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## THESIS

**INVESTIGATION INTO THE EFFECTS OF VOICE AND  
DATA CONVERGENCE ON A MARINE EXPEDITIONARY  
BRIGADE TRI-TAC DIGITAL TRANSMISSION  
NETWORK**

by

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June 2000

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CONVERGENCE ON A MARINE EXPEDITIONARY BRIGADE TRI-TAC  
DIGITAL TRANSMISSION NETWORK**

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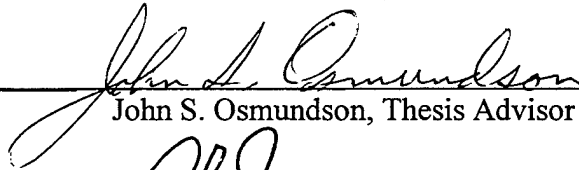
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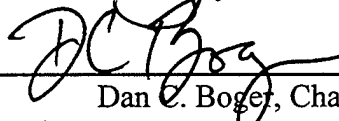
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## ABSTRACT

In the tactical environment, bandwidth demanded for data, video and voice services have increased faster than the capacity of new transmission devices are able to provide. Using Desert Knight 2000, a Marine Expeditionary Brigade exercise held in California in December 1999, as a case study, an investigation was made into the effects of network convergence on transmission system bandwidth. The focus of this thesis was on the potential gains available by making use of unused bandwidth normally reserved for the voice telephone network for other services, such as video and data.

Using data collected from the exercise, and building a network model using Imagine That, Inc.'s Extend software, several experiments were conducted under varying network conditions to determine if network convergence could be a partial solution to the increased bandwidth demands of today's command and control network. After conducting 27 model runs, results indicate that convergence can provide significantly more bandwidth to the tactical user for other than voice services, as well as better service levels for the voice network.



## TABLE OF CONTENTS

I. INTRODUCTION .....	1
A. BACKGROUND .....	1
B. OBJECTIVE AND PURPOSE .....	1
C. SCOPE AND METHODOLOGY .....	2
D. ORGANIZATION OF THESIS .....	2
II. DEFINITION OF STUDY AREA.....	5
A. DESCRIPTION OF THE TRI-TAC NETWORK .....	5
1. TRI-TAC Characteristics.....	6
2. Marine Corps Voice Telephone Switches .....	7
a. AN/TTC-42 Automatic Telephone Central Office.....	7
b. SB-3865 Switchboard .....	9
3. Digital Transmission Equipment.....	11
a. AN/TRC-170(v)5 Digital Tropospheric Scatter Microwave Radio Terminal .....	11
b. AN/MRC-142 Digital Radio Set .....	14
c. AN/TSC-85B Nodal Mesh Terminal .....	15
d. AN/TSC-93B Nonnodal Terminal .....	16
B. LIMITATIONS OF CURRENT SYSTEM .....	17
1. Bandwidth Restrictions and Inefficiencies .....	17
2. Circuit Switch Routing Restrictions .....	18
C. CASE STUDY—DESERT KNIGHT '00 .....	19
1. Exercise Purpose .....	19
2. Communications Network Architecture .....	20
a. Voice Network .....	20
b. Transmission Network .....	21
c. Data Network .....	22
d. Video Requirements.....	22
III. NETWORK MODELING AND SIMULATION .....	25
A. NETWORK MODELING AND SIMULATION DESIGN .....	25
1. Extend .....	25
a. Software Description.....	25
b. Advantages of Extend .....	26
c. Limitations of Extend.....	27
2. Methodology for DK'00 Architecture Modeling .....	28
a. Background of Modeling Process .....	28
b. Description of Desired Model Characteristics .....	29
3. Baseline DK'00 Model.....	30
a. Organization.....	30
b. Connectivity and Routing .....	30
c. Factors to be Tested .....	32
B. NETWORK MODELING AND SIMULATION EXPERIMENT DESIGN .....	36
1. Taguchi Method of Experiment Design .....	36
2. Experiment Design .....	37
a. Control Factors.....	38
b. Noise Factors.....	38
c. Orthogonal Array Construction.....	38
3. Experiment Metric Design .....	39
C. NETWORK SIMULATION EXPERIMENTS .....	41
1. Simulation Scenarios .....	41



IV. DATA ANALYSIS.....	45
A. EXPERIMENT RESULT DATA ELEMENT INPUT .....	45
1. Total Link Bandwidth .....	45
2. Bandwidth Reserved for Voice .....	45
3. Model Bandwidth Utilization .....	46
4. Completed Calls .....	46
5. Blocked Calls .....	47
B. EXPERIMENT STATISTICS COMPUTATION .....	47
1. Bandwidth Utilization Statistics .....	48
a. Bandwidth Used for Voice .....	48
b. Bandwidth Available for Other Services.....	48
c. Total System Available Bandwidth.....	49
2. Grade of Service Statistics.....	49
a. Aggregate Completed Calls and Aggregate Blocked Calls.....	49
b. Node Grade of Service .....	50
c. Aggregate Grade of Service .....	50
d. Grade of Service Sensitive Experiment Metric .....	50
3. Experiment Summary Statistics.....	50
a. Control Factor-to-Noise Factor Interaction .....	51
V. ANALYSIS RESULTS AND FINDINGS .....	53
A. EXPERIMENT RESULTS .....	53
B. EXPERIMENT ANALYSIS .....	54
1. Total System Bandwidth Available Metric Analysis .....	54
a. Experiment Results .....	54
b. Control Factor-to-Noise Factor Interaction .....	56
2. Grade of Service Sensitive Metric Analysis .....	59
a. Experiment Results .....	59
b. Control Factor-to-Noise Factor Interaction .....	61
VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH .....	65
A. CONVERGENCE IN THE TACTICAL ENVIRONMENT .....	65
B. RECOMMENDED AREAS FOR FUTURE RESEARCH .....	67
BIBLIOGRAPHY .....	69
APPENDIX A. DESERT KNIGHT '00 COMMUNICATIONS PLANNING DOCUMENTS.....	71
APPENDIX B. EXTEND MODEL BLOCKS .....	77
APPENDIX C. MODEL PROGRAMMING SHEETS .....	87
APPENDIX D. MODEL SPREADSHEET DATA .....	101
INITIAL DISTRIBUTION LIST .....	129

## LIST OF FIGURES

Figure 1. AN/TTC-42.....	9
Figure 2. SB-3865.....	11
Figure 3. AN/TRC-170(v)5 with OE-461 Antenna Group.....	13
Figure 4. AN/MRC-142.....	14
Figure 5. AN/TSC-85B with OE-361 Antenna Group.....	15
Figure 6. AN/TSC-93B.....	16
Figure 7. Transmission System Failures.....	34
Figure 8. Representative Call Arrival Distribution, 2-Minute Mean.....	35
Figure 9. Radar Graph of Total System Available Bandwidth Metric Results.....	56
Figure 10. Network Condition Interaction Graph for Total System Available Bandwidth Metric.....	58
Figure 11. Length of Mean Call Interaction Graph for Total System Available Bandwidth Metric.....	58
Figure 12. Network Loading Interaction Graph for Total System Available Bandwidth Metric.....	59
Figure 13. Radar Graph of Grade of Service Sensitive Metric Results.....	61
Figure 14. Length of Mean Call Interaction Graph for Grade of Service Sensitive Metric.....	63
Figure 15. Network Condition Interaction Graph for Grade of Service Sensitive Metric.....	63
Figure 16. Network Loading Interaction Graph for Grade of Service Sensitive Metric.....	64



## LIST OF TABLES

Table 1. Experimental Factor Levels .....	39
Table 2. Experiment Scenarios .....	43
Table 3. Inputted Data Element Sources .....	47
Table 4. Experiment Results For Total System Bandwidth Available Metric.....	55
Table 5. Experiment Results For Grade Of Service Sensitive Metric .....	60



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## **I. INTRODUCTION**

### **A. BACKGROUND**

Tactical command and control networks have increased in complexity at a rate that could be scarcely imagined when the first military digital transmission system was fielded. The tactical command and control network has also increased its appetite for bandwidth over the same period, driven by network users' service requirements unimagined when the tactical digital network was designed.

