DIGITAL COMMUNICATION SYSTEMS

TECHNICAL CONTROL

BY

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ABSTRACT

This is a study of the methods ~~of control~~ ~~of an advan~~ced military communication system. The Tactical Communication Control System has been conceived to meet the demands of military users which are currently both analog and digital but steadily evolving to all-digital. It is a study of the design and application of multiplexers, modems, processors, switches, and other nodal equipment to accommodate communications among telephone and data users in a tactical environment. The main points of interest are the communication node and the control techniques used to carry out system objectives.

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PREFACE

The purpose of this thesis is to probe into the many facets of control of a modern digital communication system. The subject of the study is the military Tri-Services Tactical Communication Control System (TCCF). The system is in the conceptual stages and, while a great deal of work has been done in these areas, a system of this scope and complexity has not yet been designed or developed. An in-depth study of the system is therefore appropriate because it represents a significant advancement in the state-of-the-art of technical communication control.

Communication systems are rapidly changing from analog to digital. Not only is a greater proportion of traffic now originating from digital sources (such as teletype, computer, facsimile, etc.) but also the main traffic load from the voice telephone is phasing into the digital realm. The impact from the advent of digital voice has been great enough so that by the mid 1980's, the basic texture of the communication system will have gone from hybrid mixes of analog and digital to all-digital users. The TCCF has been conceived with the transition period in mind (e.g., to accommodate both analog and digital users in its first implementation and eventually to evolve exclusively to digital).

Much of the work for this thesis was done by the author as a preparation for the design and development of the TCCF system. Background material has evolved from various sources that, although not appropriate for reference citation, are nevertheless basic to the formulation of the system design and concepts. Such things as military specifications, concept papers, equipment designs, and a variety of discussions

on the subject have contributed immeasurably to the formulation of the data base that went into preparation of the thesis.

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INTRODUCTION

Technical control is the management of communication resources to accomplish the objectives of the communication mission. This is a study of the methods of control of an advanced digital communication system - the Tri-Services (TRI-TAC) digital communication system. Communication resources in this case include all equipment at the communication node, the multiplexers, modems, processors, switches, radios, and operating personnel. The objectives of the communication mission, broadly stated, are to accommodate communication among all telephone and data users in a tactical, highly flexible deployment of land or sea forces.

Operation is centered around a communication node containing an automatic switch with multi-link access via cable and radio, and a technical communication control facility (TCCF) that coordinates operations at the node. It is the Communication Nodal Control Element (CNCE) of the TCCF that is the focal point of this study. The communication and study techniques used are critiqued and areas of particular interest are analyzed. Areas of concentration are traffic processing (i.e., multiplexing and switching, transmission, processor control, nodal timing and synchronization, quality monitoring and communications supervisory control).

CHAPTER ONE

THE TECHNICAL COMMUNICATION CONTROL FACILITY

INTRODUCTION

Present tactical communication systems in the field are generally analog, manual-switched systems with a high dependence on dedicated circuits for handling critical command traffic. These sytems, in general, also provide parallel alternate routes for critical circuits. This concept is inefficient in terms of transmission facilities. Furthermore, the systems are slow to react in dynamic tactical situations. The planned TRI-TAC program will provide automatic message and circuit switching capabilities for tactical systems as well as base for evolution toward totally secure digital networks. These new tactical communication capabilities combined with the changing demands placed on deployed networks resulting from changing traffic patterns, network outages and equipment degradation require a Technical Communication Control Facility (TCCF) capability not presently available in commercial, tactical, or strategic communications systems. Other systems do not place such a demand on the network controller. Of great importance is the ability of the controller to select, display, and assess pertinent information on the current status of the system configuration. After appropriate evaluation and assessment of the data, execution of various options can be effected that will optimize the performance of the available network resources in near real-time.

The Technical Communication Control Facility is composed of two major elements: a Communication System Control Element (CSCE), and a Communication Nodal Control Element (CNCE). The CSCE is the higher element in the control hierarchy, providing direction and authority to several nodes as shown in Figure 1. Other communication elements that are involved are a Communications System Planning Element (CSPE) which provides overall planning, and the Communication Equipment Support Elements (CESE) which are subordinate to the CNCE and generally provide specific equipment functions such as switching, radio transmission, power, and others that interface with the CNCE.

Figure 2 is representative of the conceivable nodal configurations that could exist in a network during the present time frame. As may be noted, it is possible to have 4-kHz analog telephones, frequency-division multiplex (FDM) analog trunks, asynchronous digital signals, pulse-code modulation (PCM) voice, time-division multiplex (TDM) digital groups, continuously variable slope delta (CVSD) digital voice, and both secure and nonsecure circuits in the same network. The present plan is that networks will evolve to a TDM all-digital system with CVSD voice circuits and end-to-end, all-secure circuits.

OVERVIEW OF THE CSCE

The CSCE provides the major system control capability for a portion of the tactical communication network, offering real-time management of the network during continually changing connectivity patterns and traffic loads. The configuration comprises two shelters such as those shown in Figures 3 and 4 illustrating the CNCE, and a facilities pallet. One shelter is identified as the Management Shelter and contains consoles for three network controllers. Visual display units and hard copy printers are the interface between the controllers and a data processor. The processing capability provides a variety of aids to the

