion at the line side of the switch in order to interface with the conventional telephone set. If, at some time in the future, the digital-to-analog conversion is placed at the telephone set, the existing wire pair can still be used for transmission. However, such an approach could impact the selection of a bus structure. The bus may have to allow for a mixture of 4-kHz analog channels and 16-kbps or 32-kbps digital signals.

In the following section we select specific bus alternatives which appear to have potential applications in the command post network.

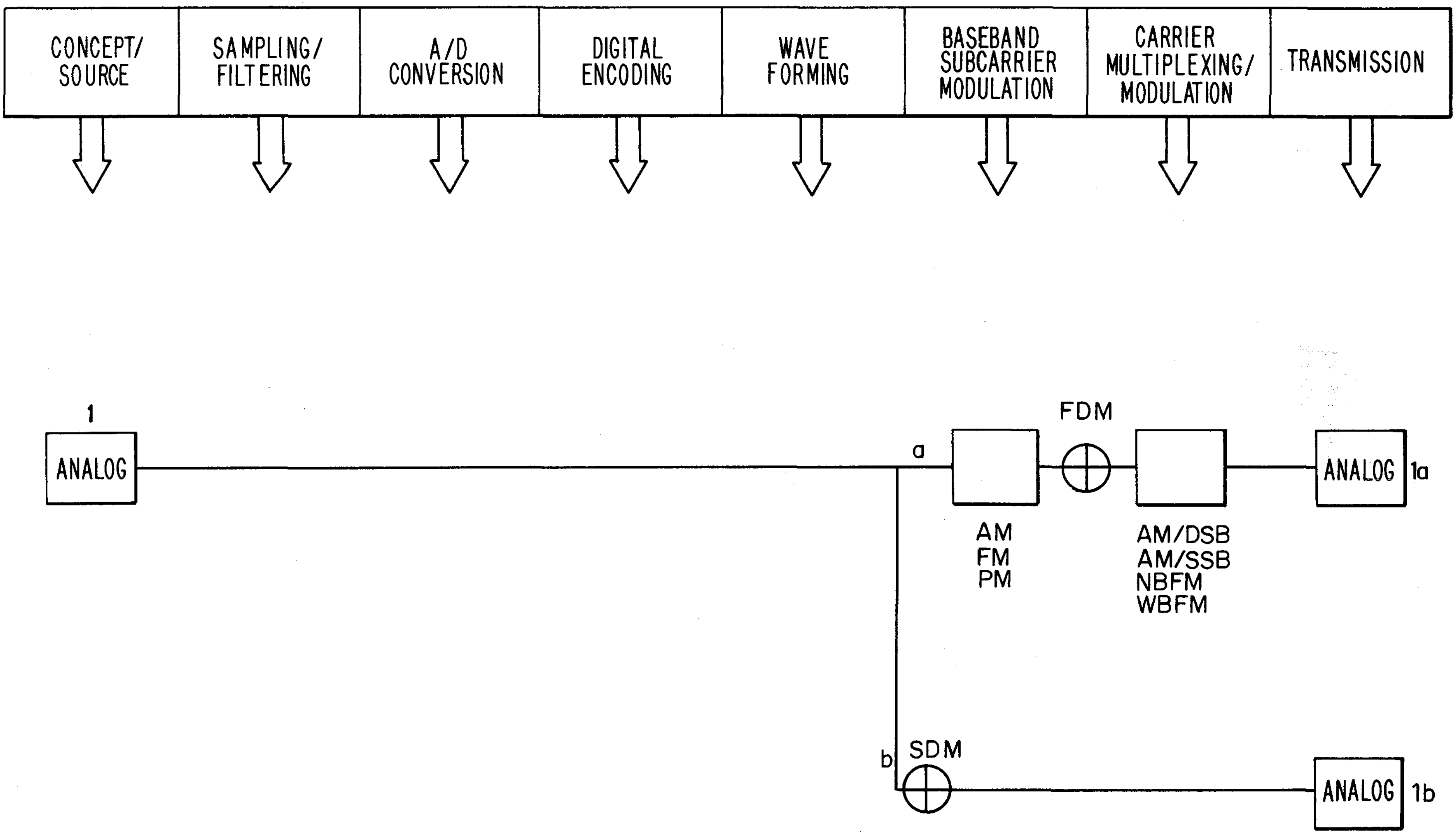


Figure 60. Transparent bus structures for time continuous analog signals.

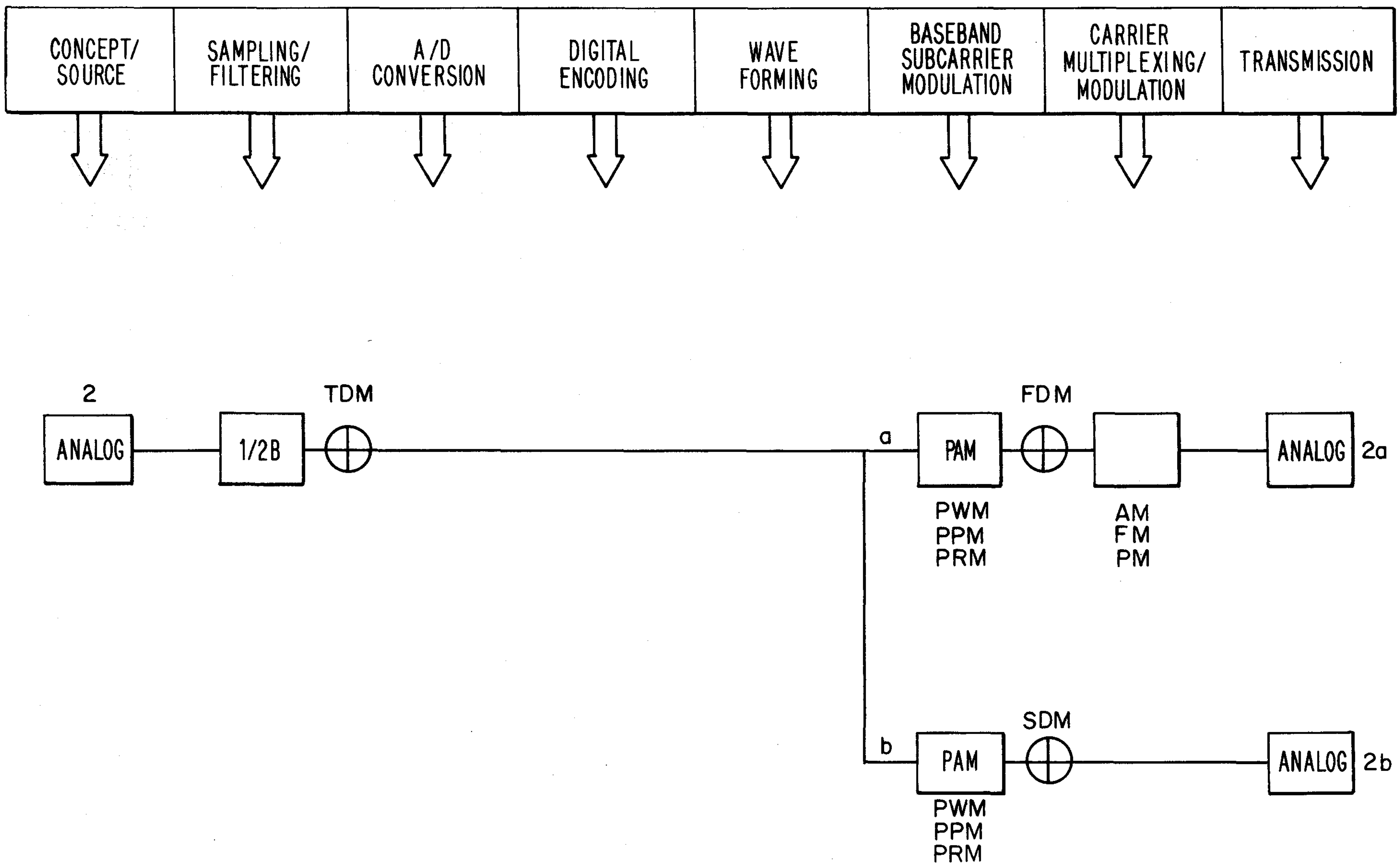


Figure 61. Transparent bus structures for time discrete analog signals.

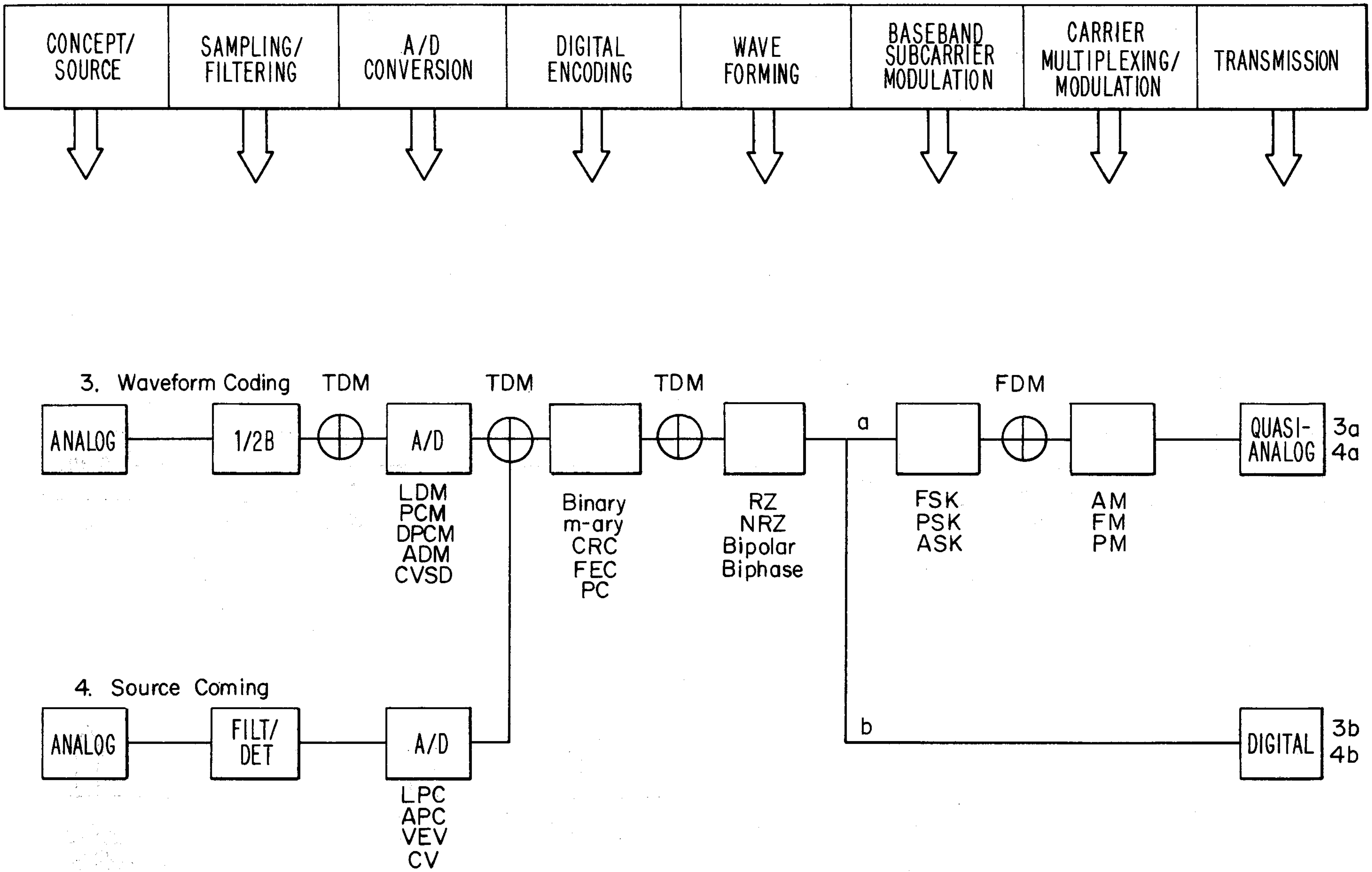


Figure 62. Transparent bus structures for digitized analog signals.