The Tri-Service Tactical Communications Program (TRI-TAC) is the joint tactical digital communications architecture in use today. It is primarily comprised of digital transmission systems, packet switches, voice circuit switches and message switches. TRI-TAC was designed when voice telephone services and record message traffic were the two services most demanded by tactical network users. These same users now demand much higher bandwidth services such as video teleconferencing, large file transfer services, e-mail connectivity and web browsing, in addition to the "traditional" voice and messaging services. The new bandwidth requirements are generating a tremendous load that the Spartan nature of the tactical network is having difficulty meeting.

### **B. OBJECTIVE AND PURPOSE**

This thesis seeks to address one possible solution to meeting the increased bandwidth demands of the tactical environment. Commercial telecommunications companies are beginning to move to a "converged" network environment; one where



voice, data and video services all are carried on a single backbone. This thesis will focus on the effects of convergence in a tactical environment, with the purpose of finding the best network architecture that meets the needs of the voice user, while making the most efficient use of limited tactical bandwidth available.

### **C. SCOPE AND METHODOLOGY**

Investigating the effects of convergence requires a modeling and simulation approach, with analysis of simulation results, as this form of network has not been used tactically. A baseline network was needed from which to build the simulation and provide a comparison case. 1<sup>st</sup> Marine Expeditionary Brigade conducted a large scale exercise in December 1999 that provided the baseline. Data was collected from this exercise and used to construct the model and provide baseline comparison.

### **D. ORGANIZATION OF THESIS**

Chapter II defines the thesis study area, with a description of the current TRI-TAC network, limitations of the current system, and a synopsis of the 1<sup>st</sup> Marine Expeditionary Brigade Desert Knight '00 exercise. Chapter III presents the modeling and simulation effort from model construction, simulation experiment design and simulation scenarios. Chapter IV is the data analysis chapter, where the results of each of the experiments are compiled and simulation factor interactions are presented. Chapter V expresses the analytical results of the experiments, and Chapter VI presents conclusions

and recommended areas of further research. Appendices are included to provide information about the Desert Knight exercise and detailed modeling information.

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## **II. DEFINITION OF STUDY AREA**

### **A. DESCRIPTION OF THE TRI-TAC NETWORK**

The TRI-TAC program was established in 1971 in order to achieve improved communications interoperability between the services. TRI-TAC sought to achieve a smooth transition from the manually operated, analog systems in place at the time, to a fully automatic, digital architecture. Over time, the TRI-TAC network evolved into a family of subscriber terminals, message and circuit switches, multiplexing equipment, and transmission systems. For the purposes of this thesis, attention will be focused on the circuit switch and digital transmission backbone segments of TRI-TAC used by Marine Corps communications units.

In Marine Corps forces, TRI-TAC systems comprise the digital communications backbone for C4I support. In general, most tactical telephone service is provided by TRI-TAC compliant Unit Level Circuit Switches (ULCS). Digital multichannel transmission equipment commonly in use by Marine Corps communications units adheres to TRI-TAC standards.

As stated in the introduction, the goal of this thesis is to study the effects of converging the current TRI-TAC voice switched network onto the existing digital backbone. This approach is based in part on the rise of commercial alternatives to switched voice services such as Voice over Internet Protocol (VoIP), and the mid-term reliance of tactical communications units on current or soon to be fielded TRI-TAC based transmission systems. By leveraging emerging voice service technologies, significant

efficiencies can be realized in the use of bandwidth available to tactical forces given the same digital transmission systems used today.

### **1. TRI-TAC Characteristics**

TRI-TAC systems are designed to accept both analog and digital signals, and then convert them to the TRI-TAC format for transmission across the network. Voice, data and video services are all carried on this network. TRI-TAC standards force channel bandwidth restrictions that are often "worked around" by communications personnel if higher data rates are required. This is usually accomplished through bypassing lower level multiplexers and inserting signals into points higher in the equipment string.

The TRI-TAC data rate hierarchy is related to the type of service a user requires. Voice telephone instruments and telephone switches are operated at a 16 or 32 kbps data rate for each subscriber channel. Low-level multiplexers are used in the network to aggregate many single subscriber loops into a larger data stream. For example, the Remote Multiplexer-Combiner (RMC) accepts 16 or 32 kbps subscriber loops and aggregates them into a 144 or 288 kbps data stream. Another low level multiplexer, the Low Rate Multiplexer (LRM) found in Ground Mobile Forces (GMF) satellite systems, has selectable single channel data rates from 0 to 56 kbps and provides an aggregated stream of up to 256 kbps. Low-level TRI-TAC multiplexers provide their aggregated data streams to a transmission device or TRI-TAC circuit switch through a higher-level multiplexer or data port.

Record message systems support 16 kbps connections between message switches and receive traffic from AUTODIN gateways from 75 bps to 2.4 kbps. Record message systems are often connected through the TRI-TAC network using circuit switches in a "sole-user patch" configuration. In this mode, a message switch connection is established by assigning a subscriber port through the circuit switch, and reserving a channel over a DTG for the circuit.

New services, such as IP routed data and video teleconferencing are supported by various means, depending on the data rate required. Commercially available multiplexers and converter cards are used to convert the information to a format that is compatible with TRI-TAC transmission systems if the data rate exceeds TRI-TAC low level multiplexer capabilities.

## **2. Marine Corps Voice Telephone Switches**

The Marine Corps has fielded two ULCS TRI-TAC voice telephone switches. Each switch is designed to support a particular echelon of command, and has capabilities and capacity appropriate for those levels.

### ***a. AN/TTC-42 Automatic Telephone Central Office***

The AN/TTC-42 is the "large" digital voice circuit switch used in Marine units. It is fielded at the Marine Expeditionary Force (MEF) Level within the MEF Communication Battalion to support the MEF Command Element (CE) or Marine Expeditionary Brigade (MEB) CE's. Additionally, the AN/TTC-42 is fielded at the Marine Division, within the Division Communications Company; at the Marine Air

Wing, within the Marine Wing Communications Squadron; and at the Force Service Support Group (FSSG), within the FSSG Communications Company, to support these MEF Major Subordinate Command (MSC) Headquarters. The AN/TTC-42 is described as follows by CJCSM 6231.02A, MANUAL FOR EMPLOYING JOINT TACTICAL COMMUNICATIONS JOINT VOICE COMMUNICATIONS SYSTEMS:

The AN/TTC-42 is a shelterized, automatic telephone central office. It is capable of 16 or 32 kbps operation using deterministic routing. It provides automatic switching and subscriber service to the TRI-TAC family of 4-wire analog and digital telephone instruments, including Digital Secure Voice Terminals (DSVTs), Digital Nonsecure Voice Terminals (DNVTs), and analog telephone terminals. It also provides switching service for 4-wire trunks, both single-channel and TDM groups. The AN/TTC-42 is sized to provide switching for 280 channels used for loops and trunks. The AN/TTC-42 provides end-to-end secure call services for subscribers equipped with DSVTs. The AN/TTC-42 also furnishes nonsecure call services for analog telephones and DNVT-equipped subscribers. Call services provided include loop-to-loop, loop-to-trunk, trunk-to-loop, and trunk-to-trunk connections. The AN/TTC-42 also performs automatic and semiautomatic switching for selected analog loops and trunks. Each AN/TTC-42 has a communications security (COMSEC) capability for secure communication through an interface that is compatible with a Trunk Encryption Device (TED), KG-94/KG-194. The AN/TTC-42 provides end-office and tandem switching functions, as well as extension of services automatically to digital subscribers located at subordinate SB-3865 switchboards. The AN/TTC-42 also acts as a COMSEC Parent Switch to the SB-3865.