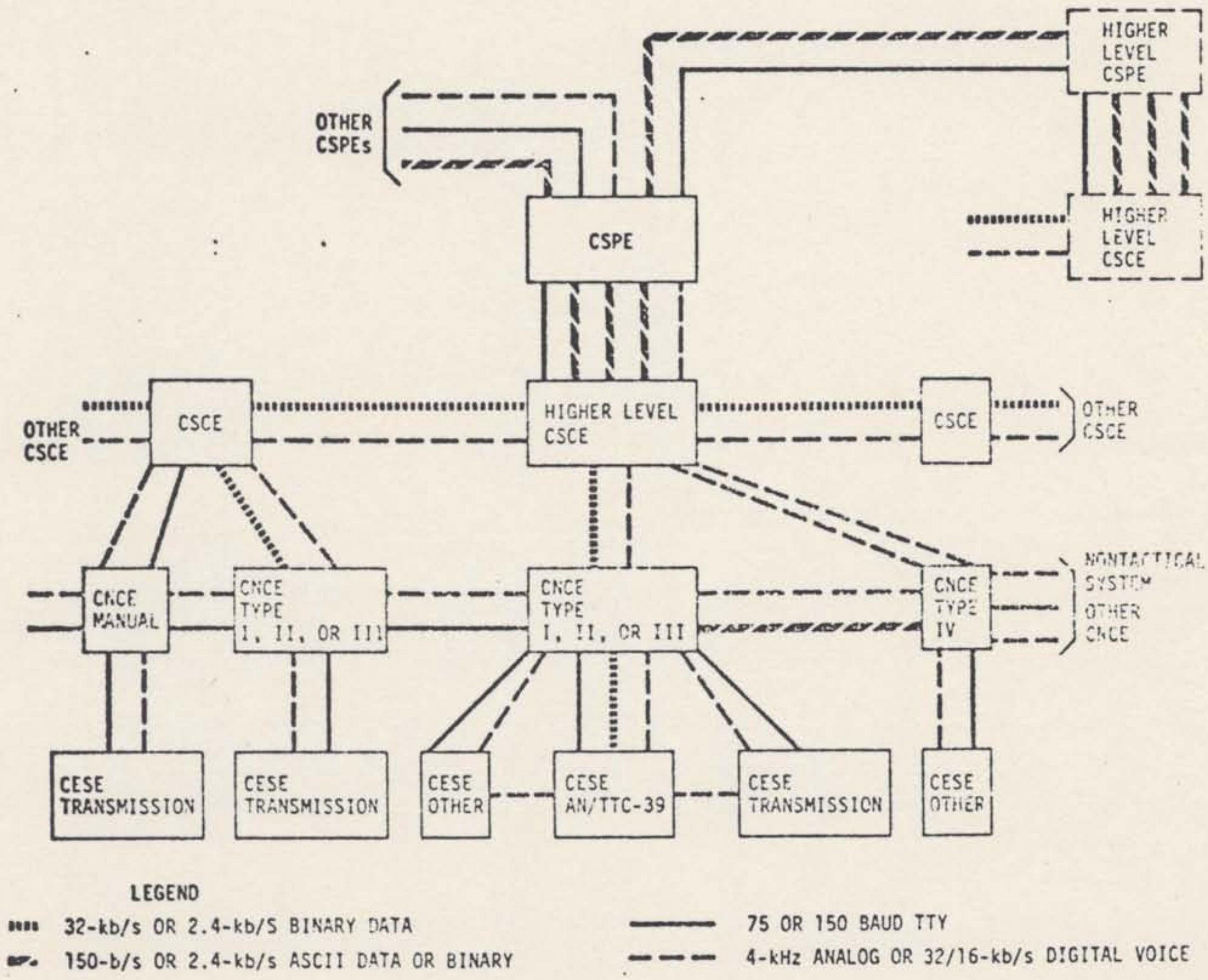


Figure 1. TCCF Control Hierarchy

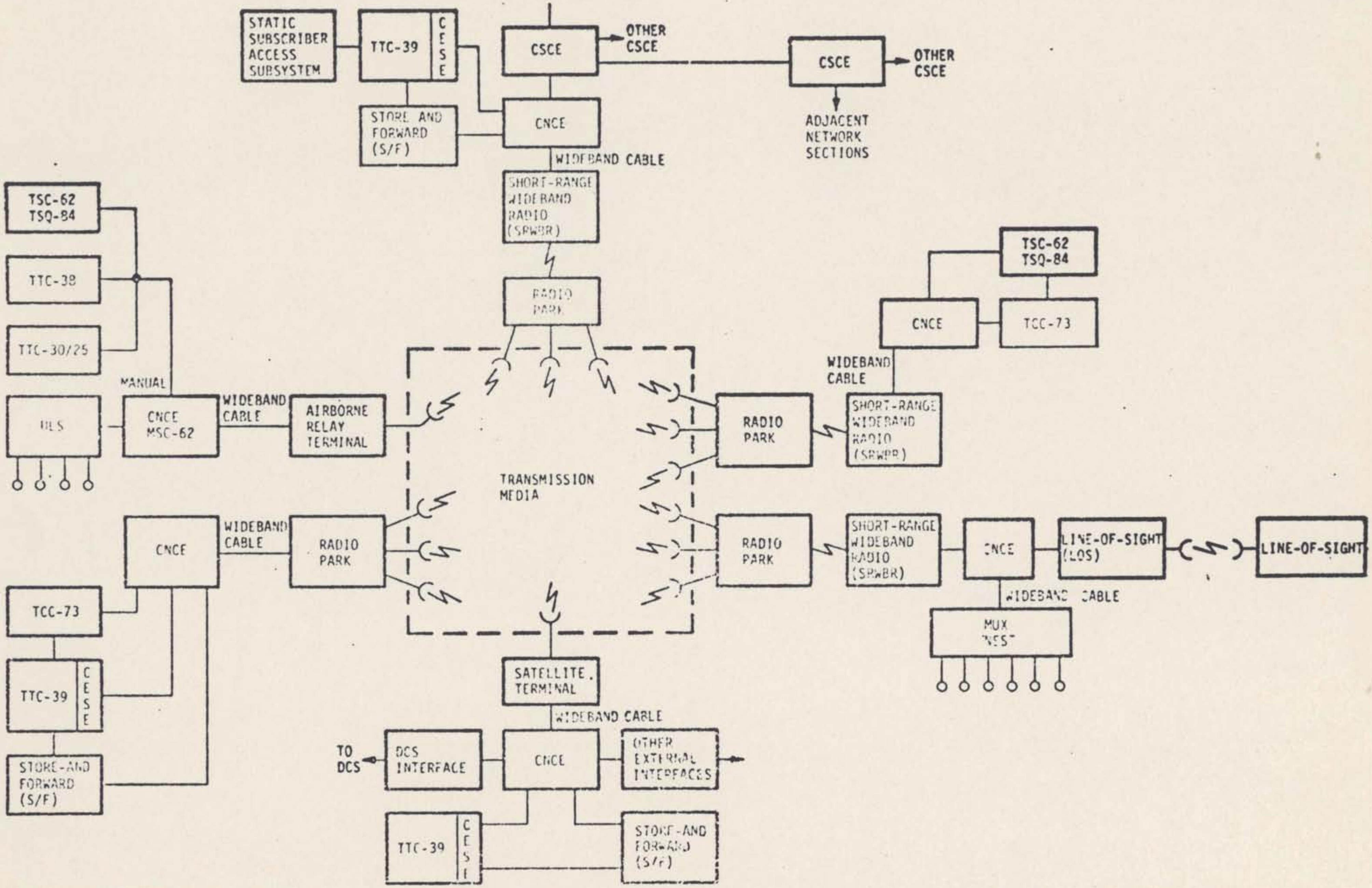


Figure 2. Possible Nodal Configurations in Tactical Communications Network

controller that quickly and accurately report the network statistics and near real-time information. A controller can rapidly display, review, and direct changes to maintain maximum system operability through the use of the computational resources and data files of the subsystem.