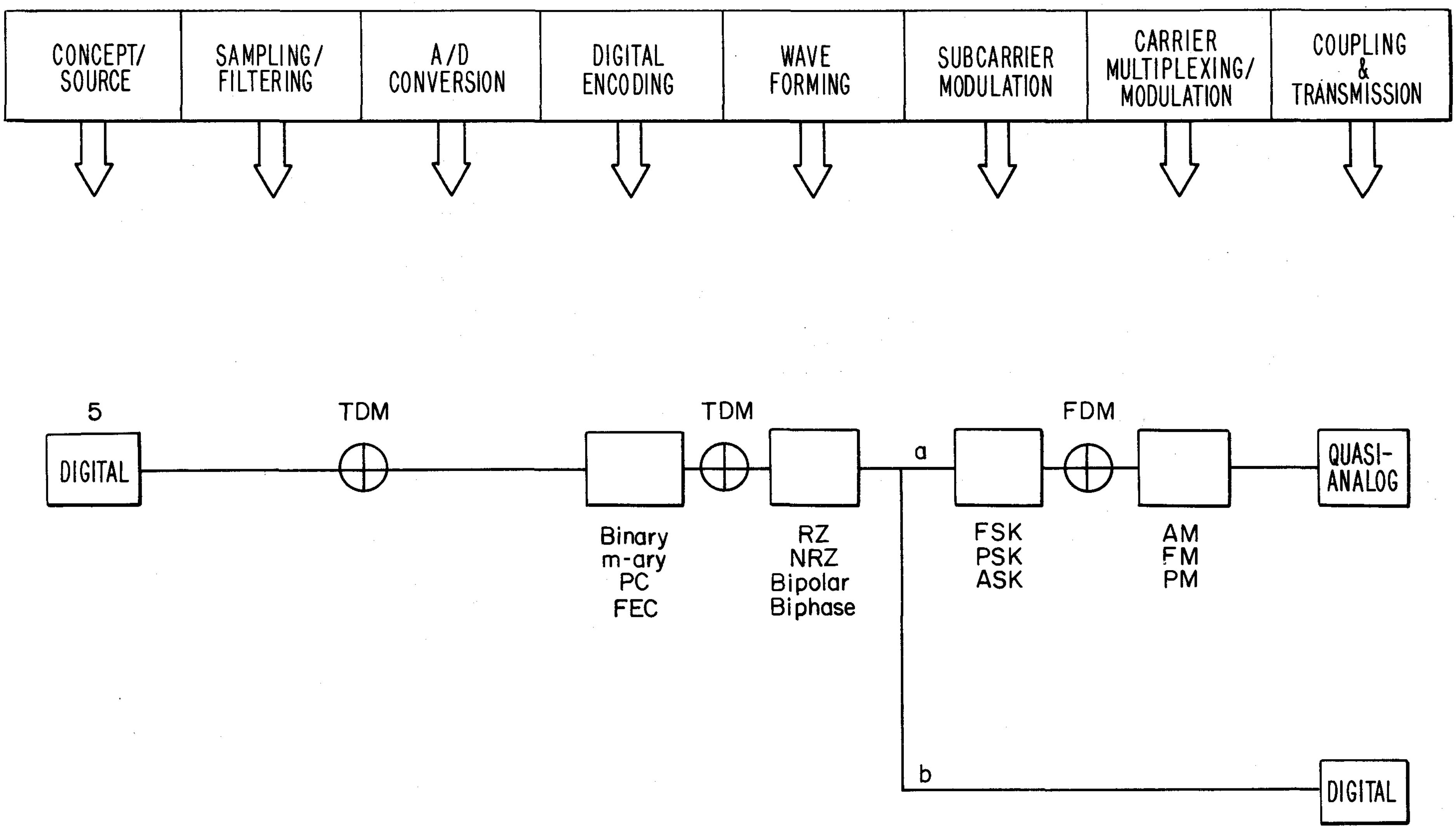


Figure 63. Transparent bus structures for digital signals.

11. SELECTION OF PREFERRED ALTERNATIVES

The previous section has indicated that the number of candidate alternatives for a CP/SC bus distribution system can be large. Here we reduce the number of candidates to a manageable size for further evaluation. We then apply certain selection criteria for choosing the preferred system.

The principal criteria used for selecting and evaluating candidate alternatives are as follows:

1. Deployment

   The extent to which deployment time and manpower can be saved. This requires a sizable reduction in weight and volume for the bus system relative to 26-wire-pair cabling.

2. Flexibility

   The design must adapt to future requirements. This includes changing from analog to digital equipment and mixes of these types of signal sources.

3. Capacity/Range

   The ability to accommodate a large number of channels on the bus. A maximum distance of 2 km with no repeaters is assumed to be one constraint. We also assume that the bus capacity should be capable of handling 120 full-duplex voice channels. This is equivalent to replacing ten 26-pair cables between any two nodes.

4. Power Distribution

   The capability of providing power to end instruments is an important consideration.

5. Security

   The desirability for equal or improved security. This includes minimizing electromagnetic signatures of the CP/SC as well as adding encryption capabilities.

6. Performance

   This includes reliability and survivability. Both should be maintained or preferrably improved over the current system. The quality of service should also be maintained or enhanced.

7. Development Risks and Cost

   The development concept should be based on proven technologies and the cost should be minimized.

8. Modularity

   The overall structure should be a transparent module requiring no external synchronization or timing signals. The bus structure should be organized into submodules which will permit adaptation to the transition from analog to digital network elements.

In the following subsections we first define the existing CP/SC link structure and then indicate alternatives to this structure. The candidate alternatives meet one or more of the desirable features listed above but not necessarily all of them. The relative advantages and disadvantages of each alternative are then summarized. Preferred alternatives are selected based on the above criteria.

11.1. CP/SC Distribution System - Existing Structure

Examples of CP/SC link structures currently employed for analog and digital source signals are depicted in Figure 64 for comparison with subsequent candidate alternatives.

Functional tradeoffs described previously are again indicated at the top of the figure. In this current system, the telephone voice signals are transferred at baseband frequencies over 26-wire-pair cables. Voice channels are 4-wire circuits and each 26-pair cable usually carries 12 two-way voice channels. Separate multipair cables are normally used to handle digital data. This is primarily teletype information which is coded in 7 bit binary form using the American Standard Code for Information Interchange (ASCII) with 3 bits added for error control. An FSK modem is often used with typically four TTY channels multiplexed onto a single voice channel using FDM techniques. Transmission may use a HDX or FDX mode depending on requirements.

During one tactical field exercise called Bold Eagle conducted in 1978 and considered typical, some 80 km of 26-pair cable were used. Thirteen C-130 aircraft and a similar number of 2-1/2 ton trucks were required to transport the cable alone. A 300 m spool of 26-pair cable weighs about 100 kg and requires two men to deploy it using an A-frame despooler. See Kleekamp and Metcalf (1979).

These numbers demonstrate the obvious advantage of a bus-type link for improving transportability and for reducing deployment time. The magnitude of improvement depends on the bus design concept employed.

The existing structure of a CP/SC distribution system has a large variation in size. The total number of telephone and teletype terminations was indicated in Section 5 for CP sizes ranging from very small to very large. For a medium size CP the number of telephones lines varies between 200 and 500. The number of teletype lines for this medium CP (assuming four FDX circuits per line) varies between 5 and 12. Not all of this traffic is necessarily carried between any two points. For the purpose of selecting and evaluating bus structures we assume that the maximum number of equivalent voice channels required between any two

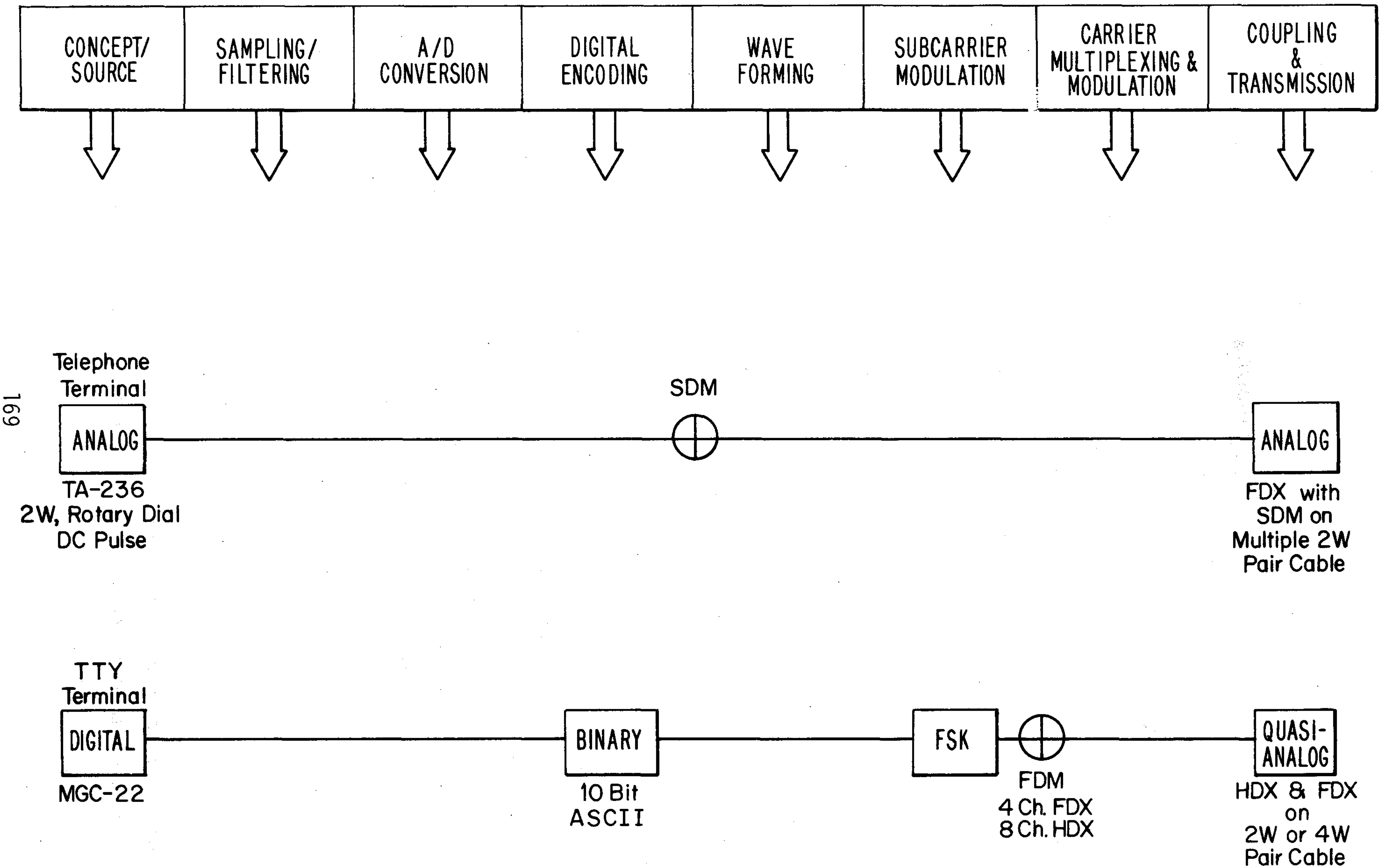


Figure 64. Existing CP/SC link structure.

points is 120. This would include teletype traffic and special control or network management signals. Such a bus would replace ten 26-pair cables. If additional channels between the two points are required (in a larger CP for example) then additional bus systems would have to be deployed.

The following CP/SC cable runs are considered appropriate for installing bus distribution systems during the initial improvement phase:

1. Clusters of analog telephones (4-wire) to the analog switch. An example would be from the field support area or the command headquarters to the switch located some distance away.

2. Ditigal teletype terminals (4-wire) to the main patch panel at the signal center.

3. Between the analog switch and the main patch panel.

4. Other 4-kHz bandwidth digital or analog terminal clusters (such as facsimile or logistic support terminal centers) requiring real-time connections through the analog circuit switch.

Examples of these existing types of cable runs are shown in Figure 65.

The bus distribution system would, in each case above, replace the multiple 26-pair cables at the switch wire frame or at the main patch panel with single or dual connecting cables. Five candidate alternatives for accomplishing this are described in the following subsections. These are evaluated and the preferred alternative selected in Section 11.8.

11.2. CP/SC Alternative I Bus Distribution System

Alternative Ia in Figure 66 is a CP/SC link structure using separate buses for analog and digital sources. The analog source is sampled but not digitized. Time division multiplexing combines several voice channels for transmission. Full duplex operation is achieved using analog transmission over 4-wire circuits. The resulting PAM signals can be switched directly in a time division switch such as a WECO 400. Digital data are time division multiplexed and transferred digitally using bipolar RZ format over a 4-wire circuit.

Alternative Ib in Figure 66 combines the analog and digital TDM signals for transmission and switching over the same 4-wire circuit. No carrier modulation is required since bandband transmission over a limited distance is achievable. Figure 67 illustrates a method for implementing Alternative Ia.

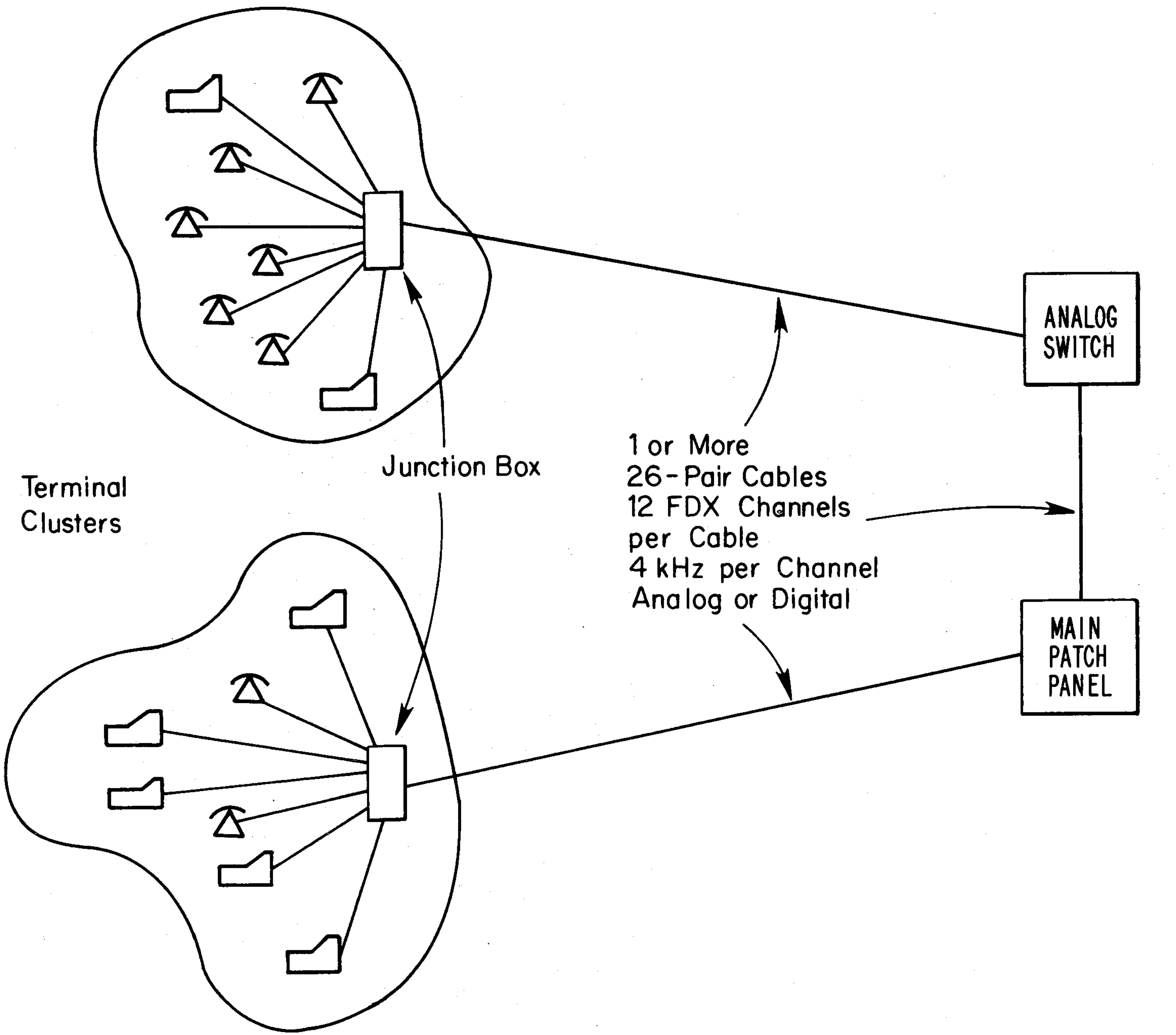


Figure 65. Existing CP/SC cable run structure.

