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Interoperability of the European Defense Communications System with Tri-Service Tactical Communications

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PREFACE

This report is part of a multiphase project to investigate survivability, interoperability, reconstitution, and performance-related issues for the European Defense Communications System (DCS). The project is being conducted by the Institute for Telecommunication Sciences in Boulder, Colorado, for the U.S. Army Communications Systems Agency (CSA) in Ft. Monmouth, New Jersey, on Project Order Number 105-RD.

This report, the third report in the series, discusses interoperability of the European portion of the DCS with the TRI-Service Tactical Communications System (TRI-TAC). The emphasis is on the European Telephone System (ETS) and the Digital European Backbone (DEB) portion of the European DCS. Both the digital pipeline and end-to-end levels of interoperability are discussed. Recommendations are made for new R&D programs to be initiated by the CSA.

Other reports in this series are:

"Requirements Analysis for the European Defense Communications Systems," by J. A. Hoffmeyer, J. Lemp, Jr., and R. F. Linfield, March 1982, 324 pages.

"Integrated Services Digital Networks, Standards, and Related Technology," NTIA Report 82-103 by D. V. Glen, April 1982, 114 pages. Available from NTIS, Springfield, VA 22161, Accession Number PB 83-107573.

The views, opinions, and findings contained in this report are those of the author and should not be construed as official U.S. Army Communications Systems Agency policy or decisions, unless designated by other official documentation.

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LIST OF ACRONYMS

ABS	-	aggregate bit stream
ACC	-	Army Communications Command
ACK	-	acknowledge
A/D	-	analog-to-digital
ADCCP	-	Advanced Data Communications Control Procedure
ADPCM	-	adaptive differential pulse code modulation
ATACS	-	Army Tactical Communication System
AUTODIN	-	Automatic Digital Network
AUTOSEVOCOM	-	Automatic Secure Voice Network
AUTOVON	-	Automatic Voice Network
BER	-	bit error rate
BITE	-	built-in test equipment
BP	-	bipolar
CAI	-	channel assignment information
CCITT	-	International Telegraph and Telephone Consultative Committee
CCN	-	Control Communications Network
CCS	-	common channel signaling
CDP	-	conditioned diphase
CEPT	-	European Conference of Postal and Telecommunications Administrations
CESE	-	Communications Equipment Support Element
CINCEUR	-	Commander-in-Chief, Europe
CNCE	-	Communications Nodal Control Element
COMSTRESS	-	Communications Under Stress
CRF	-	Channel Reassignment Facility
CSA	-	Communications Systems Agency - U.S. Army
CSC	-	Computer Sciences Corporation
CSCE	-	Communications System Control Element
CSPE	-	Communications System Planning Element
CVSD	-	continuous variable slope delta
D/A	-	digital-to-analog
DACS	-	Digital Access and Cross-Connect System
DCA	-	Defense Communications Agency

LIST OF ACRONYMS (cont.)

DCAOC	-	DCA Operations Center
DCEC	-	Defense Communications Engineering Center
DCEM	-	Digital Channel Efficiency Model
DCS	-	Defense Communications System
DDR	-	Digroup Data Reduction
DEB	-	Digital European Backbone
DEMUX	-	demultiplexer
DP	-	dipulse
DPAS	-	Digital Patch Access System
DRAMA	-	Digital Radio and Multiplexer Acquisition
DSI	-	digital speech interpolation
DSN	-	Defense Switched Network
DTIF	-	DCS/Tactical Interface Facility
DTMF	-	dual tone multifrequency
ETS	-	European Telephone System
GM	-	Group Modem
HDB3	-	high density binary - 3
HSCDM	-	High Speed Cable Driver Modem
ICD	-	Interface Control Document
IDCS	-	Integrated Defense Communications System
IRAD	-	internal research and development
INTACS	-	Integrated Tactical Communication System
ITS	-	Institute for Telecommunication Sciences
JCS	-	Joint Chiefs of Staff
JMTSS	-	Joint Multichannel Trunking and Switching System
KP	-	key pulse
LB	-	line busy
LCC	-	life cycle cost
LGM	-	Loop Group Multiplexer
LOS	-	line-of-sight
LSCDM	-	Low Speed Cable Driver Modem
LSTDM	-	Low Speed Time Division Multiplexer

MBS	-	mission bit stream
MEP	-	Management Engineering Plan
MF	-	multifrequency
MFC	-	Military Function Controller
MGM	-	Master Group Multiplexer
MIL-DEP	-	Military Department
MLPP	-	multilevel precedence and preemption
MSC	-	Maintenance Service Center
MUX	-	multiplexer
NB	-	narrowband
NCF	-	Network Control Facility
NICS	-	NATO Integrated Communication System
NRZ	-	non-return-zero
O&M	-	operation and maintenance
PBX	-	private branch exchange
PCM	-	pulse code modulation
PROM	-	programmable read-only memory
PTT	-	Postal, Telephone and Telegraph
QAM	-	quadrature-amplitude modulation
QPSK	-	quadrature phase shift keying
RADC	-	Rome Air Development Center
RAM	-	random access memory
RCOC	-	Regional Control Operations Center
RDT&E	-	Research, Development, Test, and Engineering
RECON	-	reconstitution
RF	-	radio frequency
RMC	-	Remote Multiplexer Combiner
ROM	-	read-only memory
SCBS	-	service channel bit stream
SCF	-	Sector Control Facility
SRWBR	-	Short Range Wideband Radio
SSB-AM	-	single-sideband amplitude modulation

LIST OF ACRONYMS (cont.)

SYSCON	-	system control
TB	-	trunk busy
TCCF	-	Tactical Communications Control Facility
TCF	-	Technical Control Facility
TDM	-	time division multiplexing
TGM	-	Trunk Group Multiplexer
TIF	-	Tactical Interface Facility
TRAMCON	-	Transmission Monitor and Control
TRI-TAC	-	TRI-Service Tactical Communications System
VF	-	Voice Frequency
VHSIC	-	very high scale integrated circuits
VLSIC	-	very large scale integrated circuits
WWDSA	-	Worldwide Digital Systems Architecture
WWOLS	-	Worldwide On-Line System

INTEROPERABILITY OF THE EUROPEAN DEFENSE COMMUNICATIONS SYSTEM WITH TRI-SERVICE TACTICAL COMMUNICATIONS

J. A. Hoffmeyer*

This report discusses the different types of interoperability requirements, summarizes several related research and development projects, and presents alternatives for achieving interoperability between the Defense Communications System and the TRI-Service Tactical Communications System. These alternatives are evaluated, and a preferred alternative is recommended. The report concludes with brief tasking statements which are recommended to the U.S. Army Communications Systems Agency as the next steps in pursuing a research and development program for developing interoperability of the two systems at both the transmission subsystem level and at the end-to-end subscriber level. For transmission subsystem interoperability, emphasis is placed on the Digital European Backbone and Digital Radio and Multiplexer Acquisition portions of the European DCS.

Key words: DCS; DEB; Digital European Backbone; digital radio; DRAMA; interoperability; multiplexer acquisition; TRI-TAC

1. INTRODUCTION

Communications network survivability is currently a subject of considerable interest throughout the defense communications community. One reason for this interest is that the nodes and links of the European Defense Communications System (DCS) have been shown to be quite vulnerable to sabotage, conventional warfare, and jamming in addition to the widely recognized vulnerability to nuclear attack. The emphasis in this report is on the survivability of communication services, especially to critical users, rather than on the survivability of communication facilities. A well-designed network may continue to provide essential communications services despite damage to portions of the network.

There are several approaches to enhancing the survivability of communication services. This is illustrated in Figure 1. As a starting point, one should have a robust network design with dual or multiple homing between nodes. Secondly, site hardening and the provision of physical security should be added as appropriate. Thirdly, provisions should be made for restoring communications service after a disruption caused by network damage through the use of prepositioned

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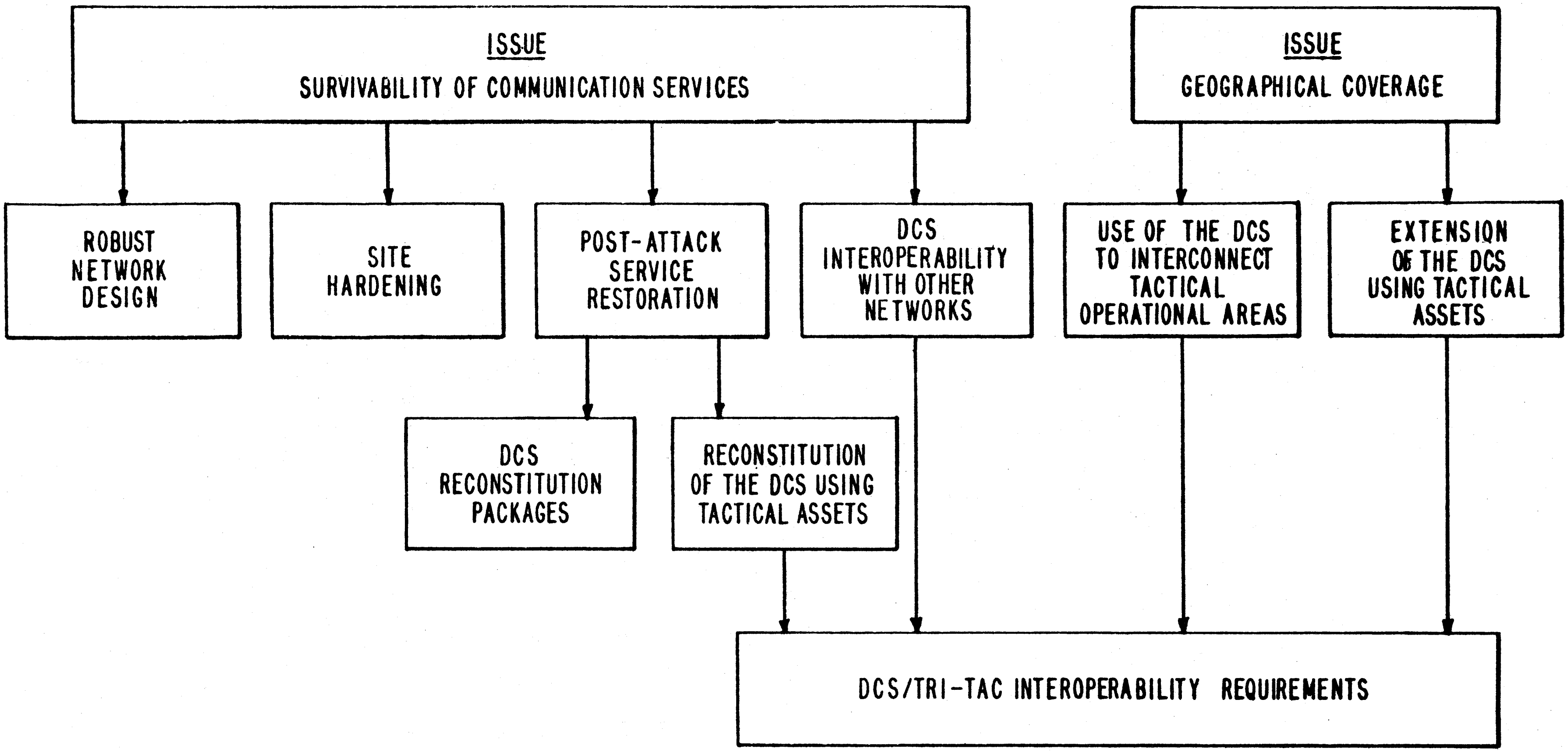


Figure 1. DCS/TRI-TAC interoperability as it relates to communications services survivability and extension of network coverage.

reconstitution packages. As a fourth step, the network should be made to be interoperable with other networks thereby providing more diversity in the paths between any pair of users. The focus of the paper will be on the interoperability approach including the use of tactical assets to re-establish service for damaged DCS nodes and links.

There is another motivating factor for the investigation of the interoperability of the DCS with the TRI-Service Tactical Communications System. The geographical coverage of the DCS could be extended using TRI-TAC facilities or, conversely, the DCS could be used to extend TRI-TAC coverage. For example, one can envision two or more geographically separated tactical operational areas interconnected using the DCS as the backbone transmission facilities between the tactical areas.

The specific problem addressed in this report is that of achieving interoperability between the Digital European Backbone (DEB) and the European Telephone System (ETS) on the DCS side of the interface and on TRI-TAC on the tactical side. A more general treatment of the interoperability problem might include ATACS (Army Tactical Communication System), NICS (NATO Integrated Communication System), AUTOVON, etc. However, it is expected that the ETS, DEB, and TRI-TAC will be the predominate U.S. communication systems in Europe starting in the late 1980's. Therefore this report will consider only these systems.

1.1 Background

This report is part of a multiphase project to investigate U.S. military communications systems requirements in the European Theater. The overall purpose of this study is to assist the U.S. Army Communications Systems Agency (CSA) in identifying R&D (research and development) programs needed to achieve the goal of a highly survivable, and high performance DCS in Europe that is interoperable with other networks. The intent is to emphasize those portions of the survivability, interoperability, reconstitution, and performance issues that influence those hardware and software items that are the responsibility of CSA. Much of this study effort is therefore oriented around multiplexer, radio, and modem requirements. Some discussion of switch requirements is also included.

Previous phases of this study have identified numerous issues in the European DCS. Of the long list of issues that have been identified, several have been chosen for a detailed analysis. These issues are listed in Table 1. The issues are divided into the near-term (1984-1990) and far-term (1988-2000) categories.

Table 1. Problem Areas Selected for Detailed Analysis

Near-Term Issues	Far-Term Issues
1. DCS/TRI-TAC Interoperability	1. Far Term Architectural Issues
2. Reconstitution	- Application of ISDN Technology to the DCS
3. LOS Multipath Fading	- Evaluation of WWDSA and Identification of R&D Programs Needed to Realize the WWDSA Goal Architecture
4. Vulnerability of High Efficiency Modems to Jamming	- Protocols and Standards
	2. Survivability Modeling

The far-term issues are those that may require major new development programs or even new architectural concepts such as the Worldwide Digital Systems Architecture (WWDSA). The near-term issues are those that are seen to be solvable, at least in part, in the 1980's.

The subject of this report is the DCS/TRI-TAC interoperability issue. Separate reports are planned that address the remainder of the issues listed in Table 1.

Figure 2 depicts the interrelationship of tasks being performed. The TRI-TAC/DCS interoperability issue is partially related to the reconstitution issue because TRI-TAC assets could, if interoperable, be utilized to reconstitute damaged or destroyed portions of the DCS.

There are three different levels of DCS/TRI-TAC interoperability that are clearly identifiable and these are shown in Figure 2. These levels are the digital pipeline level, the end-to-end interoperability level, and the highest level where the same system is used to meet the requirements for both tactical and strategic communications. The first two levels are addressed in this report. The "same system" level can be achieved only in the far, far term (post 2000), and will probably be influenced by the evolution to the WWDSA architecture. Other authors (LaVean, 1980) have identified some additional intermediate levels of interoperability for a total of seven levels. This will be discussed more fully in Section 2.

One purpose in presenting Figure 2 is to indicate completed tasks. Note that the investigation of the DCS/TRI-TAC interoperability issue has as its output recommendations for R&D programs for radio, multiplexer, or switch development or modification. These recommendations are found in Section 7 after discussing various alternatives in Sections 5 and 6.

1.2 Study Objectives and Task Breakdown

The objective of the DCS/TRI-TAC interoperability task is to identify alternatives for achieving different levels of interoperability, to evaluate these different alternatives, and to make recommendations to CSA for any new hardware or software development or modifications. The task is broken down into several subtasks as is illustrated in Figure 3. The two major levels of interoperability treated in this report, are the transparent digital pipeline level and the end-to-end subscriber interoperability level. The latter is more complex than the former because it involves such parameters as numbering plans, signaling, and routing control, while the former is merely a sharing of transmission resources.

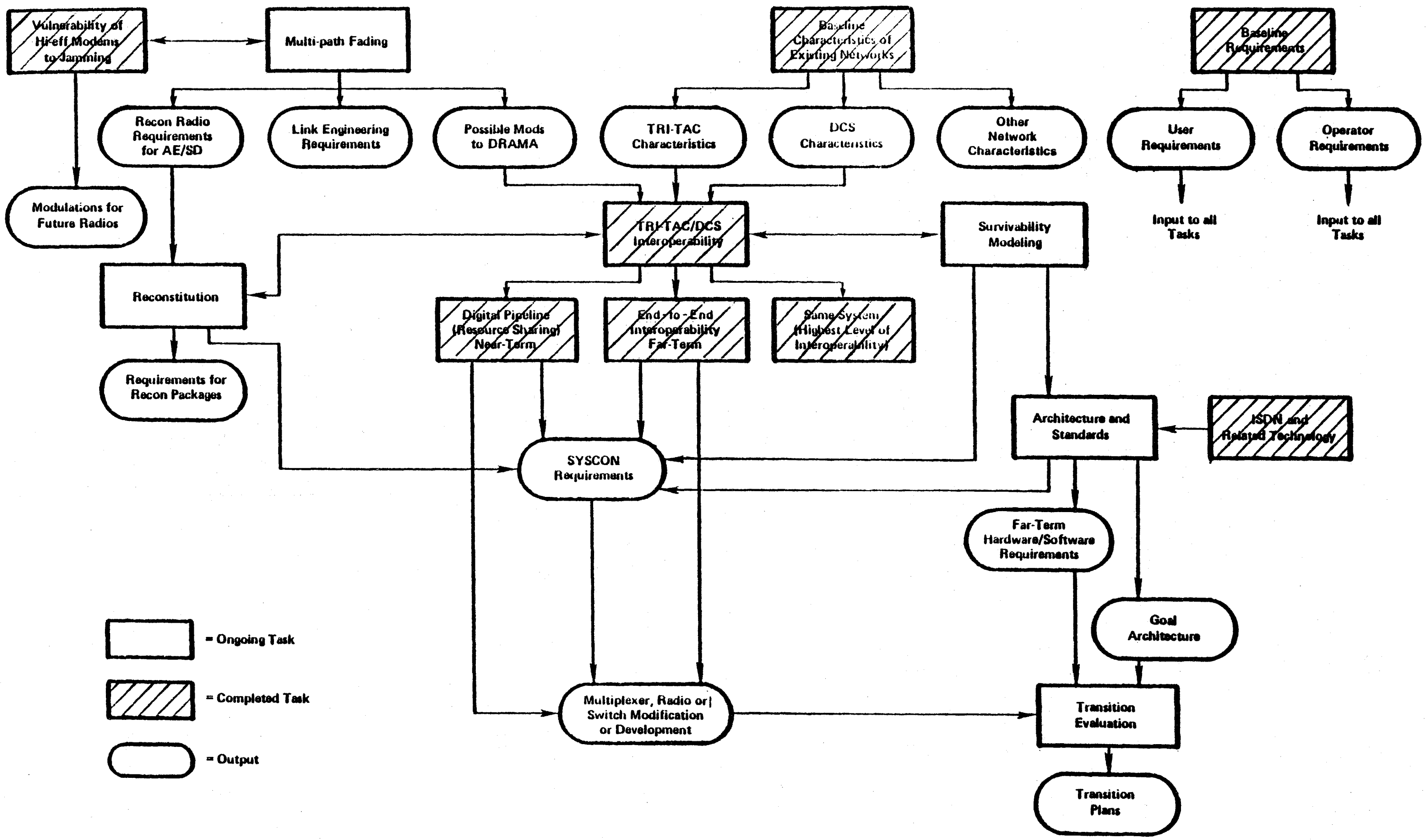


Figure 2. Interrelationship of the tasks being performed.

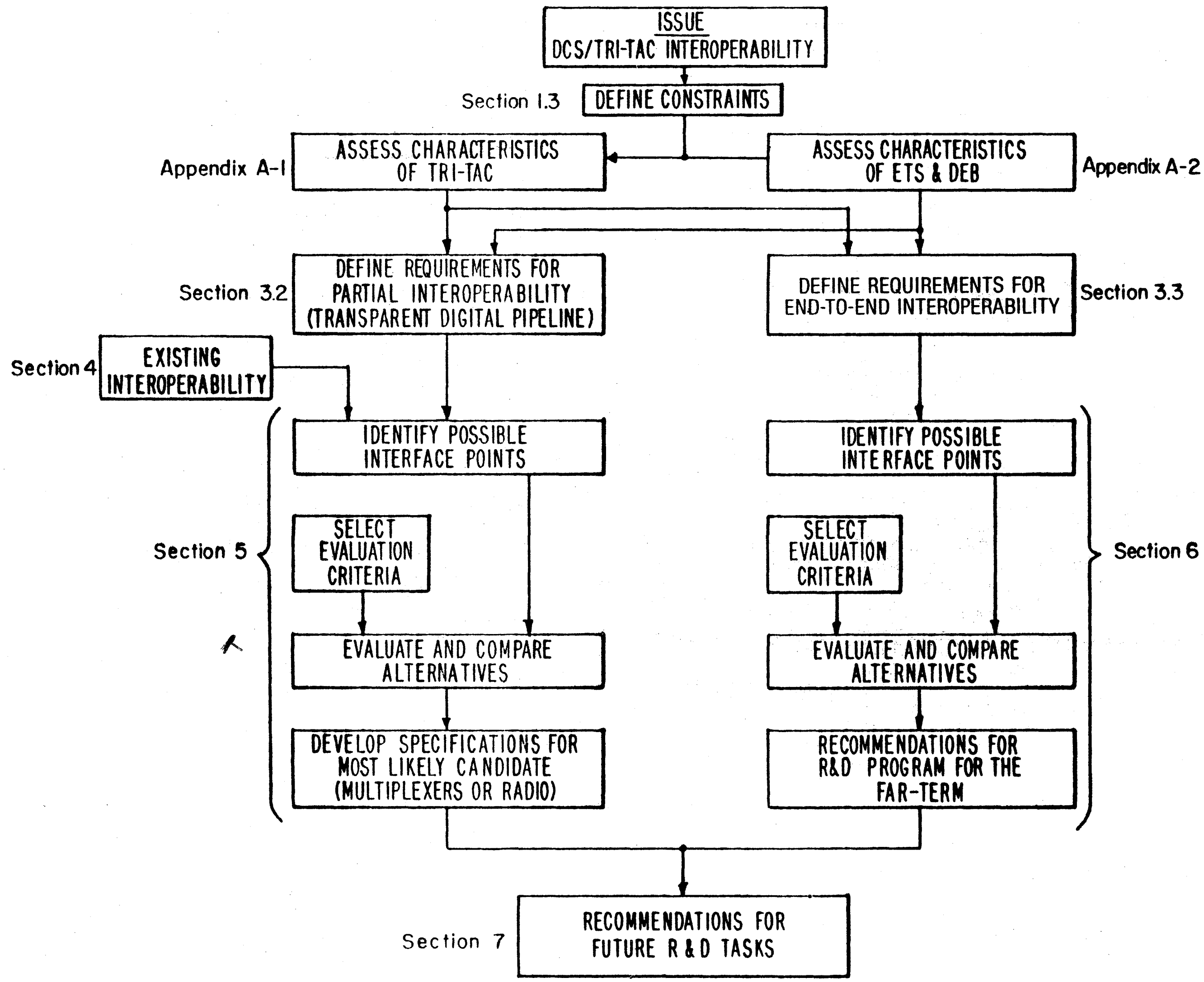


Figure 3. Interoperability issue broken into subtasks.

The end-to-end level of interoperability is thought to be a far-term problem, while the digital pipeline level is viewed as a near-term problem. The ability to make the transition from a near-term limited interoperability solution to an end-to-end or subscriber-to-subscriber level of interoperability also must be addressed. Figure 3 indicates the section number of this report in which each of the subtasks is discussed.

1.3 Study Assumptions

Table 2 lists several assumptions that have been made. The first assumption is that a requirement exists for a DCS/TRI-TAC interface at some level above the analog voice frequency (VF) level. Since the requirements for interoperability or, indeed, its very definition, are not generally agreed upon it is necessary to state at the start that the view taken herein is that there is a requirement for a higher level of interoperability other than at the VF level. Requirements which support this assumption are discussed in Section 3.

Because the traffic levels for the gateways between the DCS and TRI-TAC networks have not been fully defined, it is necessary that the interface points be assumed to have sufficient flexibility to handle a growth in traffic. Documents such as the INTACS System Architecture (Pound, 1979) identify the need for interfaces between tactical communications systems and the DCS, but do not discuss the level of traffic through the interface.

A further assumption made is that some equipment development can be accomplished in the near term, but that major new systems (such as switches) can be developed only to satisfy requirements in the far term (1988 and beyond). It is assumed that for the near term (1984-1988) that the DRAMA (Digital Radio and Multiplexer Acquisition) equipment will be fielded approximately on schedule, that the Digital European Backbone (DEB) will be implemented according to the planned schedule, and that the TRI-TAC family of digital multiplexers and radios will be available. These equipments are all assumed to be the fundamental elements of the DCS and TRI-TAC during the mid- to late-1980's. Interface alternatives will be developed in later sections of this report that will be oriented around these equipments.

1.4 Report Overview

Section 2 of this document contains a discussion of different types and levels of interoperability. Because the word interoperability means different

Table 2. Constraints

- a requirement exists for a DCS/TRI-TAC interface at some level above the analog VF level of interoperability

- the traffic has no impact on the features of the network components; the DCS and the TRI-TAC networks and their major components as well as the gateways between the networks can be designed with sufficient modularity that traffic levels need not be considered in this study

- some equipment development can be accomplished in the near-term (e.g., an intelligent multiplexer). The development of new switches or switch modification (which might be required for the full-interoperability case) could be accomplished only in the far-term

- DCS and TRI-TAC multiplexers and radios will be fielded approximately on schedule things to different people, it is important to define how the word is used in this report. Section 2 also contains a brief discussion of the characteristics of various types of interoperability and relates the types of interoperability discussed in this report to the seven levels of interoperability that have been identified by LaVean (1980).

Section 3 is a discussion of the requirements for the digital pipeline and end-to-end levels of interoperability. Section 3 concludes with a discussion of how communications network user's and operator's general requirements may be mapped into specifications for radios and multiplexers.

Section 4 is a brief description of the existing capability for DCS/TRI-TAC interoperation at the VF level. Problems and deficiencies with this type of interoperability are identified.

Sections 5 and 6 contain discussions of alternatives for achieving interoperability at the digital pipeline and end-to-end levels, respectively.

Section 7 contains recommendations for specific R&D tasks that should be conducted by CSA as the next step toward achieving full interoperability between the DCS and TRI-TAC.

Appendix A provides a summary of the major characteristics of the European Telephone System (ETS), the Digital European Backbone (DEB), Digital Radio and Multiplexer Acquisition (DRAMA) equipment, and TRI-TAC architecture and equipment. Appendix B provides a brief comparison of the performance of different voice digitization techniques. Appendix C compares different line codes.

2. TYPES OF INTEROPERABILITY

The Joint Chiefs of Staff PUB 1 provides the following definition of interoperability:

> "Interoperability - the ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together."

Unfortunately, this general definition of interoperability does not address the degree, or level, of interoperability between systems. Nor does it indicate what is meant by "services." For communications network interoperability, one needs to define whether "services" means end-to-end user services, transmission services, or some other level of service. Furthermore, the interoperability of two communications networks may consist of any of the following:

1) manually assisted interconnects at the analog VF level

2) partially automated interconnects that are achieved through the use of interface boxes for signal format conversion

3) a fully automatic interconnect.

The word interoperability means different things to different people. A white paper on interoperability prepared by the Army Communications Command (ACC, 1980) states that while interoperational needs are conceptually outlined in general terms, the specific degree, scope, and level of interoperability are not usually defined. There is no unanimity on the degree of interoperation that is required. Consequently, major systems evolve separately resulting in systems lacking common standards and having inherent incompatibilities between the hierarchies of the major systems. The ACC white paper further states that:

> "Lacking are definitive and commonly understood and accepted definitions/standards for interoperability between systems, definitions of military networks architectures for major systems ... and sufficient interoperation requirements."

In order to clarify the meaning of the word interoperability as it is used in this report, the following subsections include a discussion of some interoperability-related terminology that is frequently encountered, a discussion of the characteristics of different types of interoperability, and a discussion of the types of interoperability addressed in this report as they relate to the seven-level interoperability hierarchy defined by DCA.

2.1 Terminology

Two levels of interoperability are discussed in this report. The first is the digital pipeline (or limited) interoperability level, while the second is the end-to-end (or full) interoperability level. Figure 4 introduces these concepts. The digital pipeline concept is one in which the resources of one network are used to satisfy partially the transmission requirements of a second, while the end-to-end concept implies that a subscriber in one network can communicate directly, and automatically, with a subscriber in another network. These concepts are elaborated on in the following paragraphs.

Under the digital pipeline concept a subscriber in one network (say DCS) cannot dial directly a subscriber in a second network (say TRI-TAC), or vice versa. We restrict the pipeline concept to be a digital pipeline, because the

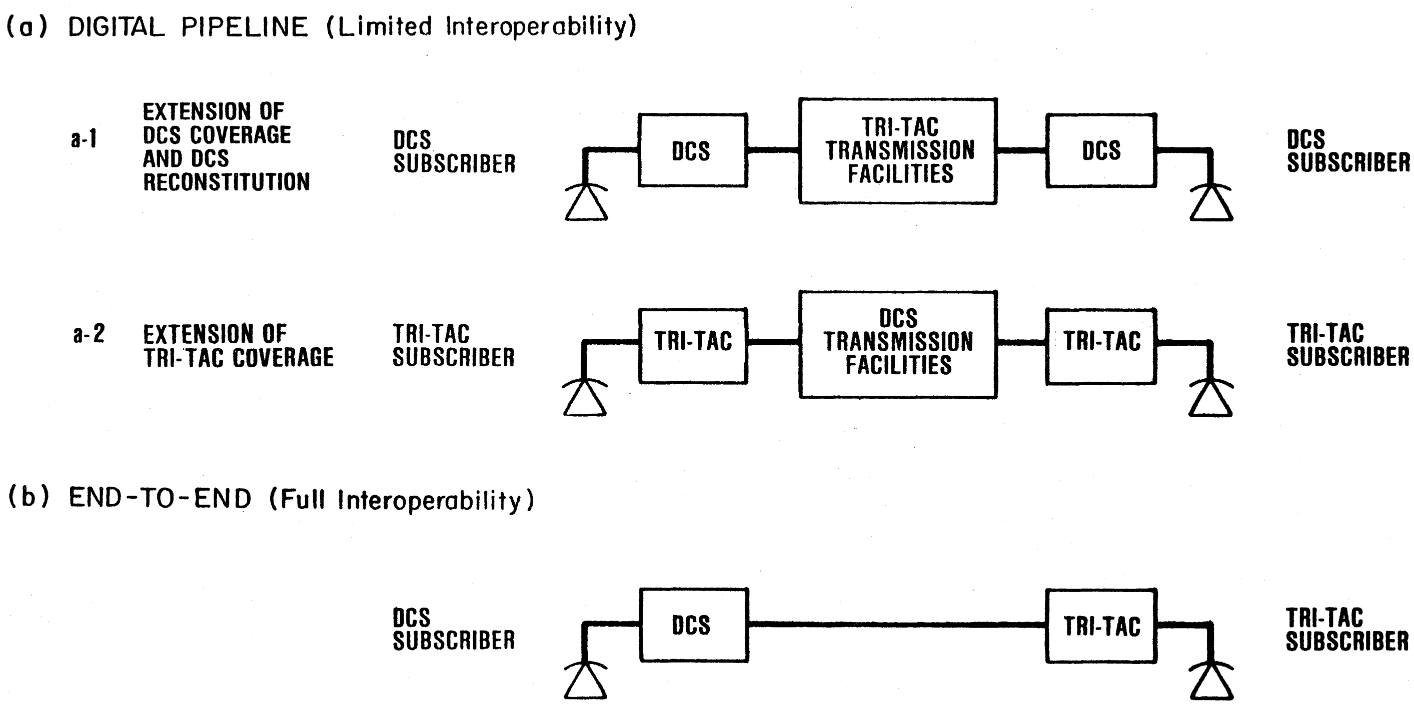


Figure 4. Examples of different types of interoperability.

transmission facilities of both the ETS and TRI-TAC will be changing toward an all digital network. In order to achieve the digital pipeline level of interoperability, there must be compatible digital bit rates between the two networks, the line codes (see Appendix C for a discription of line codes) must be compatible, and synchronization must be achieved. However, there is no need for compatibility between numbering plans, signaling techniques, routing control, etc. The pipeline is transparent to the type of information being carried. The pipeline can carry any bit stream as long as the data rates and line codes are compatible.

As depicted in Figure 4 there are two cases for the digital pipeline level of interoperability. The first is the use of TRI-TAC transmission facilities to provide connectivity between two segments of the DCS. This case may be thought of as the "reconstitution case" where tactical facilities are utilized to restore communication service between two or more disjoint portions of the DCS that have been disconnected due to damage to the network. The second case is the use of DCS transmission facilities to serve as the backbone between two geographically separated tactical operational areas. This would provide an extension of TRI-TAC coverage.

Figures 5 and 6 illustrate the need for each of the two cases of the digital pipeline level of interoperability. More will be said in Section 3 about requirements as they have been stated by DCA. Here, we shall limit ourselves to a brief discussion of how the digital pipeline might be applied in two theoretical scenarios.

Figure 5 illustrates a hypothetical use of tactical assets to restore connectivity in a damaged portion of the Digital European Backbone. A typical portion of the DEB is illustrated in Figure 5a that is typical of connectivity found throughout DEB. In our hypothetical example we assume that the back-to-back repeater site at Hohenpeissen has been eliminated either by hostile action, perhaps sabotage, or by some natural disaster. Service between Munich and Reese Augsburg could be restored using tactical assets as long as the digital pipeline level of interoperability is provided between DEB and TRI-TAC equipments. Note that there is no DCS or TRI-TAC switch involved in this interoperability requirement. While pre-positioned DCS reconstitution packages could also be used to re-establish connectivity between disjoint portions of the DCS, other options should also be considered such as the use of tactical assets.

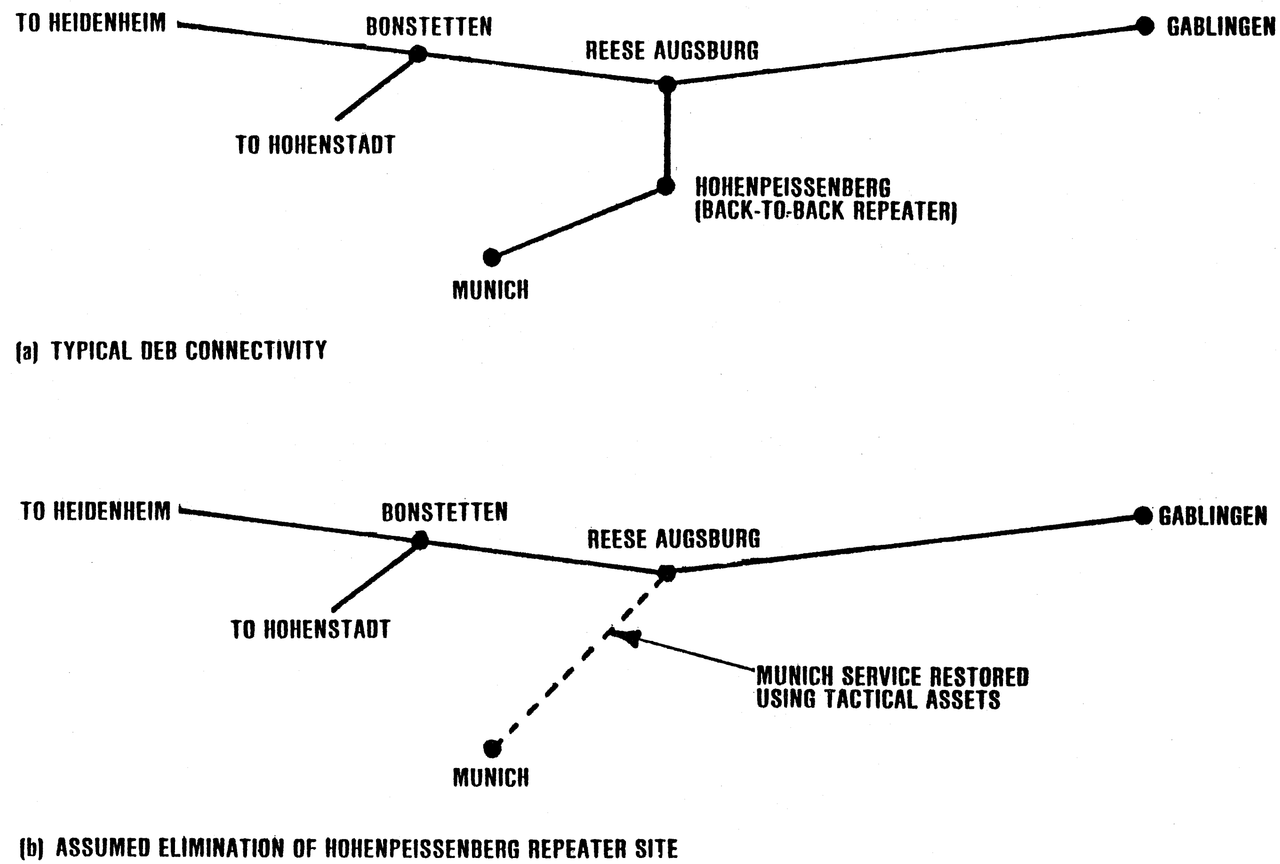
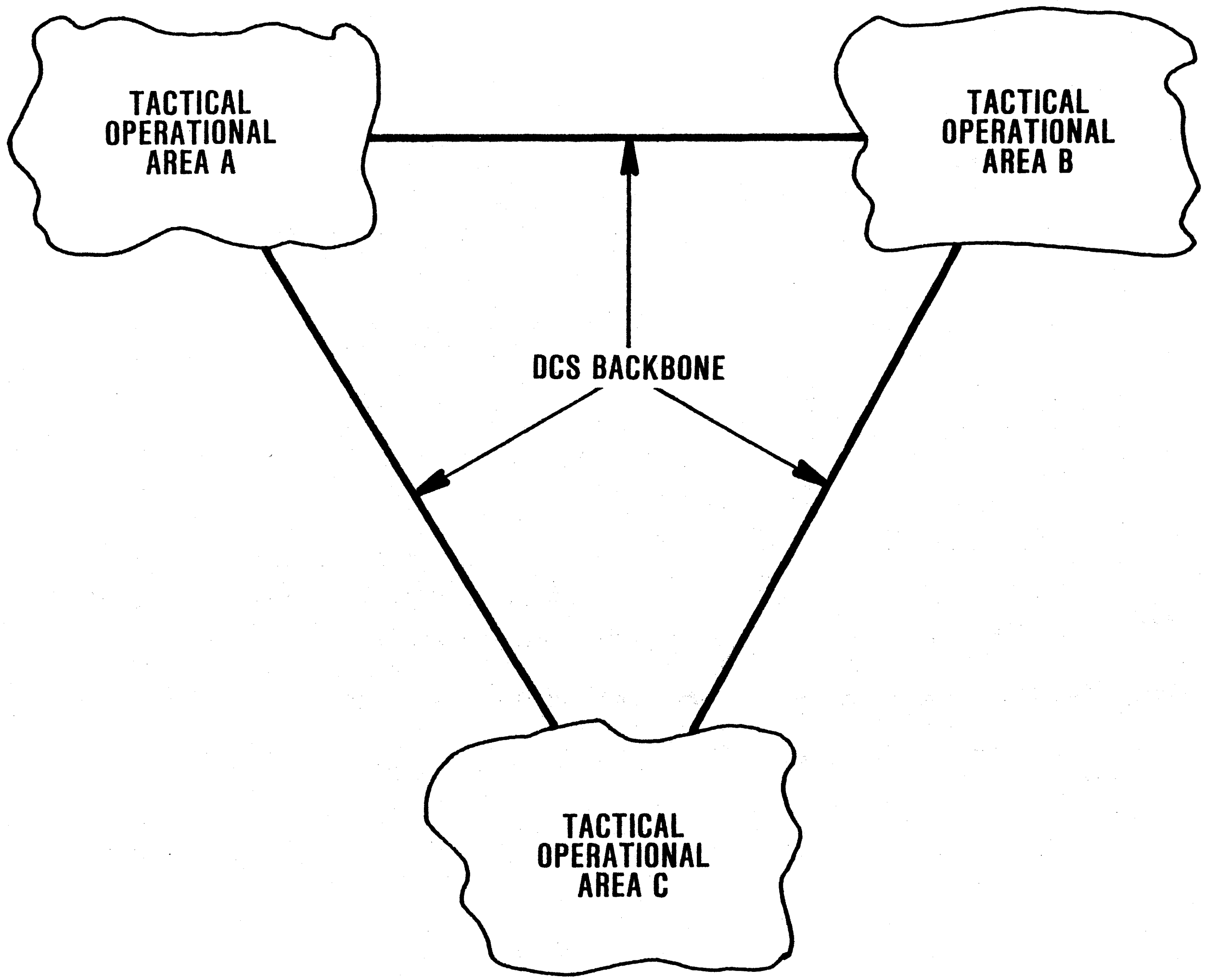


Figure 5. Example of need for DCS/TRI-TAC/DCS digital pipeline interoperability.



DEB PROVIDES BACKBONE CONNECTIVITY AMONG GEOGRAPHICALLY SEPARATED TACTICAL OPERATIONAL AREAS

Figure 6. Example of need for TRI-TAC/DCS/TRI-TAC digital pipeline interoperability.

Figure 6 illustrates the use of the DCS to serve as a transmission backbone for providing connectivity between geographically separated tactical operational areas. This, again, requires that a digital pipeline level of interoperability be developed between DEB and TRI-TAC equipment.

Table 3 lists terminology that appears in the literature that is either synonymous with, or very similar to, the digital pipeline and end-to-end interoperability terminology that is used in this report. It can be argued that the digital pipeline described previously does not represent interoperability at all, but rather connectivity. That is, the digital pipeline merely allows two networks to be connected together, but not to be interoperable. This, of course, depends on what is meant by interoperability. The argument could be, and has been, made that the digital pipeline provides interoperability of transmission facilities, but not interoperability at the user service level.

Wnuk (1981) introduces the concept of "TO" and "THROUGH" interoperability. The "THROUGH" concept is similar to the pipeline concept in which the capability exists for a communications path from Network A, through Network B, and back to Network A. Thus, Network B is providing transmission facilities or a pipeline for Network A. The "TO" concept used by Wnuk is similar to the end-to-end terminology used in this report. In the "TO" concept, a subscriber in one network can dial, and be automatically connected to, a subscriber in another network. The terminology "subscriber-to-subscriber interoperability" is synonymous with "TO interoperability." The phrase "full interoperability" is also similar to the terms end-to-end interoperability, subscriber-to-subscriber interoperability, or "TO" interoperability. The term full interoperability may be confusing, however, in regard to whether the term means subscriber-to-subscriber interoperability for all operational modes or just some modes. In this report the term end-to-end interoperability does not necessarily imply all operational modes. It simply means that a subscriber in one network can talk directly with, and be connected automatically to, a subscriber in another network in at least one operational mode.