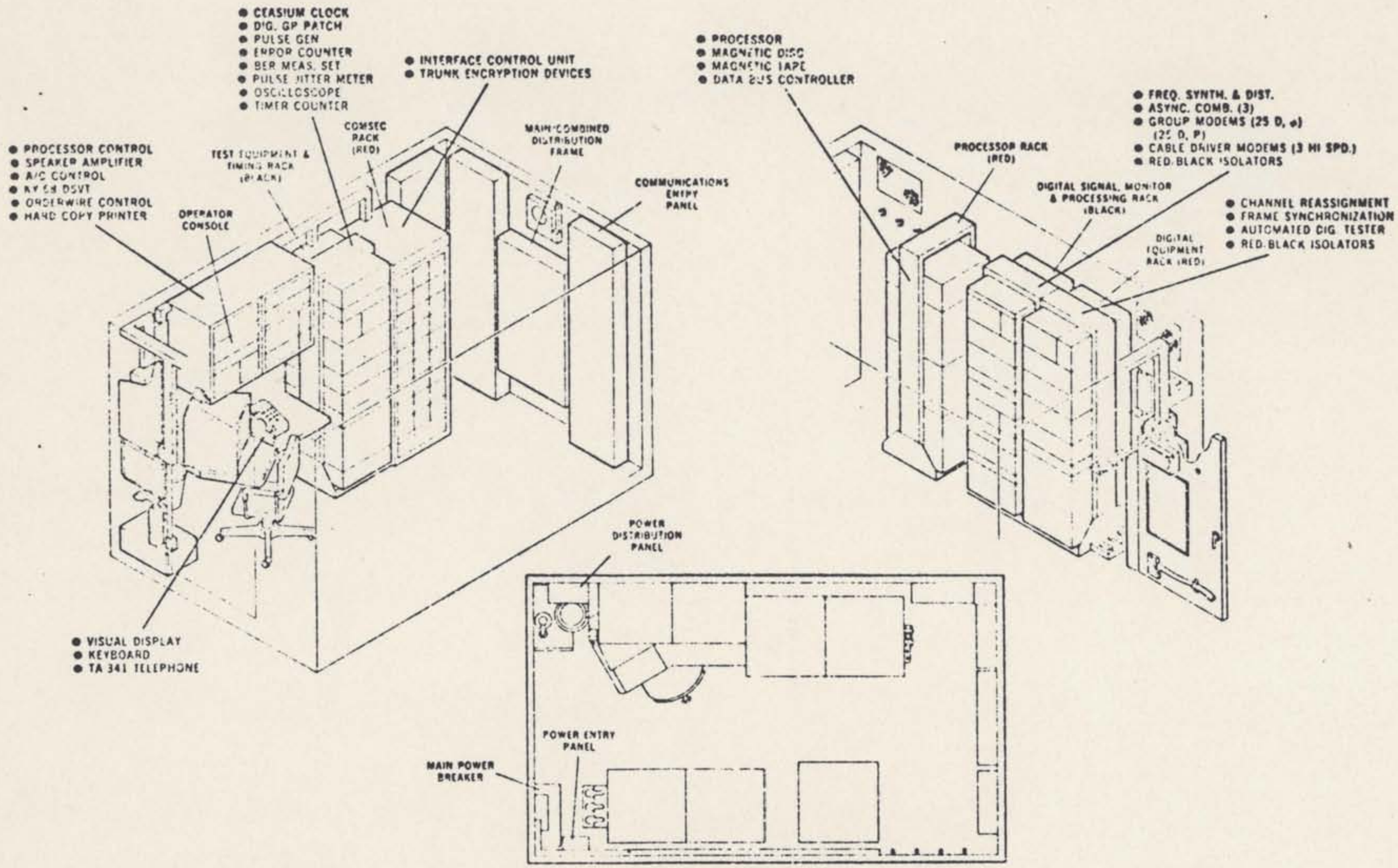
The second shelter is designated as the Technical Shelter and contains such major elements as a communications subsystem providing inter- and intra-shelter voice and data transmission; a control subsystem that directs various control and message handling operations; and a set of processors and peripherals that make up the processing capability. An operator's console is provided in this shelter that allows monitoring and control of the CSCE equipment, patching of communication lines, equipment fault detection and isolation, and similar housekeeping functions.

The facilities pallet contains an environmental control unit (ECU) for each shelter and a common power unit. The power unit provides standard power voltage and frequency to the shelters regardless of the primary source characteristics. It also contains sufficient battery power to sustain temporary operation if primary power is lost.

OVERVIEW OF THE CNCE

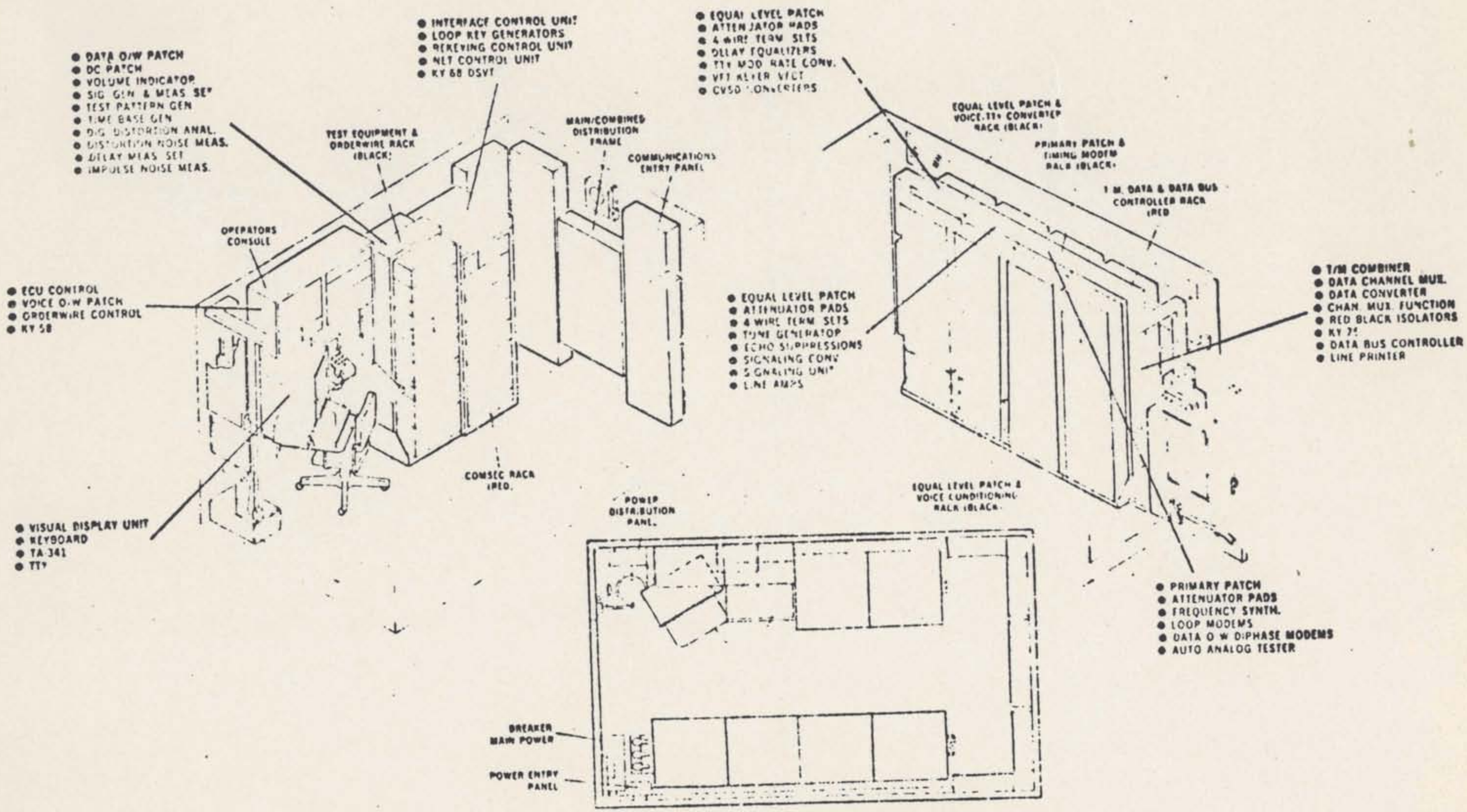
The CNCE provides control for the communication nodes within the tactical network, serving as the interface between users and the transmission facilities of the node, providing real-time management and monitoring of the communication resources at the node during continually changing traffic loads connectivity patterns, with interoperability of both analog and digital inventory of equipment.