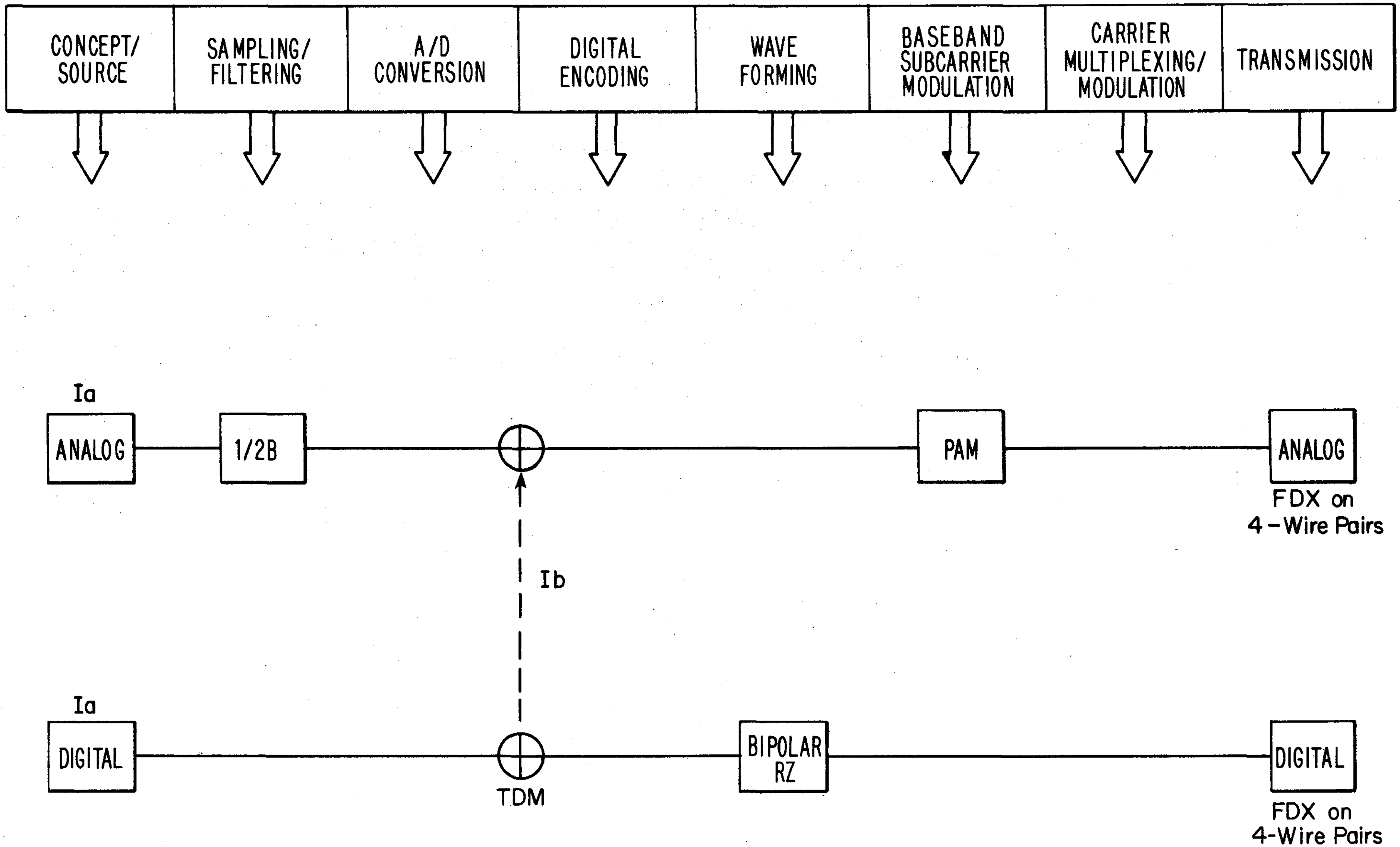
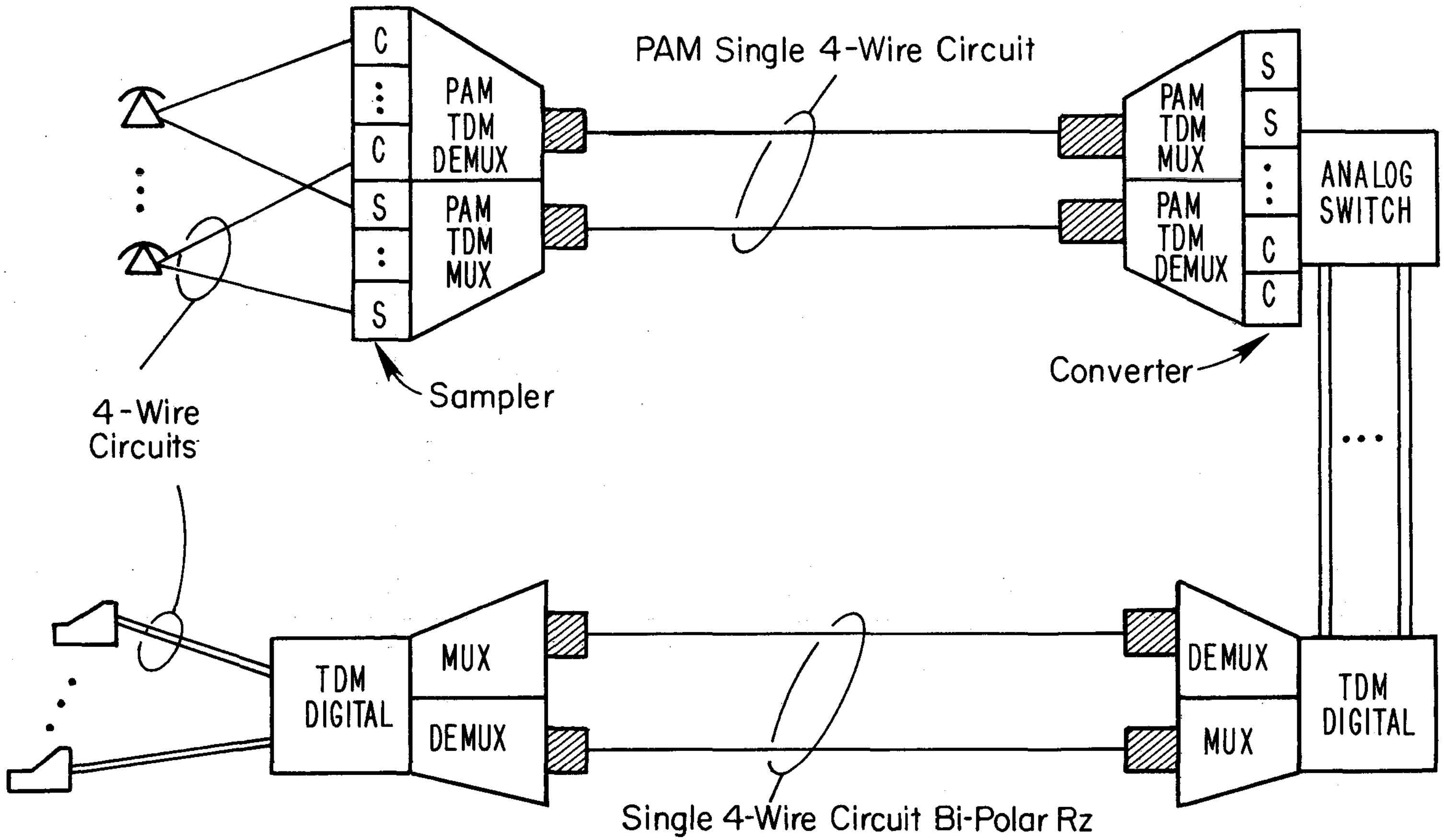


Figure 66. Alternative I for CP/SC link structure.



TDM = Time Division Multiplexer

PAM = Pulse Amplitude Modulator

Figure 67. CP/SC Alternative Ia bus distribution system.

11.3. CP/SC Alternative II Bus Distribution System

Alternatives IIa and IIb in Figure 68 use FDM techniques to combine analog and digital sources after subcarrier modulation. Analog signals modulate the subcarrier using NBFM and digital signals using FSK. Digital sources may be multiplexed using both TDM and FDM techniques. The buses may be separated for IIa or combined for IIb. Physical transmission is FDX using FDM on a single coaxial cable. Another alternative is to use separate coaxial cables. Both one-way and two-way systems are commonly used in cable television (CATV) systems using either one or two coaxial cables. The two-way transmissions on a single cable are achieved by FDM techniques and filters are required to separate upstream signals from downstream signals. A single bus system could provide bidirectional service using one half of the band for one direction and the other half for the opposite direction. Figure 69 illustrated Alternative IIb.

In a CATV system each TV channel occupies about 4.5 MHz. A 6-MHz channel is used to allow for guard bands to prevent crosstalk. Typically 20 to 30 TV channels are transmitted over the cable. About 500 NBFM voice channels could be transmitted over each TV channel. For data the number of carrier symbols per second (i.e., the baud rate) is roughly equal to the channel bandwidth in Hertz for FSK. This rate is reduced by about 20% on the channel because of noise and distortion. A 4.5-MHz channel is therefore capable of transmitting digital information at a rate given by:

$$4.5 \text{ MHz} \times 0.8 \times 1 \text{ b/s/Hz} = 3.6 \text{ MBPS}.$$

Other subcarrier modulation schemes which provide 4 b/Hz to be transmitted yield 14.4 Mb/s per TV channel. A single cable could carry up to 7000 voice channels.

11.4. CP/SC Alternative III Canonical Bus Distribution System

Alternative III is illustrated in Figures 70 and 71. This bus distribution system is described as canonical because it embodies a family of alternatives within the same overall structure. The functional process is one of analog-to-digital conversion followed by multiplexing the binary encoded voice or digital data using TDM. Finally, transmission of the TDM signal can be over three different media; 1) T-carrier with either 4-wire pairs for short distances or dual coaxial cables for longer distances, 2) single coaxial cable using dual carriers modulated with PSK, and 3) a unipolar RZ digital waveform and pulsed LED's driving dual fiber optical cables.