2.2 Characteristics of Different Types of Interoperability

Table 4 is a list of parameters that are affected by the two types of interoperability being addressed in this report. For example, the voice digitization technique employed is of concern when considering end-to-end interoperability,

Table 3. Terminology Describing Different Types of Interoperability

Digital Pipeline:	Transmission Facilities Interoperability
	THROUGH Interoperability
	Transmission Connectivity
End-to-End Interoperability:	Subscriber-to-Subscriber Interoperability
	TO Interoperability
	Full or Complete Interoperability or User Compatibility

Table 4. Parameters Affected by Different Types of Interoperability

Parameter	Digital Pipeline	End-to-End Interoperability
Voice Digitization Technique		X
Tandeming of A/D and D/A Conversions		X
Line Code	X	X
Bit Rate	X	X
Multiplexer Hierarchy (Number of Channels)		X
Framing		X
Error Control	X	X
Timing and Synchronization	X	X
Signaling		X
Numbering Plan		X
Routing		X
System Control		X
Technical Control	X	X
Security	X	X

but not when considering the digital pipeline interoperability. For a digital pipeline, it does not matter whether the bit stream has been generated using PCM (pulse code modulation) encoded voice, CVSD (continuously variable slope delta) modulation encoded voice or, for that matter, the bit stream is computer generated data. For end-to-end interoperability, knowing the type of voice encoding employed is essential. If the two networks employ different voice encoding techniques, then the interface must be able to convert from one digitization technique to the other. For A-law PCM (used in Europe) to μ-law PCM (used in North America and in the Digital European Backbone), this conversion process is relatively straightforward. It is somewhat more difficult to convert from PCM to CVSD, but devices have been developed that have this capability (Zakanycz and Betts, 1978).

Tandem conversions may be asynchronous (A/D-D/A-A/D, etc.) or synchronous (A/D1-D1/D2-D2/D1, etc.). The D1/D2 notation implies a direct conversion from one digital format to another digital format without an intermediate conversion to analog. In any event, making tandem conversions is of interest for the end-to-end interoperability case only. For the digital pipeline there is no conversion necessary from one voice digitization scheme to another. The digital pipeline is not affected by what the bits that are being transported represent.

The system parameters that are of interest in the digital pipeline case are:

line code,
bit rate,
error control,
timing and synchronization,
technical control, and
security.

More will be said about each of these parameters in Section 5, where the alternatives for achieving a digital pipeline level of interoperability between the DCS and TRI-TAC are discussed. The end-to-end level of interoperability case essentially involves all system parameters.

The difficulty in achieving either pipeline or end-to-end interoperability among the various networks in the European theater can be seen by scanning Table 5. This table itemizes some of the major parameters for DEB, TRI-TAC, ATACS, and NICS. The NATO Integrated Communication System will employ the European CCITT (International Telegraph and Telephone Consultative Committee) standards

Table 5. Characteristics of Digital Transmission Facilities and Digital Voice Networks in Europe

Characteristics	DEB	European CCITT, NICS, PTT's	TRI-TAC	ATACS
Channel Rate	64 kb/s	64 kb/s	16/32 kb/s	48 kb/s
Multiplex Hierarchies:				
1st Level	1.544 Mb/s (24 ch)**	2.048 Mb/s (30+2 ch)	256 kb/s (15+)*	0.576 Mb/s (12 ch)
2nd Level	12.928 Mb/s (192 ch)	8.448 Mb/s (120+)	2.048 Mb/s (127+)*	2.304 Mb/s (48 ch)
3rd Level	----	34.368 Mb/s (480+)	18.720 Mb/s (1144+)*	4.915.2 Mb/s (96 ch)
4th Level	----	139.264 Mb/s (1920+)	----	----
A/D Technique	8-bit PCM	8-bit PCM	CVSD	6-bit PCM
Encoding Law	μ-Law	A-Law	CVSD	3 Segment, Linear
Line Code	NRZ or Bipolar	HDB3	NRZ or CDP	NRZ or DP
Signaling	Channel associated, uses least significant bit of each 6th frame	CCITT R1, R2,	Associated CCS and in-band	Channel associated; uses least significant bit of frame
Synchronization	Station clock is rubidium. LORAN C may be used for timing reference. Internal quartz crystal oscillator (10^{-6} - 10^{-8} accuracy) may be used as a back-up.	Quartz crystal oscillators are currently used having accuracy of 10^{-6} to 10^{-8} possible future use of atomic clocks	Atomic clocks; accuracy 1×10^{-11}	Quartz clocks

*16 kb/s channel rate.
**Quantities within parentheses are the number of voice channels.

that are used by the PTT's (Postal, Telephone, and Telegraph). The table indicates that almost all of the parameters are different among the various networks. The task of achieving interoperability on a multichannel, end-to-end basis is a formidable one. Further details of the DEB, ETS, and TRI-TAC systems are provided in Appendix A.

2.3 Relation to Seven Levels of Interoperability Proposed by LaVean

LaVean (1980) defines an interoperability spectrum consisting of seven levels that has been developed by the Defense Communications Agency. The seven levels of interoperability are:

1) separate systems,
2) shared resources,
3) gateways,
4) multiple entry points,
5) conformal or compatible systems,
6) completely interoperable systems, and
7) same system.

The levels increase in degree of interoperability as the number of the option increases. The primary benefit of the "shared resources" option is that an "economy of scale" may be achieved, e.g., the cost per voice channel may be significantly less if two or more networks are sharing the same transmission link. An example of the shared resources would be the use of DEB links by both AUTOVON and AUTODIN networks.

True interoperability is achieved through the use of gateways. For example, a gateway may be provided between a tactical network and the DCS. Multiple entry points in the DCA interoperability hierarchy is simply an extension of the gateway concept. Numerous gateways (12 to 20 as defined by LaVean, 1980) would be required for the interoperability level to be classified as multiple entry points. The number of gateways is increased primarily to enhance survivability.

Conformal or compatible systems is the next highest level in the hierarchy. The systems are not identical, but the system parameters are such that it is easy to make the transition from one system to the other at the network interfaces. The completely interoperable level, on the other hand, requires an identical set of signaling formats, preemption protocols, etc. It requires that the system control elements be able to communicate with each other.

While the seven levels of interoperability discussed above provide a logical structure for addressing the interoperability issue, much work remains to be done in applying this structured approach to actual network interfaces. A classified Defense Communications Agency report provides guidance on U.S. policy on communications network interoperability. This guidance is not stated in terms of the level of interoperability, however. Consequently, most work has been concentrated on levels 2 and 3 (shared resources and gateways). In considering interoperability solutions for the far term (1990's and beyond), emphasis should be on the higher levels of interoperability (conformal or compatible systems and completely interoperable systems). The highest level (same system) may never occur because the rapid change of technology causes each network to evolve with time, and to "leap frog" others in their implementation of new technology. It is not entirely clear that the "same system" level is a desirable goal because of survivability considerations.

The Worldwide Digital Systems Architecture (WWDSA) study (DCA, 1981b) does not discuss the interoperability issue in terms of the seven levels. However, it is clear that in the recommendations made in the WWDSA study, higher levels of interoperability are a key feature of the goal architecture. For example, Feature N of the goal architecture is to "encourage common standards for all networks, where feasible, for improved interoperability." Feature M is an "improved internetwork system control between DCS, tactical, and commercial networks ...". Thus, the WWDSA goal architecture, although not related explicitly to the seven level interoperability hierarchy, appears to be oriented toward the higher interoperability levels such as level 5 (conformal or compatible systems) or level 6 (completely interoperable systems).

Table 6 relates the digital pipeline and end-to-end interoperability concepts addressed here to the seven interoperability levels discussed above. The digital pipeline is one form of resource sharing. In this case it is the transmission facilities that are being shared. The correlation between the end-to-end interoperability concept and the seven-level hierarchy is a little less clear. Depending upon the number of gateways or entry points incorporated and the degree of standardization of protocols, the end-to-end interoperability concept falls somewhere between levels 3 and 5 as shown in Table 6. In levels 3 and 4, the gateways must perform protocol conversions while in level 5 (conformal or compatible systems) some degree of standardization has been achieved which minimizes the amount of protocol conversion required. An example of this might be in the

Table 6. Relationship to the Seven Levels of Interoperability Introduced by LaVean

<table>
<tr><th>Level</th><th>Terminology Used by LaVean</th><th>Terminology Used in this Report</th><th>Parameters Affected</th></tr>
<tr><td>1</td><td>Separate Systems</td><td></td><td></td></tr>
<tr><td>2</td><td>Shared Resources</td><td>Digital Pipeline</td><td>Line code, bit rate, synchronization, security, and some technical control</td></tr>
<tr><td>3.</td><td>Gateways</td><td rowspan="3">End-to-End Interoperability</td><td rowspan="3">All of the above plus voice digitization technique, tandem A/D and D/A conversions, framing, error control, signaling, numbering plan, routing, some system control, multiplex hierarchy (number of channels).</td></tr>
<tr><td>4.</td><td>Multiple Entry Points</td></tr>
<tr><td>5.</td><td>Conformal/Compatible Systems</td></tr>
<tr><td>6.</td><td>Completely Interoperable Systems</td><td>Full Interoperability for all Operational Modes (WWDSA Goal Architecture)</td><td></td></tr>
<tr><td>7</td><td>Same System</td><td>IDSC (?)</td><td>All of the above plus users' service features.</td></tr>
</table>

signaling systems. The ETS will utilize CCITT #7 common channel and R1 signaling while TRI-TAC can use a common channel signaling system unique to TRI-TAC. Information on CCITT #7 signaling can be found in CCITT (1981). A gateway interface (level 3) could be developed to perform signaling protocol translation. For the far-term it may be found desirable to use a standard signaling system which would be part of level 5 interoperability (conformal/compatible systems).

One purpose of Table 6 is to show an orderly evolution in the interoperability of two networks such as the DCS and TRI-TAC. The evolution is from a comparatively simple digital pipeline, through a much more complex, multichannel, end-to-end interoperability concept, to the goal 1995 Worldwide Digital Systems Architecture. The far far-term goal is the Integrated Defense Communications System (IDCS) described by McKee (1982).

Having reviewed various types or levels of interoperability, the next task is to discuss the requirements for the different levels of interoperability as they have been identified in various DCA and Joints Chiefs of Staff (JCS) documents. This is briefly treated in Section 3.

3. REQUIREMENTS

A white paper on communications interoperability prepared by the U.S. Army Communications Command (ACC, 1980) concluded that:

> "... specific requirements for interoperation, particularly between major systems/networks, and their equipments and protocols, such as DCS-JMTSS, US-NATO, military-commercial, and combinations thereof, are largely unstated or inadequately defined today."

The reason that specific requirements are not well-defined is that even the general interoperability requirements are not fully agreed upon. The ACC white paper further states that:

> "... unfortunately there is no unanimity on the degree of interoperation which is satisfactory and required."

For example, it has been stated that sufficient interoperability between the DCS and TRI-TAC is achievable with a VF analog interface at the TTC-39 TRI-TAC switch. Others state that the interface should be at a digital multichannel level. Some state that the digital transmission level of interoperability is needed, but should be restricted to the case of the DCS serving as a transmission backbone between separated tactical operational areas. A view is held that there is no requirement for the use of tactical assets to restore connectivity between two disconnected portions of the DCS in a stressed environment.

The ETS will be a major portion of the European DCS in the late 1980's and beyond. However, the tactical/ETS interoperability requirements have not been defined. Therefore, the DCS tactical interoperability requirements are stated only in general terms.

Because of the widely varying points of view that have been encountered during the course of this study, it is important to establish a baseline set of DCS/TRI-TAC interoperability requirements as they have been stated in DCA and JCS documents. The unclassified reference documents reviewed that provide guidance on interoperability are DCA (1980), DCA (1981a), DCA (1981b), and Pound (1979). The classified documents reviewed were:

a) JCS Message 20 2004Z December, 1979, "The Joint Multichannel Trunking and Switching System",

b) DCEC TR 2-82, "FY-1983/FY 1989 DCS RDT&T Program",

c) DCA report, "Defense Communications System/European Communication System Interoperability Baseline",

d) DCA report, "Defense Communications Under Stress (COMSTRESS) Phase II Report",

e) DCA report, "Worldwide Digital Systems Architecture (WWSDA) Transition Plan",

f) DCEC TR 1-81, "The DCS: FY 1984 and Beyond",

g) DCEC TR 4-81, "Requirements and Overview of the Future DCS", and

h) DCEC TR 5-81, "Deficiencies of the Baseline DCS".

In the following sections, these documents will be used to show that there are valid requirements for the interoperability of the DCS and TRI-TAC at both the digital pipeline (transmission resource sharing) level and at the end-to-end (subscriber-to-subscriber) level. It will also be shown that requirements have been stated for multichannel interfaces, not merely single-channel, VF interfaces. Table 7 lists the general user requirements that are being addressed in this report. The following sections show the basis for the assertion that these are valid user requirements.

Table 7. Basic User Requirements for DCS/TRI-TAC Interoperability

Digital Pipeline (transmission resource sharing)
- Reconstitution or extension of the DCS connectivity using tactical assets
- Use of the DCS for local and long haul service for tactical subscribers
End-to-End Interoperability

3.1 General Requirements

General interoperability requirements may be found in the FY 1983/FY 1989 DCS RDT&E Program report. As stated in that document, one of eight desired attributes for the DCS is interoperability including uniform signal structure. The tree diagram for this attribute is shown in Figure 7. Note that the diagram includes not only transmission facilities but also system control and signaling. The significance of the inclusion of these latter two system characteristics is that a higher level of interoperability beyond the transmission resource level is an attribute of the DCS objective.

The DCS RDT&E document further states that:

> "The ability to utilize all possible networks to achieve transparency in an interoperable mode is the key factor to maximizing survivability and to minimizing costs through shared resources."

The interpretation taken in this report is that the shared resources should include transmission resources such as multichannel digital transmission facilities. Although not discussed in this report, interoperability of security facilities is another important facet of the interoperability issue.

The Joint Multichannel Trunking and Switching System (JMTSS) is a primary motivating force for DCS/tactical interoperability since the JMTSS consists of a mix of DCS and tactical assets. Little can be said about JMTSS on an unclassified basis. However, the Defense Communications System/European Communication System Interoperability Baseline report (a 1981 DCA report) states that:

> "The JMTSS now being planned for Europe and the Pacific poses large-scale interoperability problems between the DCS and tactical communication equipment. Interoperational and interface problems must be resolved before JMTSS can become a reality."

Although the above is a general statement of the interoperability requirement, it does state the requirement from an operational point of view. The requirement above is a network user's point of view or requirement. This must be translated into specific technical requirements from a network or equipment designer's point of view. More will be said about this translation process in Section 3.4.

3.2 Digital Pipeline Interoperability Requirements

As previously shown in Figure 4, there are two cases of the digital pipeline level of interoperability being considered in this report. The first case, which

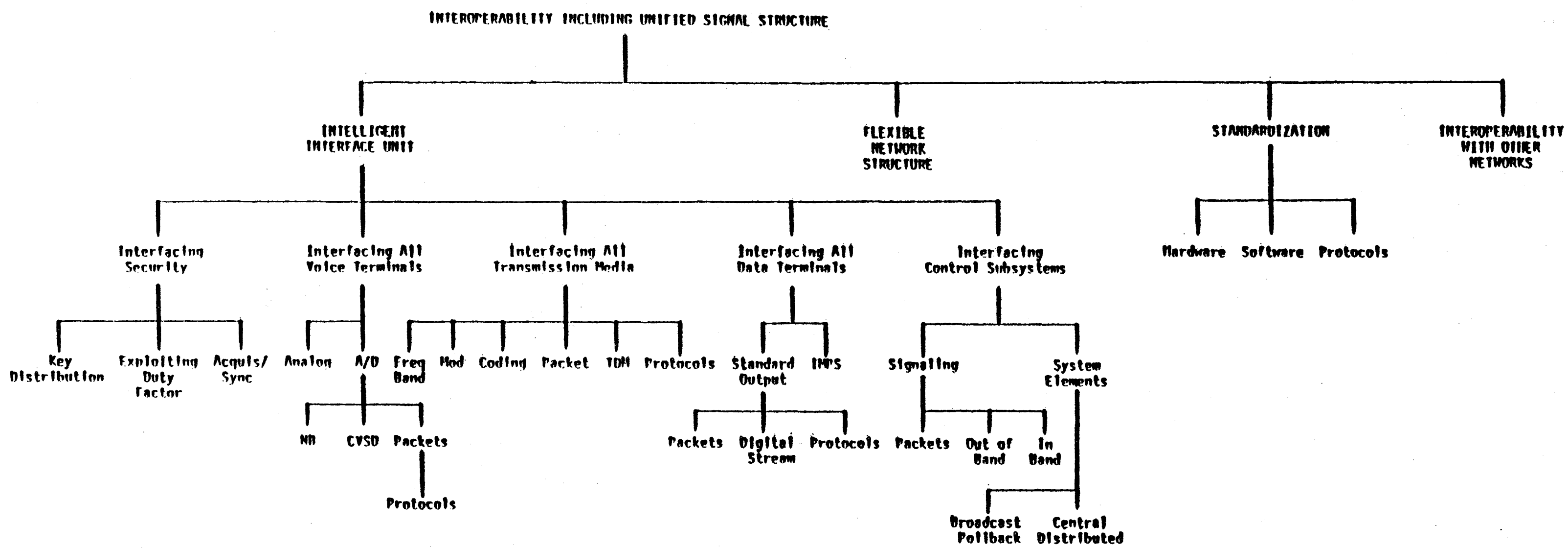


Figure 7. Tree diagram on interoperability including unified signal structure.

might be called the reconstitution case, is when tactical transmission facilities are used to provide connectivity between separated DCS nodes. The second case is the use of DCS transmission facilities to provide a transmission backbone for geographically separated tactical operational areas.

The COMSTRESS (Communications Under Stress) report, DCS FY 1983/FY 1989 RDT&E Program report, the DCS interoperability baseline report, and the DEB Management Engineering Plan (DCA, 1980) all support the contention that the capability for tactical assets to reconstitute the DCS is a valid requirement. One of the COMSTRESS study recommendations is that:

> "Reconstitution assets should consist of a mix of both DEB and tactical assets."

The requirements stated in COMSTRESS are validated requirements. The DCS RDT&E Program report states that a thrust for integrated design and system control is to:

> "Develop the control interoperability criteria and interface capability for interoperation between the DCS control processes subsystem and those of common carriers, tactical systems, and allied systems to enable service restorals through non-DCS resources."

The DCS interoperability baseline report states that:

> "tactical equipment could, if it were interoperable, be deployed to reconstitute the damaged DCS in less time than fixed assets could (even if available) be deployed and installed."

The concept of using the DCS to interconnect geographically separated tactical operational areas is introduced in the DEB Management Engineering Plan (DCA, 1980). Tactical elements will be provided direct access to the DEB through the Tactical Interface Facility (TIF). The TIF is to provide interconnect capability at VF, 1.544 Mb/s, and 12.928 Mb/s. The existing wideband interface modules for the first level DEB multiplexer "could be used for tactical data rates of 256 kb/s and 512 kb/s when the requisite timing and buffering subsystems are deployed." The DEB MEP explicitly states that:

> "Tactical interconnects are required to provide an access to the DCS backbone for tactical elements and for reconstitution in the event of wholesale destruction of the DCS."

This establishes the requirement for the use of the DCS to provide backbone transmission services for connecting tactical nodes, as well as for the use of tactical assets for re-establishing DCS communication services.

3.3 End-to-End Interoperability Requirements

The trend in military communications networks is to evolve toward an all-digital network. The primary motivating factor is that voice encryption is more readily accomplished in a digital system than in an analog system. Despite the fact that more voice circuits can be packed into an analog wideband channel (such as that provided by the Bell system's AR-6A SSB-AM radio), military transmission facilities are evolving toward an all digital system for security reasons. The long-range goal architecture is that described in the DCA Worldwide Digital Systems Architecture (WWDSA) reports. Some of the key baseline deficiencies that have been identified by the WWDSA committee in their final report are:

> "poor interoperability with tactical systems except at VF,"
>
> "slow restoration/reconstitution,"
>
> "inadequate interoperability" for secure voice, and
>
> "inadequate information transfer between networks for system control."

These deficiencies are in relation to an objective architecture that among other things requires end-to-end interoperability between networks, multichannel digital interfaces, and the exchange of system control information between fully interoperable networks.

The current DCS RDT&E Program document (DCEC TR 2-82) also supports these end-to-end interoperability objectives. Part of the thrust for the secure voice improvement program is to:

> "Develop specification and standards for secure interfaces with tactical, NATO, and civil networks to provide end-to-end secure communications across network boundaries for critical command and control users of the DCS."

Furthermore, one of the thrusts for AUTOVON/DSN is to:

> "Develop a DOD common channel signaling (CCS) concept to include interoperability with commercial and tactical systems, dynamic rerouting and provision for disseminating system control information."

The deficiencies identified by the WWDSA committee as well as the RDT&E thrusts described above plus on-going RDT&E projects (DCEC TR 2-82) support the contention that general requirements have been stated for high-level, end-to-end, multichannel interoperability between the DCS and U.S. tactical, NATO, and allied country telecommunication networks. As noted in the DCS baseline interoperability study (a 1981 DCA report) the distinction between the DCS and tactical worlds is becoming clouded. As the division line between the two becomes less distinct, higher levels of communications interoperability are required. The end-to-end level of interoperability is therefore viewed in this report as a valid requirement. The emphasis in this report is on DCS interoperability with TRI-TAC. A broader examination of the interoperability issue would also include DCS interoperability with NATO, PTT and host nation military and civil communication systems. Such a broad purview is outside the scope of this study.

3.4 Mapping of General User Requirements into Technical Specifications

To this point the interoperability requirements have been discussed in general terms and primarily from an operational or user's point of view. As noted in the introductory section of this report, the ultimate objective of this study is to identify R&D programs needed for the present DCS to evolve toward a goal DSN or eventually WWDSA that is fully responsive to the users' or operators' requirements. The task then is to translate these general operational requirements into more specific technical requirements. The focus here will be primarily on the radio, multiplexer, or modem requirements as these are the assigned responsibility of the U.S. Army Communications Systems Agency.

Figure 8 sets the framework for performing the translation of general requirements into technical requirements or specifications for multiplexers or radios. The users and network operators originate all requirements for communications network services. The network designer or equipment designer must consider many other factors in designing a network or equipment that satisfies the users' or operators' requirements. First of all, the characteristics of existing equipment or systems must be considered. Because of the large amount of existing equipment in the inventory, communications systems must gradually evolve. It simply isn't economically feasible to start over with an entirely new system. The designer must also consider regulatory requirements. For example, frequency allocations, bandwidth requirements including spectral shaping, spectral efficiency

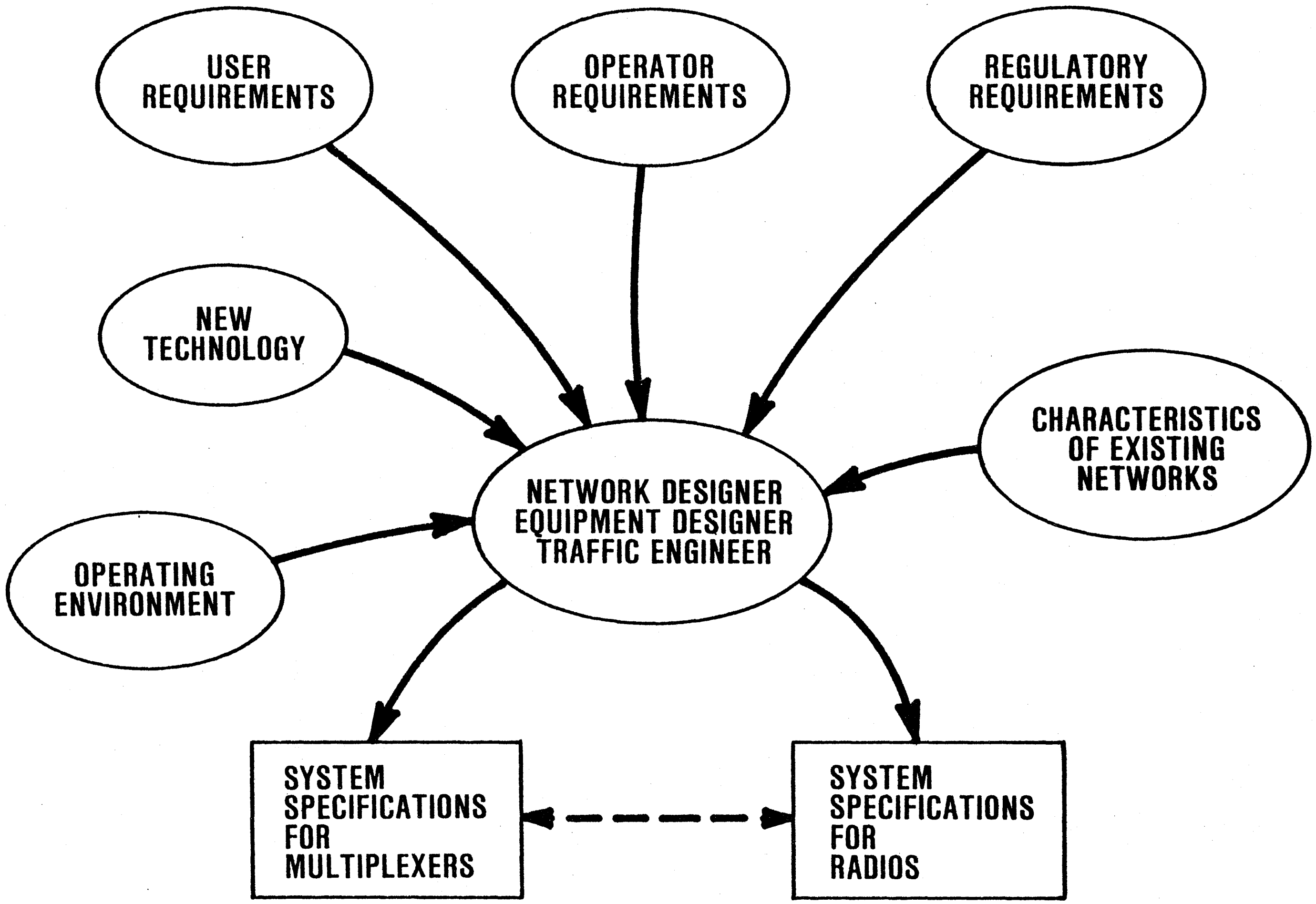


Figure 8. Factors that have an impact on radio and multiplexer specifications.

in terms of bits/second per hertz, and power limitations are all radio parameters that must comply with specifications promulgated by regulatory agencies. The availability of new technology also affects the design of new systems, radios, or multiplexers. The operating environment also is a major influence. The operating environment includes such things as flat and multipath fading, interference and jamming. The expected fading or jamming environment, obviously, greatly influences the specification of radios.

Figures 9 through 13 are an expansion of Figure 8 for radio specification while Figures 14 through 16 are an expansion for multiplexer specification. In Figures 9 through 13, the bottom portion of each figure contains the major parameters that must be specified for radios. The dashed lines indicate parameters that are closely related. The translation of users' and operators' requirements into radio specifications is shown conceptually in Figures 9 and 10. Figures 11, 12, and 13 depict the impact of new technology, regulatory requirements, and the operating environment on radio specifications.

Some elaboration is needed on Figure 10. The network operator is interested in achieving interoperability from a logistics point of view. The operator is also interested in minimizing cost. Efficient utilization of the spectrum or transmission resources is one method of minimizing costs. McKee (1982) states that the major cost factor in the DCS as a whole is transmission, not switching. The DCS RDT&E Program (DCEC TR 2-82) and WWDSA (final report and transition plan report) also indicate the importance of reducing transmission costs. There are three technical approaches to reducing transmission costs, namely:

high efficiency modulation techniques (high bits/second per hertz ratio),

efficient voice digitization, and

digital speech interpolation (DSI).

A major attribute of the future DCS as stated in the DCS RDT&E five year plan (DCEC TR 2-82) is efficient spectral utilization. One of the DCS deficiencies/drivers for this attribute is "inefficient use of transmission channels, e.g., inefficient voice A/D with high rate 64 kb/s PCM." One of the alternatives developed later in Section 5 is responsive to the requirement for efficient spectral utilization as well as the DCS/TRI-TAC interoperability requirement.

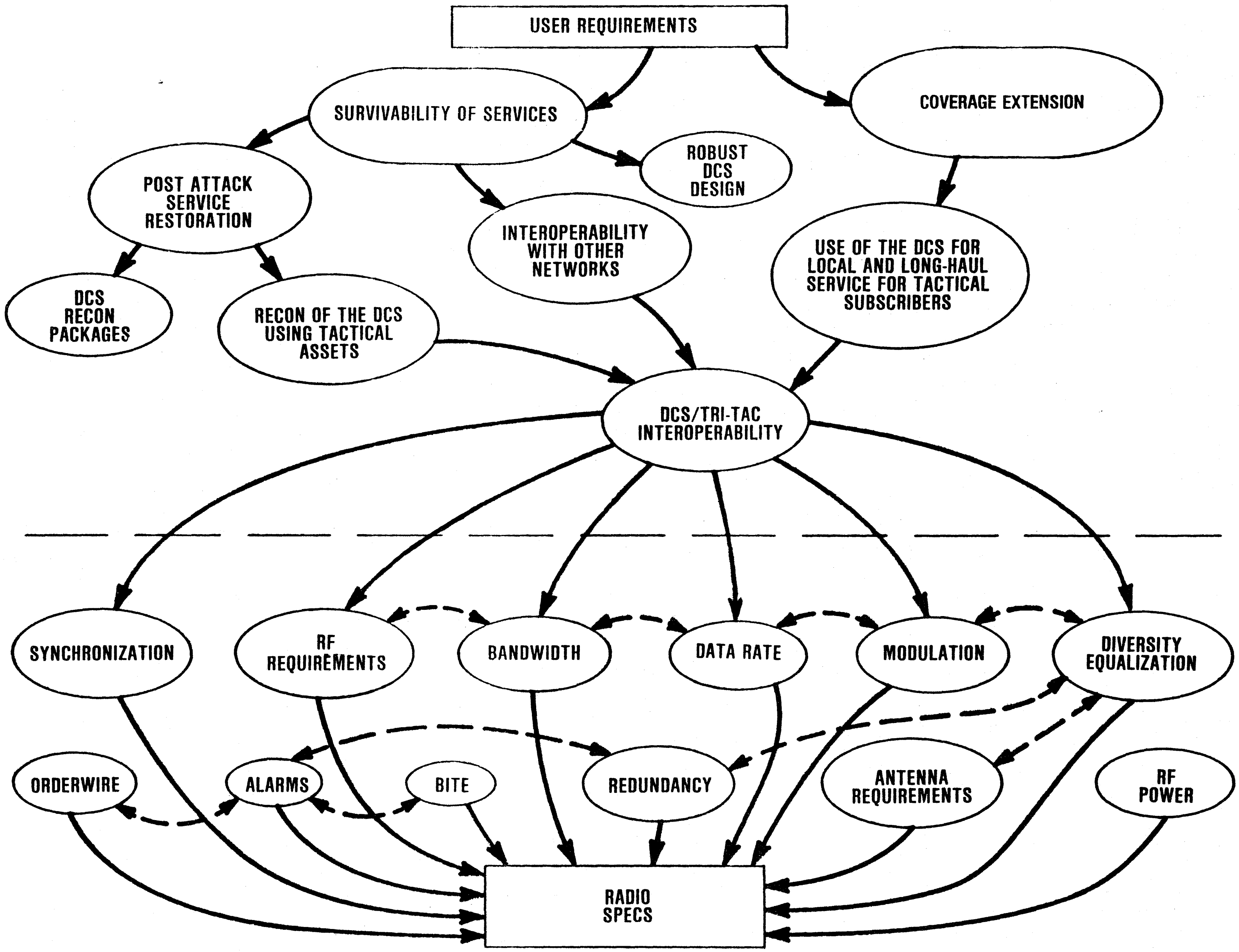


Figure 9. User requirements impact on radio specifications.

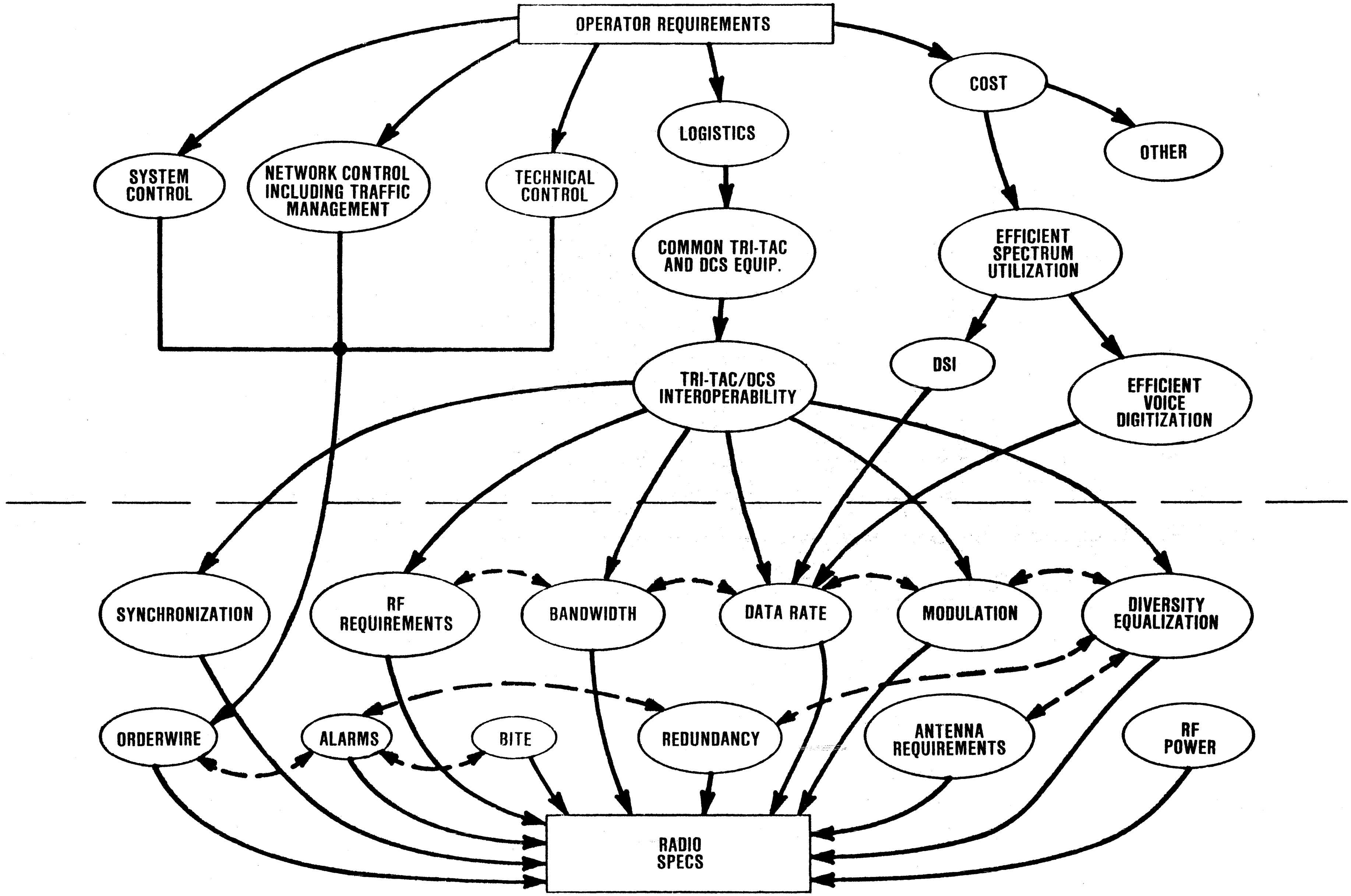


Figure 10. Network operator requirements impact on radio specifications.

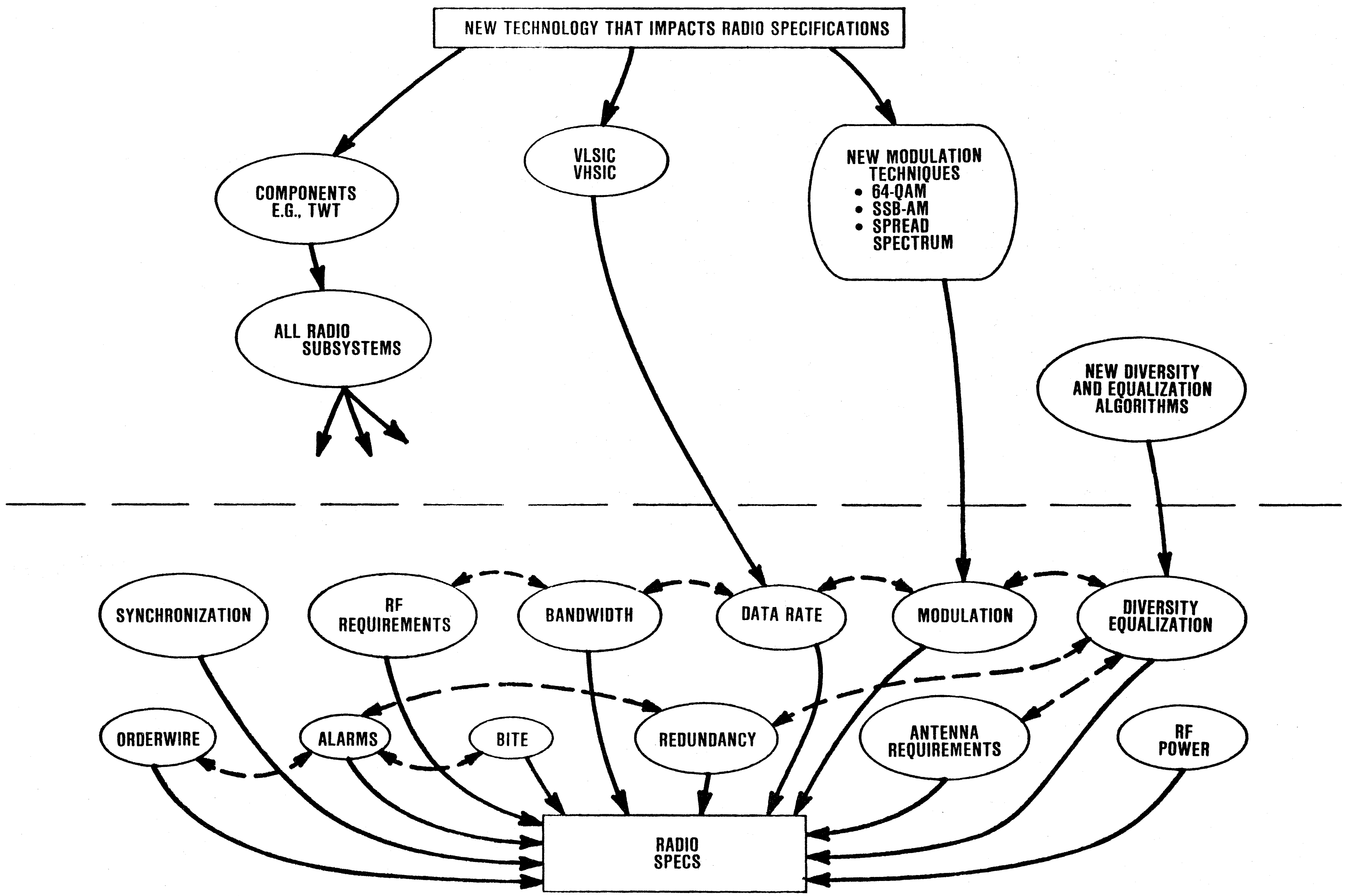


Figure 11. New technology impact on radio specifications.

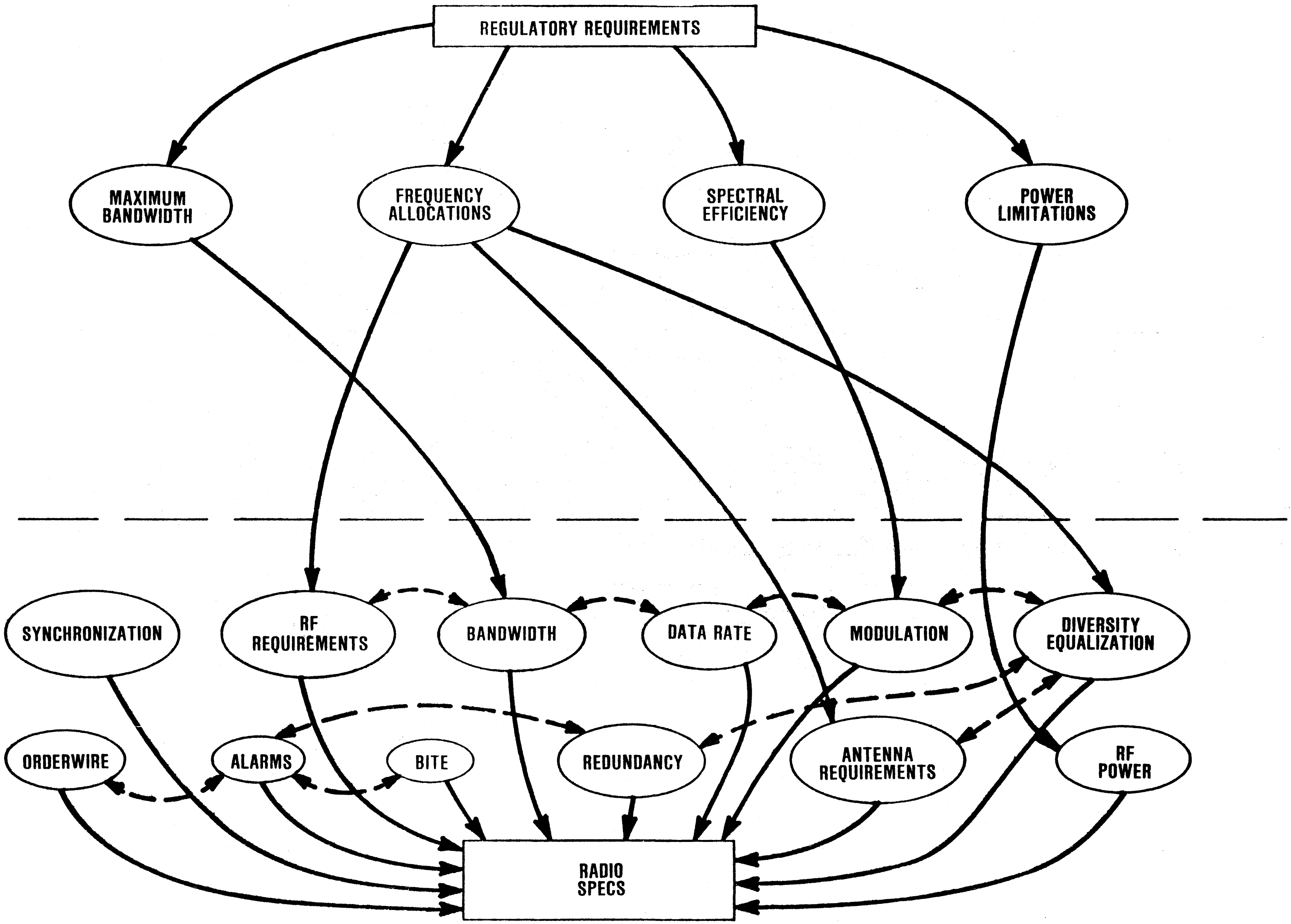


Figure 12. Regulatory requirements impact on radio specifications.