The configuration comprises two shelters shown in Figures 3 and 4



TYPE II CNCE MANAGEMENT SHELTER
OVERALL ASSEMBLY AND FLOOR PLAN

Figure 3. Type II Management Shelter



TYPE I CNCE TECHNICAL SHELTER
OVERALL ASSEMBLY AND FLOOR PLAN

Figure 4 Type I CNCE Technical Shelter

together with one environmental control/power pallet for the CNCE system. One shelter is identified as the Management Shelter and contains a visual display unit to provide the interface between the controller and the data processing unit, quality monitoring equipment, COMSEC, and other digital signal processing equipment. The processing capability provides a variety of aids to the controller that report equipment status, channel and group interconnect information, network status, and real-time equipment diagnostics information and network link quality status. A controller can display, review, and direct channel/group data changes and equipment changes to maintain maximum system operability.

The second shelter is designated as the Technical Shelter and contains patching facilities, orderwire circuits/select panel, timing module, and an operator's console and visual display unit. This console allows monitoring and control of the equipment within the technical shelter and status interface with the management shelter.

The facilities pallet contains an environmental control unit for each shelter and a common power unit. The power unit provides standard power voltage and frequency to the shelters regardless of the primary source characteristics. It also contains sufficient battery power to sustain temporary operation if primary power is lost.

SYNOPSIS OF STUDY ITEMS

The unique position of the CNCE being the focal point of nodal activities in the tactical communication system affords an ideal opportunity to examine the wide variety of communication techniques used in the most advanced of all practical voice and data communication systems. Therefore, the emphasis of this study will be on the CNCE and will only include the CSCE or other CESE as they directly support CNCE operations. The following is a summary of the system techniques to be examined.

System Operation

A description of the communication system, how it is used, and what some of the problems are. This discussion provides a framework for understanding how the system elements work together. It also provides the scope of the study. The subsystems are described in their functional usages. The supervisory function associated with technical control (such as orderwires, traffic control, and processor control) is also discussed.

Traffic Processing

A study of the methods of processing the digital links at the communication node; these are mainly multiplexing and switching operations. The methods of time-division multiplexing is discussed with frame synchronization, multiplexer hierarchies, asynchronous and synchronous combining, bit stuffing, and related techniques analyzed. A method of time-division switching is also discussed as an alternate to space-division switching.

Transmission

The transmission system is analyzed with methods of coding for cable transmission such as bipolar and dipulse and diphase coding examined. Optimum detection methods are also included. A system of supervisory channels imposed in-band and out-of-band on the transmission system is studied.

Processor Control

The function of a processor in the communication node as a means of automatic control and analysis is studied with the role of the processor in traffic load balancing analysis of quality of the links and status display analyzed.

Timing, Link Synchronization

The effects of timing differences between master timing systems (atomic clocks) of separate nodes is studied. Elastic buffering techniques and techniques to maintain and restore bit-count integrity (BCI) are also studied.

Quality Monitoring

Methods for determining the quality of the transmission links and equipment and nodal equipment are studied. A method of predicting bit-error rates (BER) by observing radio baseband eye patterns is also analyzed.

Communications Supervisory Control

The methods for communication between controller by orderwire and supervisory channels (both in-band and out-of-band) in the system of multiplexed links are studied. Methods of combining and interfacing low data rate PCM systems for this use are also studied.

Frame Synchronization

Frame synchronization is studied as it applies to the requirements of the transmission links with special emphasis on the effects of bit errors caused by radio fades. A comparison is made of three candidate systems, one of which has been designed and recommended by the author.

Further Study

Two specialized studies are suggested as a result of these investigations for making more optimum equipment designs. They are the further study of the telemetry combining techniques at remote sites and a determination of the feasibility of integrating multiplexers and cable modems into one design.

CHAPTER TWO

SYSTEM DESIGN

NATURE OF THE COMMUNICATION LINKS

Communication links that enter and leave the CNCE (i.e., those that are under the auspices of the nodal controller) can be divided into the three general categories of traffic links, control links, and test signals (Figure 5). Traffic links are those that are used by a subscriber; they originate in a field telephone, teletype machine, or computer. Control links are those that are used by communication facility supervisors, maintenance personnel, administrative personnel, or others to control the communication resources of the network. Test signals are those that are passed between elements for the purpose of maintaining the equipment; they include equipment status, test messages, test commands, etc.

An understanding of the flow of signals within the CNCE is helpful in determining the functions of the CNCE subsystems and their interactions with external devices. Refer to Figure 6 for a summary signal flow.

Traffic Signals

Subscribers may use either analog or digital telephones for voice communications; these are referred to as loops. Analog loops are normally 4-kHz signals. Digital loops may originate in digital telephones, which include 32-kb/s CVSD converters in the instrument. Analog signals may be carried throughout the system as loops or multiplexed into digital groups by multiplexers that perform analog-to-digital (A/D) conversion and time-division multiplexing. The basic group multiplexer,