The AN/TTC-42 supports 150 subscriber telephone instruments. When secure telephone calls are placed across a network, the AN/TTC-42 coordinates with the destination switch to generate a per-call variable that is provided to the calling and called DSVT. Two of the switchboard's seven modems are equipped with an internodal buffer to compensate for long delay times normally associated with satellite transmission

systems that can affect the digital timing scheme of the network. In a Joint network, the AN/TTC-42 is designed to provide gateway connectivity between Marine and Joint telephone networks. The AN/TTC-42 is a large system that can be moved only by a 5-ton truck or larger. A cut-away picture of the system is shown as Figure 1.

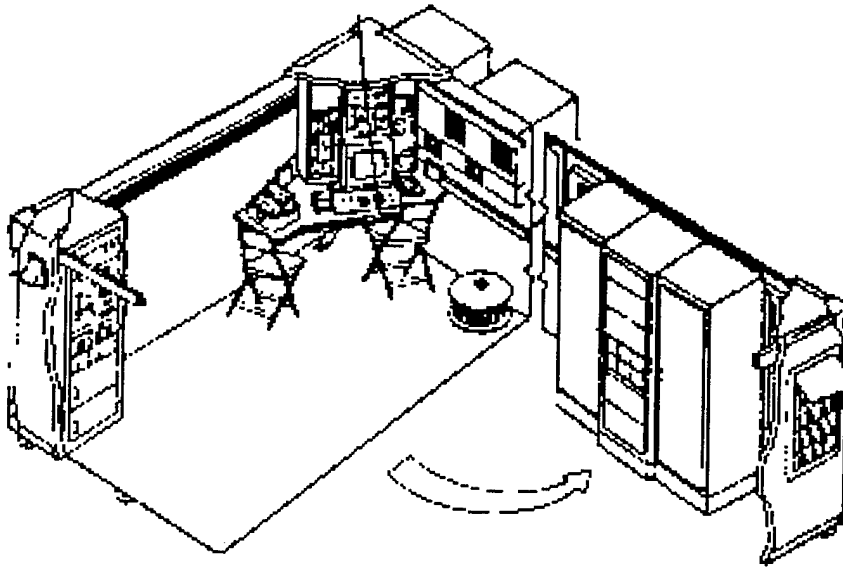


Figure 1. AN/TTC-42

**b. SB-3865 Switchboard**

The SB-3865 is the "small" digital voice circuit switch used by Marine units. It is found in the same units that field the AN/TTC-42 switch to support small units in outlying locations near the MEF or MSC CE area that require telephone services. It is fielded in the Marine Division to the Infantry Regiment and Artillery Battalion level as well as the Division Communications Company. Within the Marine Air Wing, it is found in the Marine Wing Support Squadrons in addition to the Marine Wing



Communications Squadron. In the FSSG, the Landing Support Battalion has an allowance for this switchboard in addition to the FSSG Communications Company. The SB-3865 is described as follows by CJCSM 6231.02A:

The SB-3865(P)/TTC is a team-transportable telephone switchboard that provides automatic switching service and subscriber service functions (to include but not limited to loop and trunk hunting, precedence, and preemption) to the TRI-TAC family of 4-wire, digital telephone instruments (DSVTs and DNVTs); and to 4-wire digital trunks, including both single channels and time division multiplex (TDM) groups. The SB-3865 provides automatic switching for 4-wire analog loops and trunks at a 16 or 32 kbps switch rate using deterministic routing. The SB-3865 provides switching among 64 channels. It is possible to stack two SB-3865s (two-unit configuration) and three SB-3865s (three-unit configuration) to provide up to 90-line switching capacities. The SB-3865 is a member of the TRI-TAC ULCS family.

The SB-3865 supports 30 subscriber instruments per switchboard. The total number of supported instruments is affected by the number of lines found in the digital trunk groups that connect switchboards. The total number of available switched circuits includes these trunk circuits, which can reduce the number of total supported subscriber instruments. The SB-3865 is mounted in transit cases and is man portable, although it requires a source of generator power. The SB-3865 is shown in Figure 2.

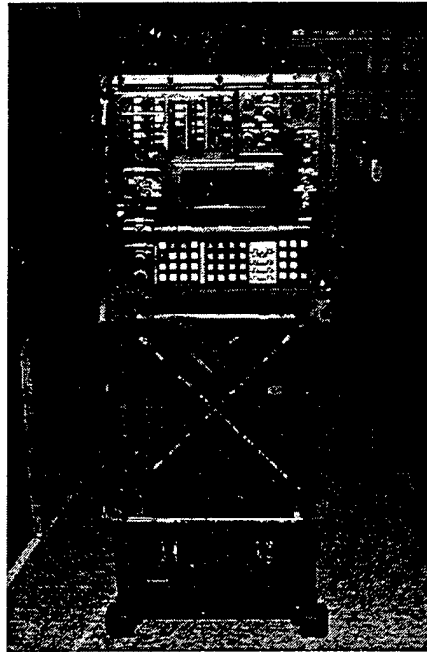


Figure 2. SB-3865

### 3. Digital Transmission Equipment

TRI-TAC compatible digital transmission equipment used by Marine Corps communications units is characterized by the ability to readily carry aggregated traffic at the data rates supplied by TRI-TAC multiplexers and circuit switches. This transmission equipment is described generally as multichannel radio equipment, and is transmitted either terrestrially, or via the space segment. A short description of each piece of equipment is provided below:

*a. AN/TRC-170(v)5 Digital Tropospheric Scatter Microwave Radio Terminal*

The AN/TRC-170(v)5 Microwave radio has the most point-to-point bandwidth capacity of any organic communications radio transmission system used by

the Marine Corps. A short description of the AN/TRC-170(v)5 is found in MCO 4400.179A, MATERIEL FIELDING PLAN (MFP) FOR THE DIGITAL TROPOSCATTER MULTICHANNEL RADIO SET, AN/TRC-170 (V) 5:

The AN/TRC-170(v)5 is a Tactical, Digital Troposcatter Multichannel Radio Set that provides digital communications in the super high frequency, (SHF) band. It has a 4.4 to 5.0 GHz frequency range. It operates in a line-of-sight (LOS) or tropospheric scatter, (troposcatter) mode and has a range of up to 100 miles. It will transmit and receive secure or plain digital voice and data traffic. The AN/TRC-170 (V) 5 interfaces with other TRI-TAC and current inventory equipment, and may be used in stand-alone applications to carry dedicated and common-user communication traffic. Such traffic might include; analog and digital voice channels; interswitch trunks; long local and point-to-point subscribers; and facsimile or teletype circuits. The AN/TRC-170 (V) 5 will be employed at the MEF, division, and wing headquarters levels.

Aggregate data rates supported by the AN/TRC-170(v)5 range from 128 kbps to 4640 kbps. A characteristic of troposcatter propagation is the degradation of data rate as distance increases. Maximum data rates at an acceptable bit error rate (BER) for digital systems to function properly also decreases in the presence of certain atmospheric conditions, such as rain or high humidity.

The AN/TRC-170(v)5 is a High Mobility Multipurpose Wheeled Vehicle (HMMWV) transportable system, with an associated trailer. The system is depicted in Figure 3.