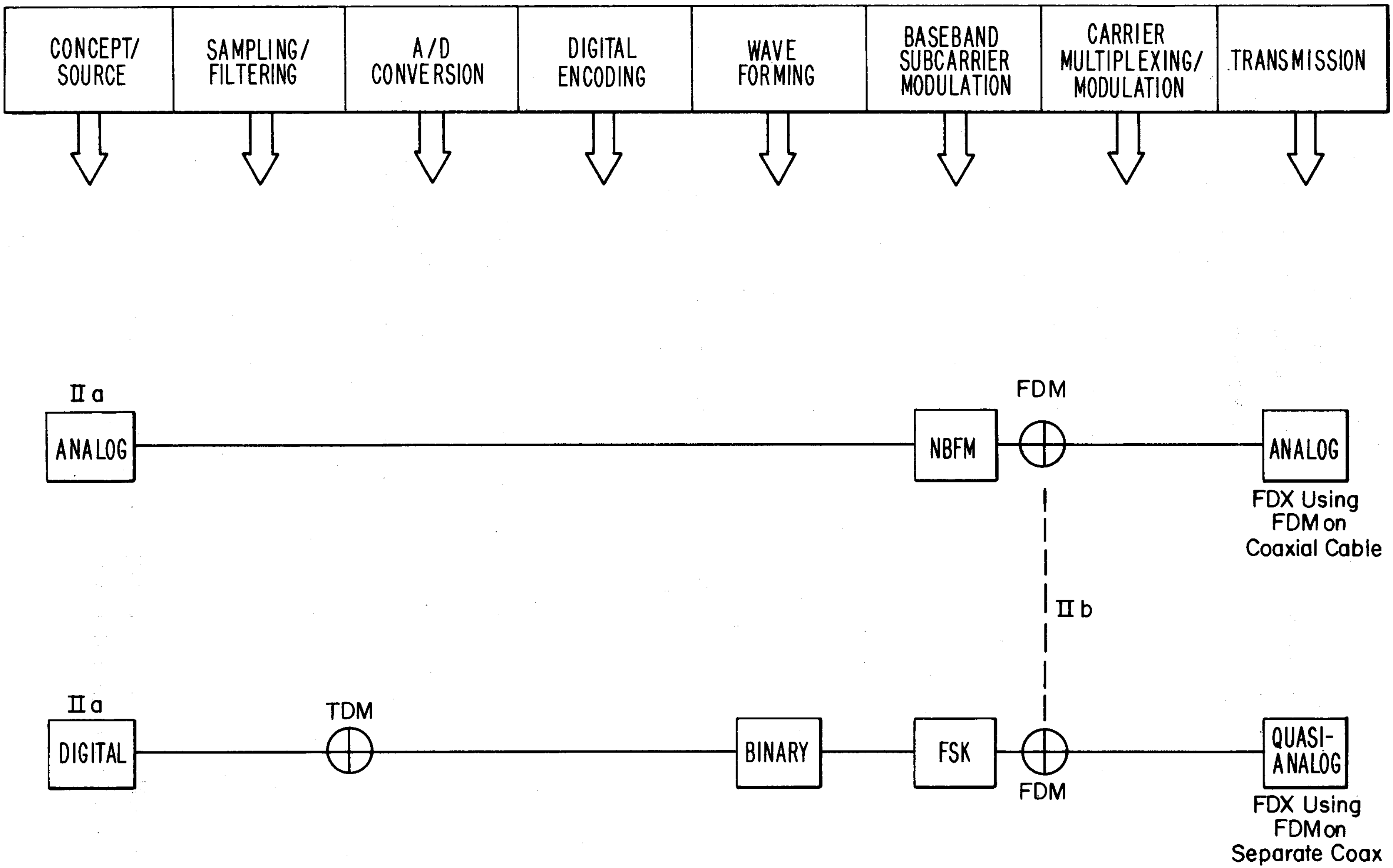
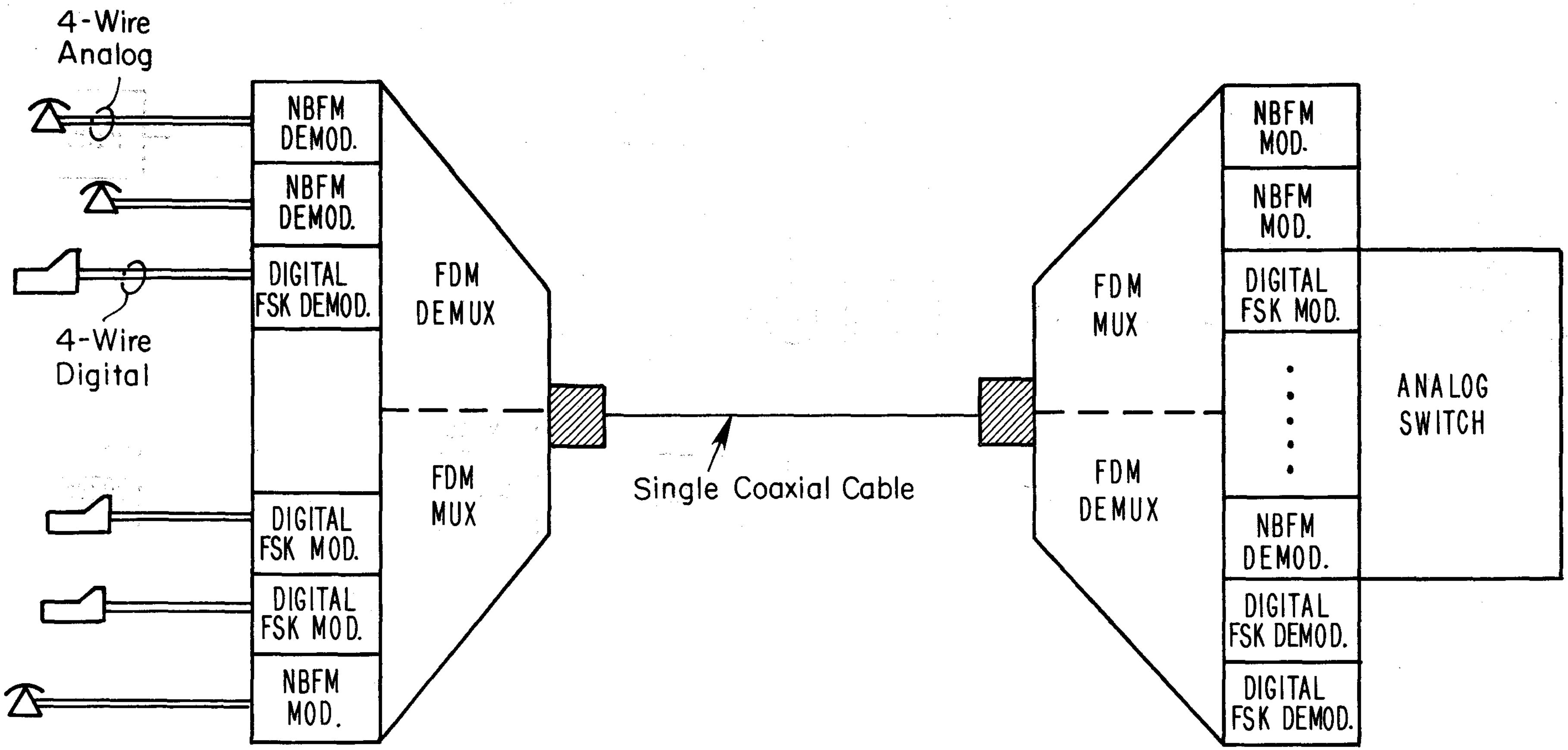


Figure 68. Alternative II for CP/SC link structure.



NBFM = Narrow-Band Frequency Modulation
FSK = Frequency Shift Keying Modulator
FDM = Frequency Division Multiplexer

Figure 69. CP/SC Alternative IIb bus distribution system.

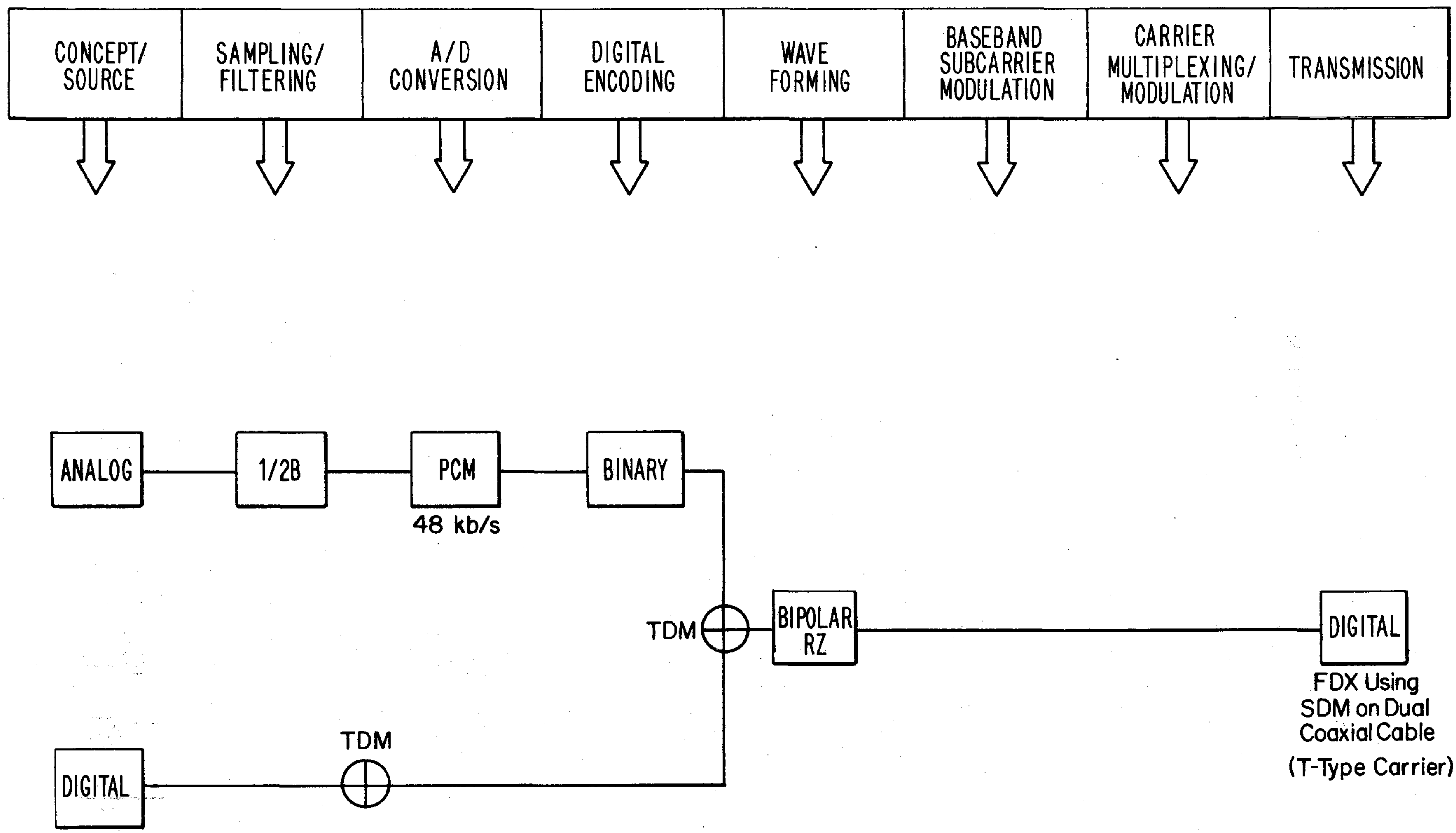


Figure 70. Alternative III for CP/SC link structure.

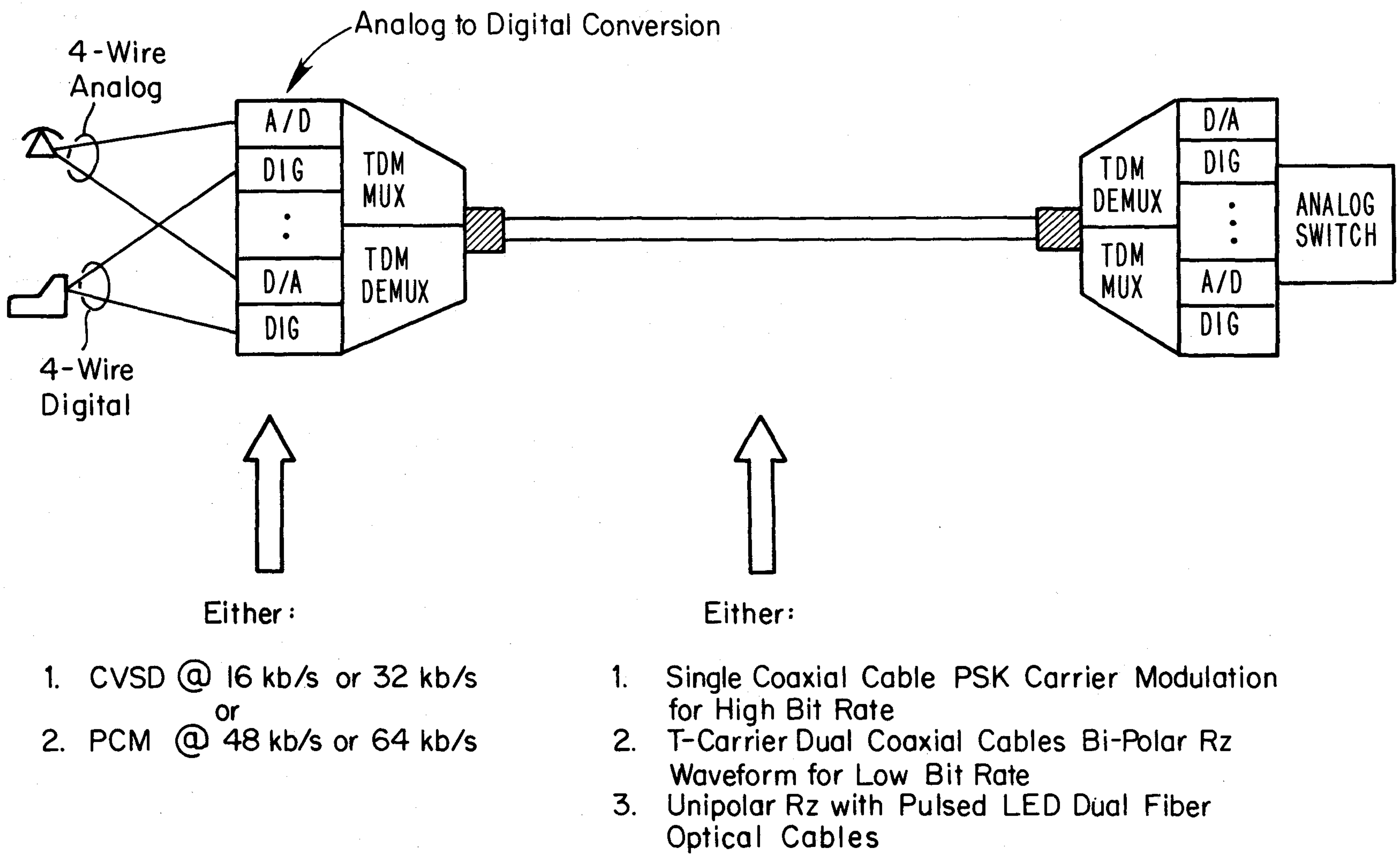


Figure 71. CP/SC Alternative III canonical bus distribution system.

The analog to digital conversion can use either CVSD at 16 kb/s or 32 kb/s or PCM at 48 kb/s or 64 kb/s.

The capacity of Alternative III is limited by the TDM device and the transmission media. In the CP/SC bus application with 120 voice channels, CVSD at 16 kb/s would require a transmission rate of 1.92 Mb/s. Use of PCM at 64 kb/s would necessitate a 7.68 Mb/s rate.