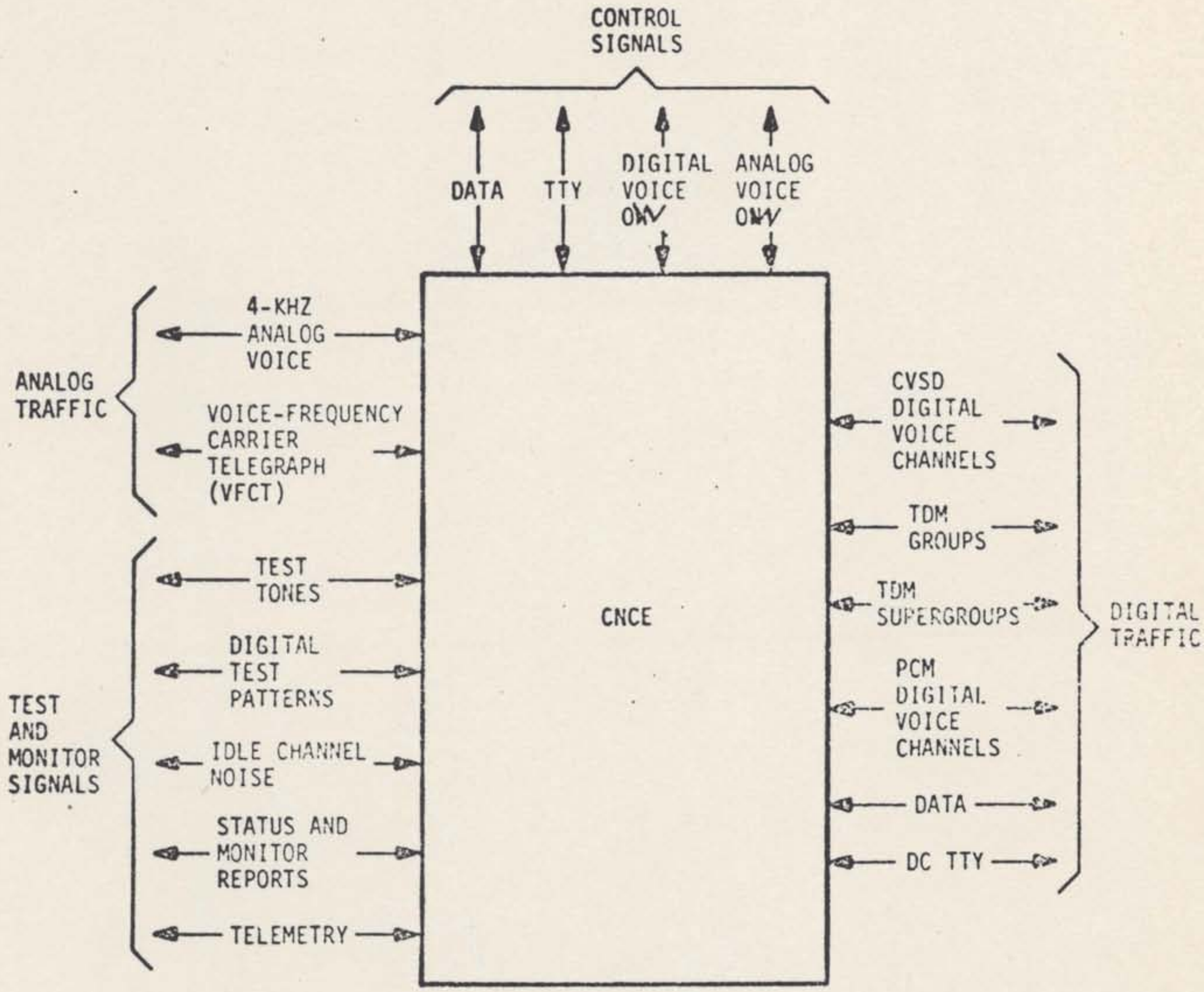


Figure 5. Classes of Signal Flow Through CNCE

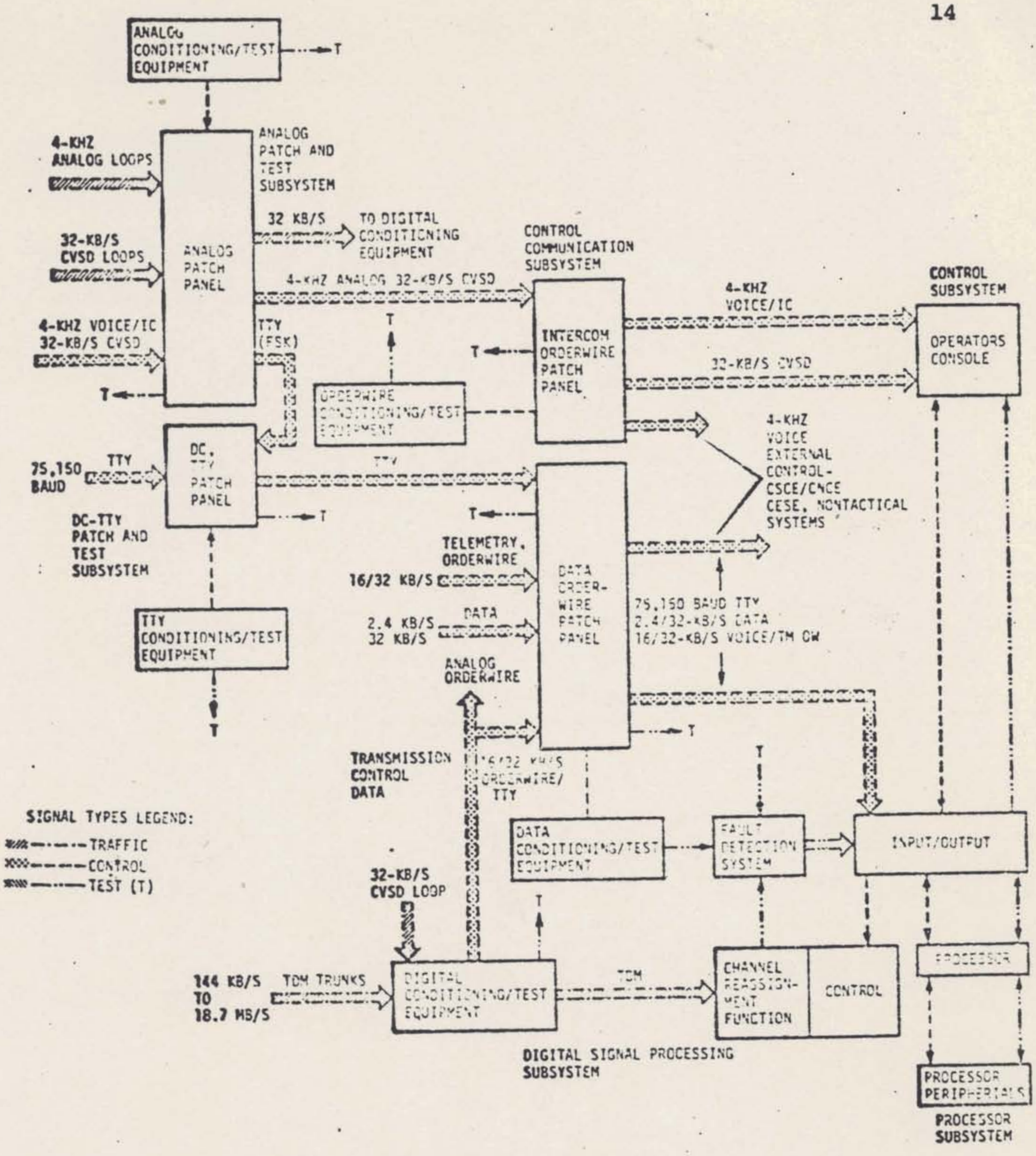


Figure 6. CNCE System Signal Flow Block Diagram

the TD-660, accepts twelve analog loops, quantizes each into 6-bit PCM, and transmits a 48-kb/s loop complete with framing pattern. One basic group is therefore a 48-kb/s PCM group. There are higher order groups formed from this basic rate that take a multiplexer up to a 4.9152-Mb/s supergroup rate. A table of these rates and trunking hierarchies is shown below.

Channel (No.)	Rate (kb/s)
1	48
12	576
24	1,152
48	2,304
96	4,608
96	4,915.2, asynchronous

Loops originating in digital telephones at the 32 kb rate can be combined into groups, trunks, or supergroups in multiplex of 32 kb up to the supergroup rate of 4.9152 mb. Rates in these hierarchies are shown in Table I-2.

TABLE I-2.

Channel (No.)	Rate (kb/s)
1	32
4	128
4.5	144
7	256
9	288
16	512
18	576

(Table I-2 continued)

Channel (No.)	Rate (kb/s)
32	1,024
36	1,152
48	1,536
64	2,048
72	2,304
128	4,096
144	4,608
150 (approx.)	4,915.2, asynchronous

Teletype traffic may be passed in single loops of 45 baud to 150 baud, depending upon the operating speed of the originating machine. These loops may be combined by teletype combiners into trunks of 300 to 1200 baud.