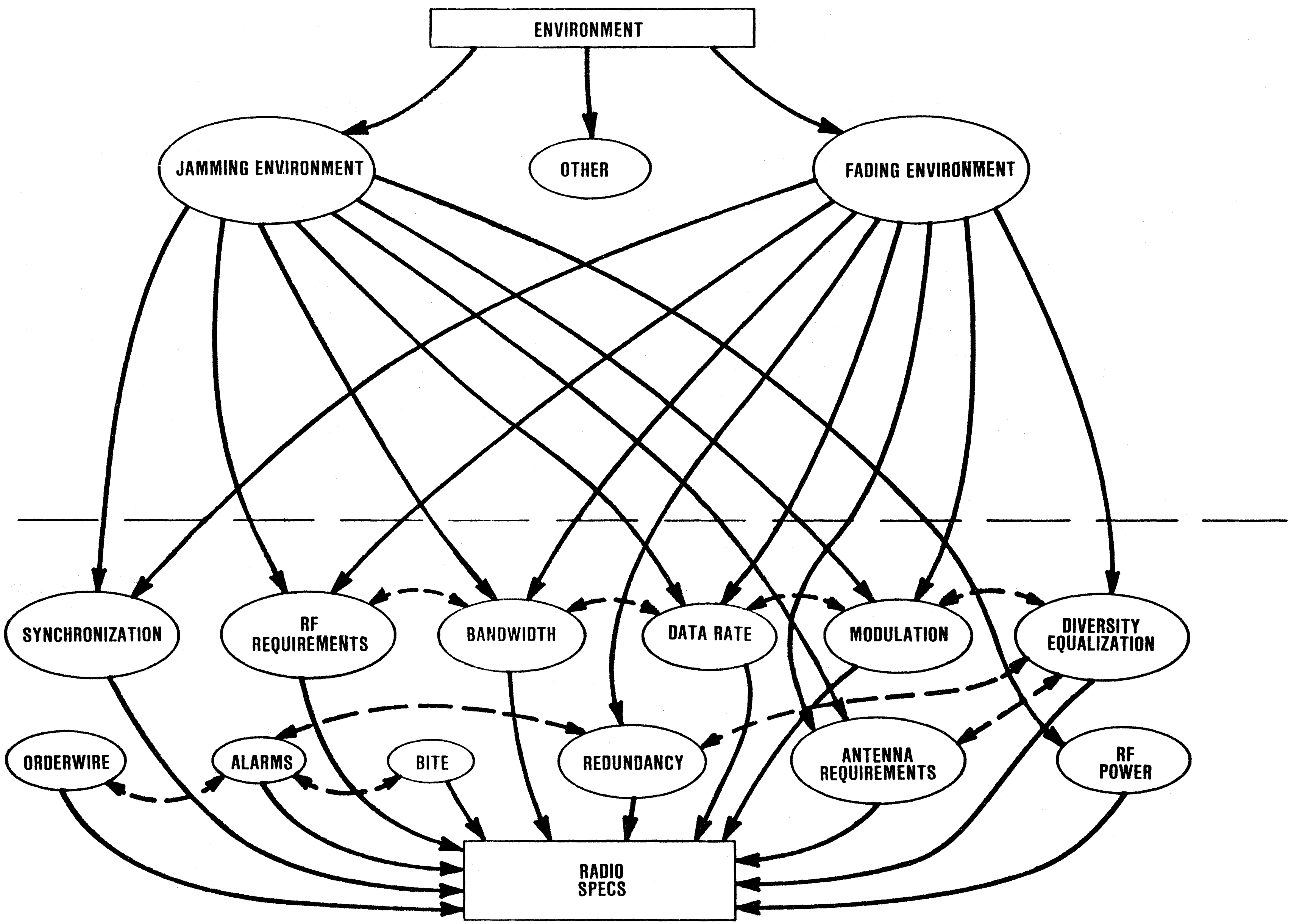


Figure 13. Operating environment impact on radio specifications.

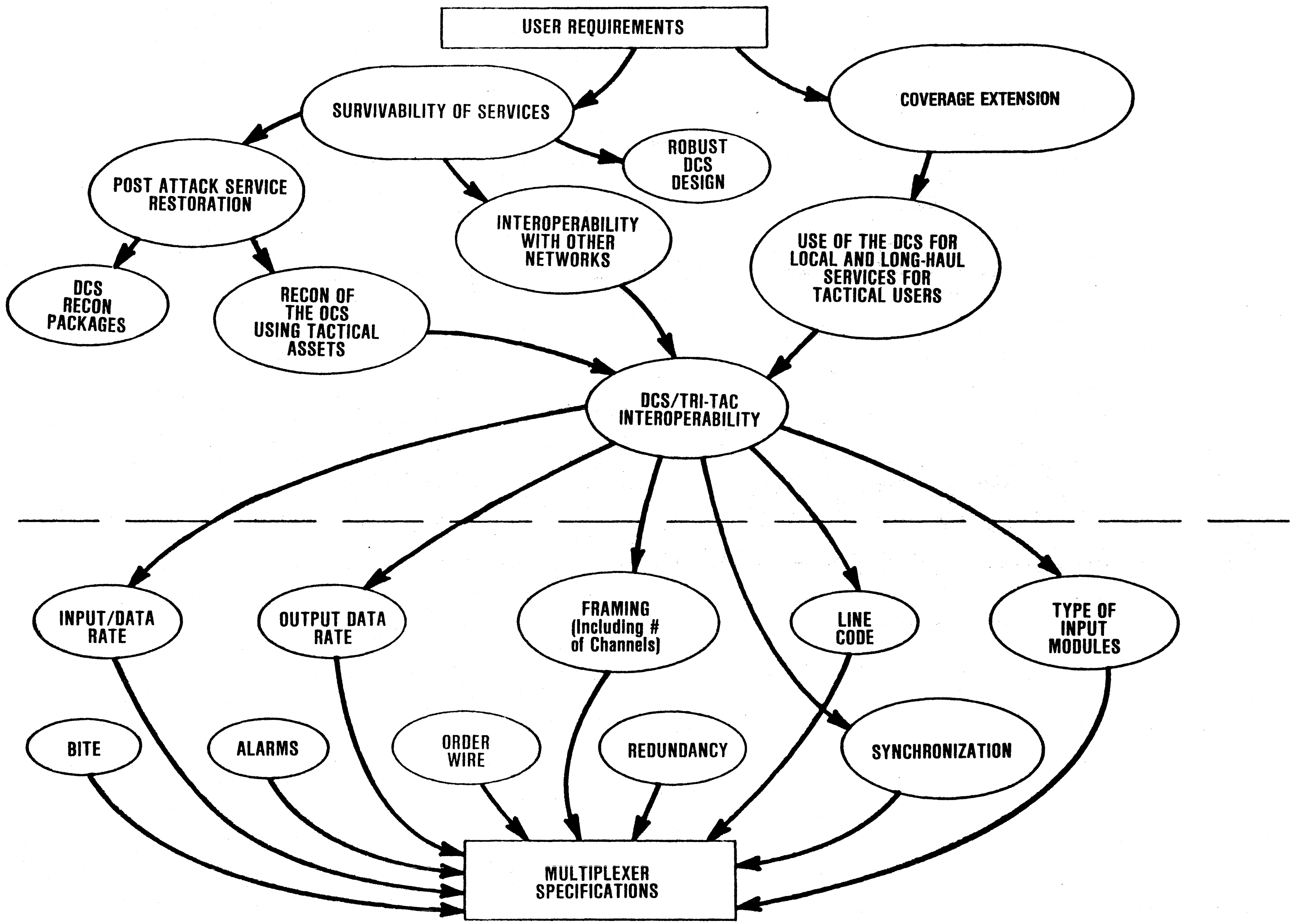


Figure 14. User requirements impact on multiplexer specifications.

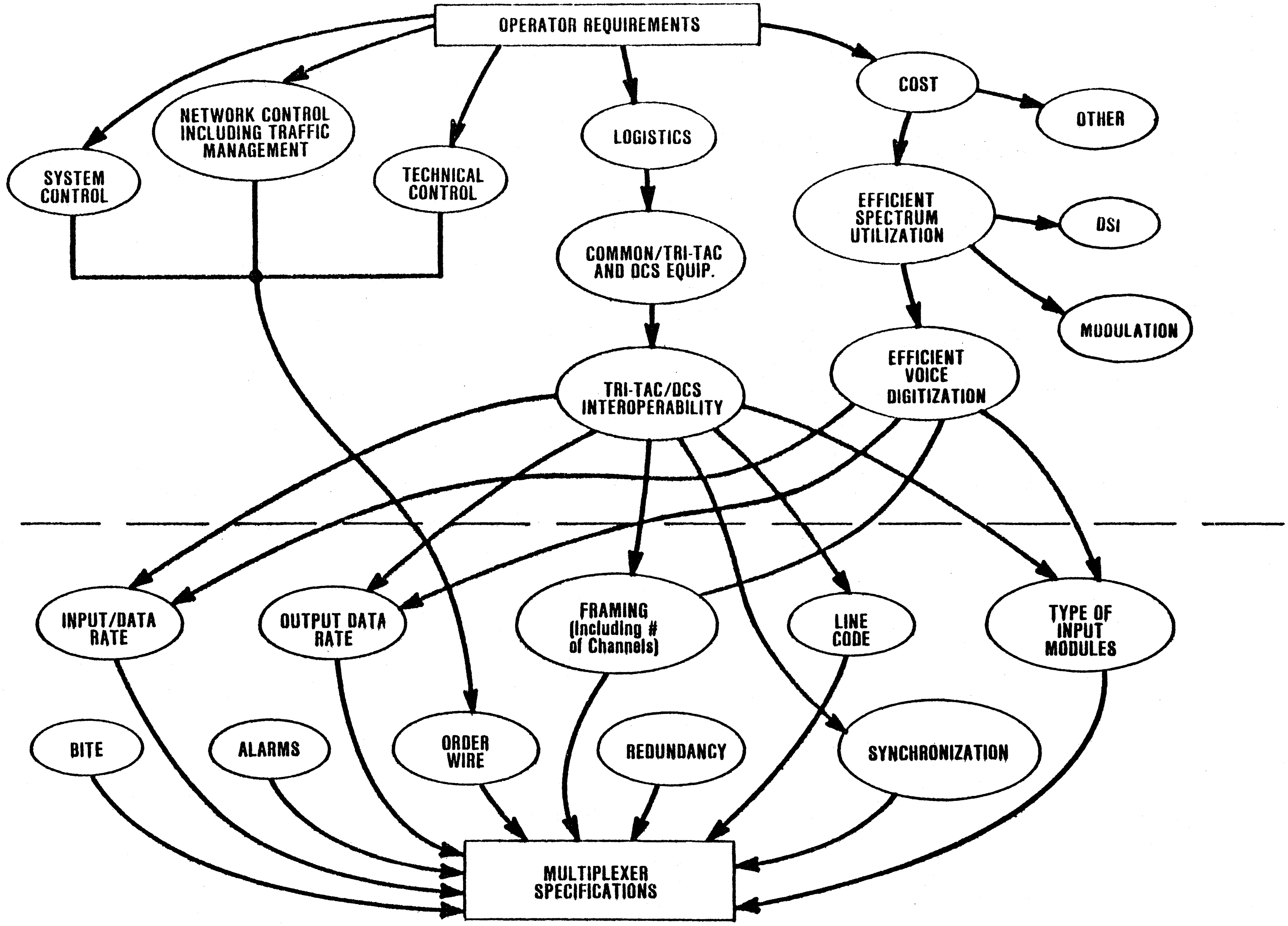


Figure 15. Network operator requirements impact on multiplexer specifications.

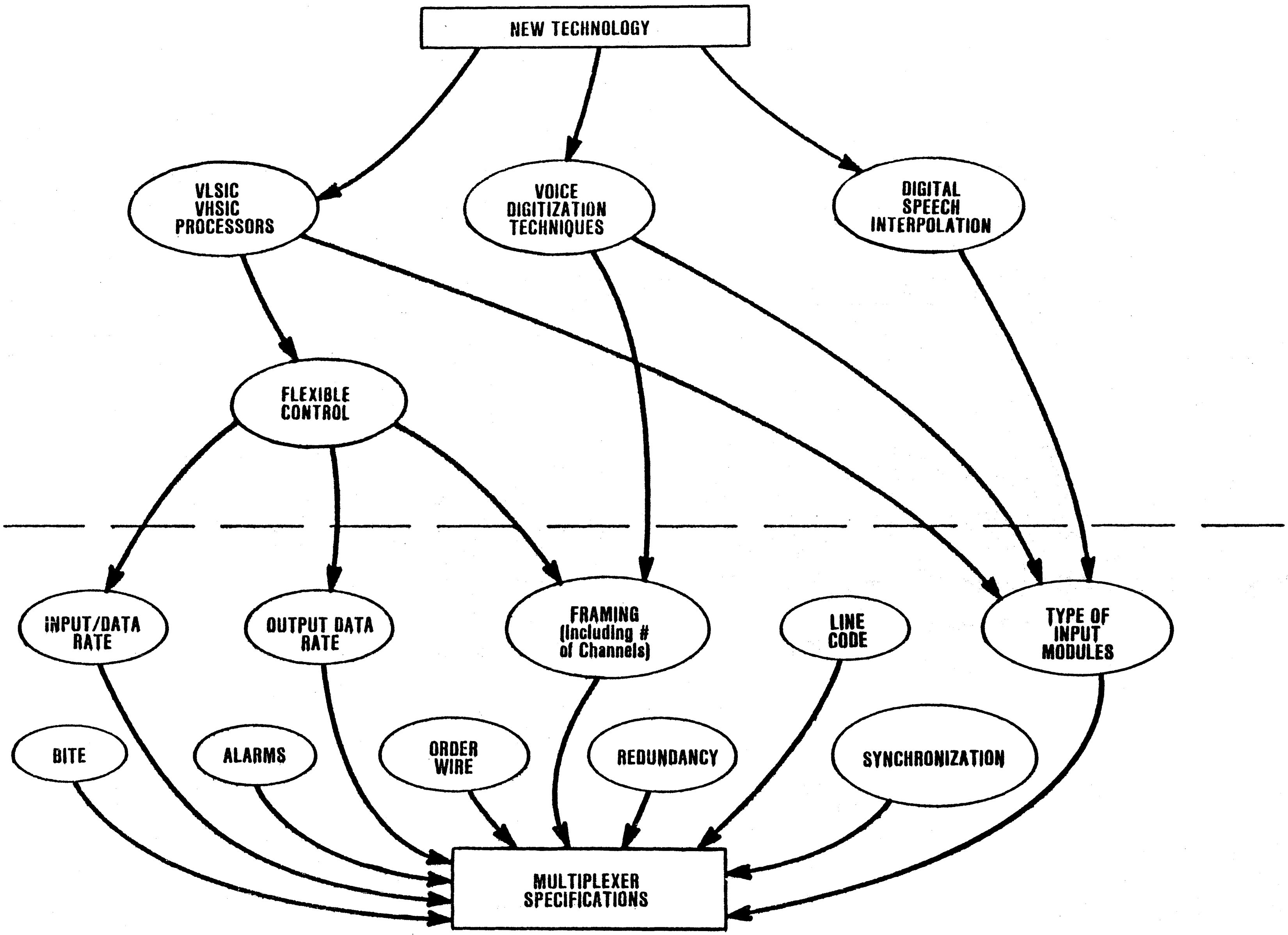


Figure 16. New technology impact on multiplexer specifications.

3.5 Specific Requirements

Table 8 lists DEB/TRI-TAC interoperability requirements as they are stated in the DEB Management Engineering Plan (DCA, 1980). A Tactical Interface Facility (TIF) with interconnects at VF, 1.544 Mb/s, and 12.928 Mb/s is a stated requirement. Interconnects between DEB and TRI-TAC could be provided at 256 kb/s and 512 kb/s (both are TRI-TAC group rates) through the FCC-98 first level multiplexer multiple rate, wideband data input module if necessary timing and buffering is provided. This buffering and timing interface has not been developed.

The WWDSA specifies the following standard transmission rates:

75×2^n b/s $\quad 1 \leq n \leq 8$
16 kb/s
64 kb/s
256 kb/s
288 kb/s
512 kb/s
576 kb/s
1,544 kb/s
2,048 kb/s

Any new multiplex equipment should support one or more of these transmission rates. Higher transmission rates such as 8.448, 34.368, 139.264 Mb/s in the European multiplexer hierarchy, 6.312, 44.736, and 274.176 Mb/s in the North American multiplexer hierarchy, 9.36 and 18.72 Mb/s in the TRI-TAC multiplexer hierarchy, and 12.928 Mb/s in the DRAMA hierarchy have not been specified in the WWDSA reports.

4. EXISTING DCS/TACTICAL INTEROPERABILITY

The current European Defense Communications System consists of AUTOVON, AUTODIN, and AUTOSEVOCOM. It is expected that the European Telephone System which is currently being implemented will eventually merge with the European AUTOVON to form the European portion of the Defense Switched Network (DSN). Plans for interfacing the ETS and tactical systems are incomplete. In the tactical world, the existing system for Army tactical communications is ATACS.

Table 8. DEB/TRI-TAC Interoperability Requirements

- Designated DEB sites will be equipped with a Tactical Interface Facility (94 sites; up to 48 tactical voice circuits per site)
- Interconnects will be at VF, 1.544 Mb/s, and 12.928 Mb/s
- 256 kb/s and 512 kb/s tactical data rates could be used if necessary timing and buffering is provided
- Modifications of DRAMA equipment to handle 288 kb/s, 576 kb/s, and 2.048 Mb/s are being considered
- U.S. Army is responsible for providing the tactical interface capability for DEB

Reference: DEB Management Engineering Plan (DCA, 1980).

However, TRI-TAC equipment is expected to be fielded in the near future according to plans received from the TRI-TAC office. The emphasis in this section on existing DCS/tactical interoperability will therefore be AUTOVON and TRI-TAC.

In this section, the meaning of the phrase "existing interoperability" has been extended to include capabilities that are planned for the very near future. Since TRI-TAC equipment has not been placed in operation in the field, there obviously is no "existing" interoperability between TRI-TAC and the DCS today. However, the specifications for TRI-TAC large circuit-switches (AN/TTC-39) include requirements for interfacing with an AUTOVON switch. This TRI-TAC/AUTOVON interface is considered to be the baseline "existing" capability for TRI-TAC interoperability with the DCS.

Section 4.1 is a brief description of the AN/TTC-39 capability for interfacing with AUTOVON loops, trunks, and switches. This is followed in Section 4.2 by a discussion of additional interface capabilities that will be needed as the European DCS evolves.

4.1 AN/TTC-39 and AUTOVON Interface Capability

The TRI-TAC specifications for the AN/TTC-39 central office circuit-switch require that the switch be compatible with the AUTOVON numbering plan, AUTOVON trunk signaling, and AUTOVON loop signaling (TRI-TAC, 1982a and TRI-TAC, 1982b). The AN/TTC-39 switch is also required to be able to act as an AUTOVON switch in signaling to and from PBX's (Private Branch Exchanges). These requirements will be briefly described in the following subsections.

4.1.1 Numbering Plan

One type of numbering plan used in the AN/TTC-39 is of the form (NYX) NNX-XXXX where:

N = 2 - 9,
X = 0 - 9, and
Y = 0 - 1.

Other numbering plans for the TTC-39 switch exist. However, the numbering plan described above is of the same format as AUTOVON, and therefore is of primary interest in this report. On calls from an AUTOVON area to a tactical area, or vice versa, each number exclusive of prefixes consists of 7 or 10 digits. If calls originate and complete within an AUTOVON area code only seven digits are required (the NYX area code is not dialed). The AUTOVON and AN/TTC-39 switches distinguish 10-digit numbers from 7-digit numbers by the fact that every area code has an 0 or a 1 as the second digit, but the NNX switch code never has an 0 or 1 as the second digit.

In addition to the 7- or 10-digit basic numbering plan, there is an optional PR prefix where the "P" is one of four special characters used to denote the level of precedence. Absence of the "P" indicates a routine call. The "R" represents a control code used to signify special service and routing requests. Detailed information on the "P" and "R" codes may be found in the Overseas AUTOVON network Switching Plan (DCA, 1967). For AUTOVON calls routed through TRI-TAC, the integrity of the PR prefix is preserved; i.e., it is transmitted on the outgoing AUTOVON trunk group unchanged. The tactical AN/TTC-39 switch uses the prefix for subscriber and transmission compatibility checks and to determine routing restrictions. For AUTOVON calls generated by tactical AN/TTC-39 subscribers it generates and transmits any prefix required to extend the call into AUTOVON.

4.1.2 AUTOVON/TRI-TAC Switch Trunk Signaling and Subscriber Loop Signaling

The signaling between the AN/TTC-39, when operating as an AUTOVON switch, and other AUTOVON switches use analog trunk signaling that complies with the DCA Circular on AUTOVON switching (DCA, 1967). The signaling is in-band, single frequency (2,600 Hz) for supervision and MF 2/6 (multifrequency) in-band confirmation or nonconfirmation address signaling. In the confirmation signaling mode, AUTOVON responds to a trunk seizure by the AN/TTC-39 switch by sending a key pulse (KP) signal. Upon receipt of KP, the AN/TTC-39 sends KP to the AUTOVON switch. The AUTOVON switch sends interdigit (ID) and the AN/TTC-39 then sends the first digit of the addressing sequence (P + R + NYX + NNX + XXXX). After each digit is sent by the AN/TTC-39, the AUTOVON confirms with interdigit. Upon completion, the AUTOVON switch sends the end of signaling (ST) digit to the AN/TTC-39 switch. After completion of the address signaling, the AN/TTC-39 takes no further action unless a busy, pre-emption, or release signal is initiated. AUTOVON completes routing of the call. The release cycle with AUTOVON is completed by applying the correct supervisory tone conditions to the trunk and marking the trunk idle. The AN/TTC-39 recognizes the trunk busy (TB), line busy (LB), and pre-emption signals generated by AUTOVON and specified in DCAC-370-V185-7 (DCA, 1967).

It is possible to program any trunk group for MF 2/6 nonconfirmation signaling. In this mode, the destination switch does not respond with a confirmation interdigit signal for every digit sent by the originating switch. The digit pulse is 70 $\pm$ 15 ms wide.

The AUTOVON telephone set is a four-wire unit, requiring common battery (48V, 60 mA nominal) power and utilizes DTMF (dual tone, multifrequency) signaling, dc loop supervision, and dc loop controlled ringing. This mode of operation can also be used with the AN/TTC-39 switch (TRI-TAC, 1982a). Through use of a special adapter on long loops, the telephone set may be converted to local battery, with E&M (rEceive and transMit) supervision. Application of a single frequency (SF) unit in conjunction with the adapter provides 2,600 Hz in-band supervision for longer loop transmission and carrier interface.

Further information on the trunk and loop signaling may be found in TRI-TAC (1982a, b), and DCA (1967). The brief overview provided above is presented to show that the AN/TTC-39 switch can be operated in an AUTOVON switch mode as far as trunk and loop signaling are concerned. The AN/TTC-39 specifications also require the AN/TTC-39 switch to be able to act as a PBX and signaling to an AUTOVON switch.

4.2 Requirements Not Satisfied by Existing TRI-TAC/AUTOVON Interoperability

The existing tactical/DCS interoperability (which currently is limited to AUTOVON/TRI-TAC interoperability) described above has several deficiencies as has been noted in WWDSA documentation (DCA, 1981b) and the DCS RDT&E Program report (DCEC TR 2-82). These deficiencies include:

poor transmission interoperability except at VF (DCA, 1981b),

need to develop "standards for secure interfaces with tactical, NATO, and civil networks to provide end-to-end secure communications across network boundaries" (DCEC TR 2-82),

need to develop a DOD common channel signaling (CCS) system concept to include interoperability with commercial and tactical systems, dynamic rerouting and provision for disseminating system control information (DCEC TR 2-82), and

a need to develop the system control interoperation between the DCS control subsystem and those of common carriers, tactical subsystems, and allied systems to enable service restorals through non-DCS resources (DCEC TR 2-82).

The following paragraphs provide some elaboration of these deficiencies.

The direction in which defense communications networks are evolving is toward all digital switching and transmission. The Worldwide Digital Systems Architecture (WWDSA) documentation (DCA, 1981b) supports this contention. One motivating factor is the ease of digital encryption compared to analog. The "existing" interoperability described in the previous section is not supportive of the goal WWDSA architecture, which specifies digital transmission, or of end-to-end secure communications defined as a thrust in the DCS RDT&E Program.

The European AUTOVON and the European Telephone System (ETS) are likely to merge into a single network by the late 1980's. According to a draft ETS system architecture document the goal ETS will utilize the CCITT #7 Common Channel Signaling. The TRI-TAC architecture utilizes its own unique version of common channel signaling protocol. The two signaling structures have been developed independently of each other. It is likely that they may be made to interoperate at least for some signaling functions. This problem will be addressed in Section 6, but a full investigation is outside the scope of this report. The point to be made here is that even though existing interoperability between AUTOVON and TRI-TAC includes signaling, the system that will service most strategic users in Europe in the late 1980's and beyond will be ETS, not AUTOVON. The ETS and TRI-TAC signaling systems are not currently interoperable.

Interoperable system control is required for network managers to efficiently control network resources. This is especially important in a stress environment where assets from other networks, such as TRI-TAC, may be utilized to restore communication services. Efficient usage of such reconstitution resources requires an interoperable system control subsystem. Types and formats of system control information between the DCS and TRI-TAC should be made compatible.

In summary, a low level of interoperability currently exists between AUTOVON and TRI-TAC. However, in comparing the existing capability against the requirements stated in Section 3, several deficiencies have been noted. Alternatives for resolving the poor transmission interoperability will be described in Section 5 on digital pipeline interoperability. The common-channel signaling and system control deficiencies will be discussed more fully in Section 6 on end-to-end interoperability. Alternative concepts for resolving the end-to-end interoperability deficiencies will be briefly discussed.

5. DIGITAL PIPELINE INTEROPERABILITY ALTERNATIVES AND EVALUATION

The digital pipeline concept was introduced in Section 2. Requirements for this level of interoperability were described in Section 3. In this present section, alternative concepts for satisfying these requirements are discussed. The section concludes with a qualitative evaluation of the alternatives and a recommendation for a suggested approach for achieving digital pipeline interoperability.

As noted previously in Table 4, the system characteristics that are of primary importance for the digital pipeline level of interoperability are:

- bit rate,
- line code,
- error control,
- timing and synchronization,
- technical control, and
- security.

The bit rate is emphasized here rather than the number of channels because the digital pipeline is impartial to the type of information being transmitted. The line code, although essential to interoperability, will not be discussed in detail, because translations between different line codes can be easily implemented (see Appendix C for a discussion of line codes). Timing, technical control, and interfacing with encryption devices are all important system characteristics that must be addressed. These parameters must be considered regardless of how the digital pipeline interoperability is achieved. The main question that needs to be addressed is the question of where in the transmission chain should the transmission level of interoperability between the DCS and TRI-TAC should be achieved. Should it be at the first level of multiplexer, second level, or at the radio? Figure 17 indicates some possible points for digital pipeline interoperability. This figure is generic in the sense that it applies to both the DCS/TRI-TAC/DCS and TRI-TAC/DCS/TRI-TAC digital pipeline cases. A corollary to the point-of-interoperation question is the question of what are the transmission bit rates that should be used. These questions will be addressed for each of the alternatives described in Sections 5.2, 5.3, and 5.4. Before turning to these alternatives, however, it is appropriate to discuss some related work for interoperability that has either been proposed or is in the development stage.

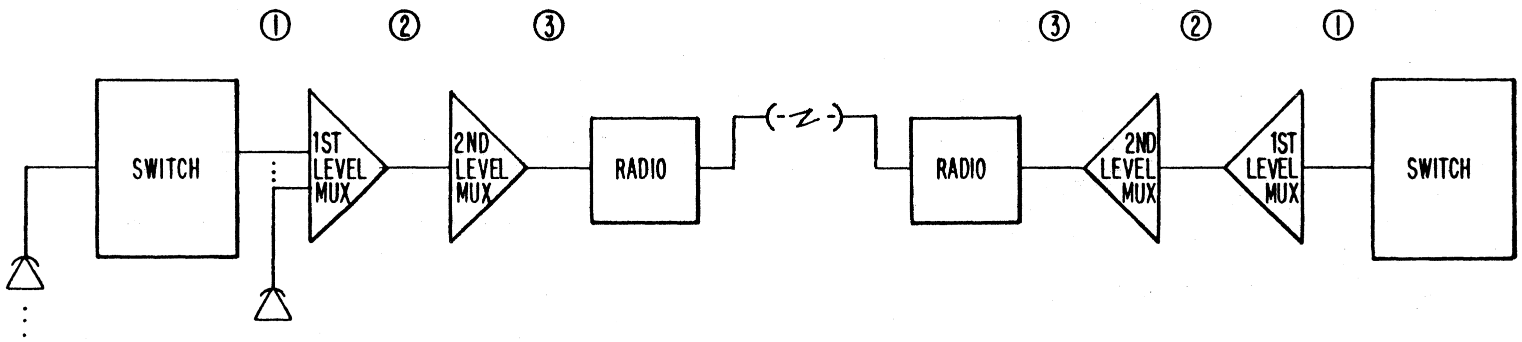


Figure 17. Possible interface points for digital pipeline interoperability.

5.1 Related Work on Pipeline Interoperability

Several different government or industrial organizations have performed studies, made proposals, or constructed engineering development models for achieving interoperability between the DCS and one or more other networks such as TRI-TAC, NATO, etc. Because specific requirements have not been identified and because of some overlap in organizational responsibilities, there is a certain amount of overlap in the objectives of these programs. The existence of these programs was made known to the author well after the ITS study was initiated.

5.1.1 Joint DCA and TRI-TAC Program Office Approaches to Interoperability

There are three approaches to interoperability that have been agreed upon between the Systems Division in the TRI-TAC Program Office and the Tactical Interface Branch in DCA. These approaches are:

1) VF analog (described in Section 4 as existing capability),

2) message switch interface using the tactical ICD-015 (Interface Control Document) standard, and

3) a digital interface.

The digital interface is to be at 512 kb/s between the TRI-TAC Trunk Group Multiplexer (TGM) and the DCS FCC-98 first level multiplexer (see Appendix A for details on these multiplexers). This interface is to provide a capability for TRI-TAC-through DCS-to-TRI-TAC only. The converse capability of DCS-through TRI-TAC-to DCS is not being addressed. There is a requirement for the latter capability, which corresponds to the case of using tactical assets to reconstitute the DCS. As noted in Section 3, the COMSTRESS report (DCA report published in 1982) states that reconstitution assets should consist of a mix of both DEB and tactical assets.

5.1.2 DCS/Tactical Interface Facility

A DCS/Tactical Interface Facility (DTIF) concept originated by the U.S. Army Center for Communications (CENCOMS) has been forwarded to various DOD agencies for comment. The DTIF concept is depicted in Figure 18. This facility would be capable of providing an interface for either tactical through DCS or for DCS through tactical. Unlike the digital interface described in the preceding subsection, the DTIF provides for rerouting DCS traffic through tactical

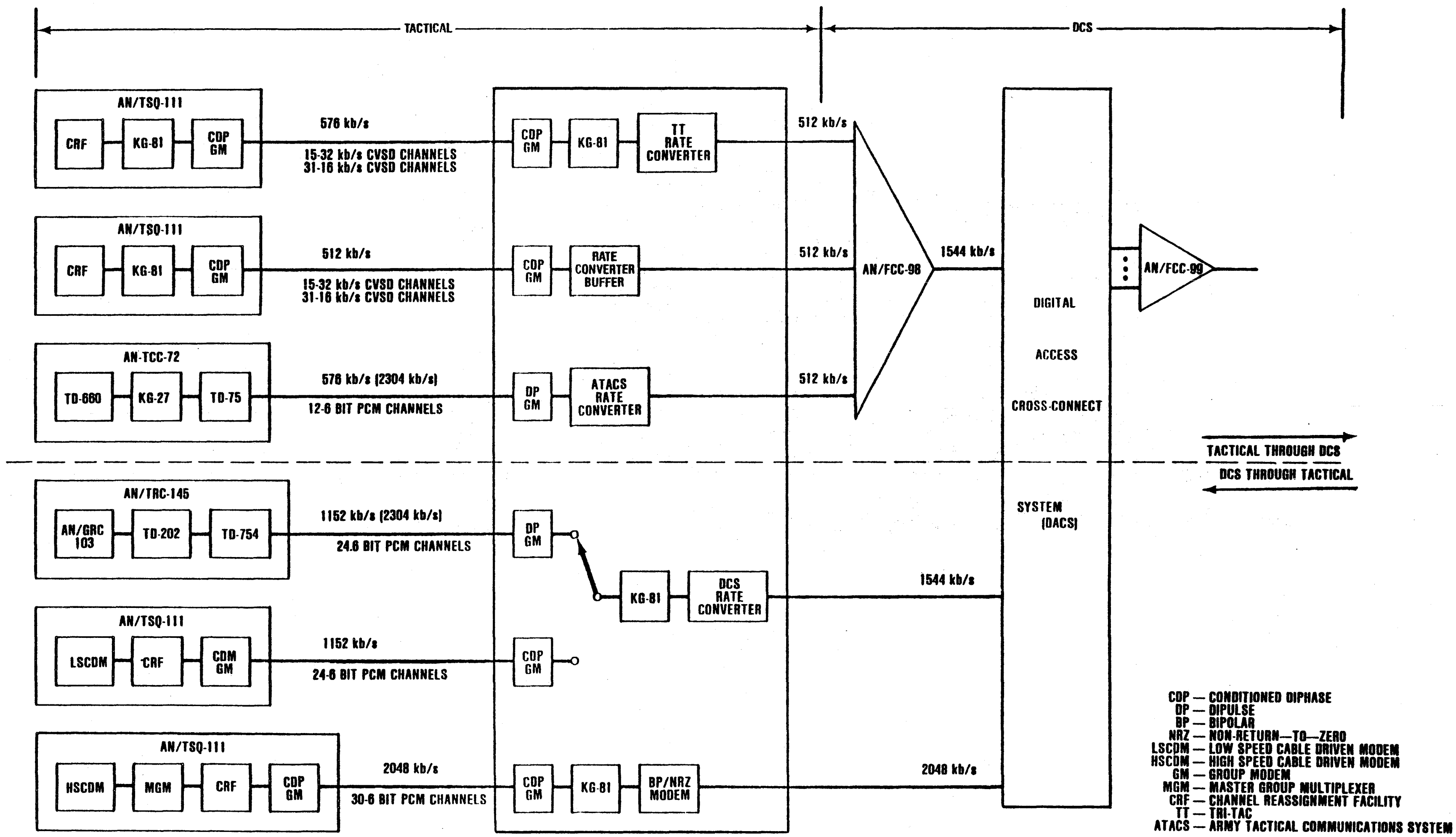


Figure 18. DCS/tactical interface facility.

transmission facilities as well as for the rerouting of tactical traffic through DCS transmission facilities. The 576 kb/s and 1,152 kb/s transmission rates are compatible with the Army Tactical Communication System (ATACS) as well as with TRI-TAC. The 1,152 kb/s transmission rate is not one of the standard rates of the WWDSA architecture, however. The proposed use of the Digital Access and Cross-Connect System (DACS) is to provide a DCS interface with the DTIF.

The DACS is not an integral or necessary equipment for achieving the tactical/DCS interoperability. The DACS is normally used for switching individual channels of a T1 carrier to a different T1 carrier. This is illustrated in Figure 19. Up to 127 DS-1 signals (3,048 DS-0 voice channels) can be accommodated by DACS. Its usefulness is in being able to switch DS0 channels (64 kb/s) from one DS-1 group (1.544 Mb/s) to another DS-1 group without conversion back to analog. This is accomplished through time slot interchange chips. The DACS can also be used for switching DS-1 groups from one port to another.

5.1.3 Digital Channel Efficiency Model

The Digital Channel Efficiency Model (DCEM) is responsive to two requirements of the DCS. The requirements are:

1) to provide interoperability between the DCS and networks using the CCITT European Standards (such as the NATO Integrated Communication System (NICS) and the PTT networks), and

2) to reduce transmission costs through efficient spectrum utilization.

A discussion of the DCEM is pertinent to this report because some of the concepts incorporated in the DCEM could also be utilized for DCS/TRI-TAC interoperability. In the DCEM concept, Digital Speech Interpolation (DSI) is used to increase the capacity of a digital transmission facility. At the same time, the DCEM provides nodes for transmission interoperability between the DCS and NATO.

Figure 20 depicts the eight operational modes of the DCEM (RADC, 1980). The first three modes are compression modes, the next two are rate conversion modes, and the final three are format conversion modes. For example, mode A is a compression mode in which two 24 channel, 1.544 Mb/s terminals (D3 channel banks) are compressed by the DCEM using DSI techniques into a single 1.544 Mb/s carrier. This compression mode is designated as 48/24/48, i.e., 48 source channels are compressed into 24 channels for transmission and then expanded into 48 channels at the destination. The three compression modes of the DCEM are:

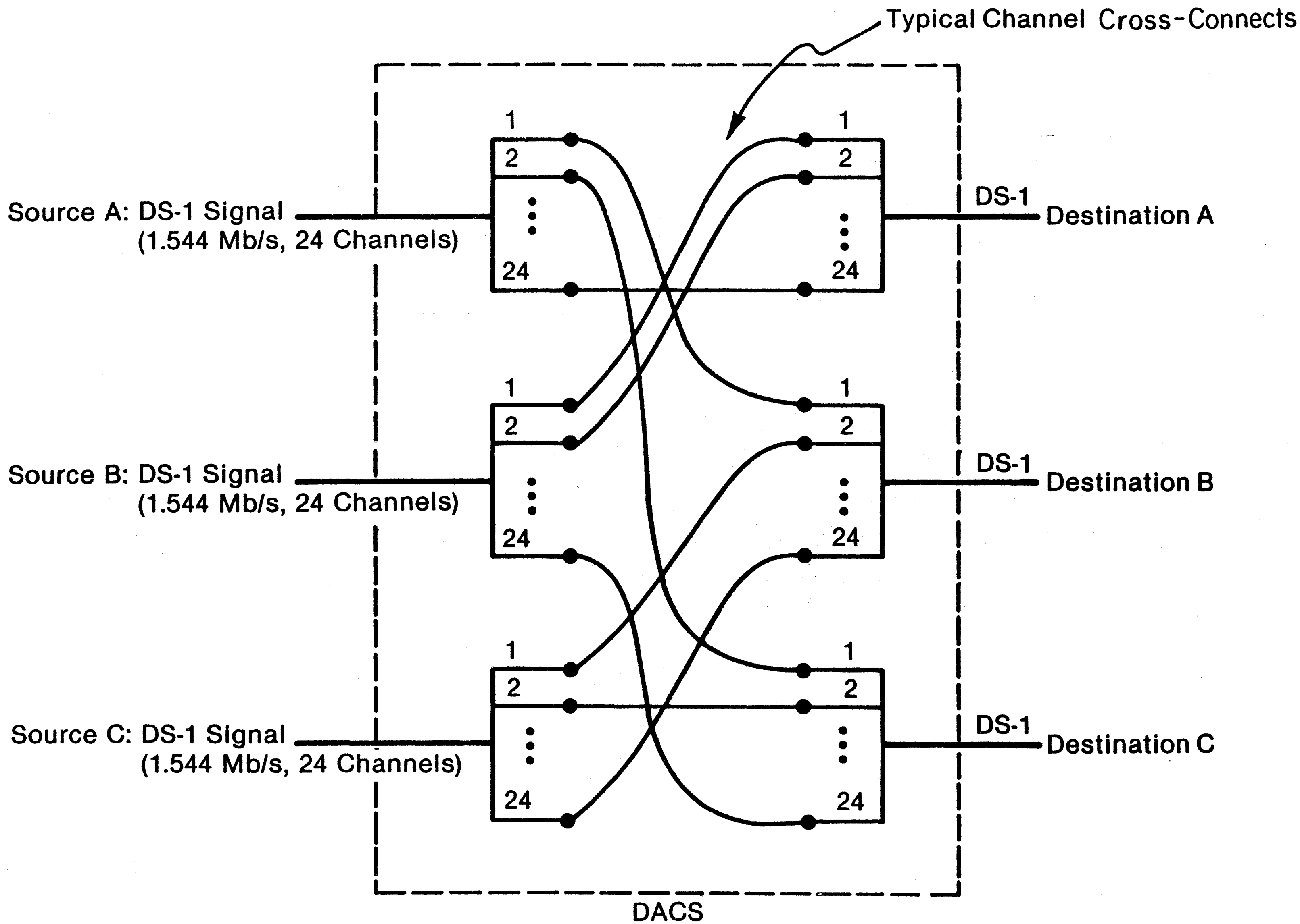


Figure 19. Digital access and cross-connect system (DACS) concept.