11.5. CP/SC Alternative IV Canonical Bus Distribution System

Alternative IV is illustrated in Figures 72 and 73. This bus distribution system is also described as canonical because it may use a number of analog to digital conversion processes. Functionally, this alternative includes analog to digital conversion of voice signals followed by a modem to drive a Frequency Division Multiplexer (FDM) for quasi-analog carrier transmission over a coaxial cable. The FDX operation is achieved over a single coaxial cable using FDM as in Alternative II. Digital data can be initially combined through TDM to a 4-kHz bandwidth equivalent rate.

11.6. CP/SC Alternative V Bus Distribution System

Alternative V in Figure 74 uses LPC or APC voice digitization to achieve 2.4-kb/s or 9.6-kb/s rates per channel. Digital data sources are combined to similar rates and then multiplexed with the digitized voice using TDM. Physical transmission is via two-fiber optical cables driven by pulsed LED's. Such a system has the information carrying capacity of several hundred voice channels using 16 kb/s CVSD and several thousand voice channels using LPC at the 2.4-kb/s rate.

11.7. Summary of Assessment of Candidate Alternatives

The relative advantages and disadvantages of the five selected alternatives are summarized in Table 26 and discussed below.

Alternative I is probably the simplest of all the alternatives to implement. Existing twisted-wire pairs and spiral-four cable can be used for the physical link. This alternative, however, is the least compatible with the transitional improvement plan which requires replacement of analog switches with digital switches. The PAM signals could, however, be switched using time division matrix as in WECO 400.

The link capacity may be limited at longer distances because of noise pickup on the lines which restricts detectability of the PAM voice channels and the data

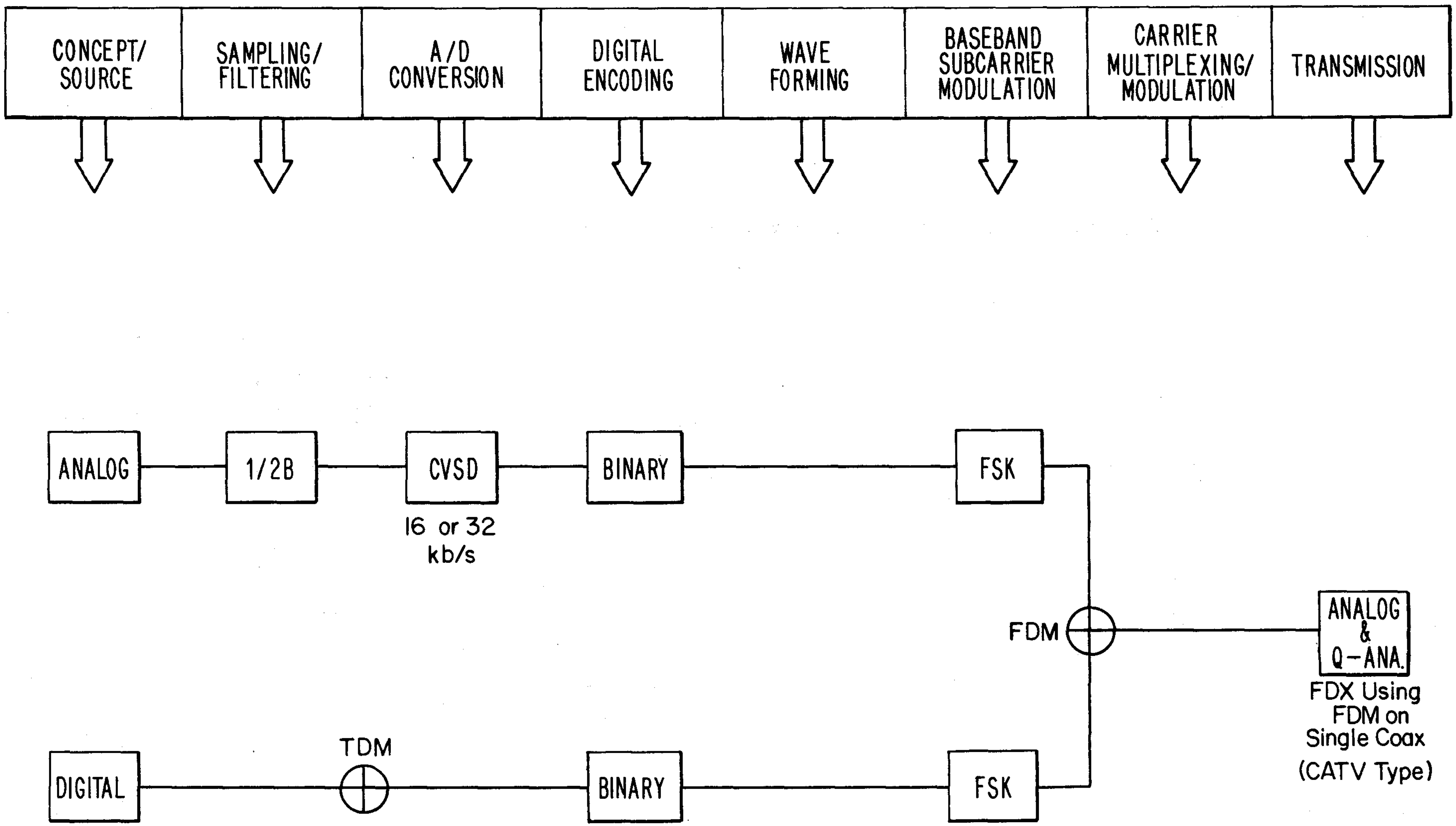


Figure 72. Alternative IV for CP/SC link structure.

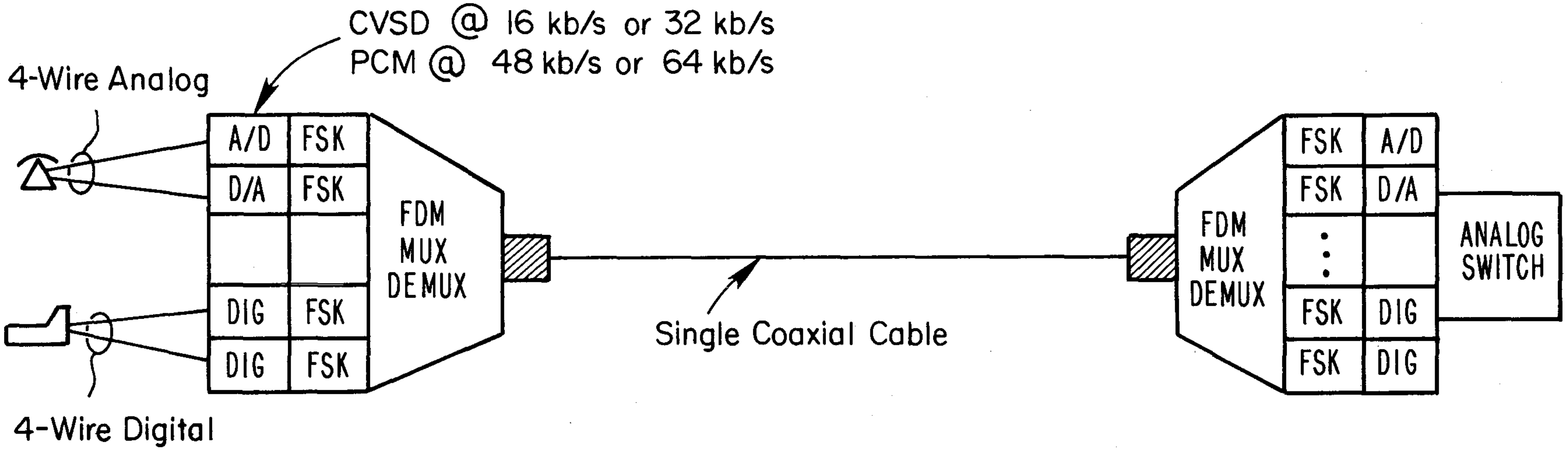


Figure 73. CP/SC Alternative IV canonical bus distribution system.

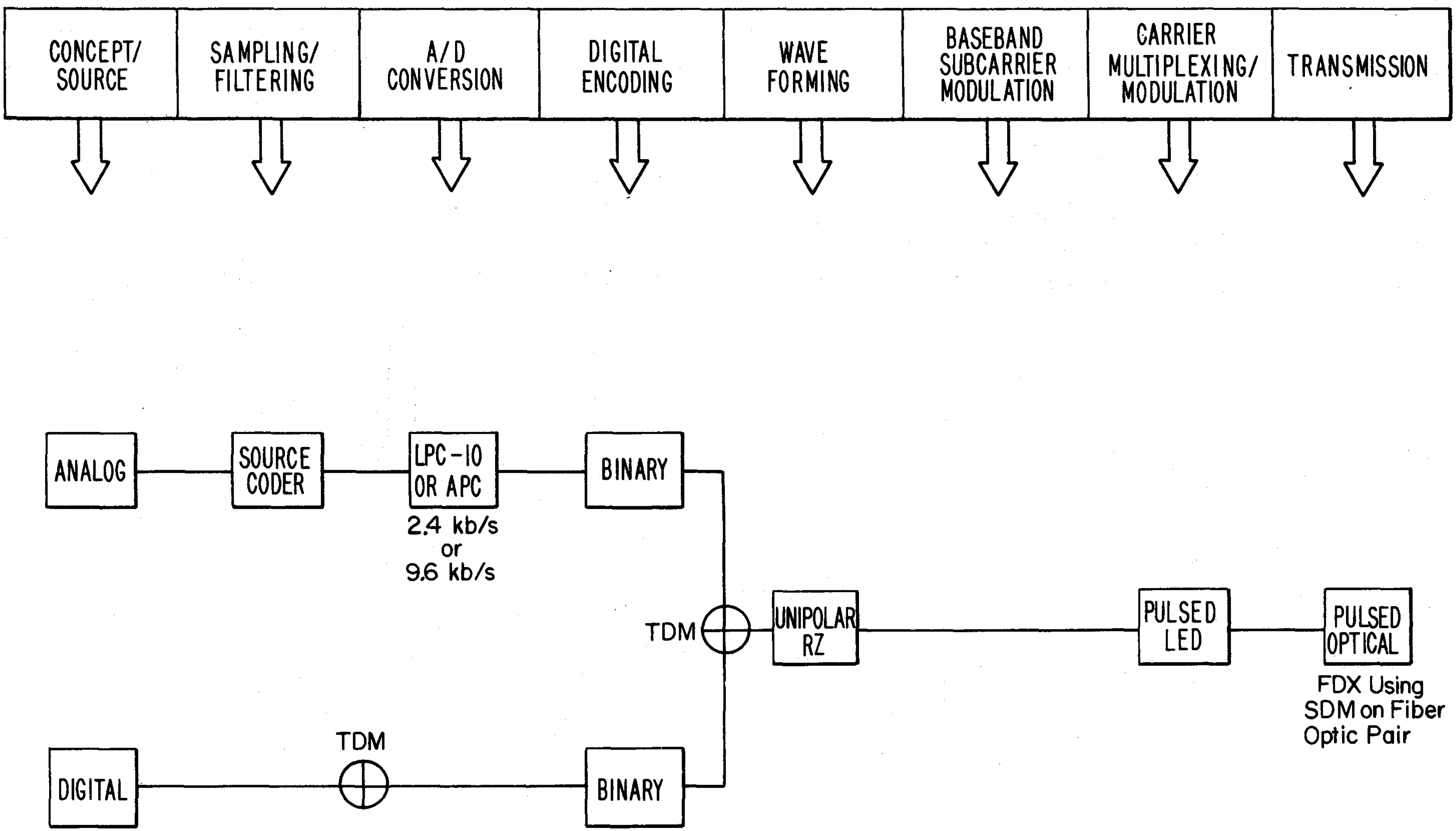


Figure 74. Alternative V for CP/SC link structure.