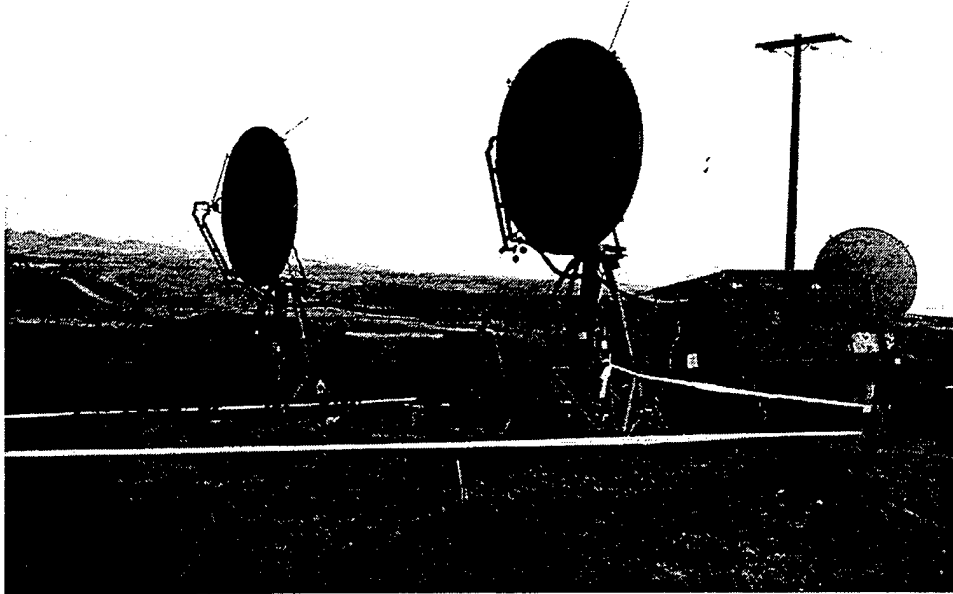


Figure 3. AN/TRC-170(v)5 with OE-461 Antenna Group

*b. AN/MRC-142 Digital Radio Set*

The AN/MRC-142 is the UHF multichannel radio used by Marine forces. It is a line-of-sight system that has a 30-mile maximum range. It operates in the 1350 – 1850 MHz range and supports aggregate channel rates of 144, 288, and 576 kbps. The AN/MRC-142 is used as a point-to-point system or can be configured to act as a repeater on a point-to-point circuit. It is fielded to the MEF Communication Battalion, the Marine Air Wing Communications Squadron, Division Communications Company and FSSG Communications Company. The AN/MRC-142's radio equipment is installed in a HMMWV and is highly mobile. The system is shown in Figure 4.

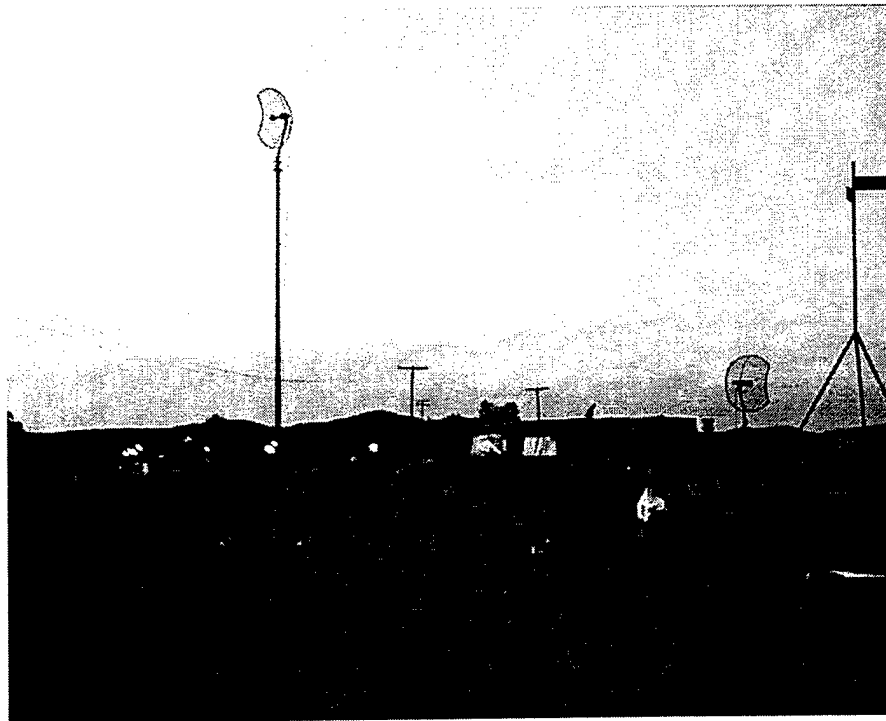


Figure 4. AN/MRC-142

c. *AN/TSC-85B Nodal Mesh Terminal*

The AN/TSC-85B(V) Nodal Mesh Terminal (NMT) is a full duplex satellite communications terminal capable of interfacing with a single satellite. It operates in a point-to-point configuration, a nodal configuration with up to four other terminals, or in a mesh configuration with up to four other terminals. It transmits a single carrier and receives between one and four carriers. It is fielded to MEF Communication Battalions. The AN/TSC-85B transmits in the 7.9-8.4 GHz range and receives in the 7.25-7.75 GHz range. It is equipped with four Low Rate Multiplexers (LRM), each of which can accept up to 12 single circuits from 37.5bps – 56 kbps. It is also equipped with the MD-1026 Group Modem which can accept up to four conditioned diphase input signals. The maximum data throughput of the AN/TSC-85B is dependent on its configuration. If used to connect to other terminals, the maximum data rate per connected terminal is 1152 kbps. This type of configuration is how Marine units normally employ the system. The AN/TSC-85B is depicted in Figure 5.

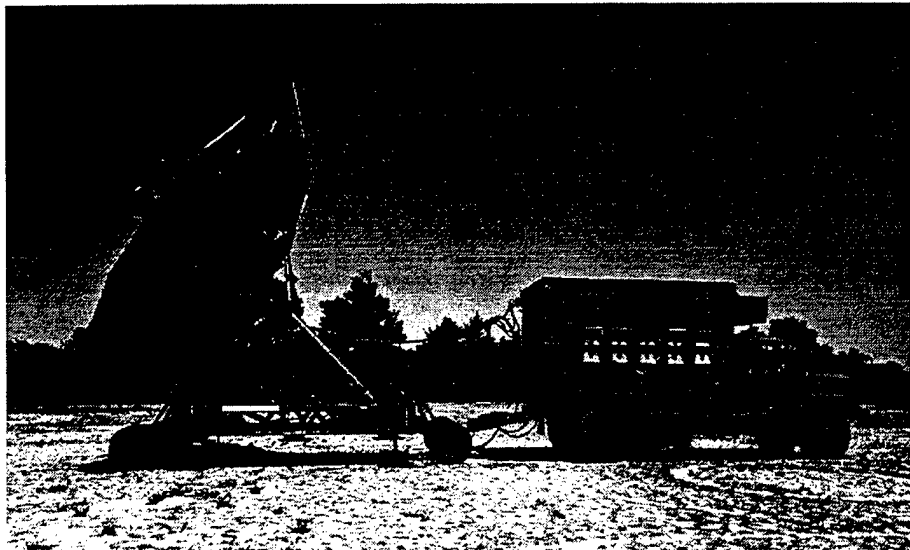


Figure 5. AN/TSC-85B with OE-361 Antenna Group

*d. AN/TSC-93B Nonnodal Terminal*

The AN/TSC-93B is a full duplex point-to-point satellite communications terminal, operating in the same frequency band as the AN/TSC-85B. It operates on a point-to-point basis, either with another nonnodal terminal such as another AN/TSC-93B or AN/TSC-94A, or as part of a nodal configuration with an AN/TSC-85B or AN/TSC-100A. The AN/TSC-93B is equipped with three LRMs. The maximum data rate the AN/TSC-93B can carry is 1156 kbps. Figure 6 depicts the AN/TSC-93B.