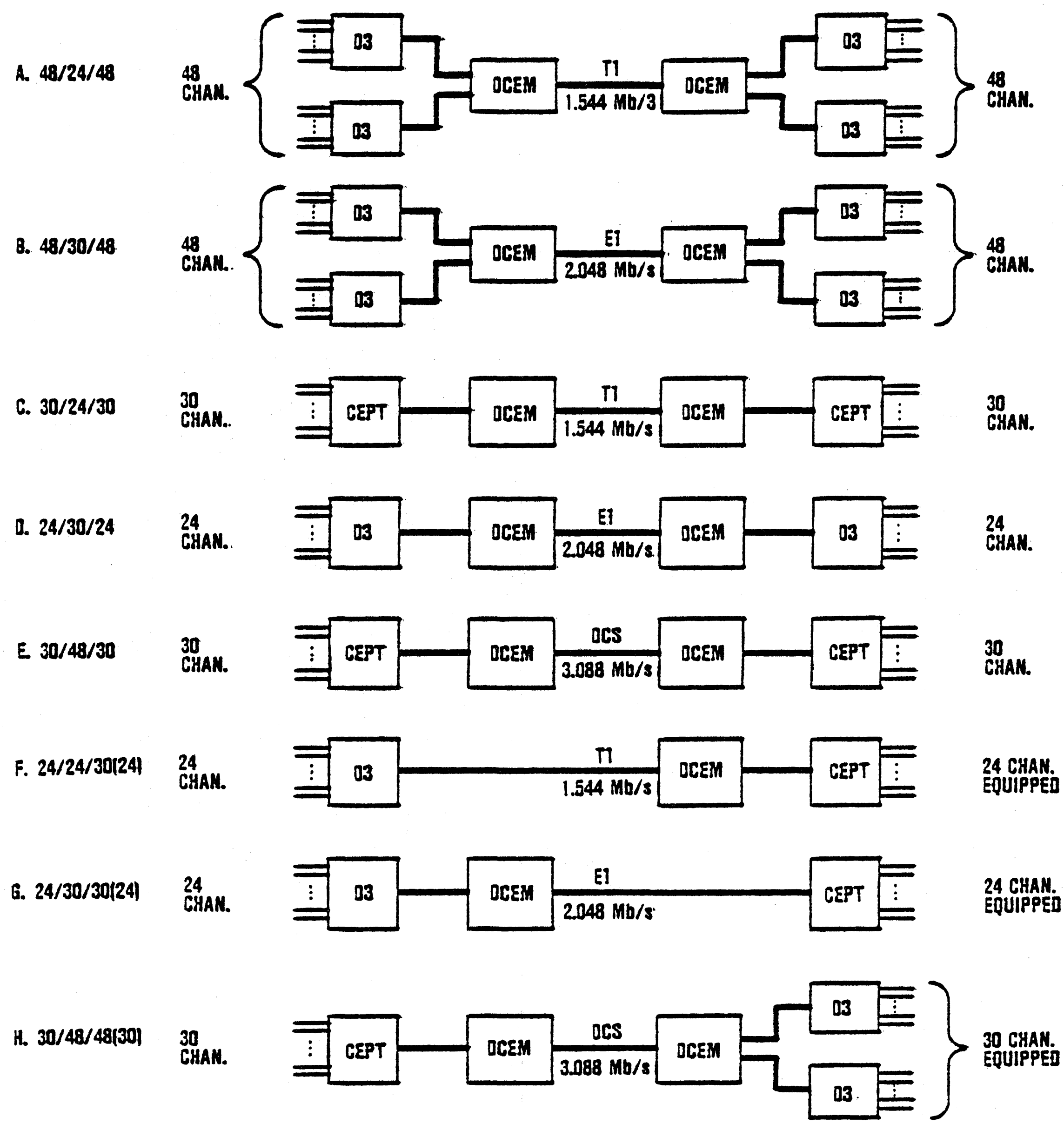


Figure 20. Digital channel efficiency model (DCEM) operational modes.

48/24/48,
48/30/48, and
30/24/30.

The latter two compression modes provide interoperability between the DCS and the CCITT European standard (30 voice channels, 2.048 Mb/s).

In the rate conversion modes (modes D and E), the incoming bit stream is simply stuffed up to the desired rate by adding framing and fill bits to each frame of data. The rate conversion mode is impartial to the data format, which allows the transmission of PCM voice encoded bit streams, encrypted PCM, computer generated data, etc. The rate conversion modes are:

24/30/24 and
30/48/30.

In the format conversion modes (modes F, G, and H), the DS-1 signal format of a D3 channel bank (CCITT North American Standard) is converted to the CCITT European Standard and vice versa. This conversion process includes companding conversion, encoding conversion, signaling conversion, and framing pattern conversion. The D3 channel bank uses μ-law companding, inverted signed magnitude encoding, and two 667 b/s in-band signaling channels per voice channel. The CCITT European Standard uses A-law companding, signed magnitude encoding with alternate digit inversion, and four 500 b/s out-of-band signaling channels per voice channel. The companding conversion (A-law to μ-law) and vice versa can be achieved through a simple table look-up. The format conversion modes are:

24/24/30 (24),
24/24/30 (24), and
30/48/48 (30).

In these modes, the full capacity at the destination end is not used. For example, in the 24/24/30 (24) mode, only 24 of the 30 channel slots available at the destination terminal are utilized, as indicated by the number in the parentheses.

The compression operating modes are the most complex. One problem with any DSI system is how to handle the situation where the number of active speech channels exceeds the number of traffic channels. One approach used in some DSI systems is freezeout which is the truncating or clipping of the speech until a channel becomes available. Another approach is to delay the speech burst until a channel becomes available. This results in nonuniform time gaps between speech bursts rather than the original, natural time gaps. A third approach is to steal the least significant bit of other channels. This reduces clipping at the expense of signal-to-noise ratios of the other channels. A fourth approach, which is the one used in the DCEM, is to use speech compression during periods of high channel activity.

The speech compression used in the DCEM is Adaptive Differential Pulse Code Modulation (ADPCM). During periods of low-channel activity the channel is encoded using 8-bit PCM. During periods of high channel activity the channel is encoded using ADPCM. The number of bits used for ADPCM is from 7 to 3 depending upon the channel activity. Systems incorporating both DSI and ADPCM have been investigated by other authors. O'Neil (1978) and other researchers at North Carolina State University conducted research that included the development of a prototype system called the Digroup Data Reduction (DDR) System. The DDR was the forerunner of the DCEM. Recent papers by Yatsuka (1982a, b) and Langenbucher (1982) are indicative of DSI/ADPCM systems in the nonmilitary sector.

Three functions that the DCEM must perform in the compression modes are:

1) detection of channel activity and the subsequent discrimination between speech and voice-band data,

2) generation and transmission of channel assignment information to the distant receive, DCEM, and

3) the coding of speech channels using ADPCM with fewer than 8 bits.

Channel activity is determined by monitoring the short-term power level of each channel. If the power level does not exceed a specified threshold, the channel is inactive and is not connected through. If the channel is active, the DCEM must then determine if the channel contains speech or voice-band data from a modem. This is necessary because voice-band data channels that pass through ADPCM would result in an unacceptable bit error rate (BER). If a channel has been identified as carrying voice-band data it will retain its PCM encoding, whereas if it is carrying voice it will be passed either as 8-bit PCM or as 7 to 3 bit ADPCM with the bits per word a function of loading. The DCEM voice/data discriminator uses an autocorrelation technique to estimate the spectral content of each channel. Those channels whose energy is concentrated below 1,000 Hz are presumed to be speech. In addition, every channel is programmable as active 64 kb/s data, speech only, inactive, or normal.

Channel assignment information (CAI) must be sent from the originating DCEM to convey channel active/inactive and speech/data information to the receiving DCEM. Because of the importance that this information be received correctly, it is encoded using a Hamming code capable of correcting single errors and detecting double errors.

Figure 21 depicts the frame format used in Digroup Data Reduction system which is the forerunner of the DCEM. The signaling rate is 64 kb/s which will accommodate the signaling from two DS-1 signals at 32 kb/s each. The channel assignment information rate is 32 kb/s. The bit rate for each voice channel depends upon the number of data channels (which are transmitted at 64 kb/s PCM) and the number of active speech channels. If there are no voice-band data channels, the 180 nonoverhead bits are shared equally among the active speech channels. If all 48 channels are active, the transmission rate per channel is 30 kb/s. Daumer (1982) has found that 32 kb/s ADPCM is rated good by listeners in a subjective listening test.

Because the signals entering the DCEM are from a D3 channel bank (or the European equivalent) the channels have been previously PCM encoded. For compression mode A, if there are more than 24 channels active, the PCM encoded channels must be converted to ADPCM encoded channels. In the DDR this is done by first converting from PCM to 14-bit linear code. This is accomplished through the use of a look-up table that is programmed in a PROM (programmable read-only memory). The DDR then converts from linear code to ADPCM. Details of this conversion are provided by O'Neil (1978). Raulin, et al. (1982) describe other techniques for PCM/ADPCM conversion.

5.1.4 Other Studies on DCS/TRI-TAC Interoperability

During the final stages of this study, ITS became aware of other on-going investigations into DCS/TRI-TAC interoperability. For example, the U.S. Army 5th Signal Command in Europe is finishing a study on interoperability for the Commander-in-Chief, Europe (CINCEUR). An in-house IRAD (internal research and development) study has been conducted by TRW.[1] Another study has been conducted for the Defense Communications Engineering Center by the Computer Sciences Corporation under contract number DCA-100-78-C-0053.

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[1]Private communications, F. Skalbania, TRW.

← 125 μsec 193 BITS →

SIGNALING	CAI	TIME SHARE SPEECH BITS	DEDICATED DATA	F
8 BITS	4 BITS	180 - 8D BITS	8D BITS	1

D = Number of voice-band data channels.
CAI - Channel Assignment Information: 32 kb/s.
SIGNALING: 64 kb/s.
f - framing bit.
e.g., No Data Channels
48 Voice Channels Active } 30.0 kb/s per voice channel

Figure 21. DCEM frame format.

DCEC[2] has developed a concept of five categories of interoperation, namely

channel interconnection,
transmission interconnection,
group interconnection,
switched system interconnection, and
restoration capability.

The first three categories are differing approaches to digital pipeline interoperability while the fourth is end-to-end interoperability. The restoration capability is similar to the transmission interconnection except that the latter is not necessarily bilateral.

Figure 22 depicts DCS/TRI-TAC interoperability concepts discussed in the draft CSC report (contract no. DCA-100-78-C-0053) for the digital channel level, the group level, and the analog VF level that are closely related to DCEC's five categories. Detailed information of the various DCS and TRI-TAC equipment shown in Figure 22 may be found in Appendix A. The key to digital channel level interoperability is the FCC-100 (low-speed time division multiplexer - LSTDM). This multiplexer has the capability of multiplexing low speed asynchronous or synchronous channels into group rates that are compatible with the FCC-99 multirate (56, 64, 128, 256, 512 kb/s) synchronous input module. The 16/32 kb/s conditioned diphase signal from the TRI-TAC LGM (loop group multiplexer) may be connected into the FCC-100 as shown in Figure 22 (a). At the group level (Figure 22 (b)) the TRI-TAC TGM (trunk group multiplexer) or the group modem have rates that are compatible with the FCC-98 multirate synchronous input module. The purpose of the group modem in this application is to convert from conditioned diphase to non-return-to-zero (NRZ). The VF interface shown in Figure 22 (c) is self-explanatory.

5.2 Alternative A: New Intelligent First Level Multiplexer

The first of the three alternatives for the pipeline level of interoperability is shown conceptually in Figure 23. The interface point for this alternative is the first level multiplexer, which is a user-level interface as opposed to a group level interface. Because various types of user interfaces exist, both voice and data, this alternative tends to be more complex than those described

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[2] Private communications, J. Mensch, Defense Communications Engineering Center.

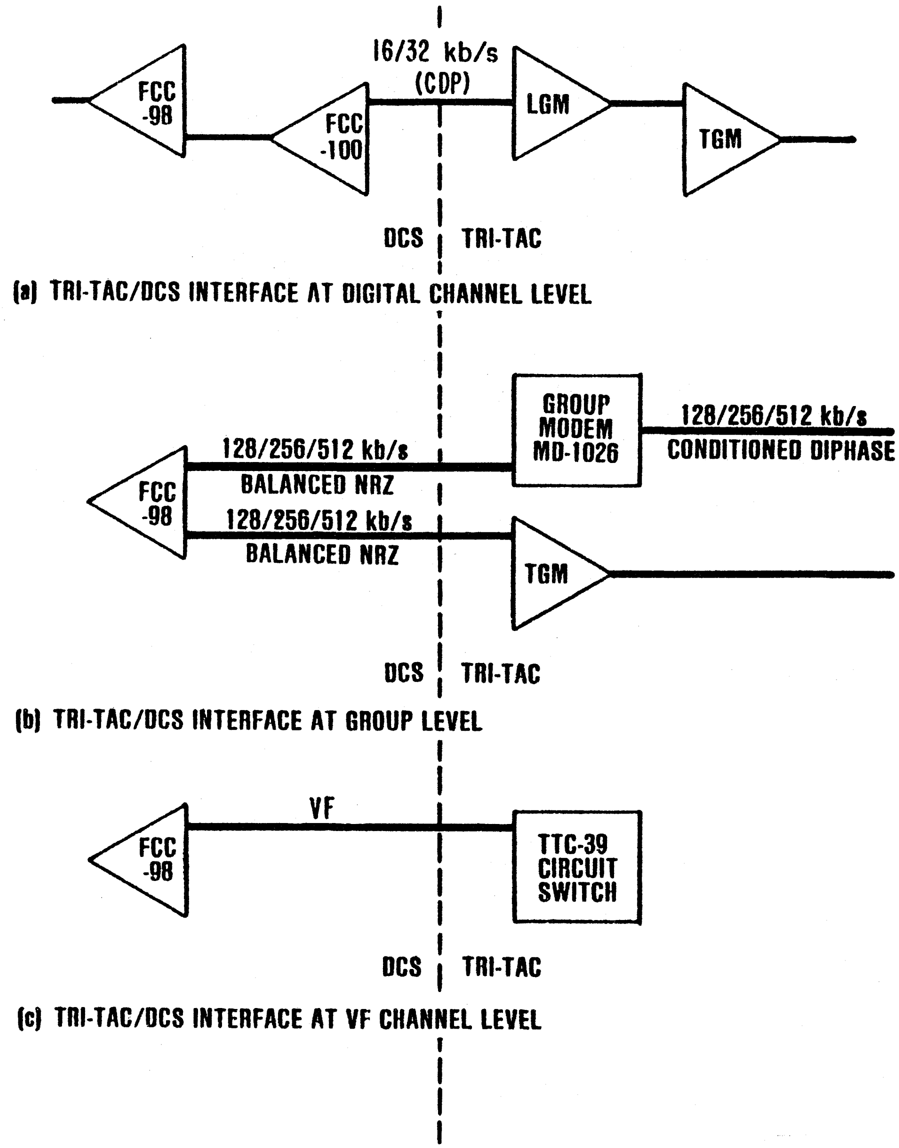
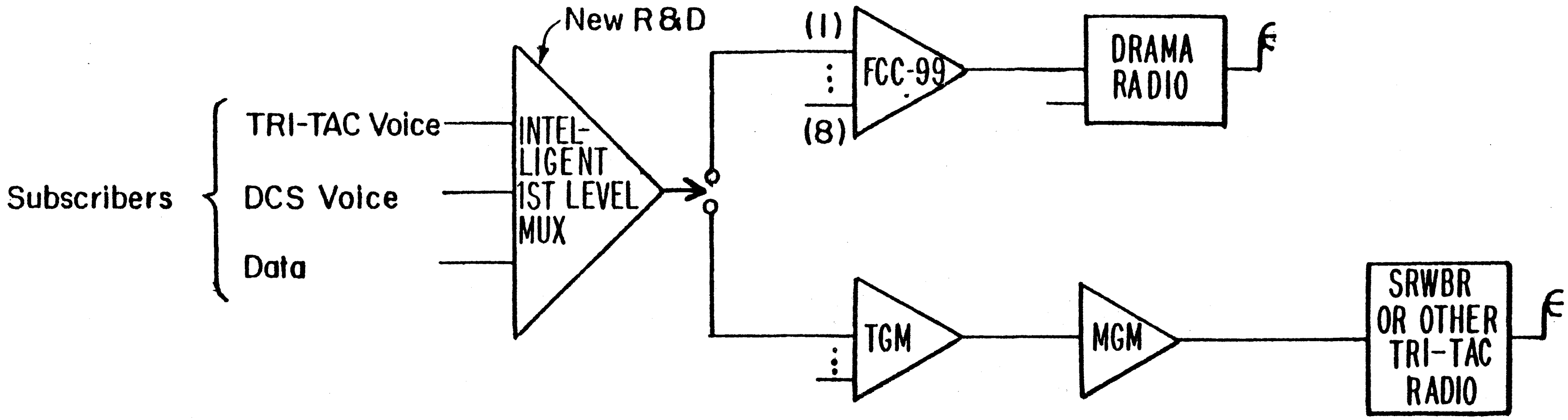


Figure 22. DCS/TRI-TAC interoperability proposed by CSC.



<u>Features:</u>

- Selectable transmission media (either TRI-TAC or DCS)
- Interface with either TRI-TAC or DCS subscribers or both
- Six basic operational modes

  DCS transmission (one mode; 1.544 Mb/s)

  TRI-TAC transmission (five modes: 128, 256, 512, 1024, and 2048 kb/s)
- New voice digitization techniques

  Window of opportunity for improving spectral efficiency. Modular design for programmable control to allow for future new voice digitization modules. (e.g. 64 kb/s PCM, 16 & 32 kb/s CVSD, and 32 kb/s ADPCM now; add 16 kb/s ADPCM later)
- DSI

Figure 23. Alternative A: intelligent, first-level multiplexer.

in the suceeding sections. However, the interface at the user level provides a "window of opportunity" for using digital speech interpolation (DSI) techniques along with adaptive voice digitization to improve transmission efficiency, while at the same time providing DCS/TRI-TAC interoperability.

As can be seen in Figure 23, not only will the new first-level multiplexer interface simultaneously with both DCS and TRI-TAC subscribers on the channel side, but it will also interface with either the second level DCS multiplexer (FCC-99) or the second level TRI-TAC multiplexer (trunk group multiplexer - TGM) on the combined channel or group side. As shown, the combined channel interface is with the FCC-99 <u>or</u> the TGM, but not both simultaneously. The operational scenario will dictate whether the transmission facilities beyond the new first-level multiplexer are tactical or DCS.

Figure 24 provides some elaboration on conceptual operational modes. In parts (a) and (b) of the figure the traffic is assumed to be a mixture of both DCS and TRI-TAC traffic. In part (a), tactical assets are used to provide transmission facilities between the new multiplexers at either end of the link. This is a capability that would satisfy both of the two following requirements:

(1) The use of tactical assets to provide temporary reconstitution of a damaged DCS link, and

(2) the use of tactical assets to extend DCS coverage.

In part (b) of Figure 24, DCS assets are used to provide transmission facilities between the new multiplexers at either end of the link. This would satisfy the requirement for the use of DCS transmission facilities to interconnect two geographically separated tactical operational areas.

Parts (c) and (d) illustrate examples of the use of the new first-level multiplexer in DCS and TRI-TAC transparent modes. The point is that the new multiplexer should be capable of replacing the FCC-98 (DCS transparent example) or the LGM (TRI-TAC transparent example). Whether the new multiplexer would need to be fully compatible with all operational modes (input and output data rates, number of channels, etc.) is an open question at this point. In this report, we wish merely to introduce examples of the potential utilization of the new first level intelligent multiplexer.

Table 9 provides examples of data rates for six basic operational modes. The basic operational modes correspond to six different output rates of the new first-level multiplexer. One of the modes is DCS compatible and five are

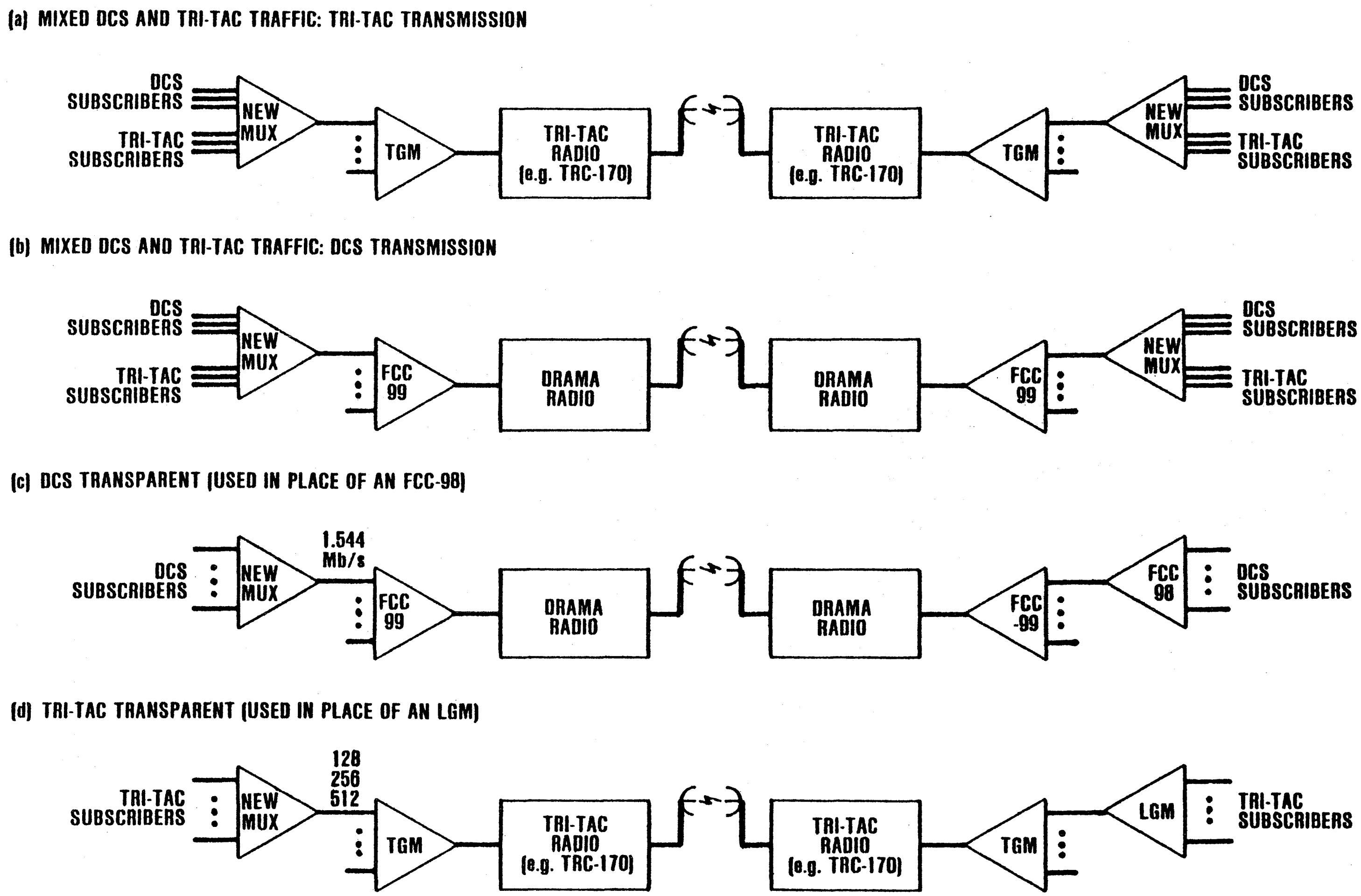


Figure 24. First-level intelligent multiplexer operational examples.

Table 9. Alternative A - Example Data Rates and Corresponding Number of Channels for Intelligent First Level Multiplexer

Mode	First Level Mux Output Rates (kb/s)	Input Rates (kb/s) 16	32	64	128	256	512	1024	Comments
I.	1544 (DCS compatible)								
	Ia.	---	---	24	---	---	---	----	DCS transparent (voice)
	Ib.	---	---	---	---	---	3	----	DCS transparent (data)
	Ic.	---	---	---	---	6	---	----	DCS transparent (data)
	Id.	---	---	---	12	---	---	----	DCS transparent (data)
	Ie.	---	---	24	---	---	---	----	DCS transparent (data)
	If.	90	---	---	---	---	---	----	TRI-TAC only
	Ig.	---	45	---	---	---	---	----	TRI-TAC only
	Ih.	---	20	12	---	---	---	----	Possible combined DCS/TRI-TAC
	Ii.	40	---	12					Possible combined DCS/TRI-TAC
II.	128 (TGM compatible)								
	IIa.	8	---	---	---	---	---	----	TRI-TAC transparent (7 VF channels)
	IIb.	---	---	2	---	---	---	----	2 64-kb/s PCM or data channels
	IIc.	---	2	1	---	---	---	----	Combined DCS/TRI-TAC (1 TT TC)
	IId.	4	---	1	---	---	---	----	Combined DCS/TRI-TAC (3 TT TC)
III.	256 (TGM compatible)								
	IIIa.	16	---	---	---	---	---	----	TRI-TAC transparent (15 VF channels)
	IIIb.	---	8	---	---	---	---	----	TRI-TAC transparent (7 VF channels)
	IIIc.	---	---	4	---	---	---	----	4 64-kb/s PCM or data channels
	IIId.	---	4	2	---	---	---	----	Combined DCS/TRI-TAC (3 TT TC)
	IIIe.	8	---	2	---	---	---	----	Combined DCS/TRI-TAC (7 TT TC)
	IIIf.	---	---	---	2		---	----	Data channel
IV.	512 (TGM compatible)								
	IVa.	---	16	---	---	---	---	----	TRI-TAC transparent (7 VF channels)
	IVb.	32	---	---	---	---	---	----	
	IVc.	---	---	8	---	---	---	----	8 64-kb/s PCM or data channels
	IVd.	---	8	4	---	---	---	----	Combined DCS/TRI-TAC (7 TT TC)
	IVe.	16	---	4	---	---	---	----	Combined DCS/TRI-TAC (15 TT TC)
	IVf.	---	---	---	4	---	---	----	Data channels
	IVg.	---	---	---	---	2	---	----	Data channels
V.	1024 (TGM compatible)								
	Va.	---	---	---	8	---	---	----	TRI-TAC transparent (63 TT TC)
	Vb.	---	---	---	---	4	---	----	TRI-TAC transparent (31/59 TT TC)
	Vc.	---	---	---	---	---	2	----	TRI-TAC transparent (31 TT TC)
	Vd.	---	---	16	---	---	---	----	16 64-kb/s PCM or data channels
	Ve.	---	---	---	8	---	---	----	Data channels
	Vf.	---	---	---	---	4	---	----	Data channels
	Vg.	---	---	---	---	---	2	----	Data channels
VI.	2048 (TGM compatible)								
	VIa.	---	---	---	16	---	---	----	TRI-TAC transparent (127 TT TC)
	VIb.	---	---	---	---	8	---	----	TRI-TAC transparent (63/127 TT TC)
	VIc.	---	---	---	---	---	4	----	TRI-TAC transparent (47 TT TC)
	VId.	---	---	---	---	---	---	2	TRI-TAC transparent
	VIe.	---	---	32	---	---	---	----	32 64-kb/s PCM or data channels
	VIf.	---	---	---	16	---	---	----	Data channels
	VIg.	---	---	---	---	8	---	----	Data channels
	VIh.	---	---	---	---	---	4	----	Data channels

Notes:
- TT TC = TRI-TAC traffic channels
- Not all DCS or TRI-TAC modes are illustrated (e.g., other first level DCS mux output bit rates are 192, 384, and 768 kb/s).
- Asynchronous data modules (0-20 kb/s and 50 kb/s modules in DCS) can replace the 64 kb/s module on a one-for-one basis.

TRI-TAC compatible. The output rate for the DCS mode is 1.544 Mb/s which is compatible with the FCC-99 multiplexer input. The output rates for the five TRI-TAC modes are compatible with the TGM multiplexer input. For each of the basic modes, numerous combinations of voice and data channels could be accommoed. Some suggested combinations are listed in Table 9 for the purpose of illustration. The exact input voice and data combinations that will be permissible is an unresolved question at this time. For the purpose of introducing the new first-level multiplexer concept, it is not necessary to answer this question.

The example operational modes and input data rates of Table 9 do not take into consideration the possible transmission efficiencies that could be achieved through the use of digital speech interpolation and adaptive speech digitization. Although efficient transmission utilization (or spectral efficiency) and DCS/TRI-TAC interoperability can be thought of as separate issues, the development of a new, intelligent first-level multiplexer provides a "window of opportunity" for addressing both issues simultaneously.

Voice encoding is currently achieved in the DCS in the FCC-98 first-level multiplexer. In the TRI-TAC system, voice encoding is performed at the subscriber instrument. Voice encoding can also take place at the multiplexers or switches. In the new, intelligent first-level multiplexer, there is an opportunity to achieve transmission efficiencies using a DSI/ADPCM concept similar to that employed in the Digital Channel Efficiency Model previously described.

There are several differences between the DCEM and the new intelligent, first-level multiplexer being considered here. The DCEM is not a multiplexer. Rather the DCEM performs compression, rate, and protocol conversion (interoperability) functions. The DCEM operates on one or more DS-1 (1.544 Mb/s) or CEPT signals (2.048 Mb/s). By contrast, the system being considered as alternative "A" performs multiplexing functions as well as compression functions. Whereas the DCEM is capable of providing interoperability between the DCS and the PTT's (or the NATO Integrated Communication System), the new, intelligent first-level multiplexer would provide interoperability between the DCS and TRI-TAC. If the intelligent first-level multiplexer concept is accepted, interoperability between the DCS and other networks such as NICS and ATACS should be considered as well.

One disadvantage of the approach used in the DCEM is that when heavy traffic conditions exist, conversion of the voice channel from PCM encoding to ADPCM must take place. In the intelligent, first-level multiplexer there would be no need for the PCM to ADPCM conversion. By assessing channel utilization prior to digitization, the appropriate digitization technique (PCM or 7-3 bit ADPCM) can be selected initially. If end-to-end digital encryption is employed, this advantage is negated.

Figure 25 is a functional block diagram of the intelligent first-level multiplexer. Note that this is the analog-to-digital conversion, data-input, and multiplexer portion only. The inverse functions of demultiplexing, digital-to-analog conversion, and data output are not shown. The basic concepts of the intelligent first level multiplexer can be described without providing the details of the inverse functions.

In Figure 25, TRI-TAC voice channels are assumed to be digitized at 16 or 32 kb/s CVSD. The DSI/ADPCM technique will not be utilized on these channels because they are already digitized at a comparatively low data rate. While hardware for converting from CVSD to PCM and vice versa has been developed (Zakanycz and Betts, 1978), it would be pointless to convert from CVSD to PCM to ADPCM just to accommodate traffic channel overloads when using DSI. As indicated in Figure 25 both digital data and CVSD encoded voice are sent to the digital multiplexer. The CVSD channels first go through an activity detector to determine if the channel is active, however.

The activity detectors for both the TRI-TAC CVSD digital channels and the DCS analog channels provide information to the microprocessor that provides the intelligence for this multiplexer. The microprocessor needs this channel activity information to determine the voice digitization technique (PCM or ADPCM) to use with the DCS analog channels, the number of bits to use if ADPCM encoding is required to avoid voice clipping for heavy channel utilization, the frame formatting employed by the digital multiplexer, and the channel assignment information which is transmitted to the new, intelligent first-level multiplexer at the other end of the link. Techniques for voice activity detection have been reported in the literature (see Drago et al., 1978, Kuhn et al., 1973, and Seitz et al., 1975, for example).

The voice/data detector is required because some of the input analog channels may be carrying voice-band data. Encoding such quasi-digital channels using ADPCM would likely cause unacceptably high bit-error rates (BER). The voice/data detector determines whether or not the channel is carrying voice-band data and informs the control microprocessor of its decision. The control microprocessor uses this information to determine whether the channel may be encoded

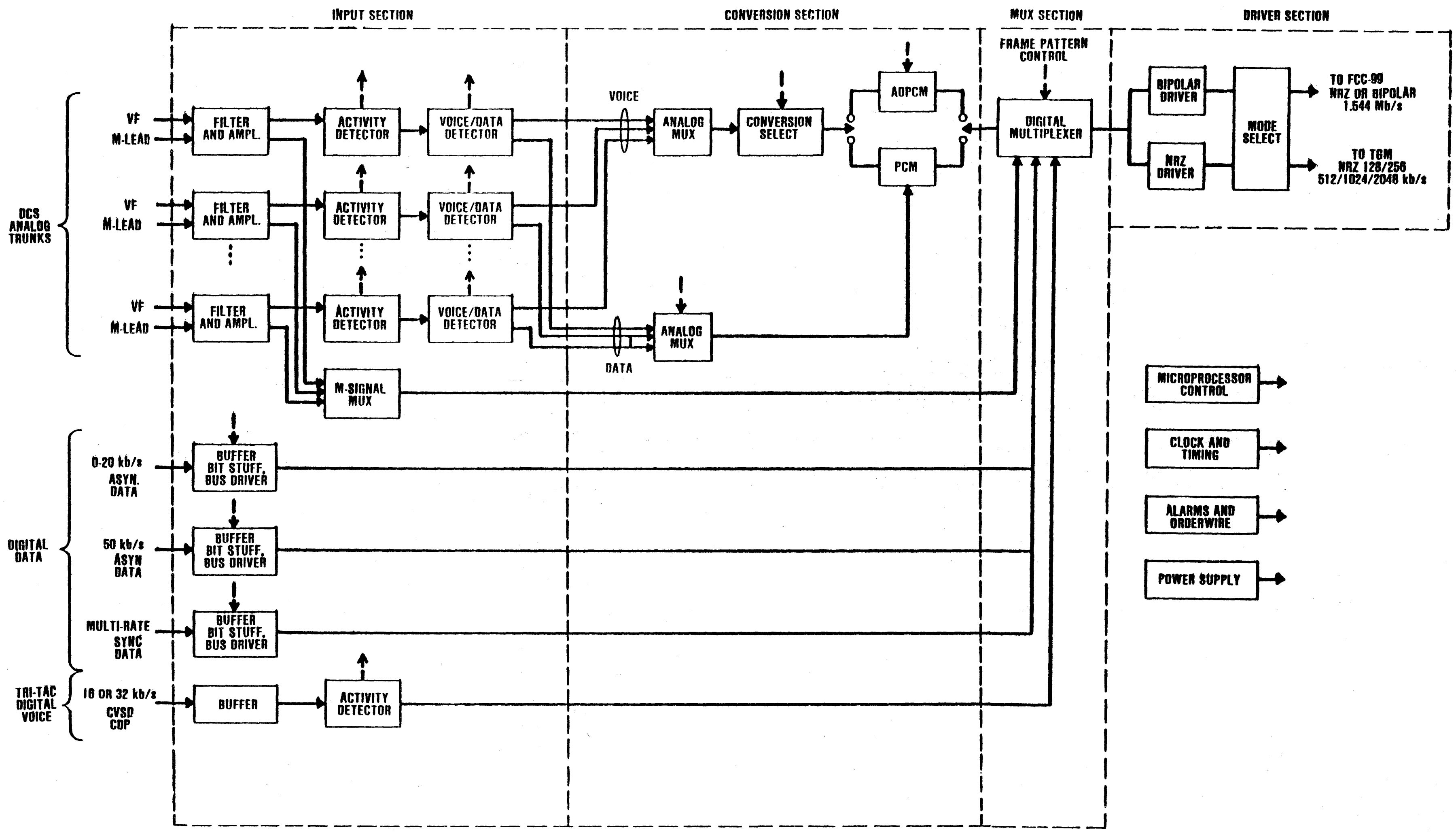


Figure 25. First-level intelligent multiplexer functional block diagram (multiplexer portion only).

using ADPCM or not. The control processor uses the information to control the two analog multiplexers shown in Figure 25, and the PCM and ADPCM converters.

In the above discussion, we have described ADPCM as the voice digitization technique to be used for low-bit-rate speech encoding to avoid speech clipping in the DSI system. ADPCM may not necessarily be the best choice. It was used here merely to describe the concept. Further study is needed of this issue prior to a final design of the intelligent first-level multiplexer. Appendix B provides the results of a subjective comparison of various low-bit-rate speech encoders. Further analysis of many papers in the literature is needed prior to making a final recommendation.

In summary, of this section on alternative "A", it should be noted that the functional block diagram of Figure 25 is presented only in enough detail to convey the concept. Many implementation decisions need to be made such as:

should the first level multiplexer also be required to interoperate with ATACS, the PTT's and NICS as well as with TRI-TAC,

what combinations of analog voice, digital voice (CVSD), and digital data input modules should be allowed,

what combined channel group rates should be used; should all input modes of the second-level multiplexers (FCC-99 or TGM) be accommodated,

how to implement the channel activity detectors,

how to implement the voice/data detectors,

what speech compression technique should be used (ADPCM or other)

what the frame format (which is variable depending upon speech activity, number of data channels, etc.) should be,

what channel assignment information must be transmitted to the distant multiplexer,

should channel coding such as Hamming code be employed to protect the channel assignment information,

what are the processing requirements for the microprocessor controller,

built-in test equipment (BITE) and redundancy requirements.

how to interface with tech-control facilities in the DCS and TRI-TAC,

how to interface with encryption devices, and

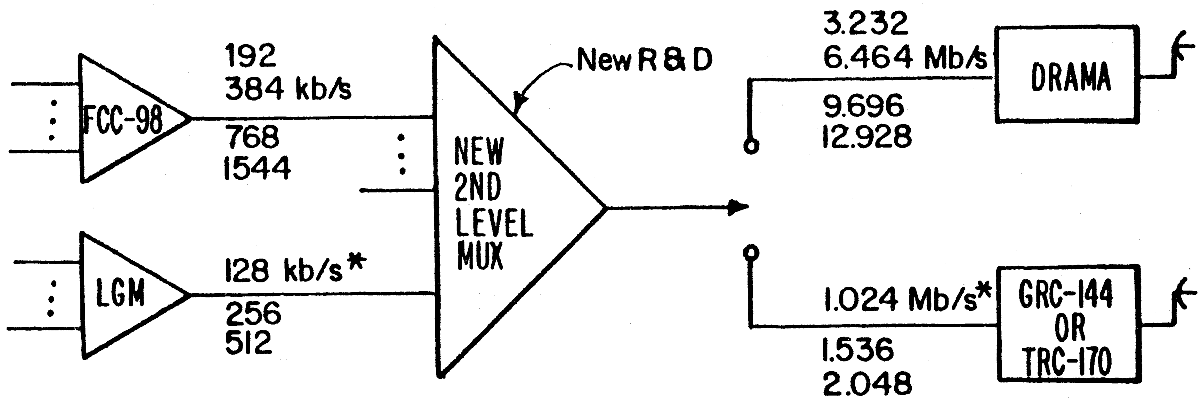
how timing and synchronization problems arising from interfacing two plesiochronous systems are overcome.

All of the fundamental building blocks of the intelligent first level multiplexer have been previously investigated by other researchers. The activity detectors and voice/data detectors are integral parts of any digital speech interpolation system. Using adaptive voice digitization to avoid speech clipping in DSI system has been under investigation by several organizations. As noted earlier, the DCEM uses the DSI/ADPCM technique. Recent papers by Langenbucher (1982) and Yatsuzka (1982) also report on combined DSI/ADPCM systems. The intelligent, first-level multiplexer, although complex, does not require any advanced or basic research. All of the pieces have been developed previously by others. The novelty in the intelligent first-level multiplexer lies in how these pieces are put together to simultaneously address the DCS/TRI-TAC interoperability requirement along with the requirement for improved spectral efficiency.

5.3 Alternative B: Advanced Second-Level Multiplexer

Figure 26 depicts the second alternative for the digital pipeline level of interoperability between the DCS and TRI-TAC. This alternative provides a DCS/TRI-TAC interface at the second multiplexer level. As shown in the figure, the new second-level multiplexer will accommodate inputs from either the DCS first-level multiplexer (FCC-98), the TRI-TAC first level multiplexer (Loop Group Multiplexer - LGM or Remote Multiplexer Combiner - RMC) or from a combination of DCS and TRI-TAC first-level multiplexers. Depending upon the operational mode selected, the combined bit stream is then fed into either the DRAMA radio for transmission through DCS facilities or into a TRI-TAC radio for transmission through tactical facilities.

Table 10 provides an example of both input data rates (group rates) and output data rates (combined group rates). Seven operational modes are suggested in the table. The seven modes are defined by the output (combined group) data rates. Four of the modes are DCS compatible, i.e., compatible with the DRAMA radio mission bit stream (MBS) while three are compatible with TRI-TAC radios. Various



Features:

- Inputs are various combinations of DCS and TRI-TAC 1st level mux outputs
- Output bit rates are selectable to be compatible with either DRAMA or tactical radios

*Subset of all possible data rates

Figure 26. Alternative B: advanced second-level multiplexer.

Table 10. Alternative B - Example Data Rates and Corresponding Number of Channels for New Second-Level Multiplexer

Mode	Second Level Multiplexer Output Data Rates (Mb/s)	Input Data Rates (kb/s)				Comments
		128	256	512	1544	
I.	3.232 (DCS compatible)					
	Ia.	---	---	---	2	DCS transparent
	Ib.	---	---	6	----	TRI-TAC input; DCS transmission
	Ic.	---	12	---	----	TRI-TAC input; DCS transmission
	Id.	24	---	---	----	TRI-TAC input; DCS transmission
	Ie.	---	---	3	1	Combined TRI-TAC and DCS inputs; DCS transmission
II.	6.464 (DCS compatible)					
	IIa.	---	---	---	4	DCS transparent
	IIb.	---	---	12	----	TRI-TAC input; DCS transmission
	IIc.	---	24	---	----	TRI-TAC input; DCS transmission
	IId.	---	---	3	3	Combined TRI-TAC and DCS inputs; DCS transmission
	IIe.	---	---	6	2	Combined TRI-TAC and DCS inputs; DCS transmission
	IIf.	---	6	---	3	Combined TRI-TAC and DCS inputs; DCS transmission
	IIg.	12	---	---	3	Combined TRI-TAC and DCS inputs; DCS transmission
III.	9.696 (DCS compatible)					
	IIIa.	---	---	---	6	DCS transparent
	IIIb.	---	---	18	----	TRI-TAC input; DCS transmission
	IIIc.	---	---	12	2	Combined TRI-TAC and DCS inputs; DCS transmission
	IIId.	---	---	6	4	Combined TRI-TAC and DCS inputs; DCS transmission
	IIIe.	---	12	---	4	Combined TRI-TAC and DCS inputs; DCS transmission
	IIIf.	24	---	---	4	Combined TRI-TAC and DCS inputs; DCS transmission
IV.	12.928 (DCS compatible)					
	IVa.	---	---	---	8	DCS transparent
	IVb.	---	---	24	----	TRI-TAC input; DCS transmission
	IVc.	---	---	12	4	Combined TRI-TAC and DCS inputs; DCS transmission
	IVd.	---	24	---	4	Combined TRI-TAC and DCS inputs; DCS transmission
V.	1.024 (TRI-TAC compatible)					
	Va.	---	---	2	----	TRI-TAC transparent
	Vb.	---	4	---	----	TRI-TAC transparent
	Vc.	8	---	---	----	TRI-TAC transparent
VI.	1.536 (TRI-TAC compatible)					
	VIa.	---	---	3	----	TRI-TAC transparent
	VIb.	---	6	---	----	TRI-TAC transparent
	VIc.	12	---	---	----	TRI-TAC transparent
VII.	2.048 (TRI-TAC compatible)					
	VIIa.	---	---	4	----	TRI-TAC transparent
	VIIb.	---	8	---	----	TRI-TAC transparent
	VIIc.	16	---	---	----	TRI-TAC transparent
	VIId.	---	---	---	1	DCS input; TRI-TAC transmission
	VIIe.	---	1	---	1	Combined TRI-TAC and DCS inputs; TRI-TAC transmission

combinations of TRI-TAC and DCS inputs are suggested for each of the seven transmission modes. As can be seen in the table the new second-level multiplexer may be configured to be either DCS transparent (FCC-99 replacement) or TRI-TAC transparent (Trunk Group Multiplexer replacement). The data rates presented in Table 10 should be considered to be exemplary only. If a decision is made to proceed with the development of this second-level multiplexer the first task would be to reach agreement on the advanced second-level multiplexer operational modes. If only a limited number of interoperable data rates are required it may be feasible to modify the FCC-99 rather than develop an entirely new first-level multiplexer.