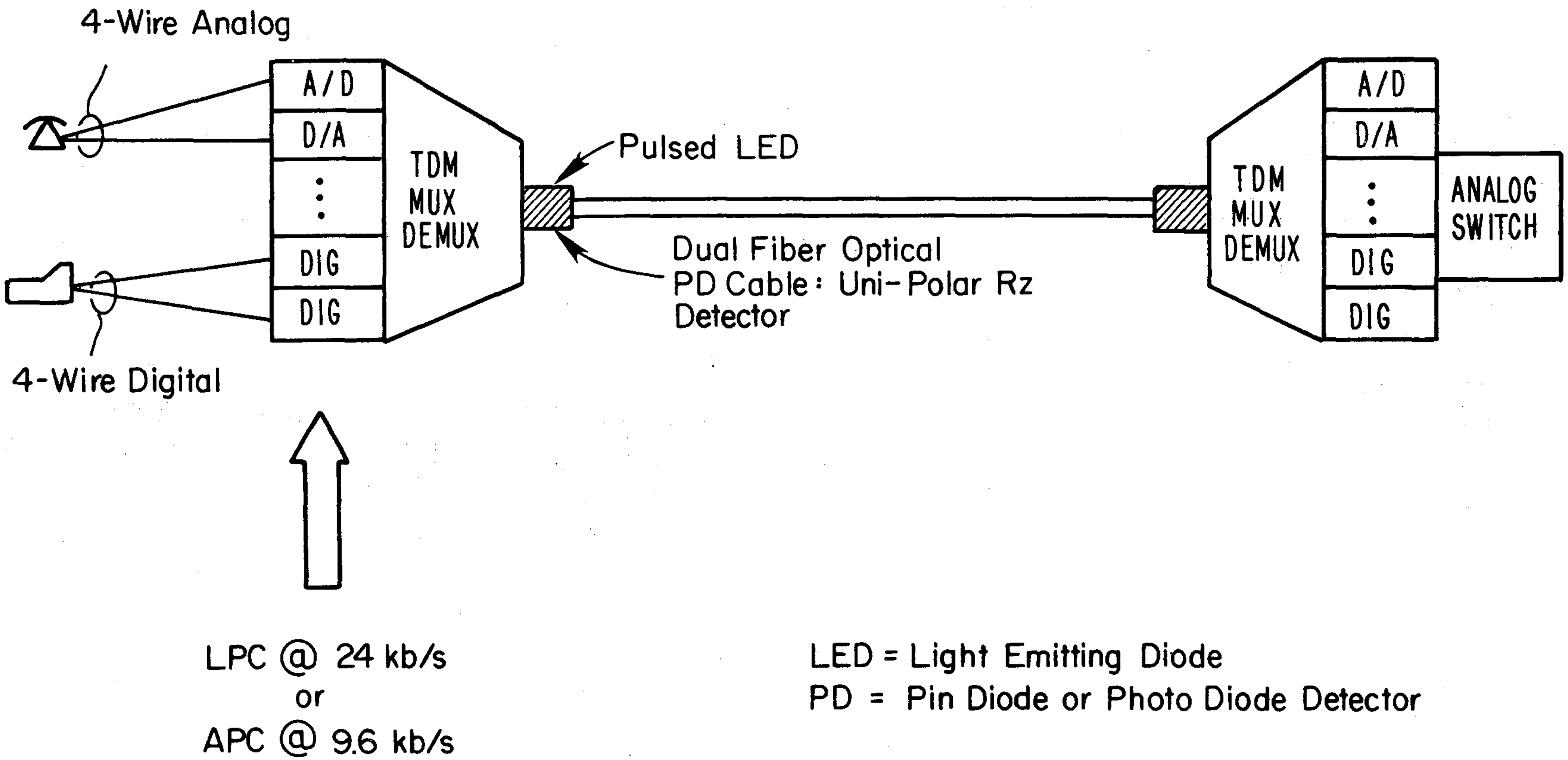


Figure 75. CP/SC Alternative V bus distribution system.

Table 26. Evaluation of Preferred Alternatives

ALT	PROCESSING	TRANSMISSION	ADVANTAGE	DISADVANTAGE	RISKS	COSTS
I	Analog: PAM Digital: TDM	A&D Baseband Over 4-Wire Pairs	Simplest to implement. Uses existing wire pairs or spiral four cable.	Requires A/D conversion to switch digitally. May be capacity limited. High EM signature not secure.	Detect-ability limits range. Requires field test to demonstrate technical feasibility. Useful range limits flexibility.	Low interface & media costs. Higher cost in far term and may not be compatible.
II	Analog: NBFM Digital: FSK	A&D-A FDM/FM over coaxial cable.	Compatible with analog switch currently used. Could include video transmission on high capacity cable.	Not compatible with digital switch unless A/D converted. Requires modems for each channel. Not secure. Low EM signature requires double shielding.	Special voice channel filters required. Otherwise similar to CATV systems.	Low for near term. Higher for far term.
III	Analog: PCM or CVSD Digital: TDM	1) Bipolar coaxial T-carrier. 2) PSK carrier on coaxial cable 3) Unipolar on fiber optical cable.	Flexibility in A/D conversion. Transmission options range from proven to development. Low EM signature.	Requires wide bandwidth per channel & D/A conversion for analog switch.	Low risk similar to T-Carrier except for for TDM unit & fiber optics option.	Medium cost for near term. Lower cost in far term.
IV	Analog: PCM or CVSD Digital: TDM	Quasi-analog FDM/FM over coaxial cable.	Flexibility in A/D conversion. Digital baseband can be switched digitally and encrypted Low EM signature.	D/A conversion required for analog. switching.	Basic elements have been demonstrated. CVSD used in tactical systems, e.g., TTC/39	Medium cost for D/A conversion in near term. Lower in far term.
V	Analog: LPC or APC Digital: TDM	Digital pulses over fiber optical cable.	Maximum number of voice channels/link. Easily encrypted. Maximum capacity/link. Minimum weight & size. Lowest EM signature.	Sophisticated terminal equipment.	Relatively new technology. Not tested in tactical environment	High processing & interface costs.

channels transmitted at baseband. The maximum useful range requires field testing.

End-to-end digital encryption is not practical and the EM signature is greater than the other alternatives.

Alternative II, although compatible (after demodulation) with analog switches currently in use, does not lend itself to future digital switching. Digital encryption is not feasible. The advantage is the high capacity available using the proven technology of a CATV type system. Some risk is involved in developing voice channel filters for the system. In the future the systems can easily be adapted to include video circuits including television and other wideband services. The EM signature is relatively low when double shielded coaxial cables are used.

The canonical Alternative III is compatible with digital switching but requires demultiplexing and conversion to the analog baseband voice channel for switching with existing analog methods. The basic T-carrier concept for transmission is a proven technology which can probably be adapted for tactical use at reasonable cost. Single coaxial cable technology is proven as well as PSK carrier transmission. The fiber optic transmission allows incorporation of the smallest, most advanced cable technology. A 300 m cable weights about 5 kilos. Current fiber optical cables can provide metallic strength strands which can serve also as power conductors. Alternative III offers considerable flexibility in choice of the analog/digital conversion and binary encoding, and in choice of transmission media. Digital TDM transmission is transparent to encrypted voice and could itself be link encrypted in the future if desired. Finally, Alternative III is compatible with future transitions to all digital operations, either with CVSD (16 or 32 kb/s), or PCM (48 kb/s and 64 kb/s).

Alternative IV offers most of the same flexibility and advantages as found in Alternative III with the exception of the transmission media. The FDM/FM quasi-analog signal is suitable for transmission over coaxial cables.

Alternative V uses a relatively new technology and requires more sophisticated equipment than the others. However, this system has the maximum voice-channel capacity per link. The weight and volume reduction of the physical link is also as great as Alternative III with the fiber optical cable. The EM signature is negligible. The transmission properties of fiber optics eliminate many problems inherent in wire or rf transmission such as electrical isolation, immunity to lightning, EMP, EMI, and crosstalk, as well as weight, volume, and power savings.

Some field tests of fiber optics for tactical communications have been conducted by the Air Force. See Kleenkamp and Metcalf (1979). The results demonstrated the technical feasibility for handling voice (CVSD) and data traffic in place of a 26-pair cable approximately 250 m long. Before operational fiber optic systems can be implemented some refinements to components may be required to ensure that they are suitable for use in the tactical environment. However, no new technology breakthroughs appear to be needed. The bandwidth capacity of fiber optics has not been fully exploited for high-traffic-density links. Combining 120 voice channels using 32 kb/s CVSD requires a data rate of about 3.8 Mb/s. This same rate could accommodate over 1500 channels using 2.4 kb/s LPC. Rates as high as 100 Mb/s have been achieved on fiber optical cables over short distances without repeaters. We have assumed 2.4 kb/s LPC or 9.6 kb/s APC for comparison purposes. The wide bandwidth of fiber optical cable, however, could easily accommodate 64 kb/s PCM in most applications and this could reduce the processing and interface costs.

Another alternative which was not included may be of interest in applications where the traffic to and from a node or a cluster of terminals is a mixture of analog voice traffic and quasi-analog data traffic. These traffic types are currently both being transmitted over wire pair circuits. Both require a nominal bandwidth 4 kHz.

It might appear that a single codec design would be suitable for digitizing both types of voiceband signals. Their digital representations could then be multiplexed using time division techniques and transmitted on a digital bus. The problem with this approach is the codec design. Quasi-analog signaling waveforms and their spectra are statistically very different from speech waveforms even though both occupy essentially the same bandwidths. Codecs designed for digitizing speech signals in an optimum manner are usually very inefficient when used to digitize quasi-analog signals generated by a data modem. It may be possible, however, to develop circuitry which detects the type of input signal to the codec and switch it to an appropriate strategy. Rather then take this approach we have assumed instead that the modems themselves should be eliminated as in Alternative III.

11.8. Selection of Preferred Alternative

The five candidate alternatives have been evaluated in terms of the ten selection criteria introduced at the beginning of Section 11. They are: Deployment Time, Flexibility, Capacity, Range, Power Distribution, Security, Performance, Development Risk, Relative Cost, and Modularity. Each alternative was rated for all criteria on a numbered basis as follows:

0 - not practical
1 - poor
2 - fair
3 - good
4 - excellent.

The results are shown in Table 27. For Alternatives III and IV, only CVSD at 16 kb/s and PCM at 64 kb/s are shown. The differences between the other rates are considered second order in this qualitative evaluation.

There are, of course, more sophisticated methods for choosing a preferred alternative and many complex factors which should ultimately be considered. For example, relative weights could be assigned to each measure of effectiveness. Weighting procedures have been developed by panels of combat officers with battalion or higher command experience by the U. S. Army Training and Doctrine Command (TRADOC). Such weighting procedures have not been used here because of the preliminary nature of this work and the limited time available.

While these ratings are admittedly subjective judgements by the authors they do demonstrate a useful method for guiding the selection of the preferred alternative. Some explanations are in order for certain numerical ratings. For example, performance is viewed from a user's standpoint. Higher voice digitization rates normally provide a higher voice quality and are more robust (i.e., less susceptible to errors). The nondigitized forms are rated the highest. The LPC source coding (Alternative V) is rated low because it is more susceptible to transmission errors.

The bus capacity may impact on the deployment time since capacity depends on the transmission media and the media affect deployment. The number of full-duplex 4-kHz voice channels versus the transmission rate or bandwidth of the media and parametric in voice digitization process or bandwidth requirements is shown in Figure 76. The number of 26-pair cables which could be replaced as a function of bus rate or bandwidth is also indicated on this figure. This number assumes each 26-pair cable normally carries 12 full-duplex voice channels. Table 28 summarizes the number of buses required for various alternatives assuming full-duplex operation and 120 voice channels per bus link.

The deployment time is difficult to assess quantitatively. Coaxial cables are rated fair to good depending on whether one or two are required. The fiber optical cable is rated highest because it has the lowest weight and volume.

The flexibility ratings depend on how many changes are required to the link structure as the nodes and terminals evolve from analog to digital. It is assumed

Table 27. Ranking of Five Bus Distribution System Alternatives

Alternatives / Selection Criteria	I	II	III						IV		V
	PAM	NBFM	16 kb/s CVSD			64 kb/s PCM			16 kb/s CVSD	64 kb/s PCM	LPC or APC
			T-Carrier	Coaxial	Fiber	T-Carrier	Coaxial	Fiber			
1. Deployment Time	1	3	2	3	4	2	3	4	2	2	4
2. Flexibility	1	2	3	3	3	3	3	3	2	2	1
3. Capacity	1	4	3	3	3	3	3	3	4	4	3
4. Range	1	3	1	3	3	1	3	3	3	3	3
5. Power Distribution	4	4	4	4	3	4	4	3	4	4	3
6. Security	1	1	2	3	3	2	3	3	3	3	3
7. Performance	2	3	3	3	3	4	4	4	3	3	2
8. Development Risk	3	2	3	3	2	3	3	2	3	3	1
9. Relative Cost	3	2	3	2	2	3	2	2	2	2	0
10. Modularity	1	1	4	4	4	4	4	4	2	2	1
Unweighted Total	18	25	28	31	30	29	32	31	28	29	21
Weighted Total	20	30	33	37	37	34	38	38	32	33	26

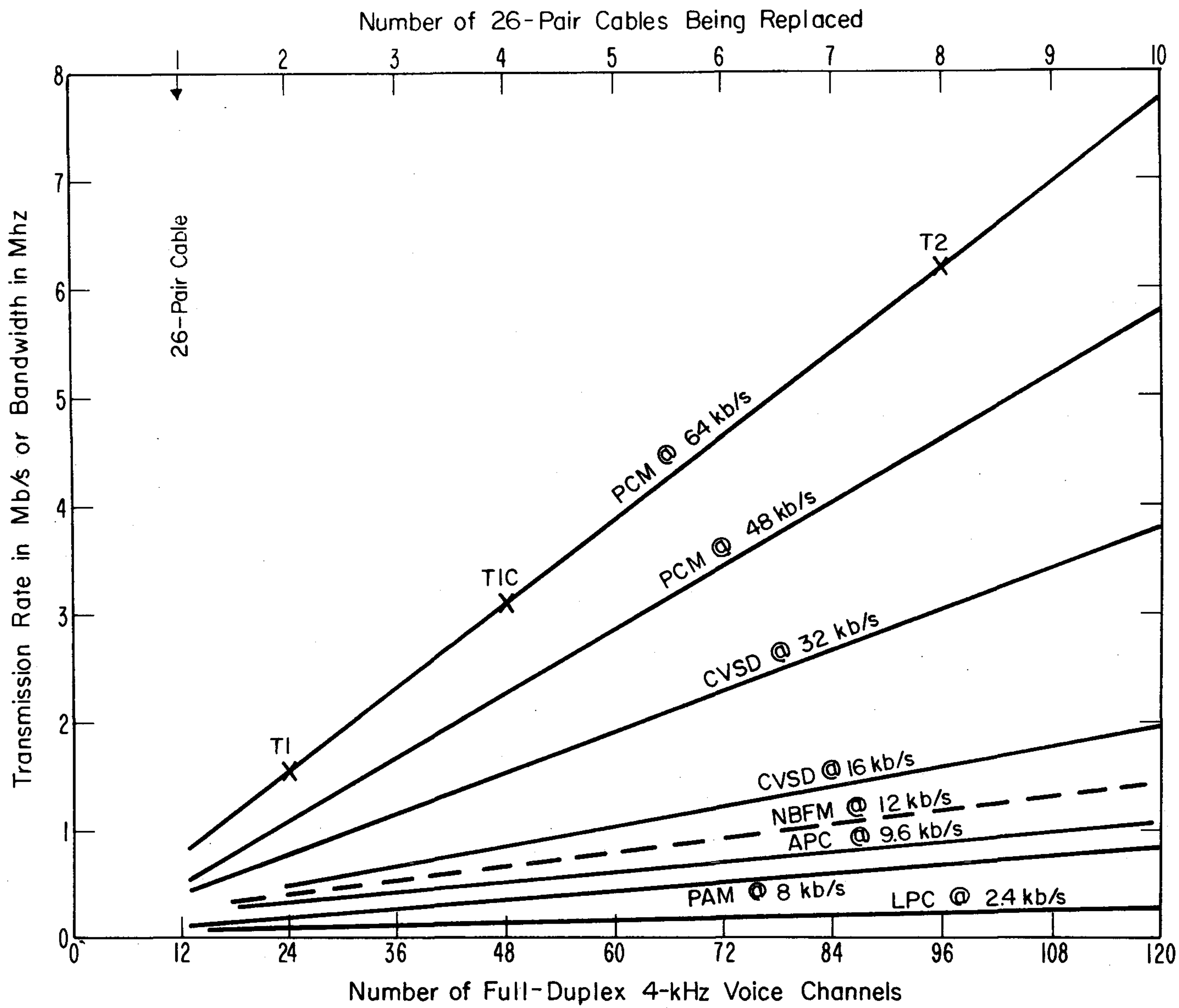


Figure 76. Estimates of bus channel capacity for various bus distribution systems.