Control Signals

These signals which are used by the network controllers, form a special network of orderwires, dedicated links, and supervisory channels overlaid on the traffic network. The traffic controllers use the same types of instruments as used by subscribers, analog and digital telephones, and teletype machines. In addition, computer-to-computer links at 2.4, 16, and 32 kb/s are used. Telemetry signals used to report status of remote equipment are passed to the controller by 150-b/s, 2-kb/s, and 4-kb/s links that are combined into trunks of 2, 4, 2.4, 16, or 32 kb/s, depending upon the complexity of the remote transmission path and the multiplexer hierarchial combining required en route to the CNCE.

Test Signals

Test signals are those used throughout the network to determine link status or to isolate faults. They include pseudorandom sequences as test multiplexes, tones, and DC signals.

SYSTEM OPERATION, MANAGEMENT, AND CONTROL

The Communications Nodal Control Element (CNCE) is designed to accommodate both existing analog and digital inventory equipment, but emphasizes the evolution to an all-digital system. This includes manual analog and DC patching; automated channel reassignment through time-division switching; processor control for re-routing and system control; real-time test and quality monitoring subsystem; advanced techniques for Bit-Count Integrity (BCI) restoral and prevention of synchronization loss.

As its prime missions, the CNCE provides the interface between transmission facilities and users, and the management of communication resources at its node. To accomplish its mission, the CNCE is provided with a group of functional subsystems and capabilities. These are the Patch and Test Subsystem, Control Communications Subsystem, Control Subsystem, Processor Subsystem, timing and synchronization capability, COMSEC capability, and Facilities Subsystem.

The functions provided by these subsystems are classified as management and technical direction; implementation and execution; line conditioning and interfacing; technical coordination; monitoring and fault isolation; re-route and restoral; reporting; and record keeping. The resources provided at the CNCE are therefore used by the operating personnel to accomplish these functions and fulfill its mission.

The system considerations included in the baseline design are:

- o Management and technical direction of the node and its subordinate elements.
- o Implementation and execution of directives from other TCCF elements.
- o Line conditioning and interface for the various users.
- o Technical coordination activities with the CSCE, other CNCE's, and other subordinate elements.
- o Performance assessment of all lines and communication resources related to its node.
- o Fault isolation for degraded/failed equipment and circuits.
- o Re-routing and restoring various types of network circuits, as required.
- o Reporting and record keeping for monitoring nodal resources status and performance.

THE ROLE OF THE PROCESSOR SUBSYSTEM

The fact that a processor is used as a primary element of nodal control is a significant advance in the state of technical control. In the past, such functions as traffic routes, status of equipment, quality of the transmission medium, control directives, message routing, alternate routing, and traffic profiles were kept by manual means and records stored in conventional files. With the complexities involved in present day communication, it is natural for these efforts to be taken over by a processor.

The processor acts as a central point of access and control for any data generated on the links, providing the current status of the communications plant. The processor receives 150-b/s telemetered data from every unit of equipment to which it is connected and displays alarm conditions when there is a malfunction. A data base is maintained that stores the network connectivity so that upon request, alternate routing of trunks may be displayed to the operator. An I/O-to-I/O link is maintained between all network processors so memory and load sharing can take place between them. One processor may substitute operation for another in case of emergency. All appropriate records and directives are maintained in disc or magnetic tape files to be recalled upon request.

The processor stores operating criteria for equipment or link quality and sets alarms if the BER or signal-to-noise margins are exceeded anywhere. The circuit monitoring data amassed in this manner is subjected to predictive trend analysis within the processor and possible problem circuits brought to the attention of the controller through use of the visual display unit. Link quality can be assessed over a period of time so degradation trends can be established. After receiving a bad trend alert through the display, the controller can call up other data base information to help him in his decision of how best to repair, alternate route, or restore the troubled circuit. Finally, after the decision is made, the controller can direct a patch to be made on an analog circuit at the patch panels in the equipment shelter or, in the case of the digital circuits, he can re-route it through the computer or directly from the control panel on the console in the management shelter. Re-routing of digital circuits is performed using the channel/group reassignment function previously described. The processor has a complete set of peripheral equipment (i.e., teletype, keyboard, hard copy printer, visual display unit, disc and magnetic tape storage, keypunch, card file, and other operating equipment).

Operational/Applications Software

The TCCF operational/application software consists of those modules that are required to perform the overall network controlling functions. These groups of modules establish and maintain the logical interface between network nodes as well as between subsystems within a node. They are responsible for network integrity and provide dynamic control of the network by constantly monitoring the status and adapting to changes in the environment. To accomplish this task efficiently, a multiple processing scheme of the operating system is employed.

CSCE System Fault Detection and Diagnostics

For the CSCE to fulfill its mission, not only must the processing function have full back-up capability, but also must use the Control and Communication Subsystem to provide for signal control and monitoring of the element. Inherent diagnostics, self-test, and redundancy features are available to assure extremely high CSCE mission availability. Diagnostics in the CSCE may be categorized in the following manner:

1 ON-LINE SYSTEM diagnostics.

2 ON-LINE EQUIPMENT diagnostics.

3 OFF-LINE PROCESSOR diagnostics.

CNCE Computer, With Display and Software, Aids In Rapid Circuit Analysis and Restoral

A minicomputer, with an associated display and a modular software approach, is used in the CNCE because of the ability of this combination to provide the most cost-effective solution to the problem of aiding the controller in his functions of Quality Assurance. As mentioned above, provision of automatic digital and analog test equipment and circuit access allows quality assurance to be carried out by the processor.

Systems Software

A general-purpose and comprehensive systems software package is used to support and control the TCCF software. The software modules are configured easily to support the wide variety of equipment to be installed in the CSCE and CNCE. At the heart of the systems software package is a real-time, communications-oriented operating system. Under control, and an integral part of the system, is a host of support software programs handling such features as:

- o Multi-programming or multi-tasking support.
- o Automatic task scheduling and rescheduling.
- o Priority task execution.
- o Dynamic memory management.
- o Input/output processing.
- o Data base management.
- o Background assembly and compiling.
- o Full-scale man/machine interface via the real-time executive.

COMMUNICATION SECURITY

One of the most fundamental reasons for the conversion from analog to digital transmission is for security. A digital bit stream can be encrypted in a much simpler operation because of its discrete nature. A simple message scrambler, for instance, can be made by modulo 2 addition of a known pseudorandom sequence to a bit stream at the transmission site, then performing the same operation in reverse at the receiver to recover the data.

In the TCCF system, all message trunks are encrypted in key generators prior to leaving the shelter and are decrypted upon entering by similar devices that act in duplex pairs. Analog loops are encrypted in analog devices wherever analog voice is used, including all orderwires. Furthermore, strict adherence to RED-BLACK (red = nonsecure; black = secure) isolation policies is retained. That is, wherever a possibility of an unencrypted voice and its encrypted counterpart being detected together exists, the two signals are strictly isolated by a classified isolation device. The need to isolate between RED and BLACK circuits is apparent in such places as input and output ports in a multiplexer that is being driven by a key generator.