Figure 27 is a functional block diagram of the advanced second-level multiplexer. Only the multiplexer function is shown (the inverse demultiplexer functions are not shown). Because of the flexibility required to accommodate the various operational modes, programmable control is included. The microprocessor controls the writing of the input channel data into the random access memory (RAM), and provides frame-format control by supervising the transfer of data from the RAM to the serial-to-parallel converter.

As was the case for alternative "A", Figure 27 presents the advanced second-level multiplexer only in enough detail to introduce the concept. Many implementation decisions need to be made such as:

- what combined group rates should be used,
- what input data rates should be accommodated,
- what are the BITE and redundancy requirements,
- what interfaces are needed with DCS and TRI-TAC tech-control facilities,
- what interfaces are needed with encryption devices, and
- how to resolve timing and synchronization problems arising from interfacing two plesiochronous systems.

The above list, as was the case for alternative "A" as well, presents some formidable technical problems. However, it would be fruitless to address these questions at this time. The decision as to where in the transmission chain to achieve digital pipeline interoperability, can be addressed without performing the detailed engineering analysis and design necessary to answer these questions.

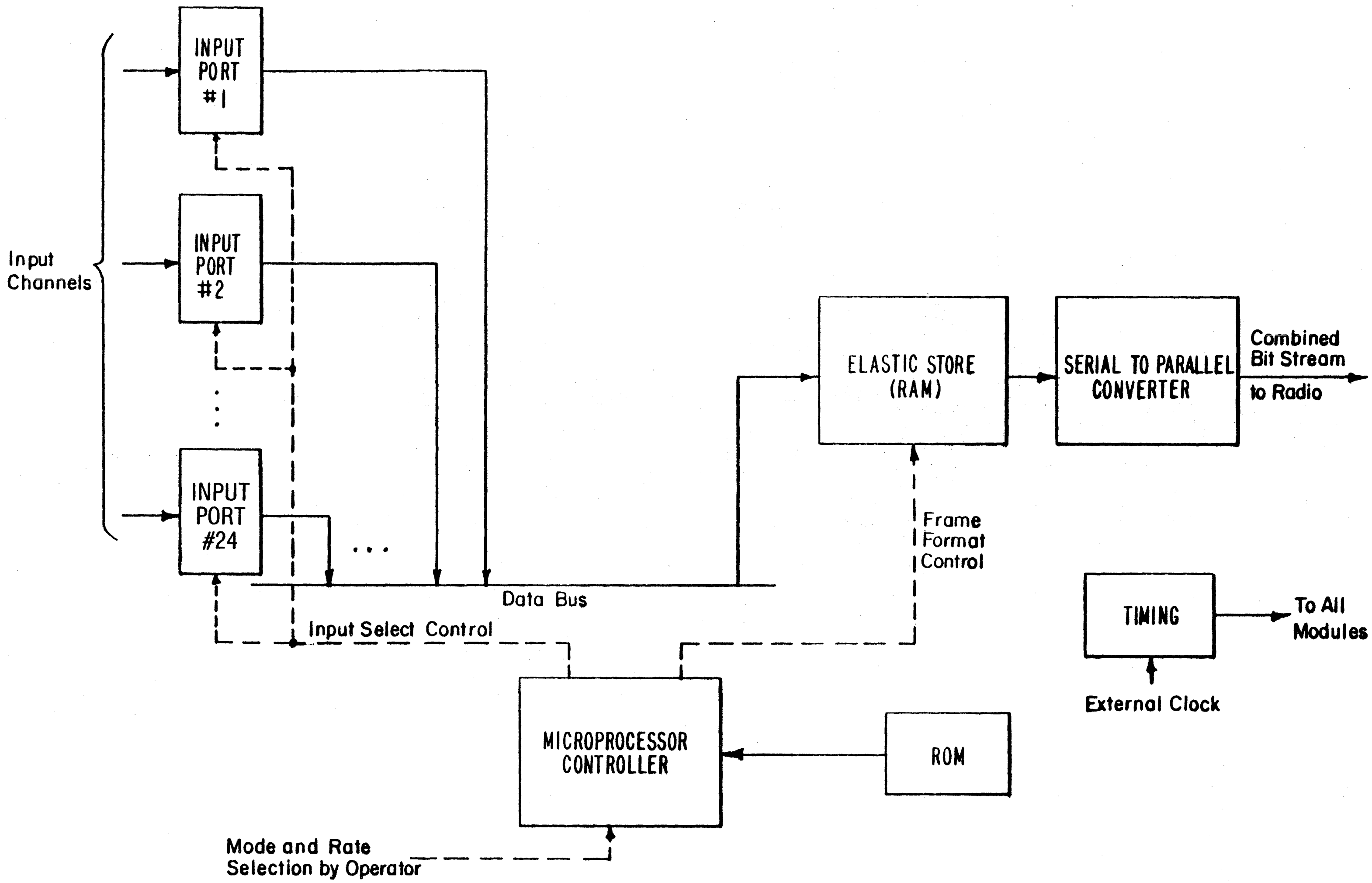


Figure 27. Advanced second-level multiplexer concept.

5.4 Alternative C: Digital Radio Interface

The DRAMA radio includes an internal multiplexer which might be considered to be the third-level multiplexer in the DCS multiplex hierarchy. The function of this multiplexer is to combine two mission bit streams from the FCC-99 second-level multiplexer into an aggregate bit stream (ABS) which is fed to the modem of the DRAMA radio (see Appendix A for details on DRAMA). Conceptually the DRAMA radio multiplexer could be modified to accommodate TRI-TAC mission bit streams from the TRI-TAC Trunk Group Multiplexer (TGM) as well as from the DCS FCC-99 second-level multiplexer. This is shown conceptually in Figure 28.

Table 11 provides some example aggregate bit stream data rates for various combinations of TRI-TAC and DCS mission bit streams. The table is exemplary only. Other combinations are feasible. Only the MBS and ABS that are specified as part of the DCS reconstitution radio have been included in Table 11. The DRAMA MBS rates of 3.232 and 9.696 Mb/s and ABS rates of 9.952 and 19.648 have not been included. Also not included are the TRI-TAC mission bit stream rates of 9.36 and 18.72 Mb/s, which are available from the Master Group Multiplexer (MGM).

Note that Alternative C bears a strong resemblance to the proposed reconstitution radio which also has a programmable multiplexer which can accommodate a variety of mission bit stream data rates.

5.5 Evaluation of Alternatives for Digital Pipeline Interoperability

Having introduced several alternatives for achieving the digital pipeline level of interoperability, it is now appropriate to subjectively compare the various approaches for pipeline interoperability. Table 12 summarizes the concepts that were introduced in Sections 5.1 through 5.4. The Digital Channel Efficiency Model is included in Table 12 because the DSI/ADPCM technology used in the DCEM to simultaneously provide spectral efficiency and interoperability between the DCS and the PTT's could be adapted to the DCS/TRI-TAC interoperability problem.

The approach currently being pursued jointly by the TRI-TAC program office and DCA does not address the requirement for transmission from DCS through TRI-TAC to a DCS destination.[3] This approach is therefore not responsive to JCS and DCA requirements as summarized in Section 4.

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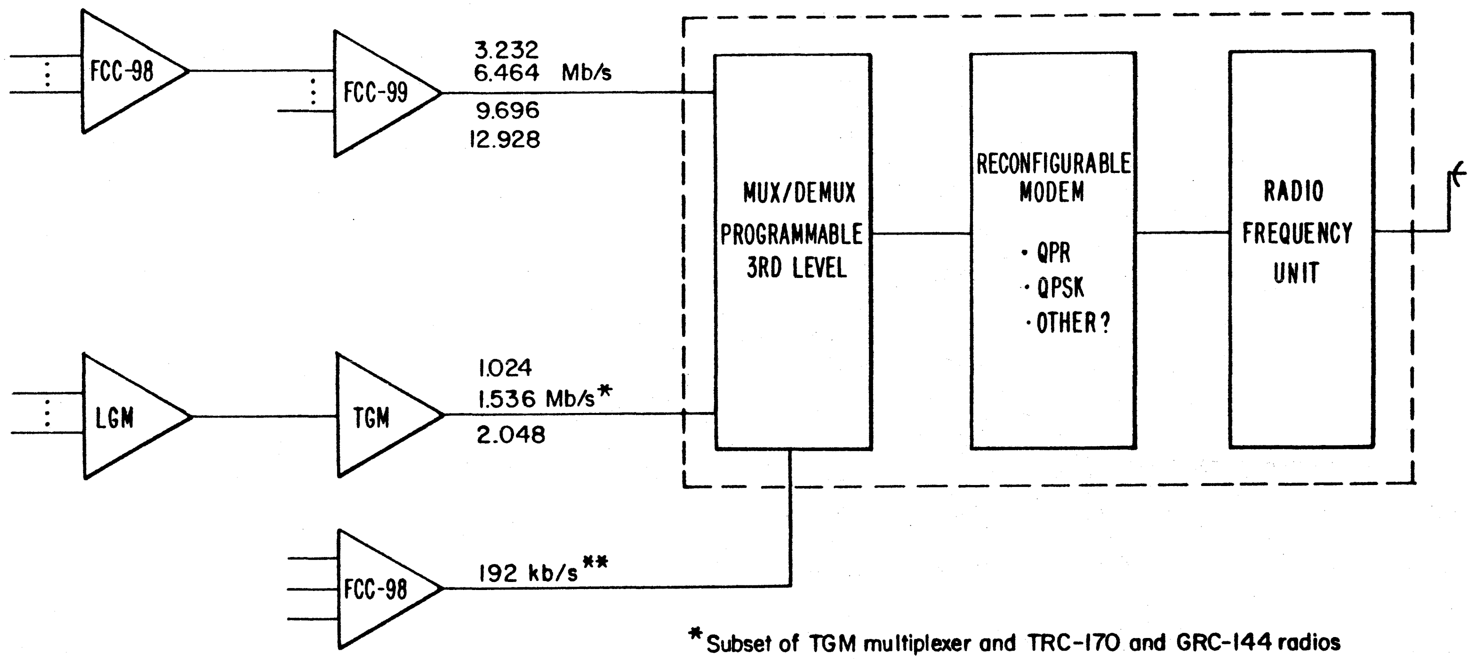
[3]Private communications, Johann Holzer, Joint Tactical Communications Office, Ft. Monmouth, New Jersey.



*Subset of TGM multiplexer and TRC-170 and GRC-144 radios
**Service Channel Bit Stream – SCBS

<u>Features</u>:

- Possibly new modulation technique (e.g. 64-QAM)
- Modulation could be changed depending upon multipath fading, jamming, etc.
- Transparent modes
  - DCS
  - TRI-TAC
- Adaptive equalization

Figure 28. Alternative C: modified DRAMA radio.

Table 11. Alternative C - Example Data Rates for Modified DRAMA Radio

Mode	Aggregate Bit Stream (ABS) Data Rate (Mb/s)	Mission Bit Stream (MBS) Data Rates (Mb/s)					Comments
		6.464	12.928	1.024	1.536	2.048	
I.	6.720						
	Ia.	1	---	---	---	---	DCS transparent
	Ib.	---	---	6	---	---	TRI-TAC input; DCS transmission
	Ic.	---	---	---	4	---	TRI-TAC input; DCS transmission
	Id.	---	---	---	---	3	TRI-TAC input; DCS transmission
II.	13.184						
	IIa.	2	---	---	---	---	DCS transparent
	IIb.	---	1	---	---	---	DCS transparent
	IIc.	1	---	6	---	---	Combined DCS and TRI-TAC inputs; DCS transmission
	IId.	1	---	---	4		Combined DCS and TRI-TAC inputs; DCS transmission
	IIe.	1	---	---	---	3	Combined DCS and TRI-TAC inputs; DCS transmission
	IIf.	---	---	---	---	6	TRI-TAC input; DCS transmission
III.	26.112						
	IIIa.	---	2	---	---	---	DCS transparent
	IIIb.	1	---	18	---	---	Combined DCS and TRI-TAC inputs; DCS transmission
	IIIc.	---	1	12	---	---	Combined DCS and TRI-TAC inputs; DCS transmission
	IIId.	---	1	---	---	12	Combined DCS and TRI-TAC inputs; DCS transmission
	IIIe.	---	---	---	---	24	TRI-TAC input; DCS transmission

Table 12. Approaches to Digital Pipeline DCS/TRI-TAC Interoperability

Interoperability Approach	Input Data Rates	Output Combined Bit Stream Data Rates	Interface Point	Capability	Comments
1. DCEM	1.544 or 2.048 Mb/s	1.544, 2.048, or 3.088 Mb/s	first level multiplexer digital bit stream	speech interpolation and DCS interoperability with PTT's and NICS	does not provide interoperability between the DCS and TRI-TAC; included because the technology utilized in the DCEM is applicable to DCS/TRI-TAC
2. TRI-TAC Office	512 kb/s	512 kb/s	TRI-TAC TGM interface AN/FCC-98 512 kb/s synchronous data input module	trunk group interface	TRI-TAC through DCS to TRI-TAC capability only
3. DTIF					
a.	512 or 576 kb/s	512 kb/s	AN/FCC-98 512 kb/s synchronous data input module	trunk group interface	ATACS and TRI-TAC through DCS
b.	1.544 or 2.048 Mb/s	1.152 or 2.048 Mb/s	Group Modem (GM) and TD-754	trunk group interface	DCS through ATACS and TRI-TAC
4. CSC					
a.	16 or 32 kb/s	16 or 32 kb/s	interface FCC-100 and Loop Group Multiplexer (LGM)	single channel	D-T-D and T-D-T at the digital channel level of interoperability; LGM and FCC-100 (Low Speed Time Division Multiplexer - LSTDM) connected directly
b.	128, 256, or 512 kb/s	128, 256, 512 kb/s	interface Group Modem and Trunk Group Multiplexer with AN/FCC-98 synchronous data input modules	group level	D-T-D- and T-D-T at the digital group level

Table 12. (continued)

Interoperability Approach	Input Data Rates	Output Combined Bit Stream Data Rates	Interface Point	Capability	Comments
5. Alternatives Described in this Report					
a.	16, 32, 64, 128, 256, 512, and 1,024 kb/s	128, 256, 512, 1,024 1,544, and 2,048 kb/s	first level multiplexer	user level interface	provides both D-T-D and T-D-T interoperability; provides spectral efficiency through the use of DSI/ADPCM
b.	128, 256, 512, and 1,544 kb/s	1.024, 1.536, 2.048, 3.232, 6.565, 9.696, 12.928 Mb/s	second level multiplexer	group level interface	provides both D-T-D and T-D-T interoperability
c.	1.024, 1.536, 2.048, 6.464, and 12.928 Mb/s	6.720, 13.184, and 26.112 Mb/s	third level multiplexer internal to DRAMA radio	highest level interface	T-D-T capability only

The approaches of the DTIF and that of CSC to DCS/TRI-TAC interoperability are responsive to both the DCS-through TRI-TAC to DCS (D-T-D) requirement as well as its inverse (T-D-T). However, the DTIF does not address the spectral efficiency issue which is addressed by Alternative A described earlier in this report. The DTIF appears to be an expensive approach because of the inclusion of the DACS which is not needed for interoperability. As noted in the study by Computer Sciences Corporation (CSC, 1982), the use of the DACS (or its military equivalent the Digital Patch and Access System - DPAS) may be an overkill for many DCS nodal requirements. The DACS can handle up to 1,524 through connected PCM channels (64 kb/s DS-0 signals). Its use may not be economically attractive in many DCS nodal applications. The use of the DACS in the DTIF does not appear warranted for interoperability purposes. Several of the studies such as the DTIF effort and the CSC study were made known to ITS only after the ITS study was nearly complete.

A subjective evaluation of the three alternatives is provided in the following paragraphs. This evaluation must necessarily be subjective because, as noted in Section 4, the DCS/tactical interoperability requirements are stated only in very general terms. Even these general requirements are not universally agreed upon. Without firmly established and agreed upon general requirements (such as the level of interoperability needed) it is obviously difficult to establish specific requirements (such as the number of DCS voice channels that interoperable TRI-TAC equipment should be designed to handle). Without these specific requirements a quantitative evaluation of alternatives is not possible. Therefore the alternative evaluation in the following paragraphs must necessarily be subjective.

The following evaluation factors will be used in comparing the alternatives for DCS/TRI-TAC interoperability:

performance,
operational flexibility,
complexity and risk, and
cost.

Performance

It is difficult to generate a quantifiable performance measure because the interoperability requirements are not specific. The identification of a viable performance measure is made more difficult because the three alternatives are at three different points in the transmission chain. One cannot compare the performance of a first level multiplexer with the performance of a second-level multiplexer. One performance measure that is common to all three multiplexer levels and which could be used for comparison purposes might be spectral efficiency. However only Alternative A addresses the spectral efficiency question or its equivalent, efficient source digitization. Alternative A (intelligent first-level multiplexer) is responsive to the spectral efficiency requirement as well as the interoperability requirement. Up to 4:1 compression has been reported (Langenbucher, 1982) for systems using a combined DSI/ADPCM approach. A 4:1 compression was demonstrated by Kuhn et al., (1973) using DSI with a variable number of quantizing bits for PCM. Depending upon the number of active TRI-TAC voice channels and number of data channels, both of which will not be compressed using ADPCM, it might be expected that a 2:1 efficiency improvement might be achieved in the intelligent first level multiplexer.

Operational Flexibility

Alternatives A and B are responsive to the requirement for both DCS through TRI-TAC to DCS (D-T-D) and TRI-TAC through DCS to TRI-TAC (T-D-T). Alternative C meets only the T-D-T requirement. Alternatives A and B have both DCS and TRI-TAC transparent modes, combined traffic modes, modes in which TRI-TAC transmission equipment is used to carry only DCS traffic (reconstitution case), and modes in which DCS transmission equipment is used to carry only TRI-TAC traffic. Alternative C does not provide for TRI-TAC RF transmission.

When considering the problem of reconstitution of the Digital European Backbone (DEB) using tactical assets, the highest level of transmission interoperability is desirable. Highest level of transmission interoperability refers to the highest multiplexer level. To illustrate this consider Figure 29 which depicts three typical DEB nodes. Suppose that node B has been made inoperational by some natural disaster, sabotage, etc. To achieve connectivity from node A to node C using tactical assets, interoperability must exist between the DCS and tactical equipment at some point in the first-level multiplexer, second-level multiplexer or radio transmission chain. If the point of interoperability is at the user-level (first level) multiplexer, more tactical equipment is required than if the point of interoperability is further along in the transmission chain. Therefore from the standpoint of operational considerations, the third-level multiplexer interface, which is internal to the modified DRAMA radio (Alternative C), is the most desirable of the three alternatives.

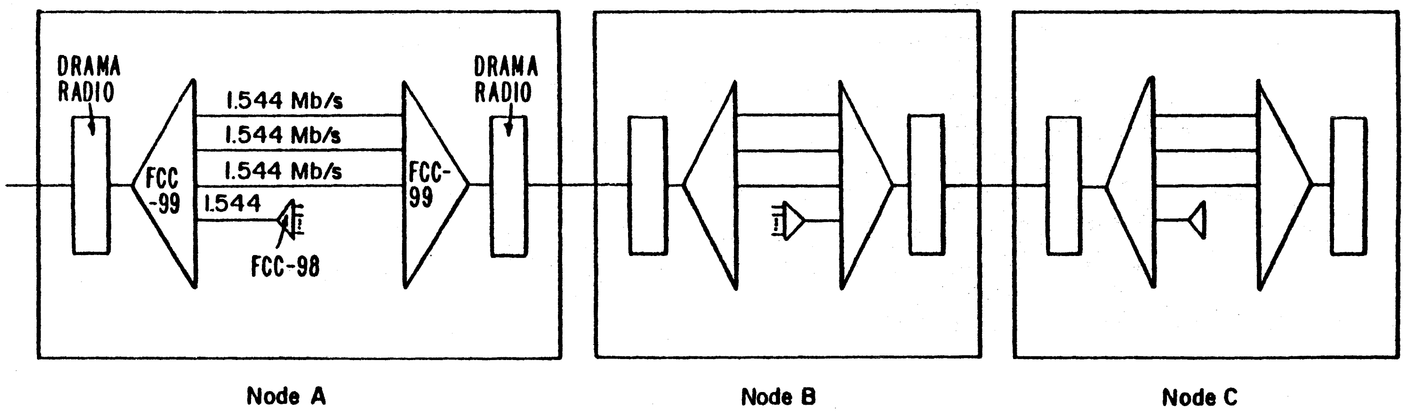


Figure 29. Typical DEB nodes.

Complexity and Risk

Alternative A (intelligent first-level multiplexer) is the most complex of the three alternatives. However, no technological breakthroughs are required. As noted earlier all of the technical concepts have been previously proven although not in the configuration that has been suggested in Alternative A.

Cost

There are two parts to the cost question. The first is the development cost while the second is the operational and maintenance (O&M) costs. Together they constitute the total life-cycle cost (LCC). The development cost is directly related to complexity. Therefore the development cost of Alternative A would likely exceed the development costs for any of the other alternatives. Estimation of O&M costs is clearly beyond the scope of this study. Note, however, that if the requirement to interoperate with the PTT's is added to the requirement to interoperate with TRI-TAC, operational costs for the Alternative A are likely to be greatly reduced because of the use of DSI/ADPCM technology. The tradeoff is between reduced operational costs and high development costs.

Recommendation

It is recommended that CSA pursue Alternative A, the intelligent first-level multiplexer, and possibly B and C as well. Despite the higher development costs of Alternative A compared to B and C, the added benefit of speech compression appears to outweigh the added complexity. Frequency assignments in Europe can be expected to become increasingly difficult to obtain. Therefore efficient spectrum utilization becomes as important an issue as the interoperability issue. The intelligent first-level multiplexer addresses both of these issues.

The importance of the spectral efficiency issue is evident by the DCS RDT&E Plan 1983-1989 (DCEC TR 2-82). One of the eight system attributes of the unified DCS/DSN RDT&E program is efficient spectrum utilization. The threads for achieving this include:

(1) exploitation of higher electromagnetic frequencies,

(2) efficient use of transmission bandwidth,

(3) improved source coding,

(4) data and voice resource sharing, and

(5) diverse common resources through interoperability.

The Alternative A concept is responsive to items (2) through (5).

Section 7 contains a suggested series of tasks that need to be undertaken in the development of a new intelligent first-level multiplexer. It is worthwhile mentioning the first task at this point, however. The first task would be to determine the operational modes (mission bit stream and aggregate bit stream data rates). In this report, we have addressed only DCS/TRI-TAC interoperability. Prior to development of the suggested new first-level multiplexer, a decision should be made as to whether the concept should be expanded to include interoperability with ATACS and the PTT's (or NICS) as well. If interoperability with the PTT's is included, then the spectral-efficiency issue takes on even greater importance. Several of the PTT's are in the process of making fundamental changes in their tariff structures. Rather than tariffs that are based on a flat rate for a specified distance, the tariffs will be volume or usage dependent. Therefore, the spectral efficiency that may be attained using the DSI/ADPCM concept of Alternative A is a very desirable attribute.

6. END-TO-END DIGITAL INTEROPERABILITY

As noted in Section 4, a limited end-to-end TRI-TAC capability for interoperation with AUTOVON is currently being planned using a VF analog interface and SF (single frequency) signaling. However, the predominate DCS network in Europe in the late 1980's and beyond will be the European Telephone System. It is expected that the ETS and AUTOVON will eventually merge and become the European portion of the DCS or its successor the Defense Switched Network - DSN. The ETS will be primarily a digital network using primarily digital trunking and hybrid switches (switching is digital, but both line and trunk interfaces may be either analog or digital). Interswitch signaling will be based upon the CCITT #7 common channel signaling (CCS) system. By way of contrast, TRI-TAC uses an entirely different set of digital transmission parameters, different hybrid switches, its own version of common channel signaling, and a system control (SYSCON) hierarchy entirely independent from that of the DCS. These differences make full end-to-end interoperability between the ETS and TRI-TAC on the digital level difficult to achieve.

As noted in Section 3, the report on the DCS RDT&E Program for FY 1983/1989 (DCEC TR 2-82) states that one of the thrusts for integrated design and system control is to develop interoperation between the DCS control subsystem and that of tactical systems. The WWDSA transition plan (DCA report published in 1982) describes the deficiencies of the DCS. One such deficiency listed is the poor interoperability between the DCS and TRI-TAC except at VF. These documents validate the requirement to conduct RDT&E programs aimed at achieving end-to-end digital interoperability between TRI-TAC and the DCS.

Table 4 listed the major parameters or system characteristics that must be investigated to achieve full end-to-end interoperability. A complete investigation of all of these parameters is beyond the scope of this report. The following two sections contain discussions of two of these parameters, namely, signaling and system control. An entire report could (and should) be written on each of these two aspects of the full end-to-end interoperability problem. An overview of these two topics is appropriate here because the U.S. Army has major responsibilities for switches, both for the ETS switch used in West Germany, and for the TTC-39 switches used in TRI-TAC. Signaling, of course, is a function of switches.

Both the U.S. Air Force and the U.S. Army have some responsibilities for DCS/tactical system control (SYSCON) interoperability. The U.S. Army has responsibility for the development of a Military Function Controller that will provide for interoperation between control elements of the DCS and those of the common carriers, tactical and allied systems in order to support rapid reconstitution and restoration of the DCS (see DCEC TR 2-82 for a description of the MFC program).

The discussions on signaling and system control will be followed by a brief discussion on voice digitization conversion. The section is concluded with the introduction of some approaches to end-to-end interoperability. It would be premature to attempt a full discussion of alternatives, and evaluation of these alternatives. Other, more detailed, analyses of specific requirements must be accomplished before such alternative definition and evaluation can be realistically accomplished. A list of suggested tasks for achieving these objectives will be presented in Section 7. The end-to-end interoperability concept in general and in particular the interoperability of signaling systems and SYSCON systems are desirable long-term goals for military communications networks. The following sections on signaling and system control will provide some insight on the complexity of the issue and for the need for more detailed analyses.

6.1 Interoperability Between ETS and TRI-TAC Signaling Systems

The discussion on the signaling aspects of DCS/tactical interoperability will be limited to ETS (since it is expected to be the major element of the DCS in Europe in the late 1980's and beyond) and to the TRI-TAC TTC-39 switch that uses CCS for interswitch signaling. There are other smaller unit level switches that are part of TRI-TAC as well as other tactical switches (existing inventory) that interface with TRI-TAC. These other switches do not use CCS. The signaling interface between tactical systems and the ETS is most likely to occur in the TTC-39 switch. Therefore, only the TRI-TAC CCS signaling will be discussed even though other signaling techniques are also used in TRI-TAC (for example digital in-band signaling is used for signaling between parent switches and subordinate switches [TRI-TAC, 1982f]).

The ETS will utilize common channel signaling based upon CCITT Signaling System #7 (DCA, 1981a). However, the military may develop its own signaling system by modifying CCITT #7 in order to meet unique military signaling requirements (DCEC, 1981). The proposed modifications to CCITT #7 for supporting unique Defense Switched Network features include support for:

multilevel precedence and preemption (MLPP),
community of interest screening,
protected hotline,
automatic off-net interconnect,
inward off-net access
zone restrictions,
call forwarding,
operator call,
satellite link limiting control,
protocol and rate checks,
conferencing, and
SYSCON.

If in fact, CCITT #7 is modified to meet DSN (including ETS) requirements, the list of modifications should include changes needed to make ETS signaling compatible with the TRI-TAC common channel signaling. Possibly the unique military requirements could be met by using the user portion of the CCITT #7 format.

One of the differences between CCITT #7 and the TRI-TAC CCS is that the latter is associative while the former may be either associative or nonassociative.

Figure 30 illustrates a typical TRI-TAC switching configuration for a call. Because the TRI-TAC CCS is associative, the signaling messages are relayed from switch to switch along the same path that the information message (digitized voice) follows.

The associative concept is further illustrated in Figure 31 where signaling messages are shown to be relayed. Figure 31 also illustrates another difference between CCITT #7 and the TRI-TAC CCS. Each signaling message in the latter system is acknowledged by the receiving switch. Acknowledgment messages are sent by each intermediate switch as well as the origination and destination switches. By way of contrast, the CCITT Signaling System #7 does not use acknowledgment signaling messages.

Table 13 provides a partial list of TRI-TAC trunk signaling messages. Certain other signaling messages that deal with satellite link control and communications security are not included because their formats are classified. Further information on these messages may be found in the TRI-TAC CCS specification. Inclusion of these messages is not pertinent to the current discussion because they would not be utilized between TRI-TAC and DCS. These messages are useful only internally to TRI-TAC (DCEC, 1981).

Table 14 provides a comparison between the TRI-TAC CCS messages previously given in Table 13 and the CCITT #7 equivalent. This table, which was prepared by a contractor for the Defense Communications Engineering Center (DCEC), is a first step in addressing the TRI-TAC CCS/CCITT #7 interoperability question. However, much additional work remains. As noted in the table there are nine TRI-TAC messages that have no CCITT equivalent. Note, however, that seven of these messages are useful only to TRI-TAC, i.e., there is no need for the message to cross the interface.

The messages in Table 14 that indicate equivalency are only roughly equivalent functionally. Obviously, any common channel signaling system must have some type of call initiation message. As shown in the top line of Table 14, both the TRI-TAC CCS and the CCITT have a <u>functionally equivalent</u> call initiation message. The content of the functionally equivalent messages listed in Table 14 differs significantly in some cases. A full field-by-field comparison of these functionally equivalent messages is beyond the scope of this report. This is a necessary (and complicated) next task. Before this task can proceed, however, it would be desirable to have a firmly established CCITT #7 that has been modified for military applications.

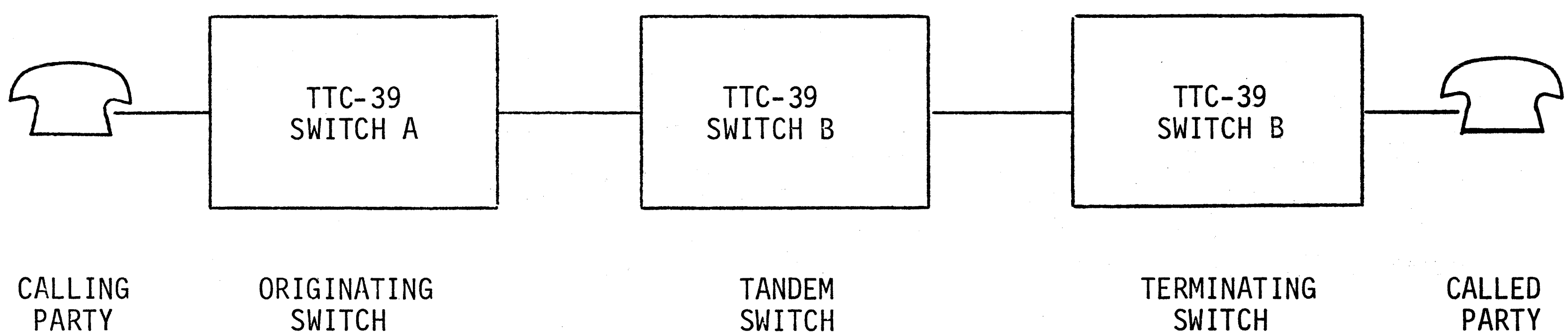


Figure 30. Typical TRI-TAC switching configuration for a call.

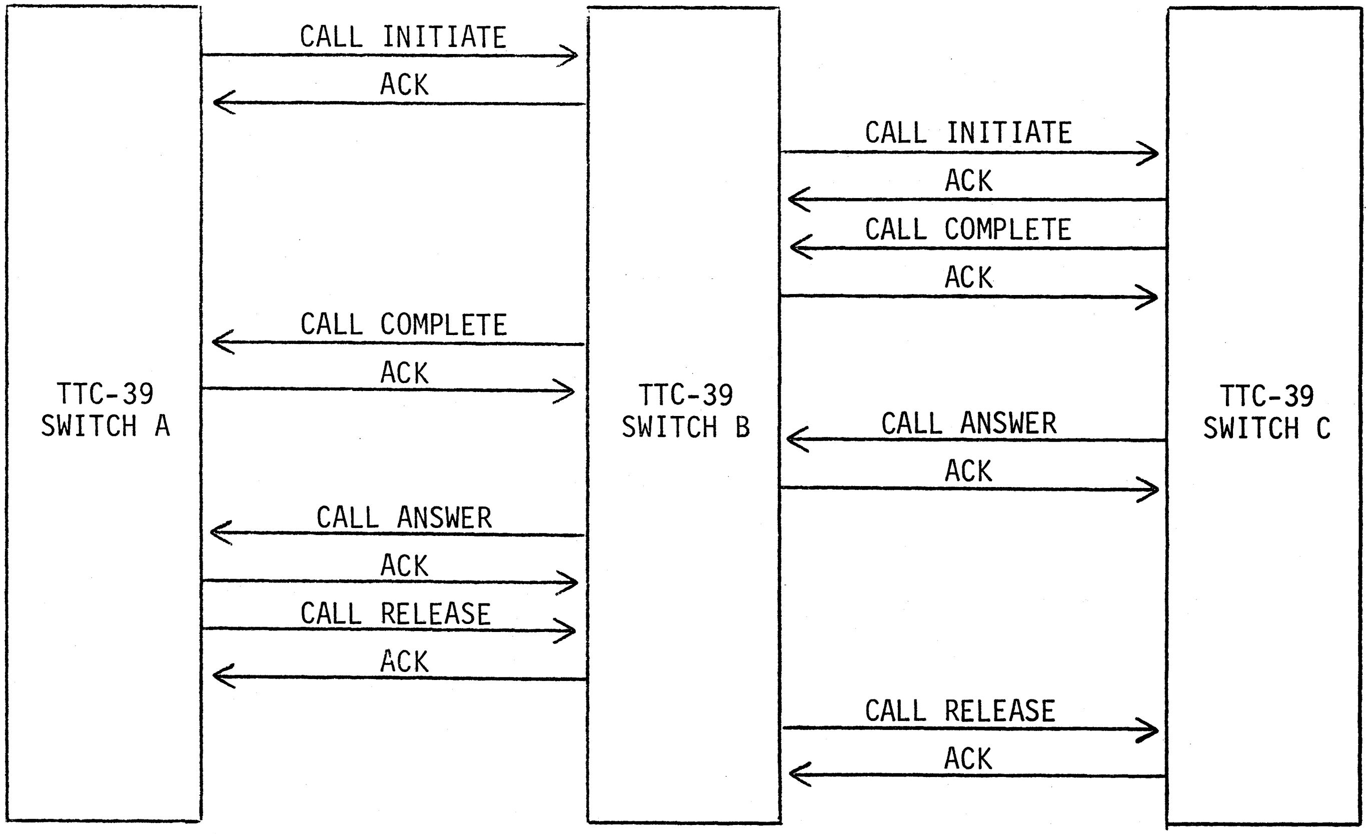


Figure 31. Typical TRI-TAC signaling generated by call setup/teardown.

Table 13. TRI-TAC Trunk Signaling Messages

1. Call Initiate	Sent to establish a call via the terrestrial and/or satellite trunking network.
2. Call Complete	Returned by the terminating switch to cause cut through of the path.
3. Call Answer	Sent by the terminating switch when the called party answers.
4. Release Messages	
(a) Call Release	Sent to release the trunks when calling or called party goes on hook.
(b) Preempt Release	Sent to release trunks in the event of preemption.
(c) Busy Release	Sent to a medial/spill forward switch, EXIT switch, Gateway Switch, Area Interface Switch, OOB/IBConversion/Terminating Switch when an ALL TRUNKS BUSY condition is encountered. BUSY RELEASE shall inhibit any further alternate routing. (See ALL TRUNKS BUSY message.)
5. Acknowledgment Messages	
(a) Acknowledge	Returned to Acknowledge Correct Reception of a numbered message.
(b) Nonacknowledge	Returned to Request Retransmission of a numbered message.
(c) Glare	Sent to indicate simultaneous seizure of a trunk has occured.
(d) Out of Service	Sent to indicate that the trunk requested in the Call Initiate message is placed out of service at the receiving switch.

Table 13. (continued)

6.	Call Incomplete Messages	
	(a) Called Party Unavailable	Returned to indicate that the called party or trunk is busy on a call of equal or higher precedence.
	(b) All Trunks Busy	Returned by a medial switch when it encounters the ALL TRUNKS BUSY condition or if the equipment necessary to complete the call is unavailable. This message is not used by other types of switches (e.g., EXIT, GATEWAY, etc.). These switches return BUSY RELEASE instead. (See BUSY RELEASE message.)
	(c) Unassigned Loop	Returned to indicate that the called number is not assigned.
	(d) Incompatible Connection	Returned to indicate that the called terminal is not compatible with the calling terminal.
	(e) Invalid Route	Returned by a switch which cannot continue to route a call because of insufficient entries in the routing table.
7.	Synchronization Message Test Sync	Sent to verify interswitch signaling channel synchronization.
8.	Trunk Test Messages	
	(a) Loop Back Trunk	Sent to have a trunk looped back on itself for testing purposes.
	(b) Loop Back Complete	Confirmation that loop back is completed.

Table 14. Equivalency Between TRI-TAC and CCITT No. 7 Signaling Messages

TRI-TAC Message	Standard CCITT No. 7 Equivalent	Comments
Call Initiate	Initial Address Message	Also Initial Address with Additional Information
Call Complete	Address Complete	
Call Answer	Answer	
Call Release	Clear Forward	Depending on Call Direction, #7 may first send Clear Back, then Clear Forward or just Clear Forward only.
Preempt Release	None	Adapted #7 will have Preempt, Preempt in Progress, and Preempt Complete messages.
Busy Release	Congestion	Causes #7 to generate Clear message to release trunks.
Acknowledge*	None	In #7 Acknowledgments are contained in the Backward Sequence Number. Not an internetwork function. Will not cross interface.
Nonacknowledge*	None	Retransmission in #7 requested by Inverting Backward Indicator Bit. But not an internetwork function. Will not cross interfaces.
Glare*	None	Adjacent switches detect glare in both networks. Not an internetwork function. Will not cross interface.
Out of Service*	None	Refers to adjacent switch trunks. Not an internetwork function. Will not cross interfaces.

*Message will not cross interface.

Table 14. (continued)

TRI-TAC Message	Standard CCITT No. 7 Equivalent	Comments
Called Party Unavailable	Subscriber Busy	
All Trunks Busy	Congestion (See Comments)	No. #7 signaling generated unless TRI-TAC has exhausted all alternate routes, then TRI-TAC sends Busy Release, + #7 sends congestion + clear.
Unassigned Loop	Unallocated National Number	
Incompatible Connection	None	Adapted CCITT #7 will include Protocol, Rate Checks and Terminal Parameter Incompatibility message.
Invalid Route	Call Failure	
Test Sync*	None	Checks Link Synchronization. Not an internetwork function. Will not cross interface.
Loop Back Trunk*	None	#7 has messages for continuity checking on a per call basis. TRI-TAC routinely tests individual trunks. Not an internetwork function. Will not cross interface.
Loop Back Complete*	None	#7 has messages for continuity checking on a per call basis. TRI-TAC routinely tests individual trunks. Not an internetwork function. Will not cross interface.

*Message will not cross interface.

Table 14 is only a one-way comparison of TRI-TAC CCS and CCITT #7, i.e., it shows all of the pertinent TRI-TAC messages, and their CCITT functional equivalent. It does not show all of the 35 CCITT messages. However, eleven of the CCITT messages have no usefulness outside of the CCITT system, i.e., there is no need for them to cross the CCITT/TRI-TAC signaling systems boundaries.

Figure 32 depicts the general CCITT #7 and TRI-TAC CCS signaling formats. These formats are the same for each of the 18 TRI-TAC signaling messages and the 35 CCITT #7 signaling messages. A meaningful comparison can be made only by looking at specific messages such as the call initiate messages.

In summary of the discussion on signaling the following differences between CCITT #7 and the TRI-TAC CCS have been noted:

1) TRI-TAC acknowledges the receipt of each message; CCITT does not,

2) TRI-TAC is associative CCS and has either a 16 kb/s or 32 kb/s digital signaling channel or a 1.2 or 2.4 kb/s analog (quasi-digital) signaling channel; CCITT #7 may be either associative or nonassociative and can accommodate data rates up to 64 kb/s,

3) there are 18 unclassified message types in TRI-TAC CCS; CCITT has 35 message types,

4) there are TRI-TAC message types that have no functional equivalent in CCITT #7 and vice versa,

5) message types that are generally functionally equivalent in the two signaling systems may differ significantly in the actual content of the message fields,

6) CCITT #7 does not accommodate some required military functions such as MLPP that TRI-TAC does perform; however CCITT #7 may be adapted to handle these functions.