Table 28. Channel Capacity of CP/SC Alternative Bus Distribution Systems

Candidate Alternative	Bandwidth or Rate Per Channel	BW or Rate for 120 HDX Channels	Transmission Media	No. Required for FDX Operation	No. Required for 120 FDX Channels at 2 km Range
I (PAM)	8 kHz	970 kHz (TDM)	Twisted Wire Pairs	2	4
II (NBFM)	12 kHz	1.44 MHz (FDM)	Coaxial Cable	1	1
III (CVSD)	16 kb/s	1.9 Mb/s (TDM)	Coaxial Fiber Optical	2	2
III (CVSD)	32 kb/s	3.8 Mb/s (TDM)	Coaxial Fiber Optical	2 2	2 2
III (PCM)	48 kb/s	5.8 Mb/s (TDM)	Coaxial Fiber Optical	2 2	2 2
III (PCM)	64 kb/s	7.7 Mb/s (TDM)	Coaxial Fiber Optical	2 2	2 2
IV (CVSD)	16 kb/s	1.9 Mb/s (FDM)	Coaxial Cable	1	1
IV (CVSD)	32 kb/s	3.8 Mb/s (FDM)	Coaxial Cable	1	1
IV (PCM)	32 kb/s	5.8 Mb/s (FDM)	Coaxial Cable	1	1
IV (PCM)	64 kb/s	7.7 Mb/s (FDM)	Coaxial Cable	1	1
V (LPC)	2.4 kb/s	0.3 Mb/s (TDM)	Fiber Optical Cable	2	2
V (APC)	9.6 kb/s	1.1 Mb/s (TDM)	Fiber Optical Cable	2	2

that security by encryption requires digitization at the terminals. Development risk and cost ratings are based on the complexity and net component developments required. Note that a high number rating implies the lowest cost.

The two summations at the end of each column in Table 27 are unweighted and weighted summations. For the weighted sum the deployment and flexibility criteria ratings have been increased by a factor of two because these are considered to be the most important. The preferred alternative is Alternative III in this subjective evaluation.

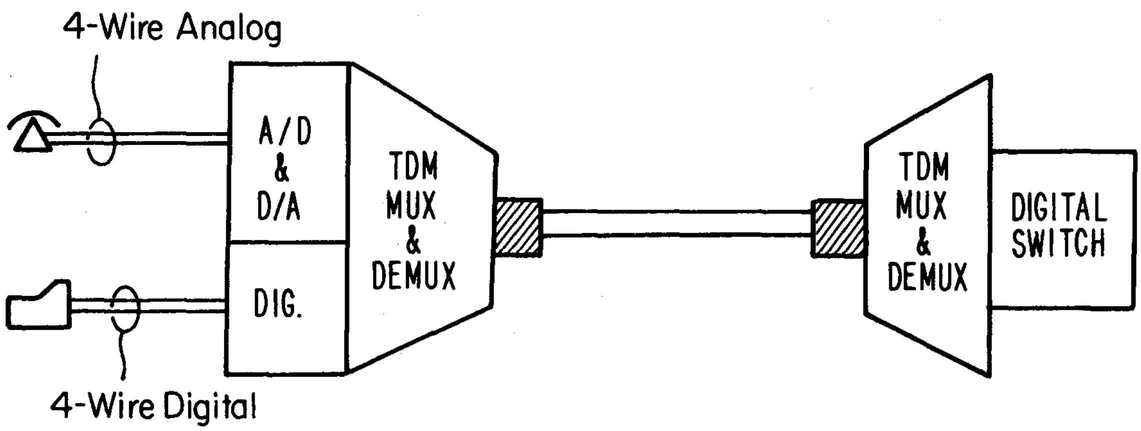
Figure 77 illustrates how Alternative III would be used as the CP/SC transition to digital switching nodes and ultimately to a structured network configuration. In 77a, the transitional improvement phase, the bus terminations at the switch no longer require A/D and D/A conversions since the switching is accomplished on the digital format. The A/D and D/A conversion may still be required at the remote multiplexer since many analog terminals are still in use. In the final improvement phase at least some of these terminals would be digitized as shown in Figure 77b.

An example of the local and remoted components for a digital circuit switch is shown in more detail in Figure 78. Here the terminals may be either analog or digital, secure or nonsecure. Multiplexing is accomplished by assigning time slots on a multiplexed loop. Switching is accomplished within a loop using time slot interchange (TSI) units. Switching is accomplished between multiplexed loops by time gating the space divided highways. This is denoted as the space switch in Figure 78. Trunk circuits to other geographically dispersed nodes are also digital.

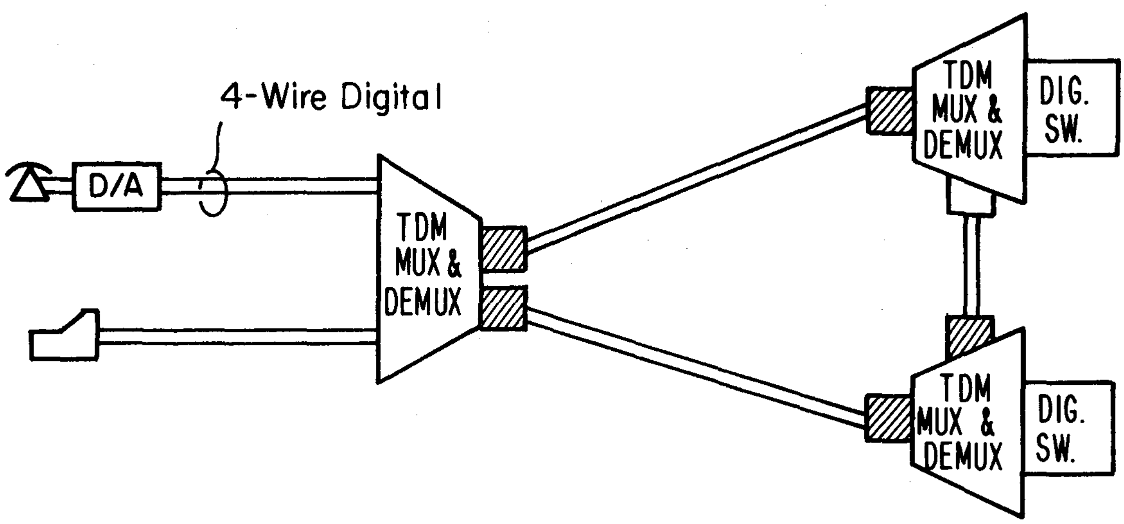
The selection of the analog-to-digital encoding method (CVSD or PCM) and the digitization rate to be used along with the transmission media for Alternative III should be done during the next concept development stage. This is discussed in greater detail in the next section.

12. FUNCTIONAL DESIGN REQUIREMENTS

The DoD procurement and development programs are normally phased through the major activities of Concept Development, Validation, System Development, System Implementation and System Operation. Each phase needs to be successfully completed before proceeding to the next phase. In order to discuss functional design requirements for the preferred bus distribution system Alternative (III), the development phase applicable must be known. While this study has clearly been part of a concept development activity, it by no means completes concept development.

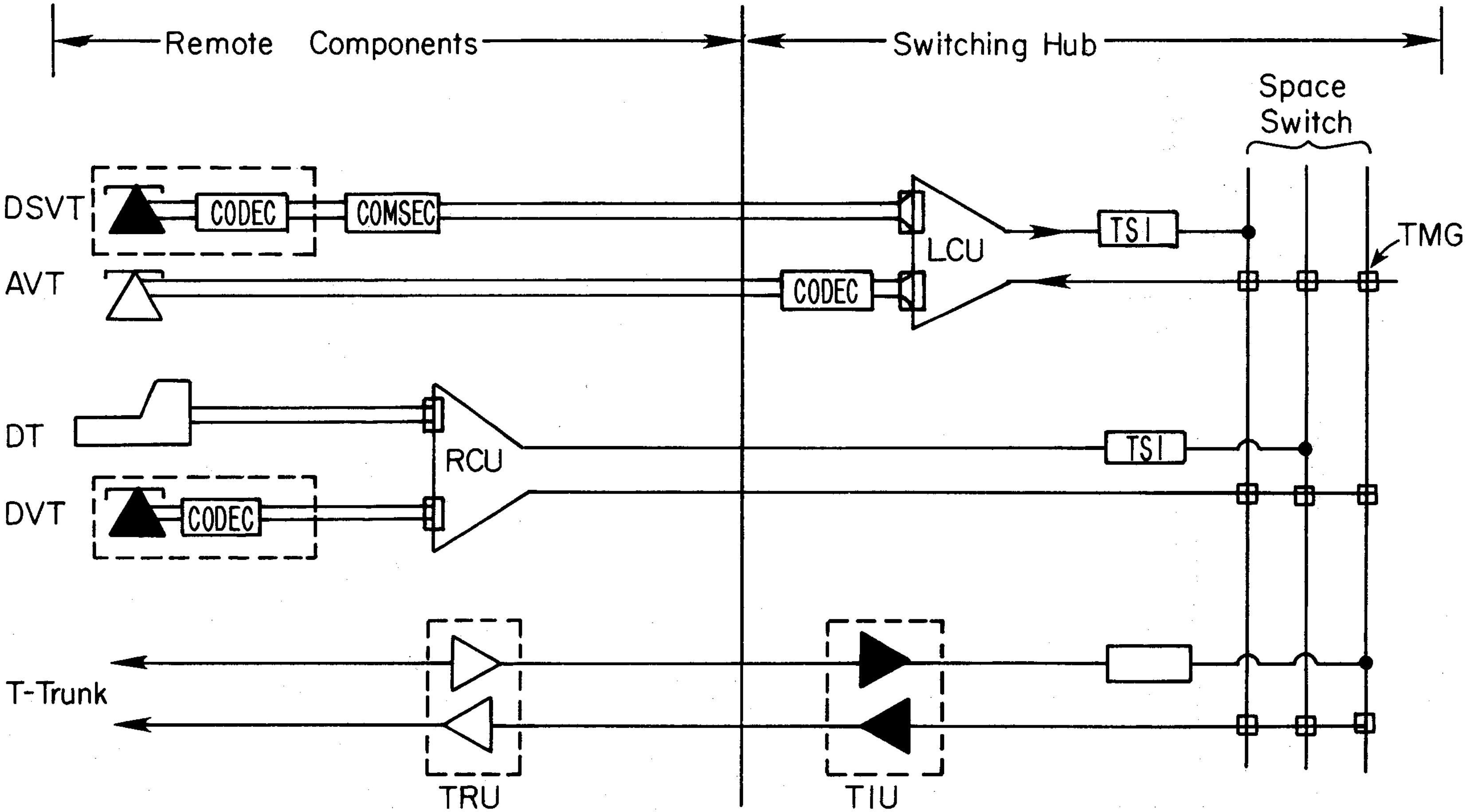


a) Transitional Improvement Phase



b) Final Improvement Phase

Figure 77. Application of Alternative III to subsequent bus distribution system improvement phases.



Legend

DSVT:	Digital Secure Voice Terminal	RCU:	Remote Concentration Unit
AVT:	Analog Voice Terminal	TRU:	Trunk Repeater Unit
DT:	Digital Terminal	TIU:	Trunk Interface Unit
DVT:	Digital Voice Terminal	TSI:	Time Slot Interchange
LCU:	Local Concentration Unit	TMG:	Time Multiplexed Gate

Figure 78. Local and remote components of a switching hub.

In order to complete concept development for a bus distribution system, the following R&D activities are recommended:

A. Development of "Proof of Principle" hardware for capacity, cost, risk and field adaptability initial evaluation;

B. Final concept development study and evaluation based on quantitative capacity, cost, and deployment time potential for analog switches and other switches in command post table of equipment.

C. Development of a validation phase plan to produce a limited quantity of bus distribution systems of the final version for field tests and evaluation.

Successful completion of A through C above would finish the concept development phase and justify start of the validation phase.

Within this context, then, functional design requirements can be established for "Proof of Principle" hardware units. Alternative III is modular, so that the four analog-to-digital units, one TDM unit and one of each of three transmission media can be developed. This would be sufficient and would eliminate development of 12 separate bus systems.