Frame sync must be maintained in a multiplexer, even though its framing pattern encrypted poses a synchronization problem for both multiplexer and key generator. The problem is solved by a method of cooperative resynchronization whereby both the key generator and framing device are interdependent.

Suppose, for instance, that a multiplexer with a 1,0 frame pattern is transmitting through a key generator that scrambles the framing pattern along with other data; how can the multiplexer on the other end of the link recover frame synchronization? During normal operation, the framing pattern is decrypted at its destination and is thus clear to the receiving multiplexer. However, if the multiplexer loses frame, was it due to bit errors, bit slippage, or due to the key generator losing sync? Furthermore, if the key generator loses sync, how does it resync if its sequence contains data from the transmitting multiplexer? To resync the key generator requires a number of bits without data or "pure key". To accommodate this situation, a cooperative resync procedure is used. When sync is lost in the receiving multiplexer, it searches for sync for a given period of time (milliseconds); failure to find sync causes its transmitting key generator to send pure key to the distant demultiplexer. Since the link is duplex, the distant demultiplexer recognizes a pure key condition and sends pure key back. This condition allows both key generators to resync since no data interferes from either direction. Once accomplished, key generator sync initiates the flow of data in both directions and allows proper detection of the framing pattern by both demultiplexers. This procedure is referred to as cooperative resync and is one reason to minimize frame resync times in the frame synchronizer of the multiplexers.

This treatment of communication security subjects is superficial because of their classified nature.

THE FAMILY OF DIGITAL GROUP MULTIPLEXERS

DGM Function in the Tactical Communications Network

The purpose of the Family of Digital Group Multiplexers (DGM) is to provide digital combining and cable transmission functions for the fielded terminal users or subscribers that are served by the node. This equipment may be located any place in the field where clusters of users create the need for trunks and can be mounted in trucks, tents, buildings, or other communication facilities where necessary.

The DGM equipment is designed only for the data rates described earlier, which are part of the TRI-TAC all-digital, synchronous system. However, since a fielded group of units could use equipment from earlier systems such as the asynchronous Army ATACS equipment or even analog telephones, the DGM equipment must operate in situations that either require direct interfaces or use of common facilities. The new DGM equipment is shown in a variety of interface situations in Figure 8. The family of DGM equipment consists of the following items:

1 Loop Group Multiplexers (LGM) - An LGM will multiplex up to 17 32-kb/s CVSD loops from digital telephone into trunks with rate from 144 to 576 kb/s.

2 Trunk Group Multiplexers (TGM) - A TGM multiplexes inputs from several LGM's into trunk rates that range from 576 to 2304 kb/s.

3 Master Group Multiplexers (MGM) - An MGM is an asynchronous device that provides an interface in the trunk network with the older asynchronous equipment, accepting TGM or LGM rates and outputting 18.72-Mb/s diphase.

Since LGM, TGM, and MGM equipment operate in situations that require a great degree of interconnecting flexibility to form hierarchies of trunks, they operate in the NRZ mode. All require modems to provide the proper cable coding and drive. A family of modems, consisting of the following, is required for this function:

1 Low-speed cable driver modem (LSCDM).

2 High-speed cable driver modem (HSCDM).

3 Group modem (GM).

In some applications, where hierarchial combining is limited, there are remote counterparts to the LGM and TGM that incorporate a cable drive in the multiplexer function; these are:

1 Remote Loop-Group Modem (RLGM) - The RLGM accepts 32-kb/s CVSD diphase inputs from digital telephones and outputs 144-kb/s diphase.

2 Remote Multiplexer Combiner (RMC) - The RMC accepts either 32-kb/s inputs from digital telephones or a 144-kb/s input from an RLGM and outputs 288 or 576 kb/s.

The system diagram of Figure 8 shows the usage of DGM equipment along with other transmission equipment as they access the CNCE.

Digital subscribers from telephone terminals and individual users are grouped for trunking at multiplexer facilities by LGM's, TGM's, and MGM's and in remote facilities by RMC's and RLGM's. Parts (A) through (E) of Figure 8, depict various assemblages of DGM multiplexers that could be used in TRI-TAC in different deployments. Multiplexer shelters shown are versions of the AN/TCC-73 and AN/TCC-72 existing today. Analog and digital subscribers can use the same trunking facility in a configuration depicted in part (A). Here, the TD-660, an analog-to-digital multiplexer with asynchronous output, interfaces with the TGM through a special interface card of the Group Modem. The use of RMC-RLGM-DSVT combinations is shown in part (C), where isolated groups of users are shown. Part (D) shows the introduction of present day Army (ATACS) analog equipment into the synchronous system at the group