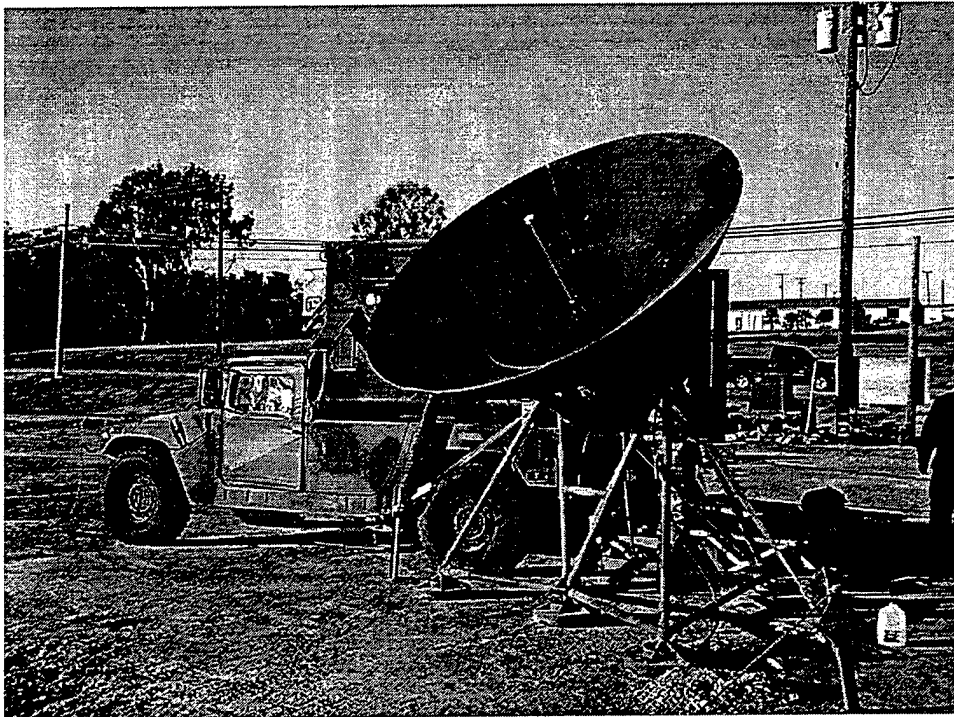


Figure 6. AN/TSC-93B

## **B. LIMITATIONS OF CURRENT SYSTEM**

The TRI-TAC architecture has many desirable characteristics that have supported the tactical user well over the transition from analog to digital systems. Reliability, security and interoperability are three that immediately come to mind. The architecture in which these characteristics were achieved now has two properties that have become problematic for the warfighter. The first is inherent bandwidth allocation restrictions of TRI-TAC that reduce the efficiency of limited bandwidth in the system. The second is the deterministic, manually assigned routing logic of the switched voice network.

### **1. Bandwidth Restrictions and Inefficiencies**

TRI-TAC voice telephone switches require a dedicated digital trunk group (DTG) established between them. A DTG consists of a grouping of trunk circuits established between TRI-TAC switches, used to carry network control and overhead data as well as voice telephone traffic that must be routed across the network. DTGs are of variable bandwidth, depending on the channel data rate and the number of trunks established between switches. In normal operations, this can vary between 144 kbps for a 9-channel group at 16 kbps per trunk to 2304 kbps for a 72-channel group at 32 kbps. Bandwidth committed to a DTG is reserved for exclusive use by the telephone network. If only one 32 kbps telephone call is placed across an 18-channel DTG, all 576 kbps of available bandwidth is dedicated to carrying that call.

Similarly, the TRI-TAC telephone network cannot dynamically reassign bandwidth if demand for telephone service exceeds the available reserved bandwidth. In



this case, telephone service is not available to users who cannot seize a channel on the DTG, even if bandwidth is available on the transmission system carrying the DTG.

When the TRI-TAC architecture was developed, high-speed data applications did not exist in the tactical environment as they do today. Services such as video teleconferencing, large graphical file transfers, and IP routed data networks such as the Secure and Non-secure Internet Protocol Routed Networks (SIPRNET and NIPRNET) have placed a premium on bandwidth requirements in the tactical environment. Bandwidth reserved exclusively for voice telephone services has become a luxury that demanding, bandwidth-intensive application environments cannot support.

## **2. Circuit Switch Routing Restrictions**

In Marine Corps ULCS systems, the switchboard operator must program all aspects of the circuit switch's operation. None is more critical to a robust and survivable network than proper alternate routing. Communications planners will try to plan for at least two DTGs over different transmission systems for each AN/TTC-42 in the network. When properly planned and executed, this path diversity significantly increases the reliability of the network.

Alternate routing is programmed by the switchboard operators into the AN/TTC-42 and SB-3865 for each directly connected switchboard and for other switchboards in the Marine Forces network. However, the switchboard logic for alternate routing is only valid for a particular direct connection to that switchboard. In other words, an AN/TTC-42's alternate routing logic is valid only over the switch's "first hop" to its neighbor

switchboard, not through the neighbor switch, or beyond. Therefore, if an intermediate switchboard is incorrectly programmed, routed telephone service may not be possible to complete across a particular route, even if a route is physically available. Similarly, a problem can occur if there is an equipment failure along an alternate route.

### **C. CASE STUDY—DESERT KNIGHT '00**

This thesis uses as a baseline a case study of Desert Knight '00. The exercise took place from 30 November to 6 December 1999 in several areas of California. The 1<sup>st</sup> Marine Expeditionary Brigade (MEB) was the MAGTF Command Element and operated from Fort Hunter-Liggett, California. Major subordinate commands operated from the Marine Corps Air-Ground Combat Center, Twentynine Palms, California and Marine Corps Air Station Miramar, California.

This exercise was chosen as the basis of this thesis because it suited the research objectives very well. Travel to the locations of the exercise to gather data needed to conduct the thesis was easily accomplished; it was a large, but not overly so operation; and it was a "Marine-only" exercise that allowed analysis of a Marine Corps network without confounding data that might arise from a larger, joint exercise.

#### **1. Exercise Purpose**

CG I MEF message 010116Z NOV 99 is the Desert Knight '00 Letter of Instruction (LOI). This message described Desert Knight '00 as: "...an overarching exercise which integrates existing exercises in order to maximize their respective training

value, validate I MEF (Fwd) core echelon (CE) command and control requirements and concepts of operation in support of the Desert Thunder/ANVIL II OPLAN. Additionally, Desert Knight will form the basis to certify I MEF's contingency response MAGTF and Maritime Prepositioning Force (MPF) capability."

After the LOI was released, I MEF (Fwd) was redesignated 1<sup>st</sup> MEB. The Desert Thunder/ANVIL II OPLAN is the United States Central Command's OPLAN in Southwest Asia and I MEF's plan to support it.

## **2. Communications Network Architecture**

The major communications units involved in supporting Desert Knight '00 were I MEF's 9<sup>th</sup> Communication Battalion (9<sup>th</sup> Comm Bn), 1<sup>st</sup> Marine Division's Communication Company, 3<sup>rd</sup> Marine Air Wing's Marine Wing Communications Squadron-38 (MWCS-38) and 1<sup>st</sup> FSSG's Communication Company. All planning documentation contained in this thesis was generated by planners at these units and the I MEF G-6. High level planning documents used by the communications elements of the exercise are contained in Appendix A.

### ***a. Voice Network***

The exercise voice circuit switched network was based on TRI-TAC compatible switches. The network, as executed was slightly different than planned. MWCS-38 added additional connectivity between the 3330 SB-3865 and the 3316 and 3315 AN/TTC-42s. The DTGs are labeled as Trunk Group Clusters (TGC) because the

network was planned with TNAPS, an automated planning tool, which assigns these numbers to ease switch-programming documentation. Throughout this thesis and in the modeling and simulation that was done, DTG is the term that is used.

The voice network is used for various command and control, coordination logistics and administrative functions. It is the primary tool used for immediate, person-to-person communications requirements between the MEB CE and its MSCs.

*b. Transmission Network*

The transmission network was planned to be as redundant as possible, given the wide geographical area the exercise covered. Primary long-haul backbone transmissions systems for Desert Knight '00 were the AN/TSC-85B and AN/TSC-93B satellite systems and the AN/TRC-170(v)5 Troposcatter Microwave Radio Terminal. The AN/MRC-142 was used for short-haul links. Cable systems, both Dual Coaxial and Fiber Optic, provided connectivity between switches and systems in local areas and provided the path for DTGs from the telephone switch to radio transmission systems.