This section first discusses the long-range objectives of our concept development plan. These objectives form the basis for determining the ultimate benefits. expected when the preferred bus structure is fully implemented. Then the functional design requirements for the preferred bus distribution system (Alternative III) are described. These descriptive parameters and the quantitative values assigned to them are needed in order to develop proof of principal hardware for evaluating the technical feasibility of Alternative III.

12.1. Objectives

The long-range objectives for improving CP/SC future system operations and configurations which are specified here apply to the CP/SC at the corps level or above. Here the overall installation capability is equivalent essentially to replacing the dial central office and local loop plant in a small city. The ultimate objectives are:

1. Increased speed in laying out cabling plant and making connections.
2. Increased flexibility in layout and service as technology undergoes revolutionary changes.
3. Sufficient redundancy and restoration capabilities to maintain critical communications in case of broken connection or equipment failure.
4. Minimum EM and IR signature so the CP/SC cannot be detected from aircraft or satellite.

5. Enhanced security using voice digitization and end-to-end encryption. Ultimately the encryption/decryption processes would be incorporated into each terminal.
6. Improved quality of service in terms of speaker intelligibility, speaker recognition, information bit-error rates and network outages.

With these goals in mind, the functional design requirements for proof of principle hardware are given. These are based on Alternative III concepts developed previously.

12.2. Functional Design of Preferred Alternative

The functional design requirements outlined here include a number of optional approaches for certain functions. These functions are: the analog channel digitization, the transmission modulation, and the physical transfer.

Following a general description, the system functional requirements are divided into four main categories - namely the distribution system, the interfaces, the synchronization and signaling and the end-to-end performance.

12.2.1. General requirements

An engineering test model of a transparent bus-type distribution system is required for field test and evaluation of different development concepts. The test results will be used to determine the optimum digitization technique, the optimum transmission modulation, and the optimum transmission media to be used in the final system implementation.

The test model functions defined here assume that the system will be used to replace eight of the 26-pair cables currently used, i.e., 96 voice channels. The test model, however, will be capable of handling only twelve (12) full-duplex channels (either analog voice circuits or data modem circuits) plus any additional control signaling information required. The system design must be expandable to handle the 96 full-duplex channels in a fully implemented system.

The maximum transmission rate will be determined by the maximum digitization rate employed on a per-channel basis for all 96 channels. The maximum range for the physical transmission link is 2 km and no repeaters are to be used on this link.

Specific functional design requirements for major system elements of the bus structure are outlined in the following section.

12.2.2. Bus distribution system requirements

We define the functions to be performed as we progress through the bus distribution structure from input to output. The system designer must recognize that the inverse functions and operations are required for all channels to provide full duplex transparent operations.

Analog-to-digital conversion requirements

The A/D conversion functions will be performed using four optional methods so that a simultaneous quality performance comparison can be made. The options are PCM at 48 kb/s and 64 kb/s and CVSD at 16 kb/s and 32 kb/s. The output of each A/D converter will be in serial form.

Time division multiplexing requirements

The serial outputs of all of the A/D converters will be multiplexed into allocated time slots for subsequent transmission over a single link. This may be accomplished on a bit-by-bit basis or in some convenient block form. The maximum transmission rate, excluding signaling and control bits, will be 8 times the rate required for 12 channels digitized at the maximum per-channel rate. (i.e., $8 \times 64 \times 12 = 6.144$ Mb/s). This will permit system tests at rates corresponding to the ultimate 96-channel system rate.

Media matching requirements

Three options for the media matching functions which include waveforming and transmission modulation are required so that three transmission media can be evaluated. Suggested requirements are 1) bipolar NRZ waveforms and PSK carrier modulation for transmission on coaxial cable, 2) bipolar RZ waveforms for digital transmission on T-carrier type cable, and 3) unipolar RZ for digital pulse transmission on fiber optical cable. Alternative forms are acceptable if other requirements are met.

Physical transfer requirements

The physical media will be a continuous link 2 km in length and spooled on a cable reel for ease in deployment. Three physical media will be furnished for alternate testing. The physical media are: coaxial cable, T-carrier type cable, and fiber optical cable. Each cable type should be capable of withstanding the tactical environment and normal deployment procedures including underground, on the surface, or overhead installation. Suitable connectors for each type of cable must be furnished so connections can be quickly accomplished at each end of the link. Suitable coupling circuitry for each type of cable will be provided and will be switch selectable for each cable type deployed.

Dual cables may be used for full duplex operations. A separate metallic wire may be included so that either termination unit can be powered from the other when necessary.

12.2.3. Synchronization, signaling and power requirements

Synchronization for multiplexing and demultiplexing in the time domain will be accomplished completely independent of all external terminals and nodes. Input signals from the A/D conversion processes may be asynchronous and bit stuffing may be necessary to achieve a synchronous link.

Control signaling waveforms, including terminal control, node control, link control, and network management signals will be A/D converted from the 4-kHz channel and shall be transferred using inband time slots. Ring signals will be detected by logic circuitry so that relays or gates can be operated to furnish ringing power on the line side to terminals. See interface requirements Section 12.2.4.

Special control bits will be included to operate loop-around relays and logic circuitry for conducting continuity and diagnostic tests on the link. Test circuitry will be included in both link terminations and operable remotely from either end. These special control signals can be transferred via an orderwire channel, i.e., using time slots especially allocated for these functions.

The power required to operate the functional elements of the bus distribution system will be furnished from the adjacent equipment node. When one link termination is used to multiplex a number of terminals the power to this terminal element will be obtained from the terminating unit on the opposite end of the link.

12.2.4. Interface requirements

The bus termination units will be furnished with connection panels containing all of the 4-wire circuit terminations needed to replace one 26-pair cable. The bus distribution system shall be easily connected to 1) 26-pair hocks on either termination end for connecting two nodes, or 2) one 26-pair hock at one termination and up to twelve (12) full duplex terminals at the other end.

The input and output terminations will be fully transparent to the user, i.e., 4-kHz analog signals at any input port will appear as 4-kHz analog signals at the corresponding output port.

The interface terminations will provide all the functions of 'BORSCHT' except the 2-wire to 4-wire hybrid. The required functions are:

B Battery feed
O Overload protection
R Ringing
S Supervision and signaling
C Clocking and channel filtering
H Not applicable
T Test

These 'BORSCHT' functions are described further in the following paragraphs.

The battery feed supplies the dc current for dialing and for the microphone on the line side. This battery voltage is typically -48 volts. A carbon microphone requires 20 mA to 80 mA of line current. The dc circuit impedance is nominally 400 ohms. The ac terminating impedance must match the 4-wire telephone cable of either 600 or 900 ohms.

Overload protection is required on all incoming lines and for the bus itself in order to protect the circuitry from high-voltage transients which may be induced. Protection against voltage levels of 1000 volts and current surges of 1 ampere lasting 1 millisecond is required.

Ringing power for conventional telephone instruments is a nominal 20 Hz tone at 86 volts rms. This will be furnished from the local termination but controlled remotely from the opposite termination using suitable signaling detection circuitry and relays.

Supervision and signaling from a terminal is normally 15 mA for dc hook status control and rotary dialing of dc pulses. These inband signals will be converted to a suitable logic level, A/D converted for transmission, and reconstituted at the other end so the link appears transparent to the user.

The clocking and channel filtering will be self-contained within the distribution system, i.e., no external synchronizing clock signals or filter banks should be required.

The test circuitry provides a means to switch the line to a test facility for diagnostic test purposes. Test signals may be injected at either end to insure proper operation of the distribution system. On the 4-wire circuit a typical 2010-Hz test signal may be injected and looped back by remote control to indicate a continuity check. This loop-back circuit should include the A/D conversion processes.

12.2.5. Performance requirements

The analog outputs will be evaluated by subjective means during the field testing of this demonstration model. Voice intelligibility, and voice recognition are the crucial criteria. Here only the service performance specifications for the digital portion of the link are given based on Interim Federal Standard FS-1033. This data communication standard provides a uniform means of specifying digital communication systems from the point of view of the service delivered to the end user. In order to apply the standard here we assume an aggregate user on the digital side of the interface. The parameter values selected are expected to meet the requirements of an end user on the analog side of the interface. This expectation must be verified by subjective tests using the link.

The FS-1033 performance parameters are listed in Table 29. Quantitative values are given for those parameters which apply to the bus structure selected. The justification for choosing specific values is given below.

Performance parameters 1 through 3 are zero since all link channels are continuously available on a dedicated basis and access is always insured. For the same reason items 23 through 26 are not applicable.

The bit-transfer time is essentially real time with an allowance made for bit stuffing for synchronization. The length of the link is 2 km, and the cabling and loading are considered to result in a propagation velocity of approximately 30 microseconds per kilometer. Additional buffer time yields the result $2 \times 30 + 40 = 100$ microseconds or 10^{-4} seconds for parameter 4.

The bit-error probability of 10^{-5} to 10^{-6} for parameter 5 is expected to yield acceptable voice quality regardless of the digitization process. At the same time this error rate should reproduce data modem outputs so that the low-speed bit-error rate of the modem itself is not degraded by the link (see parameter 10 below).

A value of 10^{-8} to 10^{-9} for bit misdelivery, bit loss, and extra bit probability (parameters 6, 7, and 8) was selected to be an extremely low but measureable quantity. This is because these parameters have an important impact when encryption is used for security. Lost bits or extra bits could result in loss of synchronization unless bit integrity is maintained on the link.

With the exception of the error probabilities and transfer rates, the bit-oriented and block-oriented transfer parameters values are assumed to be identical. Therefore parameter 9 is also 100 microseconds. This is true only if the information block or encoded sample crosses the digital interface in parallel and each block represents a fixed number of bits. For our purposes here we assume that a

Table 29. Service Performance Specification

	Part A - Primary Parameters	
1.	Access Time	0 Seconds
2.	Incorrect Access Probability	0 *
3.	Access Denial Probability	0 *
4.	Bit Transfer Time	10^{-4} Seconds
5.	Bit Error Probability	10^{-5} to 10^{-6} *
6.	Bit Misdelivery Probability	10^{-8} to 10^{-9} *
7.	Bit Loss Probability	10^{-8} to 10^{-9} *
8.	Extra Bit Probability	10^{-8} to 10^{-9} *
9.	Block Transfer Time	10^{-4} Seconds
10.	Block Error Probability	10^{-5} *
11.	Block Misdelivery Probability	10^{-8} *
12.	Block Loss Probability	10^{-8} *
13.	Extra Block Probability	10^{-8} *
14.	Bit Transfer Rate	64,000 Bits/Second
15.	Block Transfer Rate	8,000 Blocks/Second
16.	Bit Rate Efficiency	80 %
17.	Block Rate Efficiency	80 %
18.	Disengagement Time	0 Seconds
19.	Disengagement Denial Probability	0 *
	Part B - Secondary Parameters	
20.	Service Time Between Outages	62.5 Hours
21.	Outage Duration	1.0 Hours
22.	Outage Probability	8×10^{-4} *
	Part C - Ancillary Parameters	
23.	User Access Time Fraction	N/A *
24.	User Block Transfer Time Fraction	N/A *
25.	User Message Transfer Time Fraction	N/A *
26.	User Disengagement Time Fraction	N/A *

*Note: The probabilities and user performance time fractions are dimensionless numbers between zero and one.

block contains 8 bits (the PCM case) plus 1 bit for synchronization and 1 bit for signaling or a total of 10 bits. The block error probability of 10^{-5} is given for parameter 10. Note that this yields the range of 10^{-5} to 10^{-6} for bit-error probability (parameter 5) since one error in a single bit or in all the bits in a block produces a single error. A similar relationship holds for parameters 11, 12, and 13.

The bit transfer rate per channel should be 64 kb/s (parameter 14) and the block transfer rate (parameter 15) is 8000 blocks/second for each 4-kHz channel.

The bit rate efficiency and block rate efficiency (parameters 16 and 17) is 80% for the assumed 20% overhead bits. Disengagement time, parameter 18, and denial probability, parameter 19, are zero since no switching is involved.

The secondary outage parameters, 20, 21, and 22 are based on one outage per month where quality of service is degraded below acceptable levels because of equipment malfunctions and two outages per year where a total failure occurs because of equipment failures such as power supply failure, broken cable, etc. It is assumed that degraded performance conditions last for 1/2 hour and the total failures last for 4 hours. The user information time (UIT) per channel averages two 3-minute calls per hour. Therefore there are 2 x .05 UIT hours/hour x 24 hours/day x 365 days/year = 876 UIT hours/year on each channel. The value for parameter 20, the service time between outages or mean time between failure (MTBF), is therefore $876 \div 14 \approx 62.5$ hours.

The outage duration, parameter 21, or mean time to repair (MTTR) is given by

$$\frac{(12 \text{ outages})\ (0.5 \text{ hours}) + (2 \text{ outages})\ (4 \text{ hours})}{14 \text{ outages}} = 1 \text{ hour.}$$

The outage probability, parameter 22, is determined as follows:

$$14 \text{ outages/year} \div (48 \text{ calls/day} \times 365 \text{ days/year}) = 8 \times 10^{-4}$$

The resulting availability A is given by

$$A = \frac{\text{MTBF}}{\text{MTBF + MTTR}} = \frac{62.5}{63.5} = 0.984$$

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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.)*

The communications network structures currently used to interconnect terminal clusters and switching nodes within an Army tactical command post and area signal center are reviewed. With this background, five alternative structures are defined in terms of their functional requirements. These candidate alternatives are evaluated and a preferred structure is selected based on a number of critical issues including deployment time, flexibility, performance, and survivability. The preferred alternative is a transparent bus-type distribution system incorporating analog-to-digital conversion for analog sources, time division multiplexing, and digital transmission facilities. A three-phase improvement plan is also outlined. The three phases are 1) imbedding the transparent link into the existing network structure, 2) merging these links with digital switches, and 3) changing the topology by adding switches to enhance survivability.

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