6.2 Interoperability Between ETS and TRI-TAC SYSCON Facilities

Figure 33 depicts the DCS system control hierarchy (Rosner, 1980). The highest level of the hierarchy is the DCA Operations Center (DCAOC) located at DCS headquarters. There are two Area Communication Operations Centers (ACOC), one in Europe and one in the Pacific. The upper levels of the hierarchy are automated using the Worldwide On-Line System (WWOLS). The WWOLS centers are connected using the AUTODIN network. The lower levels of the hierarchy depend upon the internal control features of the various DCS subsystems and tend to be highly manual. The two upper levels of the hierarchy are managed and operated

								SIGNAL INFORMATION FIELD					
FLAG	BSN	BIB	FSN	FIB	LI	SPARE	SIO	CIC OPC DPC LABEL	H0	H1	OPTIONAL INFORMATION FIELDS	CK	FLAG

(a) CCITT #7 FORMAT

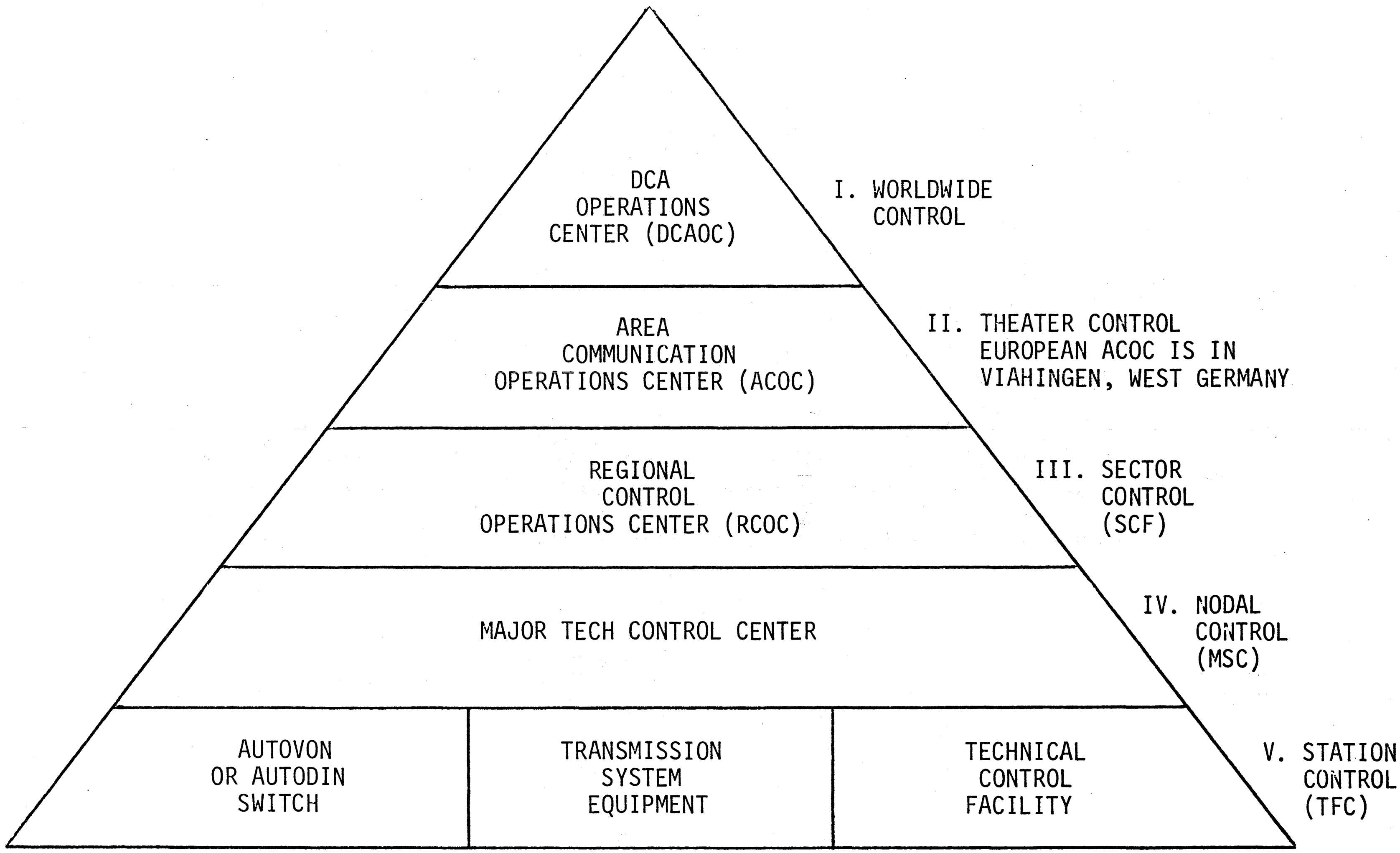
SOM	MSG TYPE	MSG NUMBER	OPTIONAL TRUNK NUMBER	OPTIONAL INFORMATION FIELDS	EOM	PARITY

(b) TRI-TAC CCS FORMAT

BSN - backward sequence number
BIB - backward indicator bit
FSN - forward sequence number
FIB - forward indicator bit
LI - length indicator
SIO - service information octet
CIC - circuit identification code

OPC - origination point code
DPC - destination point code
HØ/H1 - header information
CK - check bits
SOM - start of message
EOM - end of message

Figure 32. Comparison of TRI-TAC CCS and CCITT #7 formats.



SCF - Service Control Facility
MSC - Maintenance Service Center
TCF - Technical Control Facility

Figure 33. DCS system control (SYSCON) structure.

by DCA while the MIL-DEP's have been assigned responsibility for the lower levels. Figure 34 depicts the assignment of the SYSCON functions to the various levels in the hierarchy.

The ETS SYSCON will be designed to support the DCS SYSCON hiearachy. The Defense Communications Agency headquarters will be responsible for the overall management control of ETS. The DCA-Europe will have day-to-day responsibility for management control and configuration control. Network and traffic routing controls, network configuration management and configuration control and analysis of network performance and operation will be the responsibility of DCA. A Network Control Facility (NCF) will be established at the ACOC in Viahingen, West Germany, to support DCA's day-to-day management control responsibilities. The MIL-DEP's are responsible for operation and maintenance, configuration control of end offices, loops, and cable plants and administration of the subscribers. Two Service Control Facilities and several Maintenance Service Centers (MSC's) will be provided to support the MILDEP SYSCON responsibilities.

The ETS NCF, SCF's, and MSC's will be interconnected via the ETS Control Communications Network (CCN). Consideration is being given to the use of the common channel signaling (CCS) network for the purpose of routing real time SYSCON information, i.e., the implementation of the CCN may be on the CCS network (DCA, 1981a). Each of the nodes (NCF, SCF's, and MSC's) of the CCN will be equipped with processors, displays, data bases, and software to accomplish the processing and displaying of information. The general functional description of ETS SYSCON messages is described in the ETS System Engineering Architecture report (DCA, 1981a). As of the date of that report (September 1981), the framework for the ETS SYSCON had been generally defined. Actual implementation of the ETS SYSCON had not been specified as of that time.

Figure 35 shows the interconnection of the functional flow of the TRI-TAC SYSCON system which is known as the Tactical Communications Control Facility (TCCF) (TRI-TAC, 1981). The major components of the TCCF are:

Communications System Control Element (CSCE),
Communications Nodal Control Element (CNCE), and
Communications Equipment Support Element (CESE).

The CSCE provides dynamic operational management and control of a sector of a deployed communications system, while the CNCE provides management and technical control of communications resources at a node (TRI-TAC, 1982e). The CSCE and

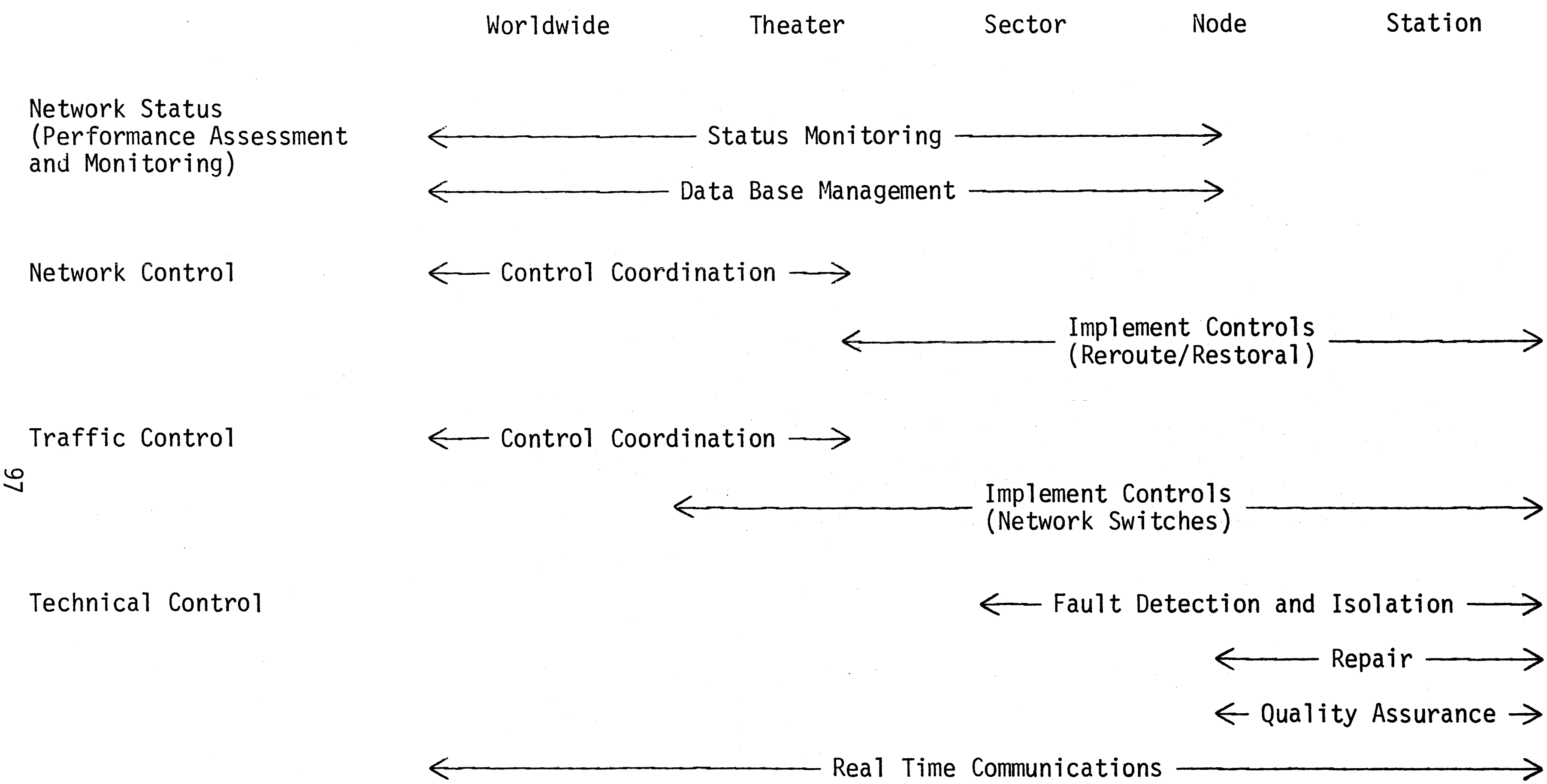


Figure 34. System control functions.

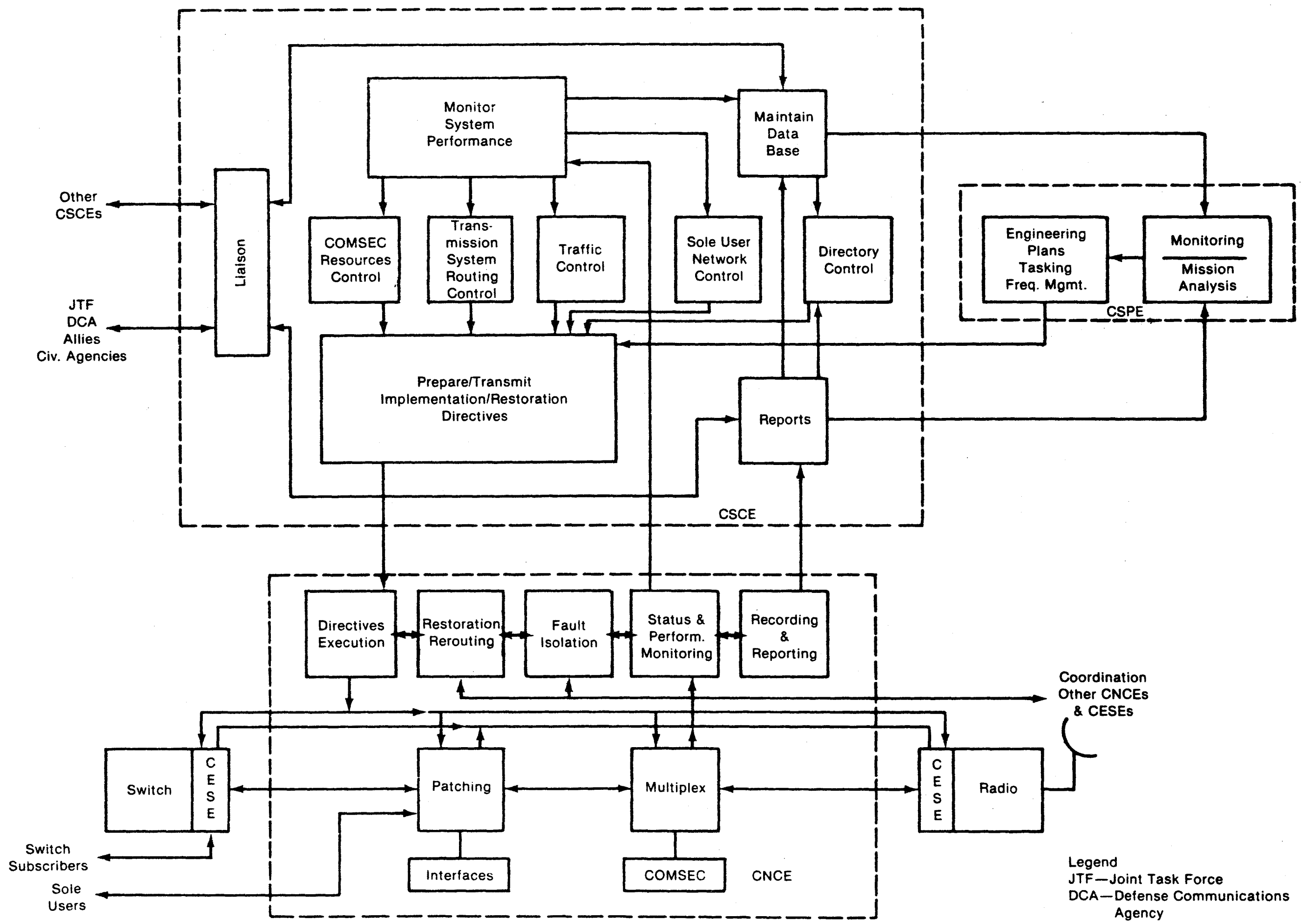


Figure 35. TCCF functional flows.

the CNCE are roughly functionally equivalent respectively to the Service Control Facility (SCF) and the Maintenance Service Center (MSC) of the ETS SYSCON. The CESE is roughly functionally equivalent to the TRAMCON (Transmission Monitor and Control) system of the DCS. A fourth element of the TCCF, the Communications System Planning Element (CSPE), has been discussed but not implemented. The CSPE would perform functions for higher level of TRI-TAC management, but not on a day-to-day basis. The CSPE would perform functions equivalent to those performed by the ACOC in the DCS.

One point in Figure 35 that should be emphasized is the connection between the CSCE and DCA, allied, and civil agency system control facilities. This interface is unfortunately not defined in CSCE specifications. This points to the need for a study to define the SYSCON interoperability requirements. Several documents (TRI-TAC, 1981; the WWDSA transition plan; and the DCS RDT&E five-year plan) provide a general requirement for tactical/DCS SYSCON interoperability. Specific requirements have not been addressed, however.

The elements of the TCCF will be interconnected using either 2 or 4 kb/s system control subchannels for direct processor-to-processor communications. In addition a 16/32 kb/s traffic channel can be used to carry up to seven SYSCON channels.

In contrast to the ETS SYSCON, the TCCF SYSCON message formats, communications protocols, and data elements have been well-defined at this point in time. The message formats and communications protocols are specified in the Interface Control Document 004 (TRI-TAC, 1982g) and the CSCE Data Element Dictionary (TRI-TAC, 1982e). A more detailed overview of the TCCF may be found in the CNCE specifications (TRI-TAC, 1981).

The brief overview given in this section of the SYSCON facilities of ETS and TRI-TAC is provided to show the complexity of the SYSCON interoperability issue. The SYSCON interoperability issue is seen as a subissue of the full, end-to-end interoperability issue. There appears to be a window of opportunity at the present time to address the SYSCON interoperability issue because the ETS SYSCON has not been fully defined (DCA, 1981a). During the future development of the ETS SYSCON provision should be made to provide ETS SYSCON interoperability with TRI-TAC SYSCON. What types of information and their format is not clear at this point. This question should be addressed during future tasks. The study should address the following:

the level(s) in the hierarchy that ETS and TRI-TAC SYSCON facilities interoperate,

the types of information that must be exchanged,

the message types and formats,

data elements,

the communications protocol (TRI-TAC uses a modified ADCCP protocol) that should be used, data transmission rates, and

the encryption and channel coding techniques employed.

It is not entirely clear as to which MIL-DEP has the primary responsibility for SYSCON. The U.S. Air Force has some responsibilities, but the U.S. Army must be involved because SYSCON involves the switches which are U.S. Army responsibility.

6.3 Voice Digitization

One of the original questions that was posed at the start of this study was how can networks that utilize different voice digitization techniques be made to interoperate. The concern at that time was interoperation of the DEB with the European PTT's since the DEB uses μ-law companding while the PTT's use A-law companding. This problem turns out to be trivially simple because A-law to μ-law conversion can be accomplished with a simple table look-up. Bellamy (1982) provides tables that can be used for this purpose. The conversion can be accomplished digitally without the need to revert back to the analog domain. There is no problem in the tandem conversions (A to μ to A to μ etc.) since it is a simple table look-up function with a one-to-one correspondence of values.

A significantly more difficult problem is the conversion from CVSD to PCM and vice versa. Zakanycz and Betts (1978), report on the development of a device to convert 64 kb/s PCM to 16 or 32 kb/s CVSD and vice versa. This conversion is accomplished digitally. Details of this conversion process may be found in the cited reference.

For end-to-end ETS/TRI-TAC interoperability to be achieved, conversion from CVSD to PCM must be accomplished. Where this conversion takes place is subject to further study. The most likely contender is a gateway switch. This again puts a further requirement on switch development or modification.

6.4 Alternatives for End-to-End Interoperability

The preceding three sections discussed the signaling, system control, and voice digitization aspects of providing full end-to-end interoperability between the ETS and TRI-TAC. The common thread through these discussions was their relationship to the switches of the two networks. The obvious conclusion, then, is that the alternatives for end-to-end interoperability will involve the ETS switch, the TRI-TAC TTC-39 switch or both. What is not clear is the extent of the hardware and software modifications that must be made. Conceivably, the development of a new switch may be required.

The WWDSA calls for the development of multirate switching and modularly expandable switches. The multirate switch will also be capable of combining lower speed bit streams into 16 kb/s or 64 kb/s composite channels through the use of an internal first-level multiplexer. Several switch makers are currently working on the development of multirate switches. Utilization of commercially available switches (modified as necessary to provide unique military features) is a desirable approach. The WWDSA multirate switching requirements and the potential availability of commercially available switches provides some credence to the suggestion that the development of a new switch is a viable alternative.

Some suggested alternatives for end-to-end interoperability are:

(a) modification of ETS switches,
(b) modification of the TTC-39 switch,
(c) combination of (a) and (b), and
(d) development of a new multirate switch.

One problem with (a) and (c) is the fact that the same switch will not be used throughout ETS. A switch from a German company will be used in West Germany, while a Canadian switch will be used in the United Kingdom. It is not clear as to what switch will be used as the ETS expands to other countries. One concern with alternative (d) is that it may be quite expensive.

Before one can perform a detailed analysis of the above alternatives (or even confirm that the list is a valid list of candidate alternatives to start with) additional studies are required. As suggested in Sections 6.1 and 6.2, signaling and system control are extremely complex issues. Separate, very detailed, studies should be made of both of these technical areas. The focus of these efforts should be on establishing requirements for switch modification or development. Section 7 includes a suggested series of tasks for further investigation of the end-to-end interoperability issue.

7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Section 1 of this report discussed the objectives and task breakdown for studies on survivability, interoperability, reconstitution, and performance-related issues of the European Defense Communications System that are being conducted by ITS for the U.S. Army Communications Systems Agency. This report is the output of the task on DCS/TRI-TAC interoperability. Section 1 also itemized several assumptions and constraints that this report is based on. This is followed in Section 2 by a discussion of different concepts of interoperability and the terminology used in this report. In Section 3 a discussion is provided of the general interoperability requirements as they have been stated in various DCA and JCS documents. As noted in Section 4, current planning for AUTOVON/TRI-TAC interoperability will not result in capabilities that will satisfy the requirements as summarized in Section 3. This background analysis set the stage for defining conceptual approaches for the digital pipeline level of interoperability in Section 5 and the end-to-end level of interoperability in Section 6. The recommendations stated in Sections 5 and 6, respectively, were to:

1) develop a first level intelligent multiplexer, and possibly in parallel perform initial R&D for the other digital pipeline alternatives outlined in Section 5, and

2) perform further more detailed studies on the end-to-end interoperability issue with emphasis on the system control and CCS aspects.

In Section 3 (requirements), Section 4 (deficiencies), and Section 6 (end-to-end interoperability) a common thread is the need for interoperable SYSCON and common channel signaling. The reason for highlighting these parts of the end-to-end interoperability issue is because of the complexity in making these subsystems interoperable between the DCS and TRI-TAC.

Throughout this report, emphasis was placed on the following:

1) interoperability and spectral efficiency requirements as specified in DCA and JCS documents, and

2) the translation of these general requirements into more specific requirements for equipment that is the responsibility of CSA (multiplexers, radios, modems, and switches).

The transition from general requirements into specific recommendations is shown in Figure 36. Sections 7.1 and 7.2 will elaborate on the recommendations for digital pipeline and end-to-end interoperability, respectively.

7.1 Recommended Tasks for Digital Pipeline Interoperability

Figure 37 presents a diagram of a sequence of decisions that should be made for the digital pipeline interoperability issue. The decision process starts off with a cryptic statement of the requirements, namely that:

1) both DCS-through TRI-TAC-to DCS (D-T-D) and TRI-TAC-through DCS-to TRI-TAC digital pipeline interoperability is required, and

2) that there is a need for improving the spectral efficiency of digital transmission.

The first decision that must be made is on the point in the transmission chain at which interoperability should be achieved. As noted in Section 5, the recommendation is that a first-level, intelligent multiplexer be developed but that parallel, initial R&D of the other alternatives possibly should also be considered. Alternative A is the only alternative that is responsive to the spectral efficiency requirement and therefore is the recommendation emphasized.

The emphasis throughout this report has been on the interoperability between TRI-TAC and the DCS. Interoperability between the DCS and NICS or ATACS was not addressed because the alternative concepts could be introduced without the unnecessary complication of considering DCS interoperability with other networks. However, the question of including NICS and ATACS compatibility should be readdressed after deciding on the appropriate interface point (first-level multiplexer, second-level multiplexer, or DRAMA radio). Following this decision, appropriate operational modes and data rates can be determined.

Section 5 contained a discussion of the pros and cons of the various alternatives. Because of the advantage that Alternative A meets the spectral efficiency requirement while the other alternatives do not, the development of a first level intelligent multiplexer is recommended. Figure 38 is the recommended series of tasks for this R&D program. Task 1 is the definition of the operational modes. The subtasks are provided in Table 15 which is an expansion of the Task 1 block of Figure 38. Similarly Table 16 is an expansion of the Task 2 block of Figure 38 for the development of the intelligent first level multiplexer specifications.

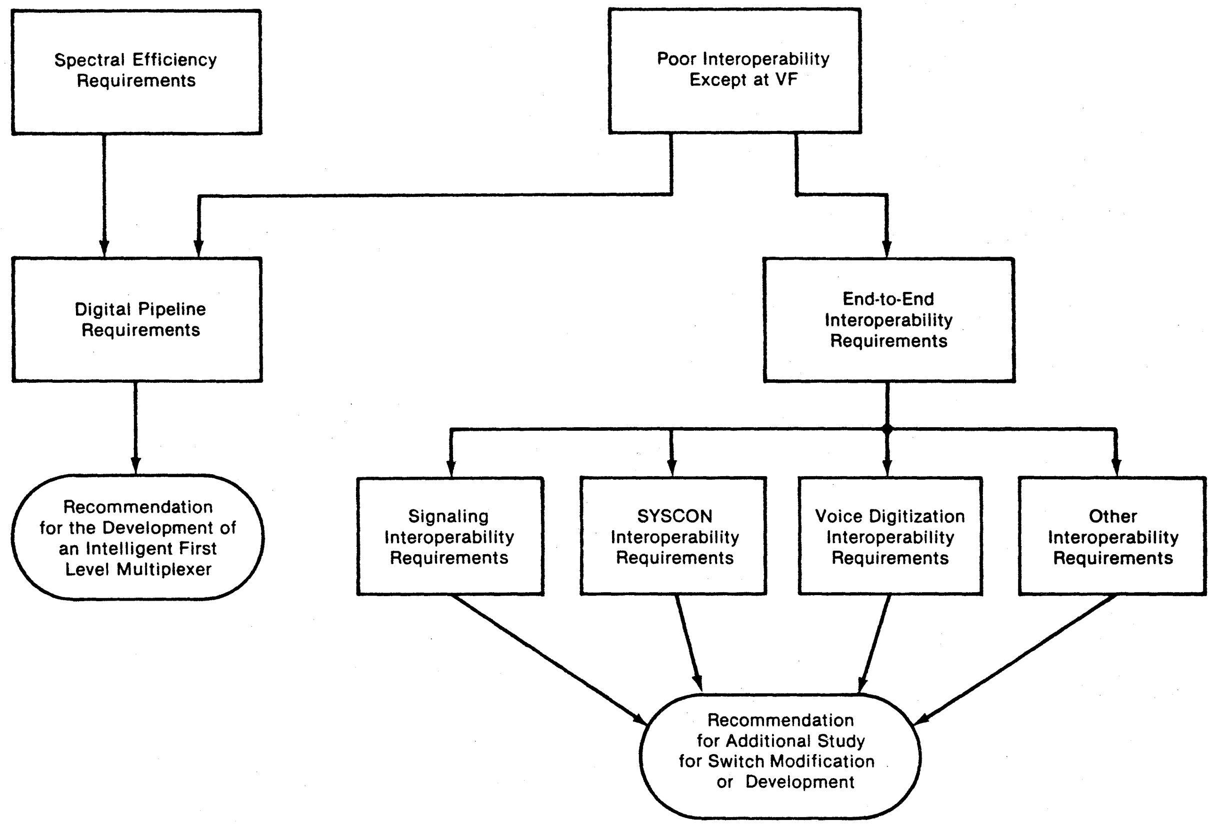


Figure 36. Translation of general requirements as stated by DCA into recommendations for new R&D programs at CSA.

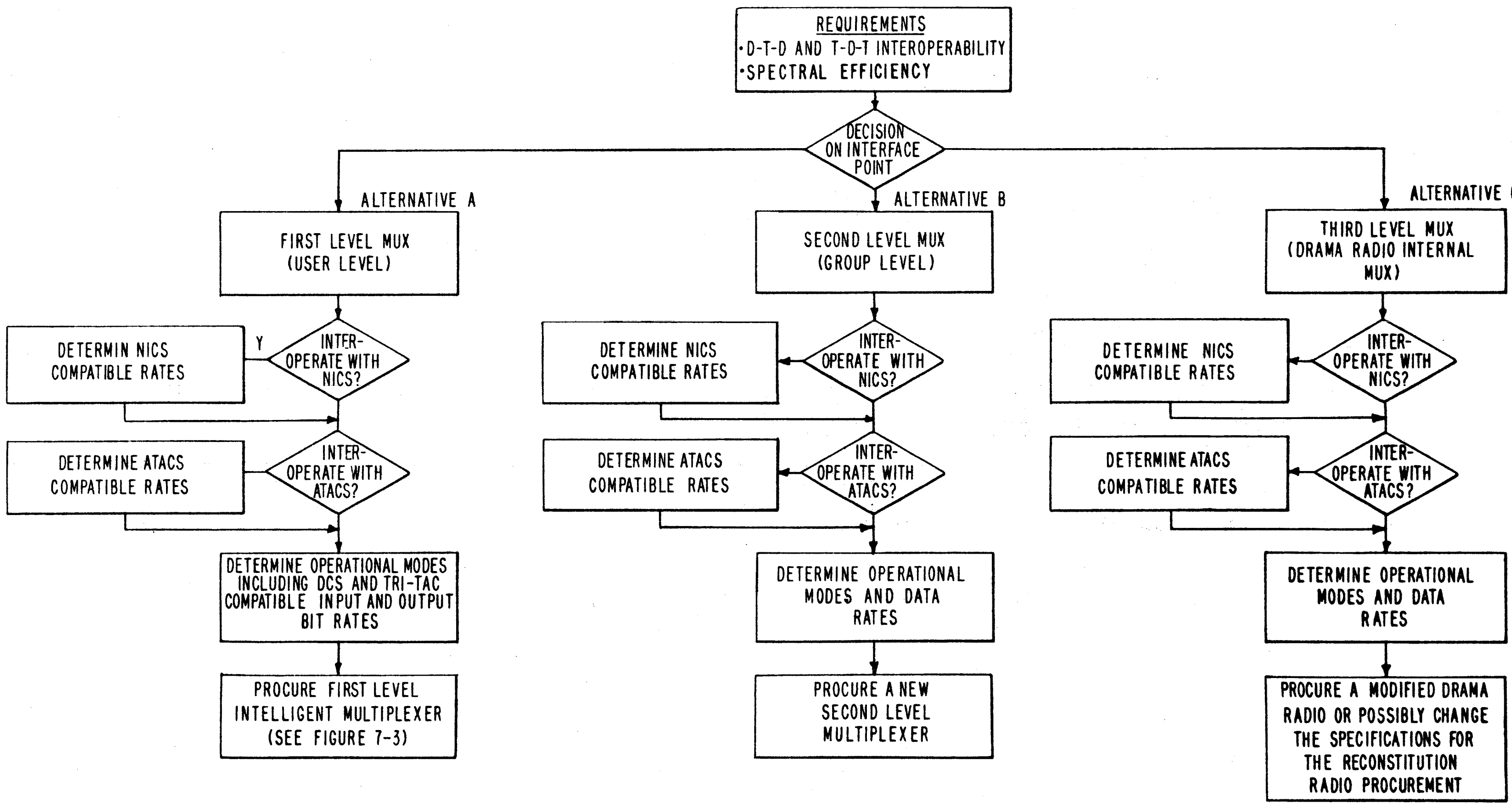


Figure 37. Digital pipeline interoperability alternatives.

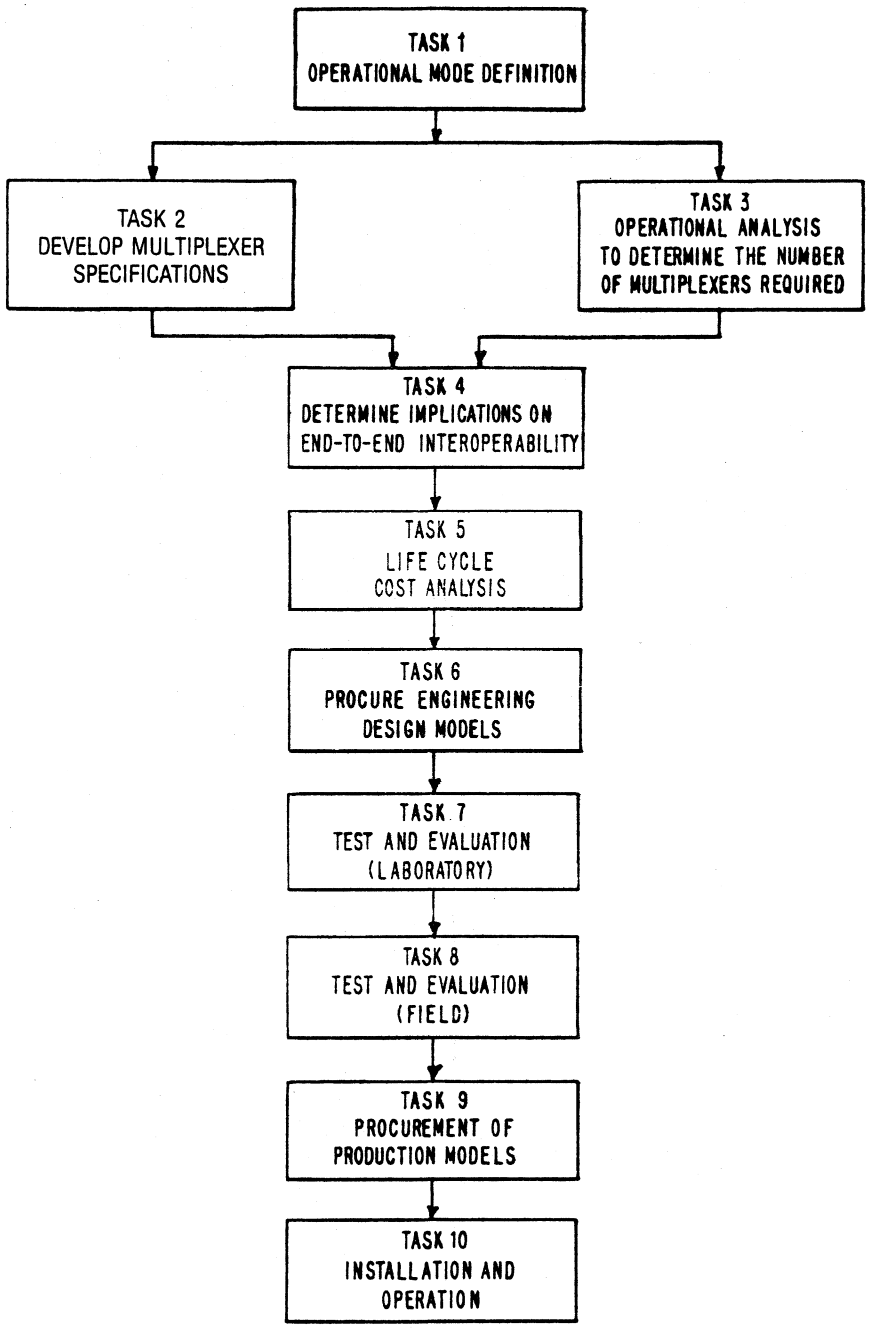


Figure 38. Recommended tasks for intelligent first level multiplexer development.

Table 15. First Level Intelligent Multiplexer Development
Task 1: Operational Mode Definition

Subtask	Description
1a.	estimate the number of traffic channels expected to cross the TRI-TAC/DCS interface
1b.	determine DCS/TRI-TAC/DCS modes including the mix of dedicated data and voice channels.
1c.	determine TRI-TAC/DCS/TRI-TAC modes including the mix of dedicated data and voice channels
1d.	define DCS transparent modes (i.e., FCC-98 replacement modes)
1e.	define TRI-TAC transparent modes (i.e., LGM replacement modes)
1f.	determine modes for interoperating with NICS (or PTT's) and ATACS

Table 16. First Level Intelligent Multiplexer Development
Task 2: Specifications Development (Detailed Design Study)

Subtask	Description
2a.	input module specification - VF input modules - 16/32 kb/s CVSD input modules - data (synchronous and asynchronous) input modules; what data rates and line codes
2b.	specification of what combinations of input modules are allowable (i.e., what combinations of CVSD digital voice, analog voice, and data are allowable)
2c.	specification for combined channel group rates that should be used; what input modes of the second level multiplexers (FCC-99 or TGM) should be accommodated
2d.	specification of channel activity detectors
2e.	specification of voice/data detectors
2f.	specification of the speech compression technique to be used (e.g., ADPCM) to avoid speech clipping for DSI; further analysis of papers on speech digitization is needed
2g.	specification of the channel assignment information (CAI) requirements
2h.	specification of the CAI channel encoding (such as the Hamming code) requirements
2i.	specification of the frame format (which is variable depending on the speech activity, number of data channels, etc.)
2j.	specification of timing requirements for both internal clock and external clocks; address the question of interoperation of two pleisochronous systems (DEB and TRI-TAC)
2k.	specification of encryption device interfaces
2l.	specification of tech control interfaces in the DCS and TRI-TAC
2m.	specification of BITE and redundancy requirements
2n.	specification of processing requirement for the microprocessor controller
2o.	specification of modularity requirements
2p.	specification of physical characteristics including physical interfaces, size and weight, and ruggedness requirements
2q.	specification of acceptance testing

This would consist of a more detailed functional design of the new multiplexer than was given in Section 5. The remainder of the tasks depicted in Figure 38 are mostly self explanatory as they consist of generic tasks that are germane to any applied R&D program that has the objective of fielding operational hardware. The life-cycle cost analysis should include both the development cost analysis and O&M (operations and maintenance) cost analysis.

7.2 Recommended Tasks for End-to-End Interoperability

Figure 39 depicts the recommended sequence of tasks for a further investigation of the end-to-end interoperability issue. The first task is to refine the end-to-end interoperability requirements that were stated in general terms in Section 3. The identification of specific requirements is a difficult problem because most interoperability requirements are stated only in general terms.

As indicated in Figure 39, Tasks 2 through 5 may be conducted in parallel. Note, however, that the SYSCON interoperability study (Task 2) and the CCS interoperability study (Task 3) are not totally independent tasks. The ETS Control Communications Network which provides the transmission media for SYSCON information may be implemented on the ETS common channel signaling network. Therefore, there is overlap between Tasks 2 and 3.

Tables 17 through 20 are expansions of Tasks 2 through 5 depicted in Figure 39.

Task 5 warrants further explanation. This task is a survey of state-of-the-art switch technology. As indicated in Section 6 of this report, the initial alternative concepts for achieving end-to-end interoperability are oriented around switch modification or development. Of particular interest is the requirement for multirate switching and integrated voice and data switching. Switch development is, of course, an expensive undertaking. Therefore, it is desirable to utilize available commercial switches (possibly with some modifications to implement unique military user service features). This is the reason that a survey of available switch technology is an essential task.

Task 6 consists of the development of alternative concepts for end-to-end interoperability with the emphasis on switch requirements. Some preliminary alternative concepts were provided in Section 6 of this report. The alternative concepts introduced were:

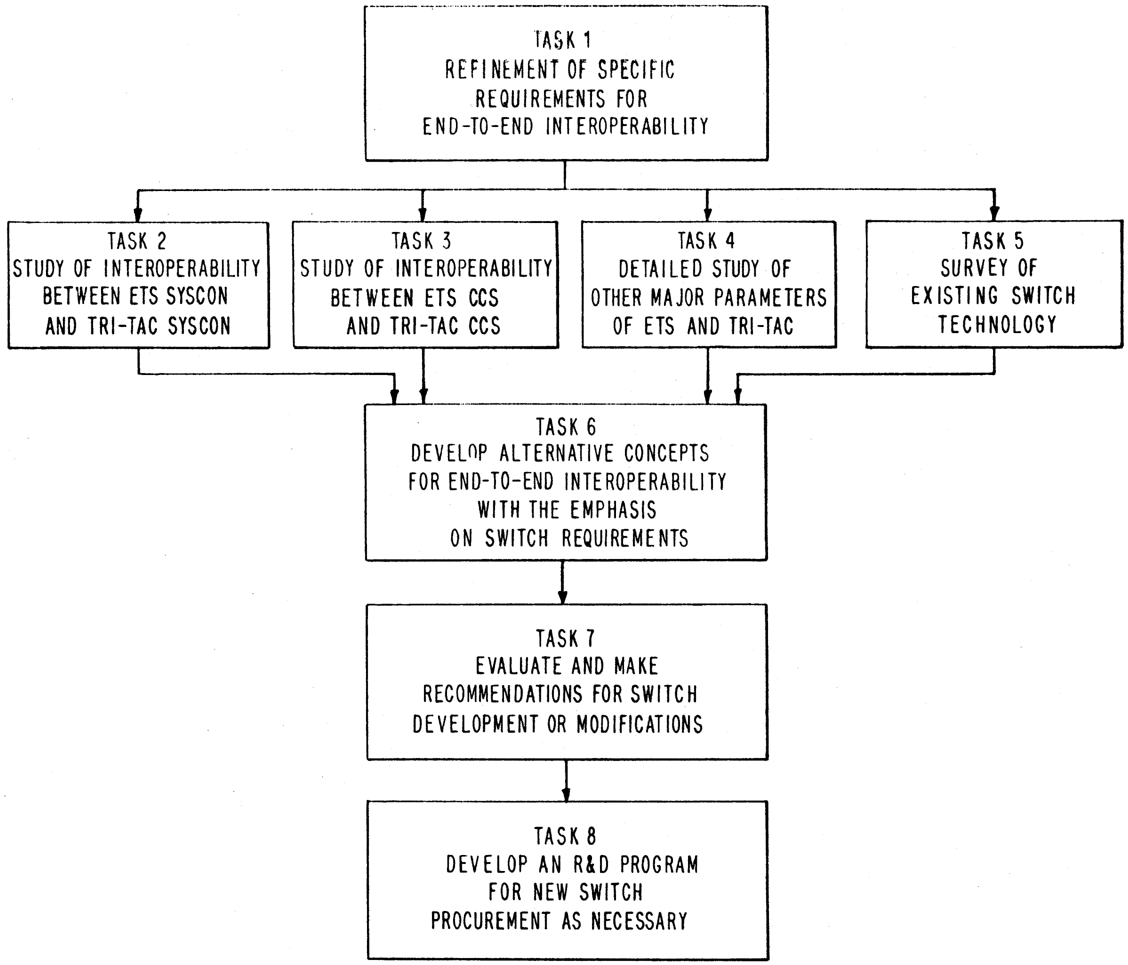


Figure 39. Recommended tasks for end-to-end interoperability.