The transmission network also provides the timing source for the digital network. The AN/TRC-170(v)5 has a Rubidium Standard timing source that provides timing accuracy to  $10^{-11}$  error rates. In nodes where a Rubidium Standard timing source was available, it was used to provide timing for the entire node. For the satellite transmission systems, timing was provided from the Ground Mobile Forces (GMF) gateway. Appendix A contains network timing and other transmission network details.

*c. Data Network*

The data network was primarily an IP based network, segregated by classification. NIPRNET provided unclassified web browsing, file transfer and e-mail services, while SIPRNET provided the same services as well as record message distribution for secret high traffic. The data rates available to each node in the Desert Knight '00 network varied greatly, based on the capabilities of the transmission systems available to support these nodes. For example, SIPRNET access was as low as 32 kbps for some disadvantaged users. To major nodes, the access rates were generally 128 kbps for SIPRNET and 96 kbps for NIPRNET.

*d. Video Requirements*

During the Desert Knight '00 Mid-Term Planning Conference held at Camp Pendleton on 30 September 1999, video requirements became a difficult issue for the communications planners to support. The initial requirement was for two video circuits to be established. The first was a Video Teleconferencing (VTC) circuit to be used by the 1<sup>st</sup> MEB Commanding General to coordinate with his Marine Air Group and Division Commanders, as well as provide connectivity to Camp Pendleton from Fort Hunter-Liggett. The second requirement was for a real-time video feed originated by VMU-1 unmanned aerial vehicles (UAV) operating at the Marine Corps Air-Ground Combat Center in Twentynine Palms to be provided to the MEB staff at Fort Hunter-Liggett.

Problems with circuit engineering due to VTC suite compatibility eventually led to the dropping of the VTC requirement. The UAV video feed was engineered and eventually supported during the exercise. The UAV feed was the circuit that caused the VMU-1 node to be reduced to a 32 kbps SIPRNET rate.

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### III. NETWORK MODELING AND SIMULATION

#### A. NETWORK MODELING AND SIMULATION DESIGN

The thesis objective for modeling Desert Knight '00 is to use the exercise as a baseline case from which network variables can be tested, and architectures compared. The fundamental thesis research question is to determine the effects of converging the current TRI-TAC based switched voice network onto a common digital backbone.

##### 1. Extend

###### *a. Software Description*

The software used for the modeling and simulation phase of the thesis was Extend version 4, developed by Imagine That, Incorporated. Extend is a visual simulation product that allows the user to break down a process into discrete or continuous actions. Extend provides built-in libraries of blocks that can be connected together to model a total process. Extend allows the user to build their own blocks to allow for greater flexibility in the modeling process.

Blocks have parameters that can be set by the user using dialog boxes. These dialogs provide the user a great amount of control over how a block behaves during the simulation. Tools are available to allow simulation parameters to be changed over a large number of blocks by changing only one value in one location of the model. The software has sophisticated tools that facilitate debugging the model.



The software can run on any PC platform with a 486 or faster processor or on a Macintosh with a Power PC processor. For this thesis, a Pentium III processor running at 500 MHz was used.

*b. Advantages of Extend*

The graphical nature of Extend allows for rapid development of models without a requirement to write extensive code. Logical relationships between blocks are established with visual connections. Block behavior is controllable using the dialog boxes previously mentioned. The dialog boxes allow a tremendous amount of control over the behavior of the blocks. If one desired to change the behavior of a block not allowed for in the dialog, the code is available and can be modified to support these requirements. Due to the graphical interface, intuitive nature of the software, and no requirement to code block behavior directly, Extend requires minimal training to develop models.

Building a scalable network was simple to achieve using Extend. Custom libraries can be built that save user-defined blocks for reuse later. The graphical nature of Extend supports copy and paste functions that facilitate rapid model building. Extend supports a layered model approach where low level functions, or functions taking place within a node, can be built into higher level processes. A custom block can contain several layers of functionality, each one supporting a particular aspect of the decomposed process.

Extend is particularly useful for modeling processes at an overview level. Other simulation packages such as OPNET III and COMNET readily model processes at a circuit or transistor level. In this thesis, Extend easily supported the macro view simulation required by the primary research question.

Of primary consideration to many organizations is cost. Extend is a program that provides a wide range of functionality for the price. A fully functional Extend package that includes additional functional libraries such as Business Process Reengineering (BPR), Manufacturing, and Industry processes is \$1495.00 for a single user license.

*c. Limitations of Extend*

Care must be used when using Extend to recognize its limitations. It has a range of computational limitations, contained as an appendix to the program's documentation. None of these limitations impacted the conduct of this thesis. Other limitations of Extend are related to its ease of use. The process one models must be well understood by the modeler. Of course, this is true of other simulation software as well, but Extend does not have ready-built blocks that model particular pieces of equipment. OPNET and COMNET, for instance, have libraries that contain ATM switches, Ethernet segments, fiber optic equipment and radio equipment. With Extend, the model must be built from the ground-up, with an eye on model function rather than on equipment strings. Once this limitation is recognized, the ease of use of Extend compensates for its rather limited equipment "vocabulary."

## **2. Methodology for DK'00 Architecture Modeling**

Model construction of the Desert Knight '00 architecture was the key step to accurately addressing the focus of this thesis. The model needed to "act" just as the "real" architecture did during the exercise, and support different network characteristics and variables that were chosen to investigate the process.

Some compromises in the model were required to simplify the "real-world" network for model building purposes, but the overall process is believed to remain true to observed results during the exercise.

### ***a. Background of Modeling Process***

Information was gathered during the planning phase of the exercise through liaison with 9<sup>th</sup> Communication Battalion planners. Proposed network diagrams were used to begin development of a prototype model using Extend. On September 30, 1999, a Mid-term Planning Conference was held at Camp Pendleton, California. At this conference, support issues were discussed and necessary changes were made to the network. After the conference, an updated set of planning documents was used to continue development of the model.

During the Desert Knight '00 execution phase, data was collected from each of the major switch nodes in the network. This data was required to determine network conditions during the exercise and use these observations to build the baseline model in Extend. During the exercise, the installed network varied slightly from the original planned network as well. At the conclusion of the exercise, final documentation

of the installed network was taken. The final network topology and observed voice circuit switch data taken from the AN/TTC-42's in the network were then used to construct the baseline model.

***b. Description of Desired Model Characteristics***

The model should provide for behavior that is found on the TRI-TAC network, such as call routing, to include alternate routing; provision for blockage of calls on the network; accurate reflection of call load levels; and random caller behaviors, such as length of call and demanded service. The model also had to facilitate data collection to support later data analysis. The parameters of the model had to be easily set in one location to support the sensitivity analysis that was conducted. Fortunately, Extend supported all these requirements well. One characteristic that would have increased the realism of the model that Extend did not easily support, and was not implemented in the model was priority and preemption of calls. In a TRI-TAC phone network, a higher precedence telephone call will cause a lower priority call to be dropped from the network if all resources across that path are utilized. In the observed data from the exercise, only a very small percentage of total calls were placed at a greater than routine priority, and therefore, it was felt that this model feature could be ignored.

### 3. **Baseline DK'00 Model**

#### *a. Organization*

The model organization reflects the logical TRI-TAC voice network used during DK'00. The Extend model assumes a connection-oriented, exclusive use approach to complete the circuit from end-to-end. Extend supports resource allocation and assignment in a straightforward manner, so this approach was used to provide paths through the model for voice service. The model takes into consideration the number of end-user telephone instruments available when checking for validity of call completion, but no attempt was made to simulate a direct dial-up, or person-to-person connection. Contained in Appendix B are Extend diagrams that depict the structure of the model's elements.

#### *b. Connectivity and Routing*

Connectivity in the physical world is based on logical connections of circuit switches through transmission devices. The model simplifies this somewhat in that the transmission devices themselves are not modeled. Carrying capacity of these transmission devices is modeled as resource availability, in terms of 32 kbps channels.