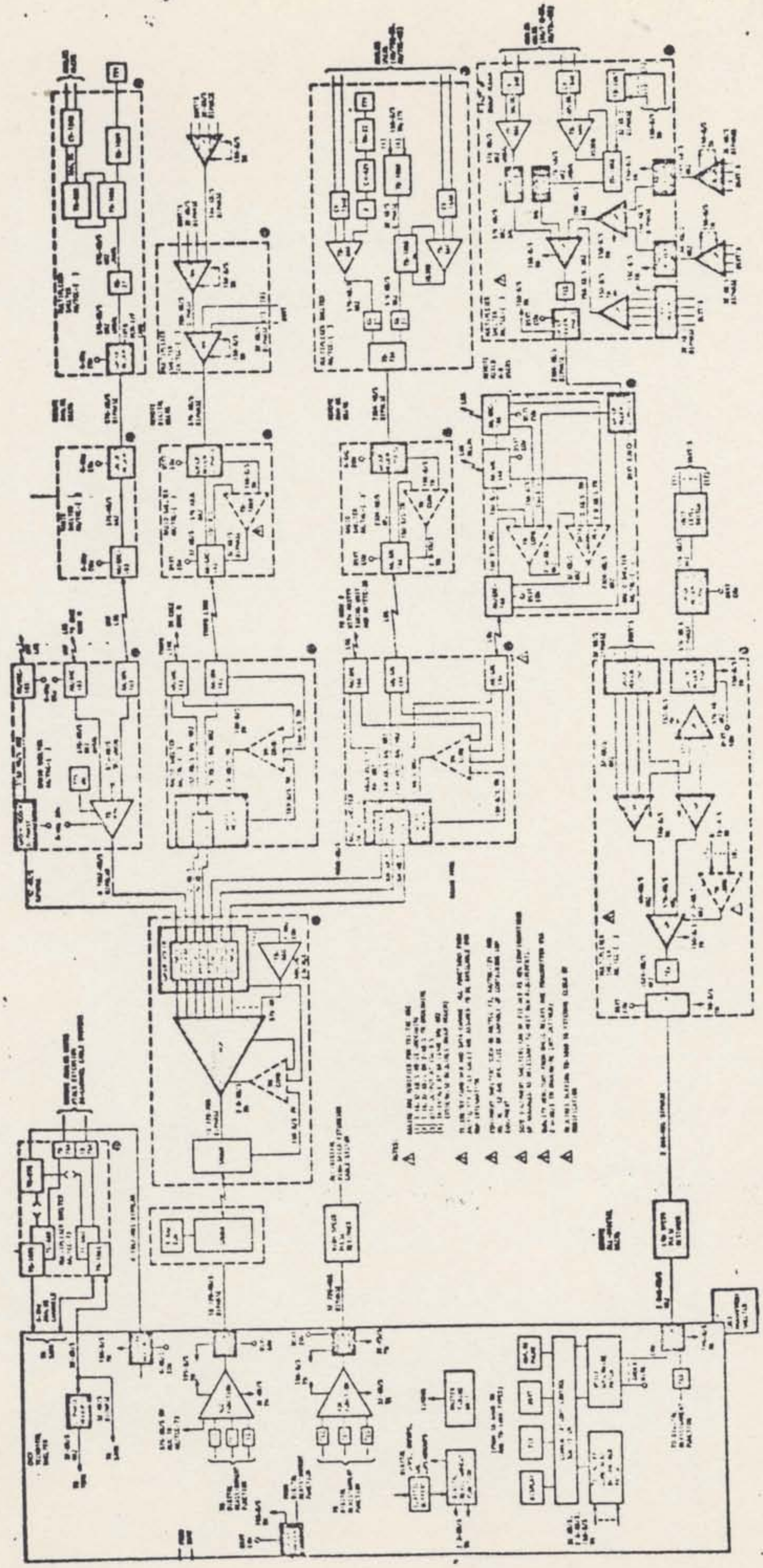


Figure 8 DGM Functional Block Diagram

modem by 576-kb/s diphase transmission. Also depicted is the use of a manual teletype in ATACS to report equipment quality instead of the automated telemetry system of TRI-TAC. An all-TRI-TAC application is shown in part (E) where digital telephones, DSVT's, access a small, unit-level, switch, the output of which is further combined with other loops and trunked into the CNCE. Here, orderwires are all-digital and telemetry outputs from the DGM equipment are externally combined in a CNCE-type telemetry combiner.

Cable transmission and radio interface functions are provided by Group Modems, Cable Driver Modems, and Pulse Restorers. The functions of this equipment is to provide the interface between multiplexing and radio modulation functions, which are typically NRZ, and codes conditioned suitably for transmission such as diphase, bipolar, and dipulse. The introduction of the DGM group modem that can accept diphase and bipolar codes, which are used by ATACS, provides the versatility of interfacing hybrid systems at any suitable point in the cable or radio system. The radios are shown in parts (G) through (I). The short-range, wide-band radio (SRWBR) at the top-of-the-hill, part (M), transmits supergroups to the CNCE technical shelter via a colocated SRWBR. The MGM in the SRWBR at radio park collects trunks and orderwire from both synchronous and asynchronous systems, from TRI-TAC and ATACS deployments, and from other nodes.

The system of orderwires in the network provides the necessary communication link between network operators and the facilities controller at the CNCE or elsewhere. The DGM equipment provides 16/32 kb/s, 2-kb/s, and 4-kHz orderwire capability, both in-band and out-of-band channels, and automated BITE in the form of 150-b/s telemetry outputs from DGM equipment. Compatibility must be maintained between ATACS orderwire, which are mostly 4-kHz, and provide only limited BITE capability. Some methods of transmitting orderwire and telemetry are depicted in Figure 8. The interoperation of the orderwire system is discussed in later paragraphs.

The DGM equipment in facilities, extended throughout the network, ultimately interfaces with complementary equipment in the CNCE. The modems in the CNCE are identical to those in the DGM. The asynchronous combining function in the CNCE is identical to the DGM MGM and the channel multiplexing function, which is part of the channel reassignment function, is identical to the multiplexing functions of the DGM. The DGM orderwire and telemetry functions are compatible with the CNCE orderwire functions such as the telemetry combiner data channel multiplexer and orderwire end instruments. Generally, the DGM equipment does not interface with the circuit switch. However, it is possible to access the switch at any of the DGM rates and formats. The switch accesses the DGM through the CNCE via digital trunks. Where analog loops are involved, it is possible to access the switch through the CNCE in the analog domain. In this mode, it is necessary to demultiplex digital ATACS groups in an AN/TCC-73 or equivalent and provide loop access from the TD-660's through the CNCE patch panels. This configuration is shown in part (N) of Figure 8.

There is normally no access of DGM equipment to the CSCE since it is exclusively accessed by a CNCE, CSPE, or other CSCE. However, it is possible to access the CSCE from a DGM loop or orderwire equipment; in which case, the 32-kb/s diphase, 150-b/s telemetry, and 4-kHz voice orderwire are compatible with CSCE orderwire and DSVT equipment.

Interoperability of DGM Orderwires

The orderwire and telemetry functions in the DGM equipment interoperate effectively with the facilities control in the TCCF and with existing ATACS orderwires. They are part of the network of system orderwires that are used by system controllers and network operators to coordinate supervisory and maintenance activities of a deployed tactical system. The DGM equipment interfaces, for the most part, with facilities control equipment in the TCCF (CNCE) and with fielded units of the ATACS system that are part of the hybrid analog-digital system deployed during the transitional periods from hybrid to all-digital phases.

The characteristics of orderwire systems are summarized in the table below. By designing the DGM with orderwire functions as specified, compatibility at the system interface is assured (e.g., the 4-kHz analog orderwire used in ATACS is compatible with the DGM and TCCF equipment at both bipolar and dipulse modems, where the system interface occurs). The system interface between DGM equipment and the CNCE occurs generally at diphase modems or at an MGM, in which cases, 32- and 2.0-kb/s diphase orderwires are compatible.

The capability of the DGM multiplexers and modems to carry 150-b/s ASCII telemetry in the TDM band is compatible with the capability of the TCCF multiplexing functions to demultiplex and use this data. The telemetry combiner, which accepts 150-b/s ASCII outputting 2.0 kb/s, and data channel multiplexers and data converter, which accept 2.0 kb/s outputting 32 kb/s are compatible with rates and formats generated in the

decision made to go into sync. This action would then have inhibited the limit decision of all other positions in the matrix except t_1. The reset of the bits-per-frame counter at time t_4 would then change the modulo-N counter indexing to start the true sync position at t_1 and the system would be in sync. If, at any time, errors in the pattern would cause -L to be activated, the system would revert to the search mode.

It can be seen that prior to detecting a sync pattern, all positions are tested and a running "book" kept of each position. Since false sync positions build confidence more slowly than true and all false sync positions are tested along with true, the advantage of the bookkeeper synchronizer is retained without requiring the suboptimum condition of no errors in search and no false sync pattern in one frame. Errors are allowed in the sync pattern. The confidence count is based upon SPRT results from the assignment of weights; and there is no storage of the data stream required for synchronization. Therefore, the synchronizer incorporates all advantages of the bookkeeper and SPRT synchronizers with none of their disadvantages.

CNCE Applications

The framing formats in CNCE equipment are in the two general types of those with distributed pattern and those with contiguous pattern bits. Synchronous equipment such as the digital channel multiplexers and data channel multiplexers generally use the distributed 1 - 0 pattern because interface is made with the synchronous traffic network, which uses distributed patterns in other equipment. Asynchronous multiplexers use contiguous pattern bits probably because there is more freedom of choice