Table 17. End-to-End Interoperability Task 2: Detailed Study of SYSCON Interoperability

Subtask	Description
2a.	determine the levels in the system control hierarchy that ETS and TRI-TAC SYSCON facilities should interoperate
2b.	determine the types of information that must be exchanged
2c.	define the SYSCON message types and formats
2d.	define the data elements
2e.	define the communications protocol to be used (TRI-TAC uses a modified ADCCP protocol)
2f.	determine the data rates to be used and the transmission facilities to be employed (ETS employs a separate network for SYSCON information transmission)
2g.	determine the encryption and channel coding techniques to be employed

Table 18. End-to-End Interoperability Task 3: Detailed Study of Common Channel Signaling Interoperability

Subtask	Description
3a.	investigate differences in CCITT #7 CCS and TRI-TAC CCS protocols
3b.	determine how the CCITT #7 CCS will be modified to meet special military requirements for MLPP, community-of-interest screening, hotline, etc.
3c.	perform a detailed comparison of the functional equivalency of CCITT #7 and TRI-TAC CCS messages
3d.	for CCITT #7 and TRI-TAC CCS messages that are functionally equivalent, perform a field-by-field comparison of the message information content
3e.	devise a methodology for implementing new message formats as required to resolve problems of missing information fields (derived from Task 3c above) or messages that have no functional equivalency (derived from Task 3b above)
3f.	investigate the ramifications of differences in CCS data rates (CCITT #7 uses 64 kb/s while TRI-TAC uses 16 or 32 kb/s)

Table 19. End-to-End Interoperability Task 4: Detailed Study of Other Major Parameters of ETS and TRI-TAC

Subtask	Description
4a.	study voice digitization techniques for minimizing and controlling the number of tandem conversions between CVSD and 64 kb/s PCM; determine where to convert from CVSD to PCM and vice versa
4b.	detailed study of ETS and TRI-TAC numbering plans and routing control
4c.	detailed comparison on the ETS and TRI-TAC multiplexer hierarchies with emphasis on the number of channels rather than transmission rate
4d.	study of timing and synchronization problems encountered when interfacing two plesiochronous networks
4e.	study encryption differences
4f.	investigate user service feature requirements for both TRI-TAC and ETS

Table 20. End-to-End Interoperability Task 5: Survey of Existing Switch Technology

- integrated voice/data
- multirate switching
- line capacity
- user service features
- ability to interface with both North American standard and European standard digital groups

(a) modification of ETS switches;

(b) modification of the TRI-TAC AN/TTC-39 switch;

(c) combination of (a) and (b), and

(d) the development of a new multirate switch.

Examination of these alternatives in detail as valid alternatives must be deferred pending the outcome of Tasks 1 through 5. Task 6 then would define these or other alternatives in detail.

Tasks 7 and 8 involve the evaluation of the alternatives formulated in Task 6 and the development of an R&D program for implementing the selected alternative.

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APPENDIX A: EUROPEAN DCS AND TRI-TAC ARCHITECTURE AND EQUIPMENT CHARACTERISTICS

This appendix contains numerous figures and tables that provide information on the ETS, DEB, DRAMA, and TRI-TAC architecture, radios, multiplexers, and switches. A detailed description of each of these tables and figures is not provided because they are all fairly self-explanatory. It was necessary to investigate the characteristics of these DCS and TRI-TAC equipments in order to have sufficient background to generate alternatives for achieving DCS/TRI-TAC interoperability. The figures and tables of this appendix are the result of that investigation. Because they are thought to be useful reference material, they are included in this report. If detailed descriptions of this equipment are desired the reader is referred to the bibliography at the end of this appendix.

The figures and tables are grouped by subject matter as follows:

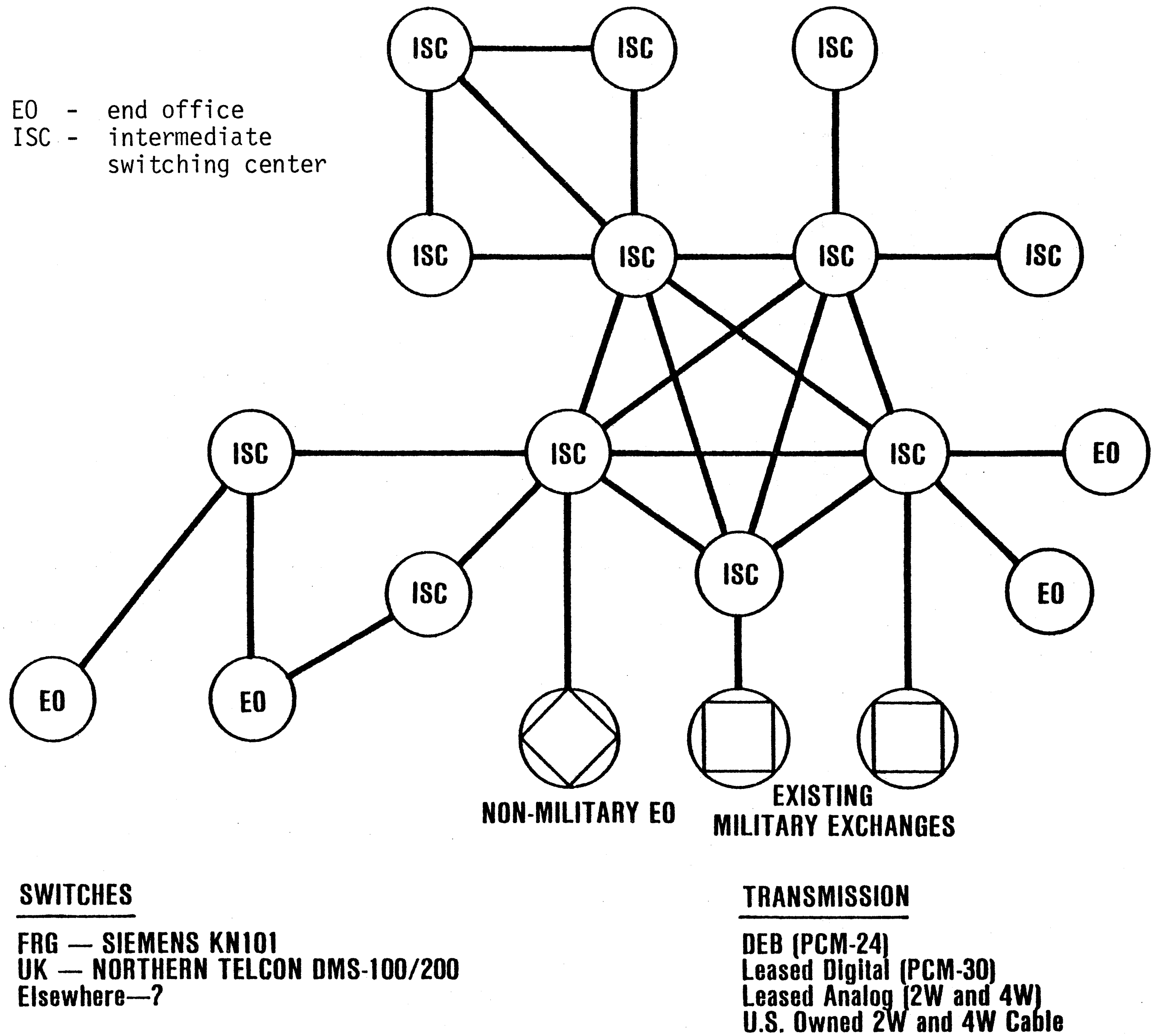


Figure A-1. ETS architecture.

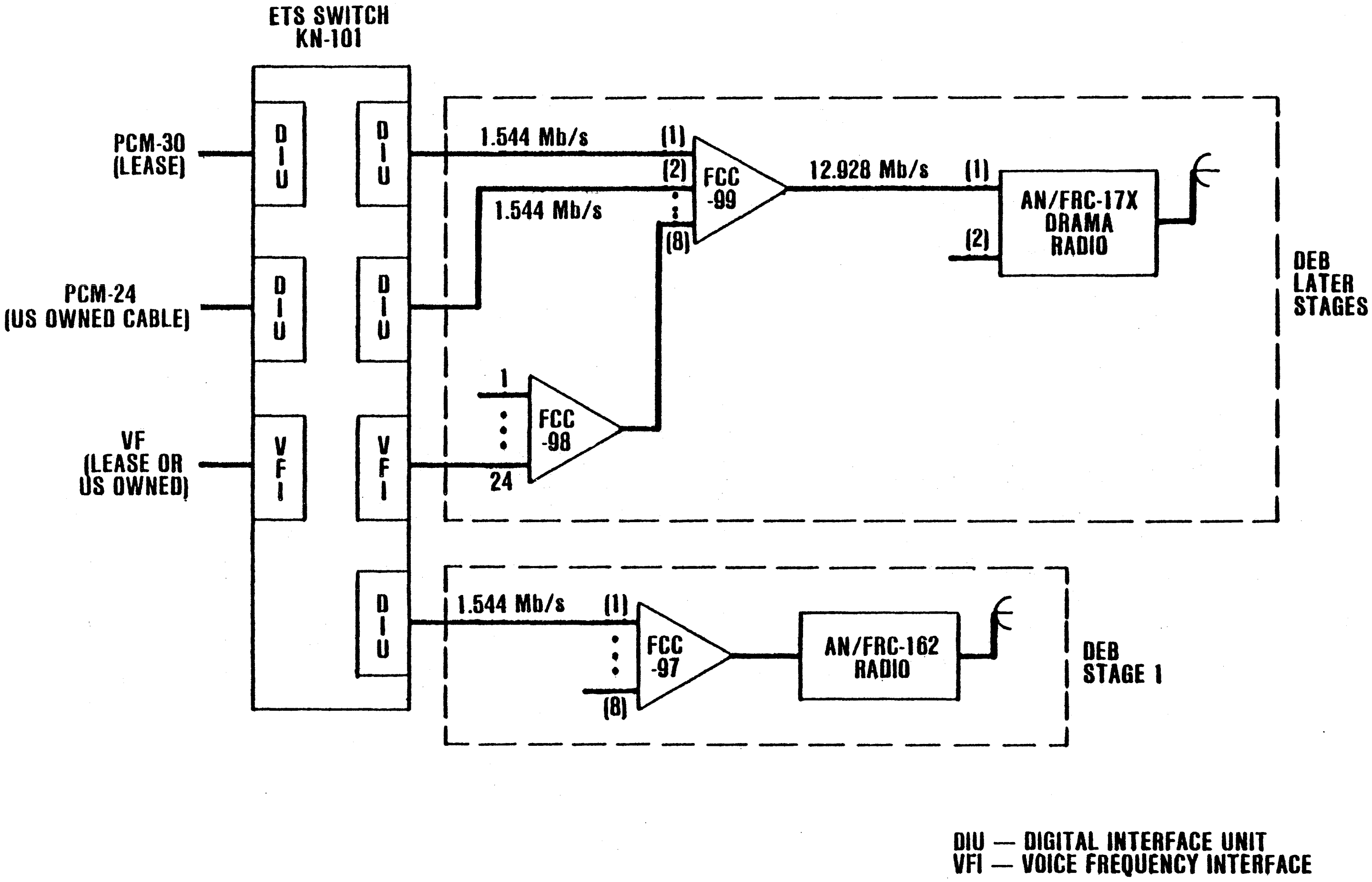


Figure A-2. Typical ETS switch and DCS transmission node.

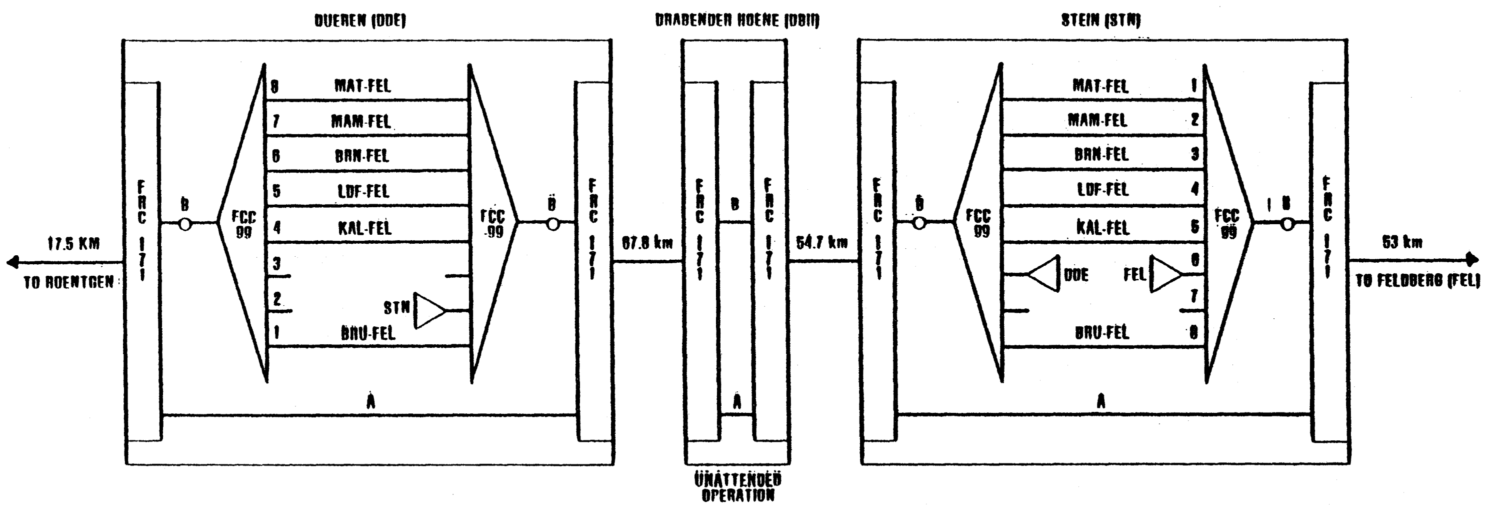


Figure A-3. Typical DEB nodes using DRAMA equipment.

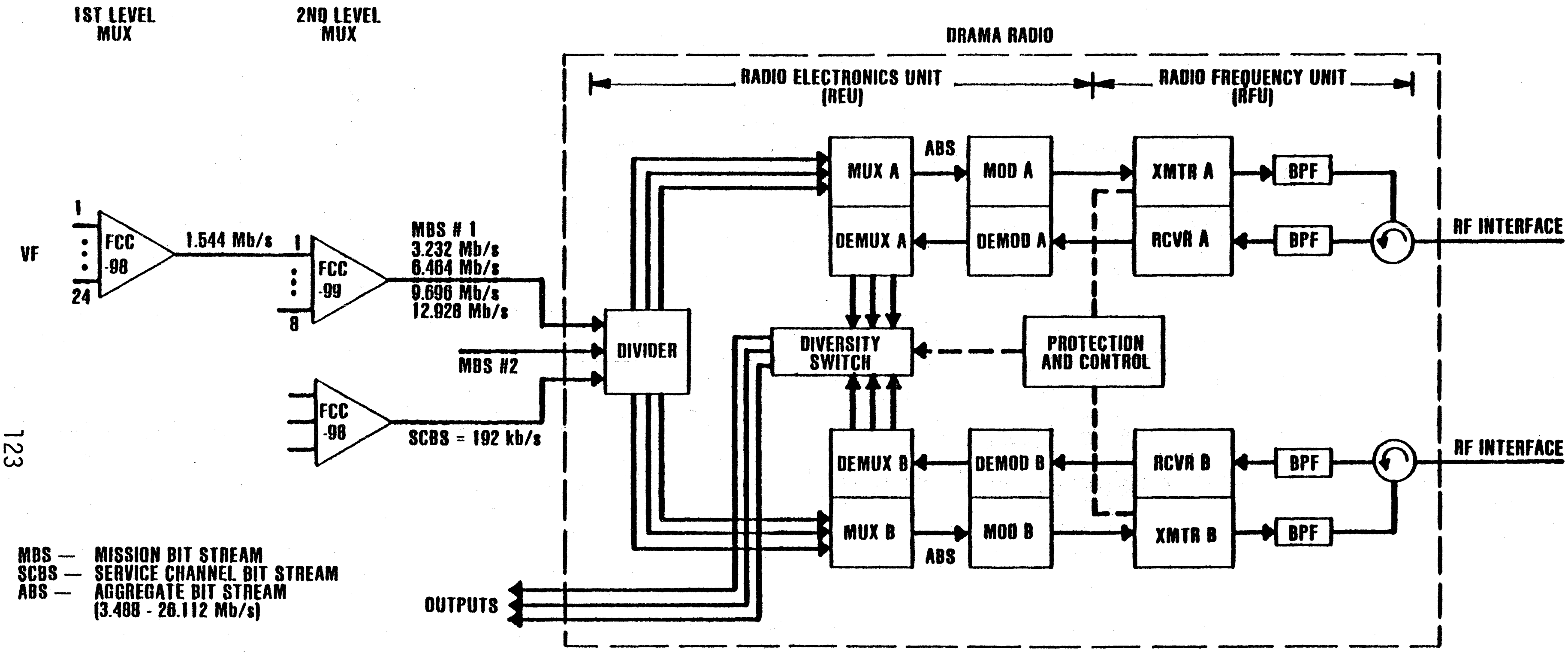


Figure A-4. DRAMA multiplexers and radio.

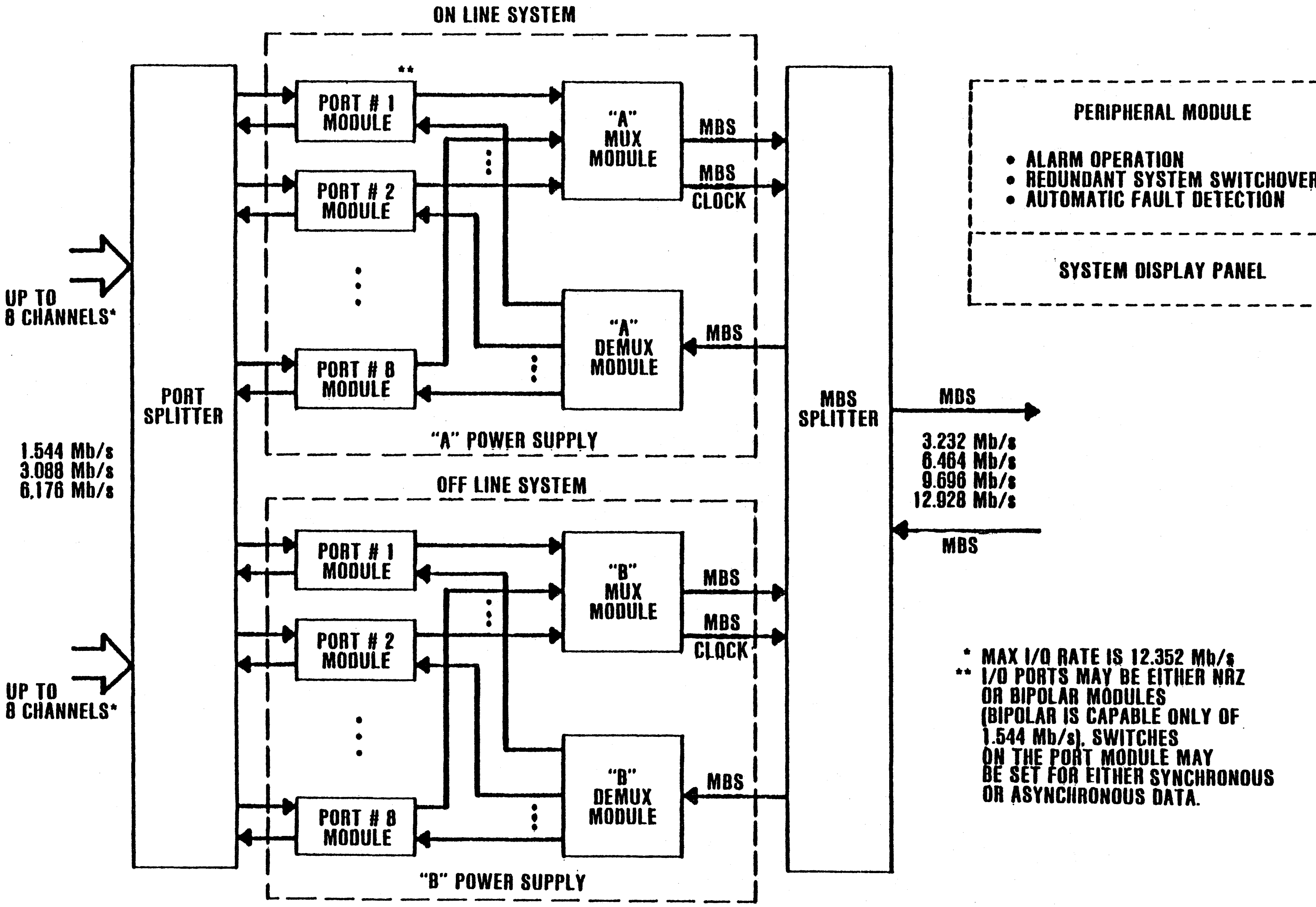


Figure A-5. AN/FCC-99 block diagram.

Table A-1. Characteristics of DRAMA Radio

Frequency: 4 GHz and 8 GHz

Modulation: QPSK and QPR

IF: 70 MHz

Bandwidth: 3.5, 7.0, 10.5, 14.0, or 20 MHz depending upon modulation and ABS data rates

Frequency and Space Diversity - no adaptive equalization

Aggregate Bit Stream Data Rates:

MBS Rate	1 MBS	2 MBS's
3.232	3.488	6.720
6.464	6.720	13.184
9.696	9.952	19.648
12.924	13.184	26.112

Table A-2. DRAMA Radio Versions

AN/FRC-170 (V)	4 GHz, space diversity
-171 (V)	8 GHz, space diversity
-172 (V)	4 GHz, frequency diversity
-173 (V)	8 GHz, frequency diversity

Radio (V) Number	# of MBS Ports	MBS Rate (Mb/s)	ABS Rate (Mb/s)*	Modulation	Bandwidth (MHz)
2	2	3.232	6.720	QPSK	7
1	1	6.464	6.720	QPSK	7**
5	2	6.464	13.184	QPR	7**
9	2	6.464	13.184	QPSK	14**
3	1	9.696	9.952	QPR	7
6	1	9.696	9.952	QPSK	10.5
7	2	9.696	19.648	QPR	10.5
11	2	9.696	19.648	QPSK	20
4	1	12.928	13.184	QPR	7**
8	1	12.928	13.184	QPSK	14**
10	2	12.928	26.112	QPR	14**
12	2	12.928	26.112	QPSK	20

*Includes 0.192 Mb/s SCBS and 0.064 Mb/s overhead.
**Reconstitution Radio Modes.

Table A-3. FCC-98 Configuration Options

Data Timing Module	24 ch version or 3/6/12/24 channel version
Bite	1 each
Input Power Module	-48 VDC or 117 VAC or 230 VAC
VF Channel Modules	$\leq$ Max. No. in mode - No. Data Channel Modules
Data Channel Modules	

	3/6/12/24 channel version channel mode				24 channel version data format	
	3	6	12	24	bipolar	NRZ
0-20 Kb/s Asynchronous	3	6	12	12[1]	12[2]	12[1]
50 kb/s Asynchronous	3	6	12	12[1]	12[2]	12[1]
56 kb/s Synchronous	3	6	12	12[1]	12[2]	12[1]
64 kb/s Synchronous		3(0)	9(0)	12[1]	12[2]	12[1]
128 kb/s Synchronous		1(0)	4(0)	12(6)	6[2]	12(6)
256 kb/s Synchronous			2(0)	6(3)	3[2]	6(3)
512 kb/s Synchronous			1(0)	3(1)	1[2]	3(1)

1) Limited by power consumption could go to 18.
2) Limited by 1's density.
3) Numbers in () are from specification.

Table A-4. AN/FCC-99 Second Level Multiplexer I/O Rates

Input	
3 Rates:	1.544, 3.088, 6.176 Mb/s
2 Modes:	synchronous/asynchronous
2 Formats:	NRZ/bipolar
Output	
4 Rates:	3.232, 6.464, 9.696, 12.928 Mb/s

Table A-5. FCC-99 Port Data Rate Combinations

Port Slots								Minimum MBS Rate
1	2	3	4	5	6	7	8	
1.544								3.232
1.544	1.544							3.232
1.544	1.544	1.544						6.464
1.544	1.544	1.544	1.544					6.464
1.544	1.544	1.544	1.544	1.544				9.696
1.544	1.544	1.544	1.544	1.544	1.544			9.696
1.544	1.544	1.544	1.544	1.544	1.544	1.544		12.928
1.544	1.544	1.544	1.544	1.544	1.544	1.544	1.544	12.928
3.088								3.232
3.088	1.544							6.464
3.088	1.544	1.544						6.464
3.088	1.544	1.544	1.544					9.696
3.088	1.544	1.544	1.544	1.544				9.696
3.088	1.544	1.544	1.544	1.544	1.544			12.928
3.088	1.544	1.544	1.544	1.544	1.544	1.544		12.928
3.088	3.088							6.464
3.088	3.088	1.544						9.696
3.088	3.088	1.544	1.544					9.696
3.088	3.088	1.544	1.544	1.544				12.928
3.088	3.088	1.544	1.544	1.544	1.544			12.928

Table A-5. (continued)

Port Slots								Minimum MBS Rate
1	2	3	4	5	6	7	8	
3.088	3.088	3.088						9.696
3.088	3.088	3.088	1.544					12.928
3.088	3.088	3.088	1.544	1.544				12.928
3.088	3.088	3.088	3.088					12.928
6.176								6.464
6.176	1.544							9.696
6.176	1.544	1.544						9.696
6.176	1.544	1.544	1.544					12.928
6.176	1.544	1.544	1.544	1.544				12.928
6.176	3.088							9.696
6.176	3.088	1.544						12.928
6.176	3.088	1.544	1.544					12.928
6.176	3.088	3.088						12.928
6.176	6.176							12.928

Table A-6. Features of KN-101 Switch

<u>Line Trunk Group Features</u> Subscriber Line Circuits, Analog (SLCA) - converted to 64 kb/s digital Subscriber Line Circuits, Digital (SLCD) Attendant Consoles - digital interface Trunk Lines - E&M, CCITT R1/R2 signaling PCM Digital Interface Units - PCM-24 and PCM-30 maximum of 4 DIU's per LTG <u>Subscriber Features</u> attendant recall, conferencing, camp-on, speed calling, call forwarding, etc. <u>Attendant Features</u> busy override, busy verification, displays, night service, information console, etc. <u>Switching System Features</u> AMA, classes of service, redundancy, priority and preemption, etc.

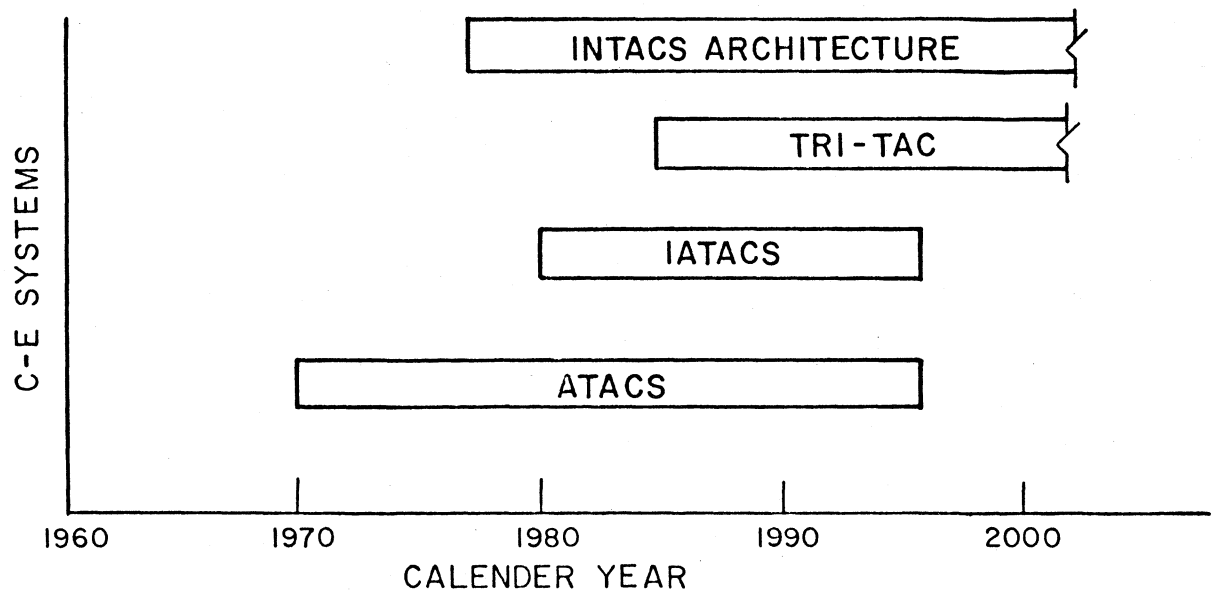


Figure A-6. Evolution of Army tactical communications to the INTACS objective system.

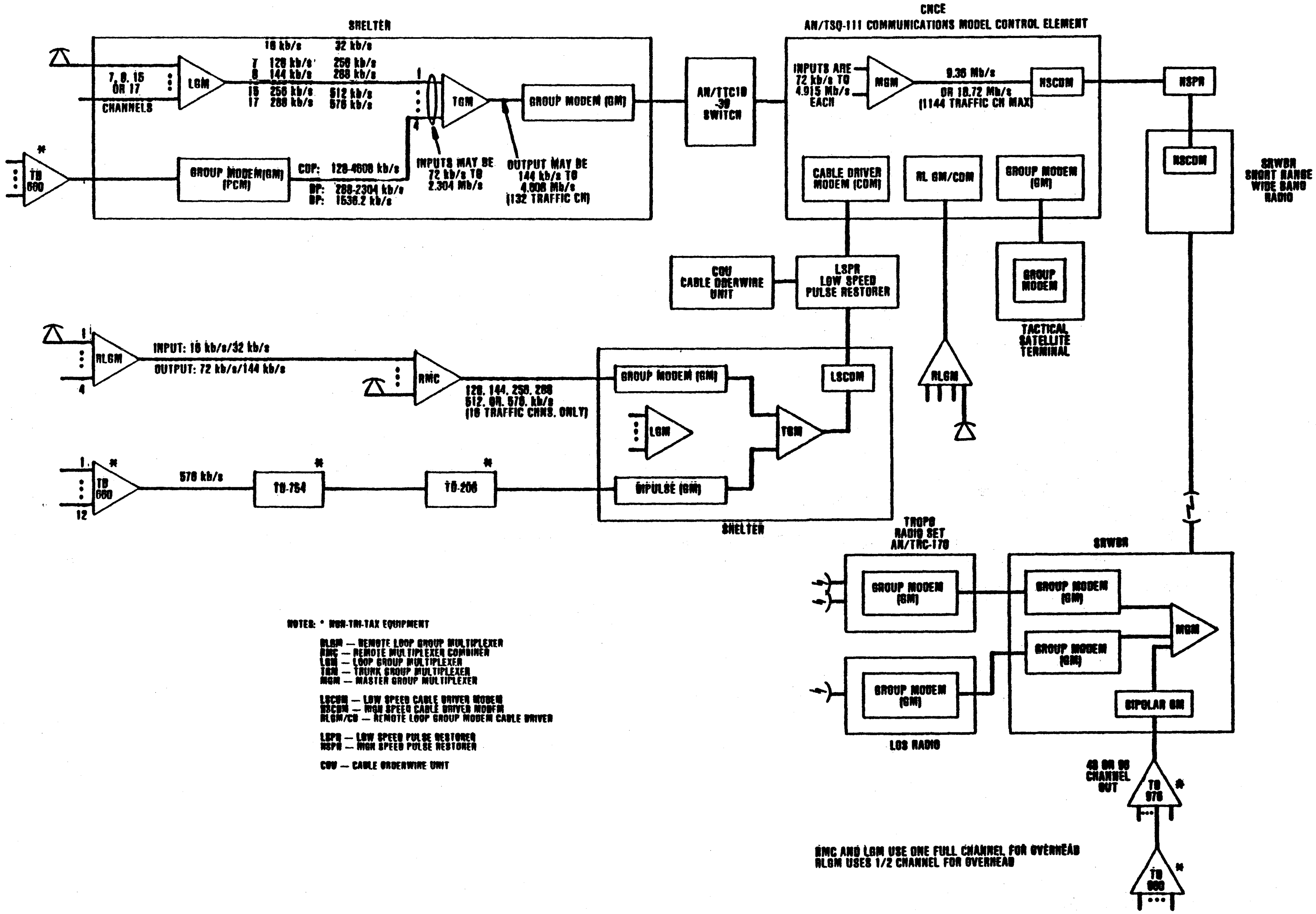


Figure A-7. Typical TRI-TAC equipment interconnects.

Table A-7. Equipment Being Developed for TRI-TAC

TRI-TAC Equipment		Equipment Status*	Comments
Switches			
AN/TTC-39	Large Circuit Switch	Jul 83	600 line switch; expandable to 2,400 lines
AN/TTC-42	Medium Circuit Switch	May 86	150 line switch; up to 24 analog
SB-3865	Small Unit Level Circuit Switch	May 86	30 line switch; 2 or 3 switches can be converted
AN/TTC-39	Large Message Switch	July 83	Store and forward message switch; 50 lines
AN/TYC-11	Medium Message Switch	TBD	12 line switch; part of MTCC
AN/GYC-7	Small Unit Level Message Switch	May 84 (IOT)	12 line switch
Note: all switches are digital with varying degrees of analog termination capability.			
Radios			
AN/TRC-170	Digital Tropo Radio	Jun 84	4.4-5.0 GHz; 2.048 Mb/s; 200 miles (320 km); 4 digital groups of 15 channels each
AN/GRC-144 (mod)	Short Range Wideband Radio	Jan 84	Used in AN/TRC-139 (mod) and AN/TRC-175
---	Short Range Wideband Radio (SRWBR)	TBD	
C-6709	Basic Net Radio Interface Unit (BNRIU)	Apr 83	Connects single channel radios to analog input of switch
---	Secure Digital Net Radio Interface Unit (SDNRIU)	May 86	Connects single channel radios to digital input of switch
Multiplexers, Modems, and Associated Equipment (Digital Group Multiplex Family - DGM)			
TD-1233	Remote Loop Group Multiplexer (RLGM)	May 84	4 channels
TD-1234	Remote Multiplexer Combiner (RMC)	May 84	8 channels
TD-1235	Loop Group Multiplexer Combiner (LGM)	May 84	17 channels
TD-1236	Trunk Group Multiplexer (TGM)	May 84	4 groups
TD-1237	Master Group Multiplexer (MGM)	May 84	12 groups
TD-1218	Low Speed Pulse Restorer (LSPR)	May 84	
TD-1219	High Speed Pulse Restorer (HSPR)	May 84	

*Equipment status dates are initial production dates unless otherwise indicated. Dates obtained from TRI-TAC office, April 1982 - Not for public release.

IOT - initial operational test; TBD - to be determined; UNK - unknown or unavailable.

Table A-7. (continued)

TRI-TAC Equipment		Equipment Status*	Comments
Multiplexers, Modems, and Associated Equipment (Digital Group Multiplex Family - DGM) (cont.)			
MD-1023	Low Speed Cable Driver Modem (LSCDM)	May 84	2.048 Mb/s
MD-1024	High Speed Cable Driver Modem (HSCDM)	May 84	18.720 Mb/s
MD-1025	Remote Loop Group Multiplexer Cable Driver (RLGM/CD)	May 84	Interfaces with 2 RLGM's; 2 mile cable length
MD-1026	Group Modem (GM)	May 84	Interfaces with 6 group multiplexers
MD-1065	103 modem	May 84	
C-10716	Orderwire Control Unit (OCU-1)	May 84	OCU's provides operator access to analog and digital voice orderwires. Used with different assemblages.
C-10717	Orderwire Control Unit (OCU-2)	May 84	
TS-3647	Cable Orderwire Unit (COU)	May 84	Cable link test set
Tactical Communications Control Facilities (TCCF)			
AN/TSQ-111	Communications Nodal Control Element (CNCE)	Nov 85	Technical control
AN/TYQ-16	Communications System Control Element (CSCE)	UNK	Near real-time allocation of resources; routing control
Note: CSCE's and CNCE's are interconnected by 2 kb/s SYSCON channels.			
Terminals			
TA-954/TA-984	Digital Nonsecure Voice Terminal (DNVT)	Oct 83	4 wire, 16/32 kb/s CVSD
CV-3591	Advanced Narrowband Digital Voice Terminal (ANDVT)	Jun 83 (IOT)	2,400 b/s LPC-10; interface with SDNRIU
TSEC/KY-68, TSEC/KY-78	Digital Subscriber Voice Terminal (DSVT)	UNK	4 wire, 16/32 kb/s CVSD; TDF/SST/DTE interfaces
AN/UXC-4	Tactical Digital Facsimile (TDF)	Sep 84	16 shades of grey; 1.2, 2.4, 4.8, 9.6, 16, 32 kb/s
AN/UGC-74	Single Subscriber Terminals (SST) Keyboard Print	Aug 85	Intelligent TTY; compose, edit, store, transmit and receive messages

*Equipment status dates are initial production dates unless otherwise indicated. Dates obtained from TRI-TAC office, April 1982 - Not for public release.

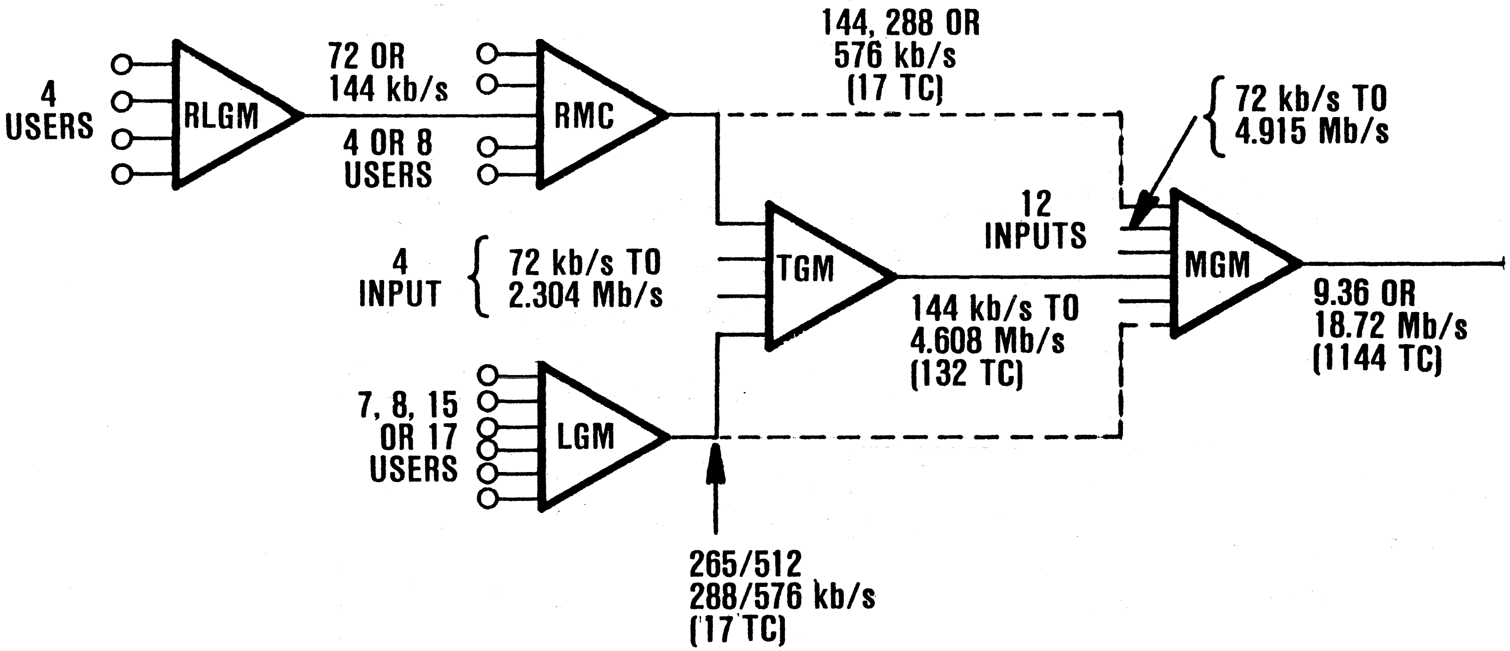
IOT - initial operational test; TBD - to be determined; UNK - unknown or unavailable.

Table A-7. (continued)

TRI-TAC Equipment	Equipment Status*	Comments
Assemblages		
Modular Tactical Communications Center (MTCC)	TBD	Includes TYC-11, terminals, and COMSEC devices
Mobile Subscriber Equipment (MSE)	TBD	Will include switches, transmission, control, COMSEC
Modular Record Traffic Terminal (MRTT)	---	Family of terminals; includes SST

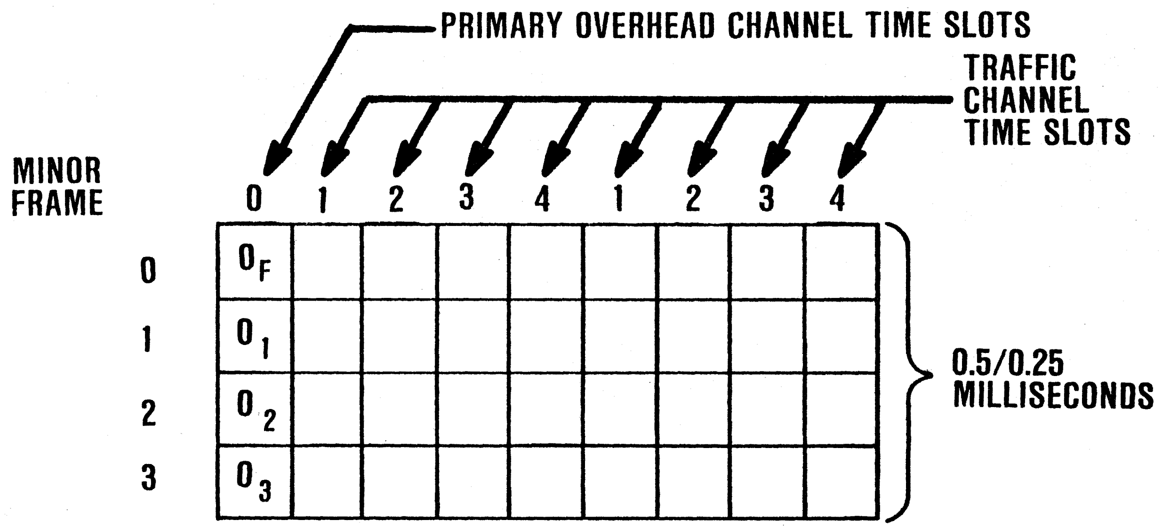
*Equipment status dates are initial production dates unless otherwise indicated. Dates obtained from TRI-TAC office, April 1982 - Not for public release.

IOT - initial operational test; TBD - to be determined; UNK - unknown or unavailable.



- RLGM = REMOTE LOOP GROUP MULTIPLEXER
- RMC = REMOTE MULTIPLEXER COMBINER
- LGM = LOOP GROUP MULTIPLEXER
- TGM = TRUNK GROUP MULTIPLEXER
- MGM = MASTER GROUP MULTIPLEXER
- TC = TRAFFIC CHANNELS (max capability shown)
- USER = 16 or 32 kb/s DIGITAL SUBSCRIBER

Figure A-8. TRI-TAC multiplexer hierarchy.