In the "real" world, telephone calls are generated from a particular instrument associated with a telephone number requesting a connection to another particular instrument by dialing that instrument's telephone number. If resources are available to grant the connection request, the call is connected until one of the subscribers

terminates the connection by hanging up the telephone. The model was simplified by treating telephone calls as a load generator that had certain behaviors in terms of how long a telephone call was, how often telephone calls were generated, and to where telephone calls were being placed. By requiring no instrument-to-instrument connectivity, the model is optimistic in the grade of service (GOS) levels achieved in the model runs, but this condition was adhered to for all model runs conducted.

TRI-TAC circuit switches have a limited ability to provide for alternate routing of voice circuits. The alternate routing is accomplished when the phone call is being set up. The switches do not have the ability to "alt-route" an established circuit if the call is pre-empted by a higher priority call. The switch's routing table selects an alternate path out of the switch if all circuits on the primary path are busy. The routing table does not support "end-to-end" route establishment. The call is instead passed on to the switch at the end of the alternate route, where an attempt is made to send on the call down the primary route according to the second switch's routing table. If a circuit is unavailable from end-to-end, the call is not completed, or blocked. In a TRI-TAC network, great care must be taken in the design of the network's routing tables to ensure that the logic of the system prevents bottlenecks and does not result in poor performance.

In the model used, routing is pre-determined. A path is plotted through the planned Desert Knight '00 architecture, and modeled in the simulation as a "hardwired" route. The primary route was chosen to be the most efficient route between two desired connections. Usually, this was accomplished by choosing the shortest route, but occasionally, another route was chosen to spread the network load over circuits if

possible. Alternate routes are provided for in the model as well. The "alt-routes" are hardwired, as the primary routes are. Alt-routes were chosen to have path diversity as compared to the primary route, yet be as short as possible. In the model, if a call attempt is blocked over a primary route, it attempts the alternate route automatically. In some node-to-node call paths, a second alt-route exists. This path is attempted if the primary and first alt-route are unavailable.

A shortcoming in the data collected on Desert Knight '00 was the lack of a report generated by the AN/TTC-42 to indicate how many telephone calls were being placed to a particular destination switchboard. Based on the author's experience, a call matrix was generated for each node, assigning call attempts to other nodes in the network as a percentage of the total calls generated by the node. These assigned percentages are provided as Appendix C.

*c. Factors to be Tested*

The model was built to test four factors in the network. The first factor is system architecture. The baseline architecture is the current TRI-TAC system. This architecture is characterized by fixed channel and DTG bandwidth. DTG bandwidth is exclusively reserved for circuit switches to connect voice circuits. Bandwidth not assigned to a DTG is unavailable to TRI-TAC circuit switches to provide voice services. Whether no voice traffic flows across the DTG or all channels are busy, the bandwidth reserved for voice services remains fixed. Throughout this thesis, this architecture is referred to as Architecture 1. The second architecture is based on current bandwidth

limitations for voice services, but allows for bandwidth not needed to support voice requirements to be made available for other services. In this architecture, voice service can never exceed the Desert Knight '00 based bandwidth threshold, but bandwidth unused for voice services is made available for other network services. Throughout this thesis, this architecture is referred to as Architecture 2. The third architecture assumes no restriction on voice bandwidth assignment. All bandwidth is available, with voice services having a priority over other network services. In this architecture, as much bandwidth that is required to support voice services over a particular connection path is made available to voice services; remaining bandwidth is available for other network services. Throughout this thesis, this architecture is referred to as Architecture 3. All architectures assume a 32 kbps voice channel requirement.

The second factor to be tested is network condition. This factor is designed for three levels. The first factor level is the nominal condition. This level assumes the network transmission systems are all operational, as they are planned to be. The second factor level assumes that two network transmission systems are not operational. The links chosen to be non-functional were two AN/TRC-170 links: the first between one of the 1<sup>st</sup> Marine Division AN/TTC-42 switches and the CSSE's AN/TTC-42; and the second between the CSSE's AN/TTC-42 and one of 3<sup>rd</sup> MAW's AN/TTC-42's. This failure might simulate a generator failure at the CSSE site. The third level of network condition assumes the loss of four links. These lost links are the two from level two and the loss of an additional AN/TRC-170 link between 1<sup>st</sup> Marine Division and 3<sup>rd</sup> MAW, and an AN/MRC-142 link between 1<sup>st</sup> Marine Division and 7<sup>th</sup> Marine Regiment.



Figure 7 graphically shows the lost links, with those labeled 2 depicting Level 2, and with the addition of those labeled 3, depicting Level 3.

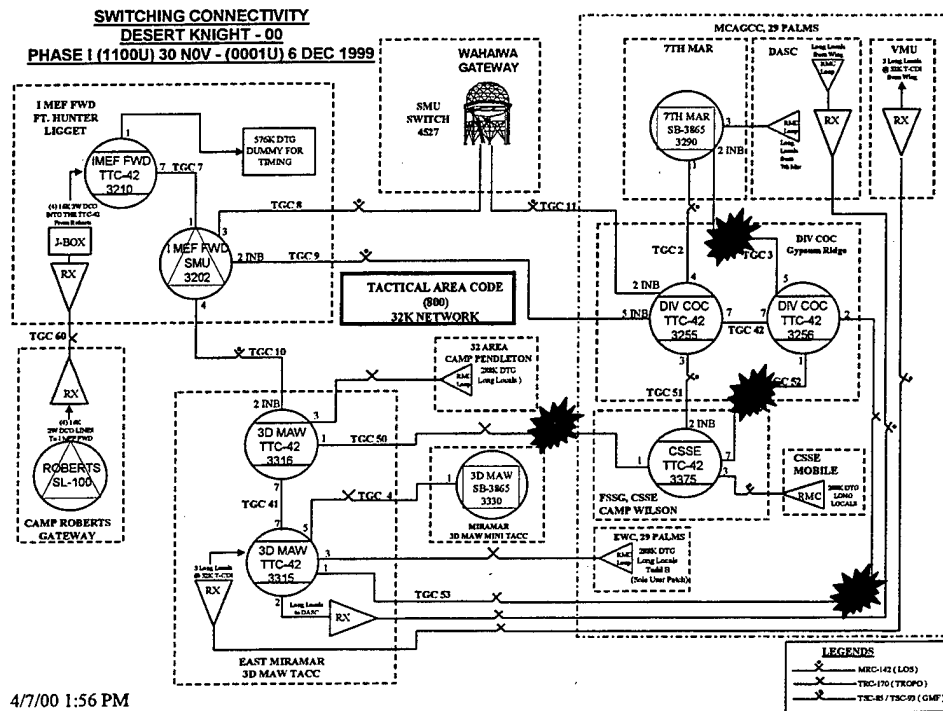


Figure 7. Transmission System Failures

The third factor to be tested is the network-wide mean length of telephone calls. The model generates a random length of call for each simulated call according to a decaying exponential distribution. Three mean lengths of call were used to as the mean for the distribution. The levels chosen were 2, 5, and 10 minutes. In normal use, a tactical telephone network should not be subjected to a high call “hold” time of 10 minutes as a mean. However, this high time is an extreme network condition that could occur, and provided interesting simulation results.

The fourth factor to be tested is the network load condition. In effect, this factor describes the demand on the network. The model introduces telephone calls according to an Erlang distribution, with a  $k$  argument of 2. The  $k$  argument describes the shift of the Erlang distribution from an exponential distribution for an argument of 1 to a more normal distribution for higher arguments. The Erlang distribution was chosen with  $k = 2$  because it closely resembles distributions used in telephone traffic engineering texts describing interarrival times to a telephone network. A representative distribution graph is provided as Figure 8. Three levels were used in the model. The first was the nominal case. This nominal level was derived from the data gathered during the Desert Knight '00 exercise, and reflected the load on the network during this exercise. The second level was the double the nominal case. In the model development, this level is referred to as the +100% case. The third level was double the second level. In model development, this is referred to as the +200% case.