ORDER OF TRANSMISSION, LEFT TO RIGHT, TOP TO BOTTOM

0_F IS THE FRAMING BIT TIME SLOT

0_1 0_2 0_3 OVERHEAD CHANNEL TIME SLOTS

EACH MINOR FRAME PROVIDES TWO TIME SLOTS FOR EACH TRAFFIC CHANNEL

Figure A-9. TRI-TAC multiplexer signal format organization - four minor frames (used in RLGM).

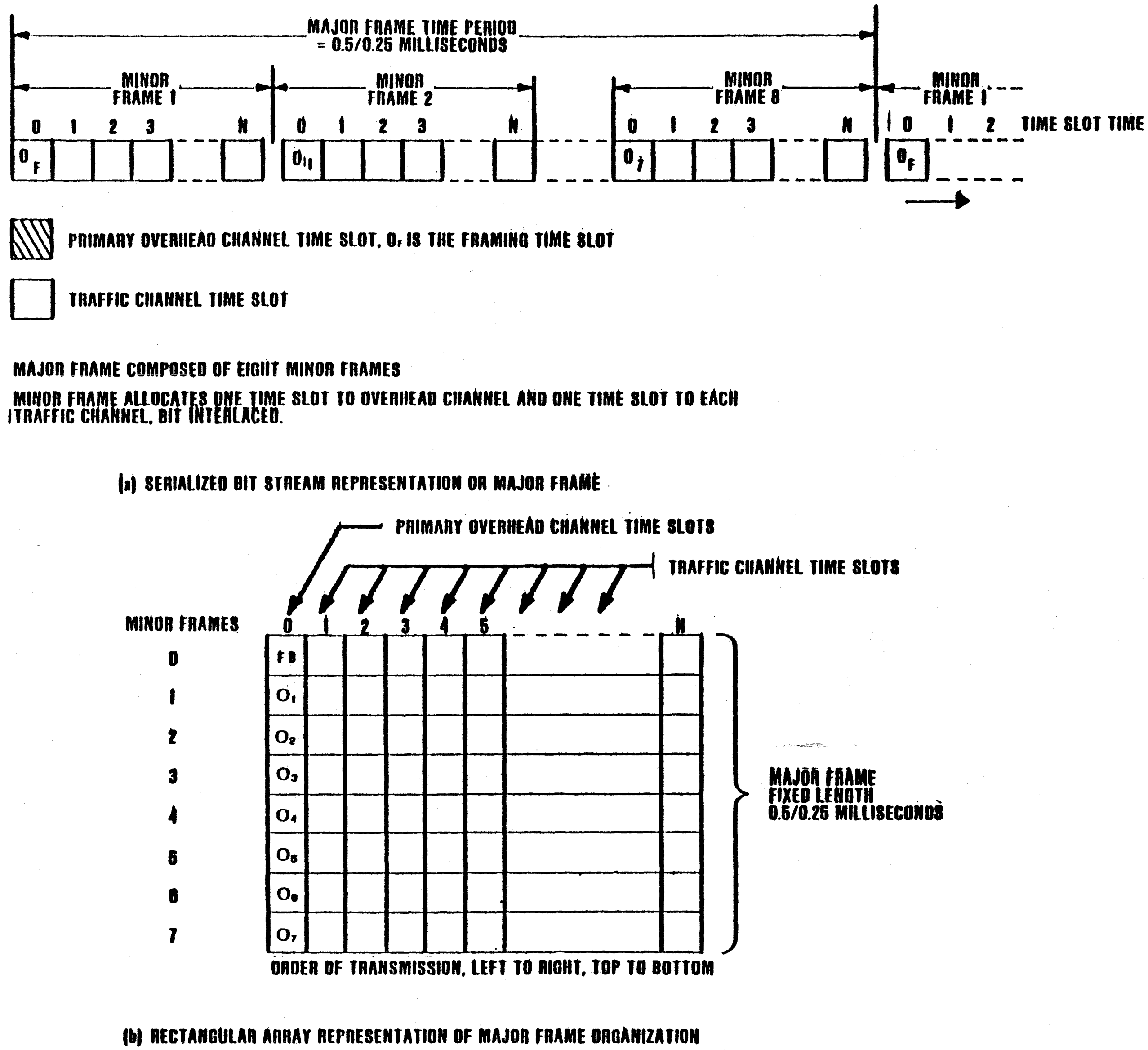


Figure A-10. TRI-TAC multiplexer signal format organization - eight minor frames.

Table A-8. Characteristics of TRI-TAC Multiplexers

Equipment	Input Characteristics					Output Characteristics		
	Number		Bit Rates		Format	Maximum Number of Traffic Channels	Bit Rates	Format
	Channels	Groups	Channels	Groups				
Remote Loop (RLGM) TD-1233	up to 4	---	16 or 32 kb/s	---	CDP	4	72 kb/s for 16 kb/s channels 144 kb/s for 32 kb/s channels	CDP
Remote Multiplexer Combiner (RMC) TD-1234	up to 8	1	16 or 32 kb/s	72, 128, 144 256, or 288 kb/s	CDP	16	128, 144, 256, 288 512, or 576 kb/s	CDP
Loop Group Multiplexer TD-1235	7, 8, 15 or 17	---	16 or 32 kb/s	---	CDP	17	# chns 7 128/256 kb/s 8 144/288 kb/s 15 256/512 kb/s 17 288/576 kb/s	NRZ
Trunk Group Multiplexer (TGM) TD-1236	---	up to 4	---	1. 128, 256, 512, 1,024, and 2,048 2. 144, 288, 576, 1,152, and 2,304 kb/s	NRZ	143	1. 128, 256, 512, 1,024, 1,536, 2,048, and 4,096 kb/s 2. 144, 288, 576, 1,152, 2,304, and 4,608 kb/s	NRZ
Master Group Multiplexer (MGM) TD-1237		up to 12		1. 128, 256, 512, 1,024, 1,536, 2,048, and 4,096 kb/s 2. 72, 144, 288, 576, 1,152, 2,304, and 4,608 kb/s 3. 4,915.2 kb/s	NRZ	1,144	9.36 and 18.72 Mb/s	NRZ

Table A-9. Remote Multiplexer Combiner (RMC)

16 kb/s Input Channels					32 kb/s Input Channels				
Number of Input Channels	Number of Input Groups	Total Number of Channels	Input Group Rate (kb/s)	Output Bit Rate (kb/s)	Number of Input Channels	Number of Input Groups	Total Number of Channels	Input Group Rate (kb/s)	Output Bit Rate (kb/s)
3	1 (4 channels)	7	72	128	3	1	7	144	256
7	---	7	---	128	7	---	7	---	256
8	---	8	---	144	8	--	8	---	288
4	1 (4 channels)	8	72	144	4	1 (4 channels)	8	144	288
8	1 (7 channels)	15	128	256	8	1 (7 channels)	15	256	512
8	1 (8 channels)	16	144	288	8	1 (8 channels)	16	288	576

Notes: a. 1 equal rate channel is used for overhead including framing and telemetry.
b. All channel quantities refer to traffic channels.

Table A-10. DGM Equipment Usage

	TRI-TAC Assemblage									
DGM Unit	AN/TRC-173	AN/TRC-174	AN/TRC-175	AN/TRC-138 MOD	AN/TRC-170 V1	AN/TRC-170 V2	AN/TRC-170 V3	AN/TSQ-111 Type I	AN/TSQ-111 Type III	AN/TTC-42
TD-1233 (RLGM)										
TD-1234 (RMC)	4									
TD-1235 (LGM)					2	2	2			
TD-1236 (TGM)	2				1	1	1			
TD-1237 (MGM)			2	1				2	1	
MD-1023 (LSCDM)	2	3			1	1	1	8	6	1
MD-1024 (HSCDM)			2	1				2	1	
MD-1025 (RLGM/CD)	4							6	4	
MD-1026 (GM)	2	1	6	2	1	1	1			
MD-1065 (GRC-103 MODEM)	1	2								
C-10716()/TRC OCU-1	1	1								
C-10717()/TRC OCU-2			1	1						

Table A-11. Digital Transmission Group Bit Rates (Nominal)

Total Channels (Includes Primary Overhead)	N Maximum Available Traffic Channels	Bit Rate at VDR of 16 kb/s (kb/s)	Bit Rate at VDR of 32 kb/s (kb/s)
4 1/2 [1]	4	72	144
8	7	128	256
9	8	144	288
16	15	256	512
18	17	288	576
32	31	512	1024
36	35	576	1152
48	47	----	1536
64	63	1024	2048
72	71	1152	2304
96	95	1536 [2]	----
128	127	2048	4096
144	142	2304	4608

Notes: 1. 8/16 kb/s overhead channel, 16/32 kb/s traffic channels.
2. TGM capability only.

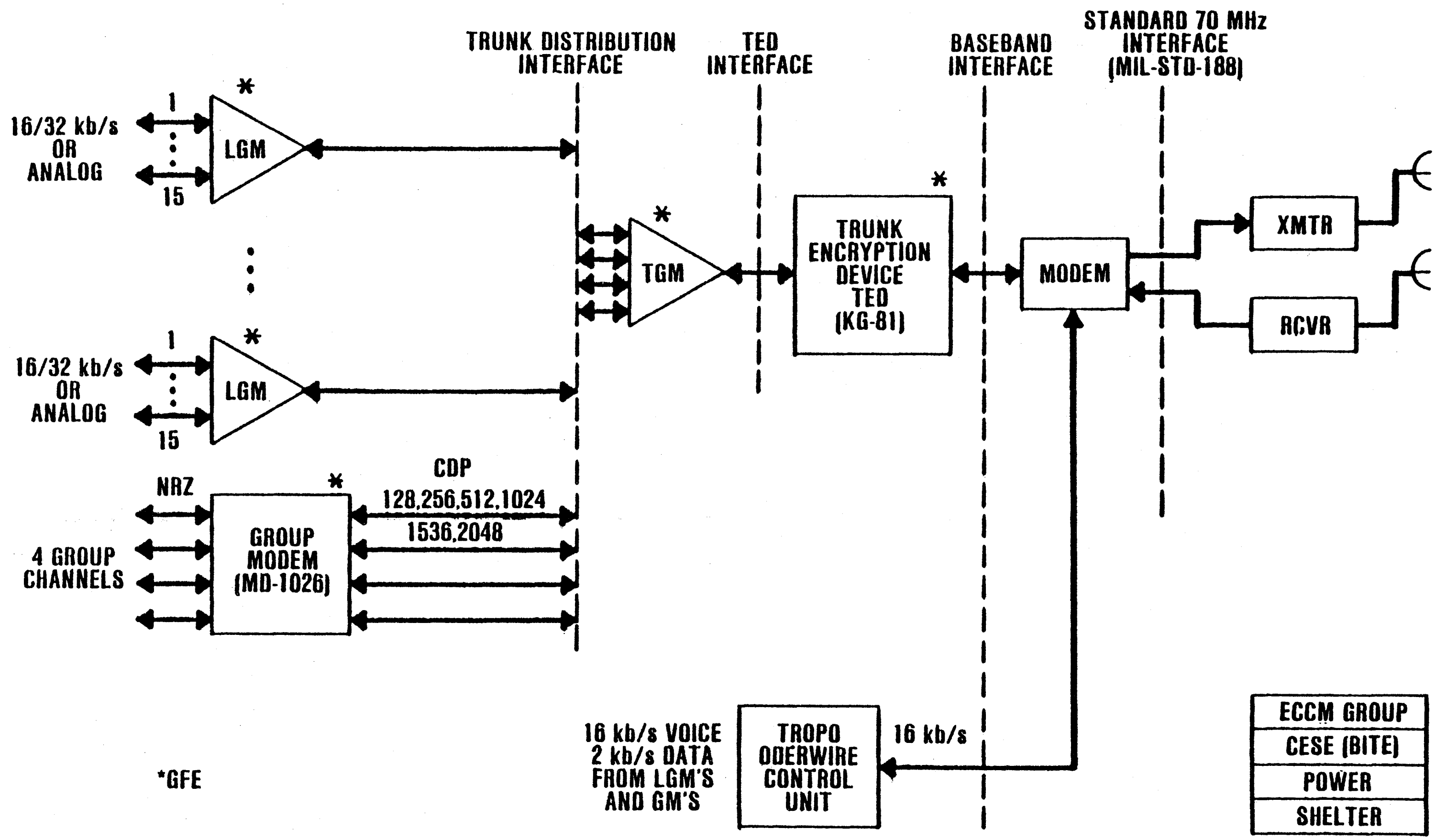


Figure A-11. TRI-TAC AN/TRC-170 radio terminal set.

Table A-12. AN/GRC-144 Radio Characteristics

	AN/GRC-144 (V3)	AN/GRC-144 (V4)
Frequency:	4.4-5.0 GHz	14.4-15.0 GHz
Tuning:	6,000 RF channels (100 kHz steps)	2,000 RF channels (300 kHz steps)
Mode:	high capacity LOS	short range wideband radio (SRWBR) - "down the hill communications"
Range:		8 km for data rates from 9.36-18.72 Mb/s 24 km for data rates up to 9.36 Mb/s
IF Bandwidth:	5.0 MHz	10 MHz for 9.36 Mb/s data rate 20 MHz for 18.72 Mb/s data rate
Data Rates:	1,024, 1,152, 1,536, 2,048 2,304, 4,096, 4,608, 4915.2 kb/s	same as for V3 plus 9.36 and 18.72 Mb/s
BER for a simulated path loss of 107.7 dB:	10^{-5}	10^{-5}
Interfaces:	MGM on channel side, group modem (GM)	high speed cable driver modem (HSCDR), master group multiplexer (MGM)

Table A-13. AN/TRC-170 Radio Characteristics

Frequency: 4.4-5.0 GHz

Tuning: 100 kHz steps

Mode: Troposcatter or LOS

IF: standard 70 MHz (MIL-STD-188)

IF Bandwidth: 3.5 and 7.0 MHz

Three Sets Having Differing Capabilities:

- Set 1: 200 mile (320 km) range; capable of transmitting simultaneously at two different frequencies
- Set 2: 150 mile (240 km) range; two frequencies
- Set 3: 100 mile (160 km) range; single frequency

LOS Mode:

- All sets are capable of LOS mode
- Lower power; interface with existing LOS antennas
- 3.5 MHz IF bandwidth only

Data Rates: 128, 256, 512, 1,024, 1,536, 2,048 kb/s (both LOS and tropo modes)

BER: 10^{-5}

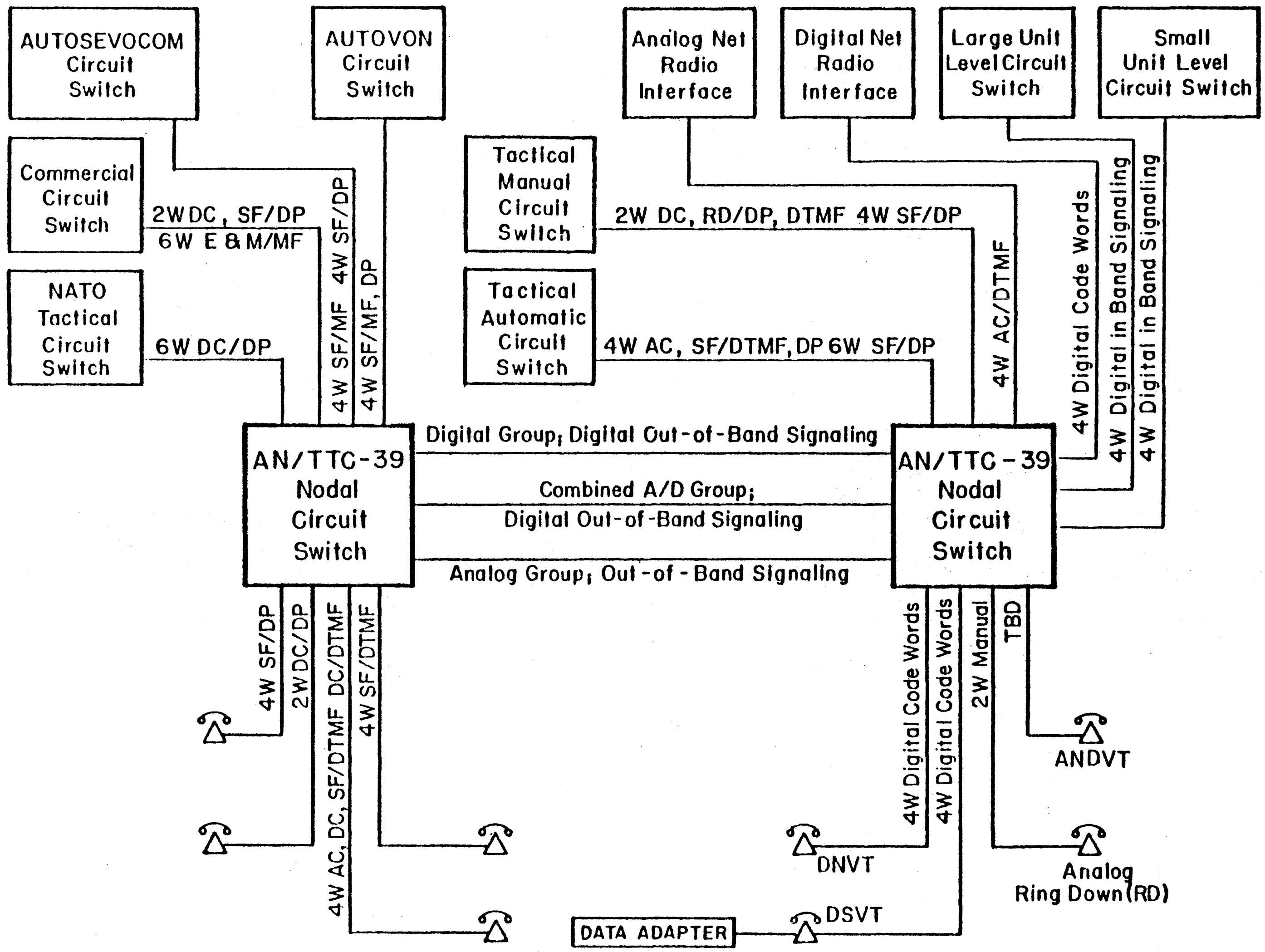


Figure A-12. AN/TTC-39 nodal circuit switch interconnectivity.

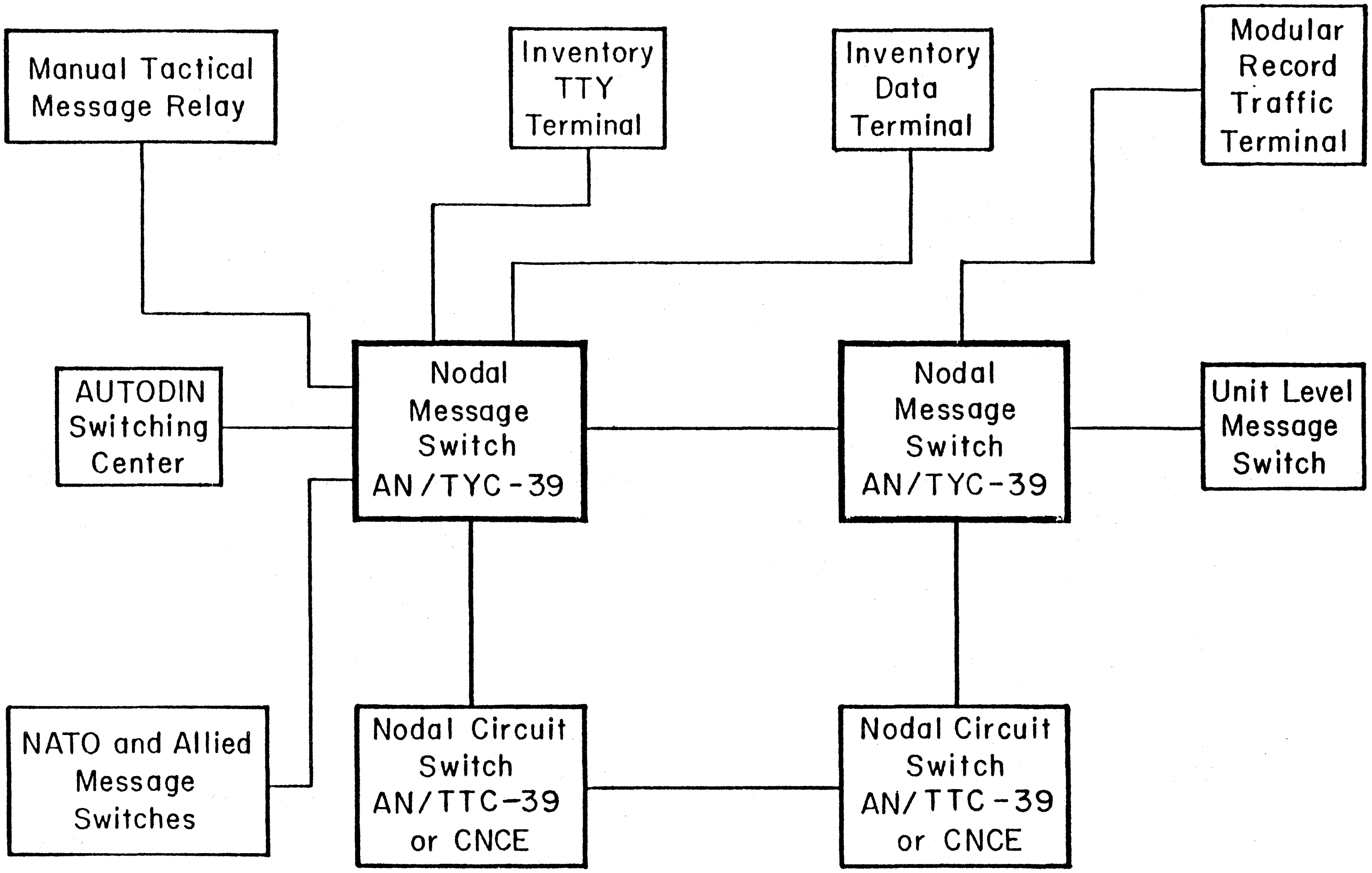


Figure A-13. Nodal message switch (AN/TYC-39) interconnectivity.

Table A-14. AN/TTC-39 Hybrid Circuit Switch Interface Capabilities

Interface Type	Line Type	Bandwidth or Bit Rate	Supervision	Signaling
I. Analog Loops	2W	nominal 3 kHz	AC, SF, DC	DTMF, DP, manual
	4W	nominal 3 kHz	AC, SF, DC	
	6W	nominal 3 kHz	AC, SF, DC	
	4W	nominal 50 kHz	SF	DP
II. Analog Trunks	2W	nominal 3 kHz	AC, DC, SF, E&M	DTMF, DP, MF 2/6, MF
	4W	nominal 3 kHz	AC, DC, SF, E&M	DTMF, DP, MP 2/6, MF
	6W	nominal 3 kHz	AC, DC, SF, E&M	DTMF, DP, MF 2/6, MF
	4W	nominal 50 kHz	SF	MF, DP
III. Digital Loop	4W	16 or 32 kb/s	digital codewords TT-A3-9015-0046	digital codewords TT-A3-9015-0046
	4W	2.4 kb/s	TBD	TBD
IV. Digital Trunk	4W	16 or 32 kb/s	digital in-band signaling TT-A3-9012-0055	digital in-band signaling TT-A3-9012-0055
V. Digital Trunk Group	4W	256-4,608 kb/s	digital out-of band signaling TT-A3-9016-0056	digital out-of band signaling TT-A3-9016-0056

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APPENDIX B: VOICE DIGITIZATION COMPARISON

A full description of the many voice digitization techniques that have been developed, and subjective comparisons of voice quality resulting from the use of these various techniques is clearly outside the scope of this report. Flanagan et al., (1979) provides an excellent tutorial on voice digitization, as well as a long list of references on the subject. In this appendix, the intent is to provide brief discussions of some of the factors that need to be considered when selecting a voice digitization technique and the results of a subjective comparison of several voice digitization techniques.

Table B-1 lists some of the factors that should be considered when evaluating voice digitization algorithms. Obviously the relative importance of these various parameters or characteristics is dependent upon the particular application. Some applications may require very high quality speech (toll quality or even commentary quality) while for other applications communications quality may suffice.

There is no single voice digitization technique that excels in each of the parameters listed in Table B-1. For example, continuously variable slope delta (CVSD) modulation is less susceptible to high bit-error rates (BER) than pulse code modulation (PCM), but PCM is degraded less by tandem processes than CVSD. As a second example consider adaptive transform coding (ATC) which is a frequency domain coding technique (Crochiere et al., 1982). The ATC algorithm provides excellent voice quality at 24 kb/s and quite good quality at 16 kb/s as judged in subjective listener tests (Daumer, 1982) but is very complex in its implementation (Flanagan et al., 1979; Crochiere et al., 1982).

Figure B-1 presents the speech quality versus codec complexity for several bit rates. This figure was derived from information originally presented by Crochiere et al., (1982). Flanagan et al., (1979) assign a complexity figure of merit to various codecs as follows:

Codec	Relative Complexity
ADM	1
ADPCM	1
SBC	5
PP-ADPCM	5
APC	50
ATC	50

Table B-1. Evaluation Factors for Voice Digitization Algorithms

- Voice Quality (communications quality, toll quality, commentary quality, etc.)
    - o performance in the presence of background noise, bit error rate, network losses echoes, etc.
    - o subjective measures: intelligibility, speaker recognition, voice naturalness, etc.
    - o objective measures
- Bit Rate
- Complexity of Hardware
- Cost (directly related to complexity)
- Tandem Capability
    - o asynchronous (A/D-D/A-A/D etc.)
    - o synchronous (A/D_1-D_1/D_2-D_2/D_1 etc.)
- Delay (related to tandem encodings)
- Voice-Band Data and Signal Tone Encoding
- Dynamic Range
- Submultiple of 64 kb/s

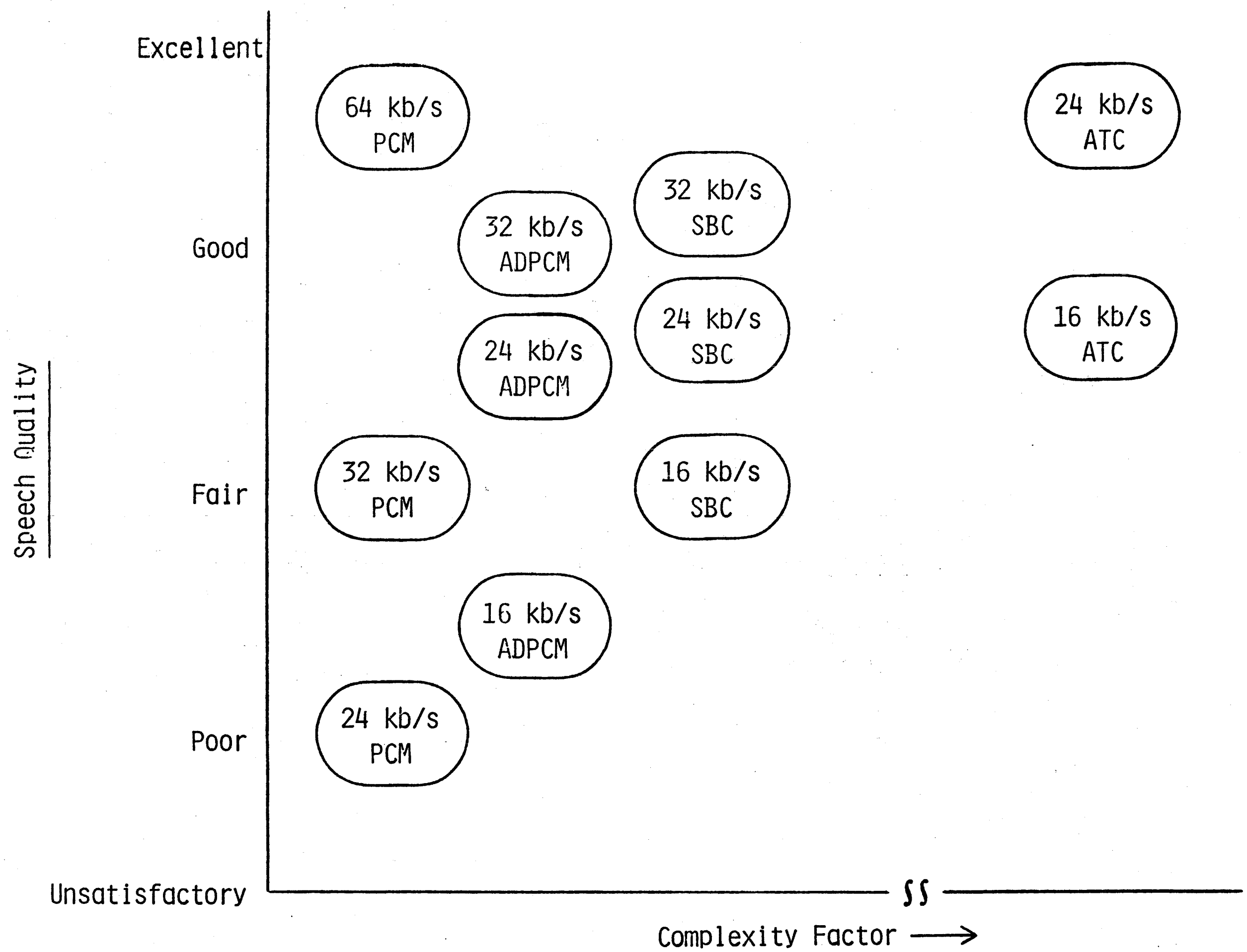

Figure B-1. Speech quality versus codec complexity for several bit rates.

Table B-2 is a comparison of voice digitization techniques that summarizes the results obtained by Daumer (1982) of subjective listening tests. While the testing was not exhaustive and some variation in the results could reasonably be expected for a different set of listeners or test phrases, the results nevertheless are indicative of the type of performance that can be expected for the various low bit-rate voice coders. The test consisted of seven speech samples (both male and female) that were evaluated by 42 listeners thereby giving 292 votes for each voice encoding technique. Each listener gave a rating from 5 through 1 (excellent, good, fair, poor, and unsatisfactory). The mean opinion score (MOS) is simply the arithmetic mean of the ratings. The voice encoding techniques evaluated included:

PCM (pulse code modulation)

ATC (adaptive transform coding)

APC (adaptive predictive coding)

SBC (sub-band coding)

CJF-ADPCM (Cummisky-Jayant-Flanagan adaptive differential PCM), and

PP-ADPCM (pitch predictive ADPCM)

Both single and tandem encodings were evaluated. The tandem encodings included both asynchronous conversions (A/D/A/D etc.) and synchronous conversions (A/D1/D2/D1/D2 etc.).

As can be seen from Table B-2 32 kb/s CJF-ADPCM was actually rated higher (but not significantly higher) than 64 kb/s PCM. High ratings were also given to 24 kb/s APC and ATC for single encodings. The point is that for single encodings (which is the case for an all-digital network) substantial improvements in bandwidth utilization can be achieved without significantly degrading voice quality. For tandem encodings, there is little degradation in the voice quality for PCM while the degradation for other voice encoders may be significant. As noted earlier the acceptability of the performance of a particular voice encoder is dependent upon the network requirements such as the expected number of tandem conversions and the voice quality required (communications quality, toll quality, etc.).

The reader is cautioned that the results in Table B-2 were arrived at without considering such realistic network characteristics as the allowable encoding delay limitations and the existence of nonvoice signals such as voice band data in in-band signaling. Furthermore, the testing did not include modeling of

Table B-2. Comparison of Voice Digitization Techniques

Single Encoding		Tandem Encoding (asynchronous)		Tandem Encoding (synchronous)	
Technique	MOS	Technique	MOS	Technique	MOS
32 kb/s CJF-ADPCM	4.44	Single Conversion			
64 kb/s μ-255 PCM	4.43	64 kb/s μ-255 PCM	4.53		
Sources	4.39	32 kb/s CJF-ADPCM	4.30		
32 kb/s PP-ADPCM	4.27	16 kb/s APC	3.98		
24 kb/s APC	4.25	16 kb/s SBC	3.18		
32 kb/s SBC	4.25				
24 kb/s ATC	4.11	Double Conversions		Double Conversions	
32 kb/s CJF-ADPCM	4.04	64 kb/s μ-255 PCM	4.53		
24 kb/s SBC	3.91	32 kb/s CJF-ADPCM	3.70		
16 kb/s APC	3.86	16 kb/s APC	3.62	16 kb/s APC	3.68
24 kb/s PP-ADPCM	3.86	16 kb/s SBC	2.44	16 kb/s SBC	2.65
16 kb/s ATC	3.75				
12 kb/s APC	3.42	Four Conversions		Four Conversions	
16 kb/s PP-ADPCM	3.12	64 kb/s μ-255 PCM	4.38		
16 kb/s SBC	3.11	32 kb/s CJF-ADPCM	3.20		
32 kb/s μ-255 PCM	2.90	16 kb/s APC	2.74	16 kb/s APC	2.73
24 kb/s CJF-ADPCM	2.52	16 kb/s SBC	1.86	16 kb/s SBC	2.00
16 kb/s CJF-ADPCM	2.52				
9.6 kb/s ATC	2.39	Eight Conversions		Eight Conversions	
16 kb/s PCM	1.06	64 kb/s μ-255 PCM	4.16		
		32 kb/s CJF-ADPCM	2.40		
		16 kb/s APC	1.74	16 kb/s APC	1.89
		16 kb/s SBC	1.41	16 kb/s SBC	1.51

MOS = mean opinion score

network losses, noise, and echoes. The conclusions reached are for particular implementations of the algorithm; other implementations may result in different performance evaluations.

Another point that should be emphasized is that voice performance alone is a necessary, but not sufficient, figure of merit for evaluating coder performance. If the network also carries voiceband data, the BER that results from passing such signals through the codec must be considered. Many codecs are optimally designed for the unique spectral and temporal characteristics of the speech signal. Voice band data BER performance for low bit-rate codecs is degraded in comparison to the BER performance for the same data passing through a PCM coder. The higher voice band data rates such as 4,800 b/s are especially susceptible to degraded BER performance for some codecs. For such voice band data signals the codec may have to be bypassed entirely.

Table B-3 summarizes the conclusions that may be drawn from Table B-2. Obviously more work must be done in evaluating all of the factors listed in Table B-1 for a particular set of network requirements. This is clearly outside the scope of this appendix.

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Table B-3. Conclusions of Speech Coding

Single Encoding

- PCM is greatly degraded at bit rates lower than 64 kb/s
- PP-ADPCM performs better than CJF-ADPCM
- delays introduced by PCM and CJF-ADPCM are negligible
- complex coders introduce more delay e.g., vocoder driven ATC has a delay of about 128 ms
- no coding techniques below 16 kb/s are acceptable for high quality telephone service

Tandeming

- 64 kb/s PCM is degraded very little by tandem encoding
- SBC and APC perform poorly in either asynchronous or synchronous tandeming
- asynchronous tandem encoding is more of a problem than synchronous tandem encoding (although the difference is small for SBC and APC)
- as many as 4 tandem conversions are acceptable for 32 kb/s ADPCM

General

- coder selection is highly dependent upon the application (voice quality required, expected number of tandem conversions, economics, etc.)
- more work is needed

APPENDIX C: LINE CODES

Line code compatibility is necessary to achieve digital pipeline interoperability. Numerous types of line codes have been developed. Some line codes are self-synchronizing in that they always have a transition between levels during the middle of a bit interval. Other considerations in choosing a line code are:

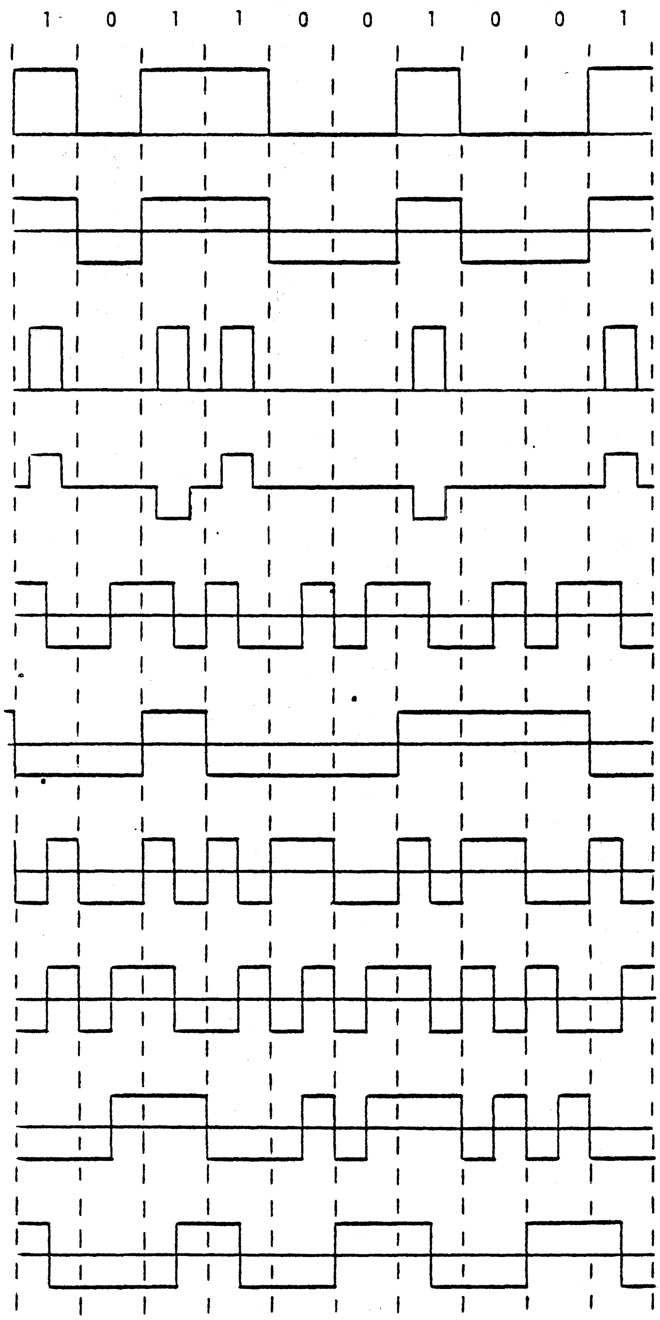
a. spectrum of the code and the available bandwidth,

b. noise and interference levels,

c. synchronization acquisition times, and

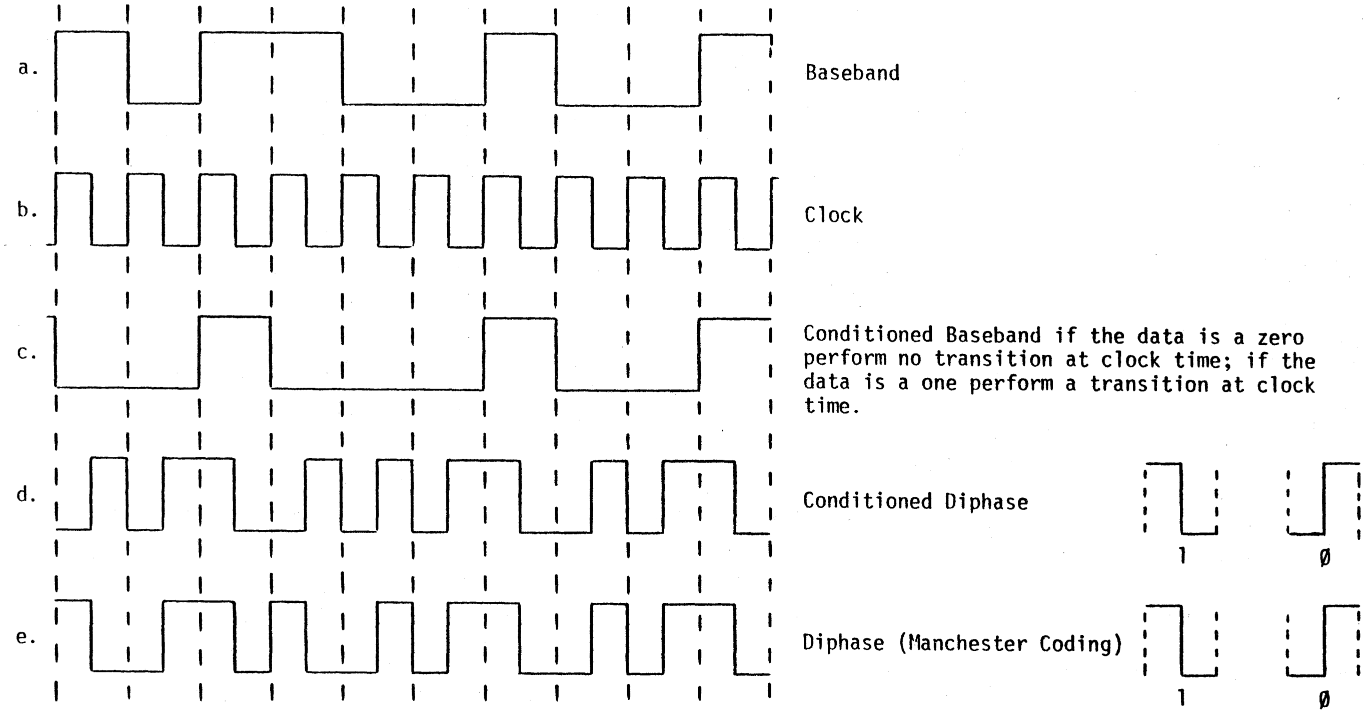
d. implementation requirements.

Figure C-1 provides a comparison of the most commonly used line codes including non-return-to-zero (NRZ) which is used in both TRI-TAC and DCS equipment. Figure C-2 provides a detailed comparison of conditioned diphase (CDP) which is used in some TRI-TAC equipment and regular diphase (Manchester) coding.



Notes: NRZ-S (not shown) is the inverse of NRZ-M. Bi-Ø-S (not shown) is the inverse of Bi-Ø-M.

Figure C-1. Comparison of commonly used line codes.



The conditioned diphase signal is formed by a two step process of first conditioning the baseband signal and then applying the diphase (Manchester coding) algorithm.

Figure C-2. Comparison of conditioned diphase (CDP) encoding with diphase (Manchester) coding.

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14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report discusses the different types of interoperability requirements, summarizes several related research and development projects, and presents alternatives for achieving interoperability between the Defense Communications System and the TRI-Service Tactical Communications System. These alternatives are evaluated, and a preferred alternative is recommended. The report concludes with brief tasking statements which are recommended to the U.S. Army Communications Systems Agency as the next steps in pursuing a research and development program for developing interoperability of the two systems at both the transmission subsystem level and at the end-to-end subscriber level. For transmission subsystem interoperability, emphasis is placed on the Digital European Backbone and Digital Radio and Multiplexer Acquisition portions of the European DCS.

16. Key Words *(Alphabetical order, separated by semicolons)*

DCS; DEB; Digital European Backbone; digital radio; DRAMA; interoperability; multiplexer acquisition; TRI-TAC

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