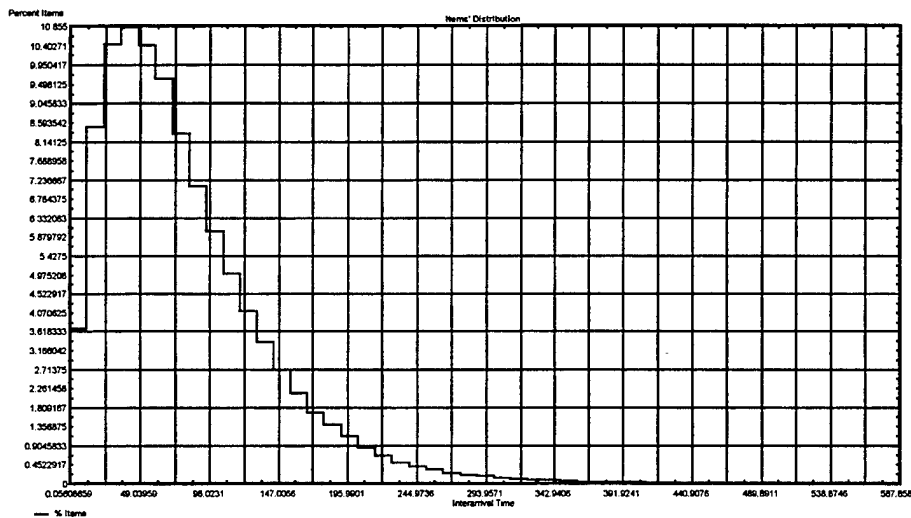


Figure 8. Representative Call Arrival Distribution, 2-Minute Mean

## **B. NETWORK MODELING AND SIMULATION EXPERIMENT DESIGN**

### **1. Taguchi Method of Experiment Design**

The Taguchi Method of experiment design is an approach developed by Dr. Genichi Taguchi in post-World War II Japan. Dr. Taguchi developed methods of improving research and development productivity and product quality for the Electrical Communication Laboratories, which was charged with the rebuilding of Japan's telecommunications infrastructure. The focus of his work was on the optimization of experiment design, but the philosophy behind the statistical tools is what made the Taguchi method with management experts such as W. E. Demming.

"Taguchi Method" describes statistical analysis of a limited number of the total possible permutations of experiment factors and their effects on the outcome of the experiment and between themselves. Dr. Taguchi accomplished this by developing a series of orthogonal arrays that contained the factors to be tested along with factor levels or conditions. The arrays he developed allowed factors to be tested for factor interaction as well as for main effects. Taguchi methods also include data analysis of the experiment results. By analyzing the results in the orthogonal array, overall main effects and factor interaction can be quantified in an efficient manner, without the requirement to test all possible combinations. For example, an experiment that has 5 factors to be tested, each with 4 levels associated with each factor would require  $4^5 = 1024$  experiments to accomplish all possible combinations. Using the Taguchi Method, this can be reduced to

16 experiments, and yet retain the ability to determine the effects associated with each factor and level of factor.

The goal of a Taguchi experiment is optimization. This is because the Taguchi Method is a quality-driven approach that seeks to reduce wastage in processes and engineering. Different analysis methods are used depending on which of three quality goals is chosen for the experiment. The three forms are: Larger is better, Nominal is better, and Smaller is better. Each Taguchi form has application depending on what the experiment seeks to accomplish. For this thesis, metrics were developed that described availability of network bandwidth, and therefore, the “Larger is better” approach was taken. A detailed description of the Taguchi methods can be found in Ranjit Roy’s *A Primer on the Taguchi Method*.

## **2. Experiment Design**

Taguchi developed a special purpose experiment to handle factors that are not controllable by the system’s design. Such factors impact the performance or quality, of a system but are not controllable by the designer of the system. These factors do influence system design considerations, and therefore are included in the experiment design. This is accomplished by using two orthogonal arrays; the first tests the control factors, and the second the uncontrollable, or noise factors. In Taguchi’s terminology, the first array is the inner array, and the second the outer. Each result across the inner array is tested against each result in the outer array, thus allowing analysis of the effect of the noise factors on the performance of the control factors.

*a. Control Factors*

In this thesis, the Taguchi experiment design resulted in only one control factor: System Architecture. The three architectures tested were described previously. This “one-factor, three-level” control factor results in a very simple orthogonal array of one column with three experiments, one for each architecture. The result of this design is an experimental series that runs each combination of the Noise Factor orthogonal array against each architecture. The advantage of this set-up is that each architecture is compared under the same noise conditions, giving very clear results.

*b. Noise Factors*

The three noise factors are Network Condition, Length of Call, and Network Load. These factors influence directly the effectiveness of the overall architecture, but are not controllable by the designer of the network. Each of the noise factors has three levels, as described earlier. The resulting outer orthogonal array has three rows, one for each of the noise levels, with nine columns, or experiments required to satisfy Taguchi’s requirements. Each of the nine resulting noise conditions are run against the three control factors for a total of 27 experiments to be conducted.

*c. Orthogonal Array Construction*

The resulting experiment orthogonal array is depicted as Table 2 on page 43. The numeric values within the tables reflect the indicated factor’s value or condition. Experiment variation was conducted by reading across the architecture value row to the

appropriate noise factor condition cell. The first experiment run for example, was conducted under conditions consisting of Control Factor Level 1, Noise Factor 1 Level 1, Noise Factor 2 Level 1, and Noise Factor 3 Level 1. This corresponds to Architecture 1, under ideal network conditions, a mean call time of 2 minutes, and nominal network loading. The last experiment was conducted under Control Factor Level 3, Noise Factor 1 Level 3, Noise Factor 2 Level 3, Noise Factor 3 Level 2, corresponding to a Voice Bandwidth unconstrained architecture, operating with 4 transmission links removed, mean call time of 10 minutes, and +100% network loading. Table 1 depicts the level values for each factor in the experiment.

	<b>Level</b>		
<b>Factor Parameter</b>	<i>1</i>	<i>2</i>	<i>3</i>
<i>Architecture</i>	Architecture 1	Architecture 2	Architecture 3
<i>Network Condition</i>	Ideal (As Planned)	Two Links Down	Four Links Down
<i>Length of Mean Call</i>	2 Minutes	5 Minutes	10 Minutes
<i>Network Loading</i>	Nominal (As Observed)	+100%	+200%

Table 1. Experimental Factor Levels

### 3. Experiment Metric Design

Taguchi methods require a “quality” standard to compare experiment results. The thesis objective was to determine the architecture that provides the best efficiency of use in terms of bandwidth available for services other than voice. This view of quality was used because of an early interview with LtCol Cantrell, then head of the C4I Architectures Branch, Requirements Division, at the Marine Corps Combat Development

Command, Quantico, Virginia. His posed question was, "What would be the effect of migrating the voice network onto the data network?" The quality metric used in this thesis needed to measure the relative impact of voice services on the total network. The most straightforward manner to do this was to frame the metric in terms of bandwidth not committed to voice services.

This bandwidth metric is derived from the bandwidth available for services other than voice across the entire network. Extend generates a utilization measure for each resource required to connect a simulated call. After the simulation run, this utilization factor was used to compute the effective used bandwidth for that resource over the simulation. Each resource required to terminate a call, except for local subscriber instruments, underwent the same calculation for bandwidth used. These totals were then summed, and then subtracted from the total bandwidth available in the system, except for local subscriber instruments. The total bandwidth available was determined from the Desert Knight transmission system planning documents, which listed the data rates across links in the network. Local subscriber instruments were excluded from the bandwidth calculation because they did not consume transmission system bandwidth. From a different view, each individual subscriber instrument has a dedicated wire connection to the telephone switch, and therefore does not contend with other subscribers to seize bandwidth to the telephone switch. Once a call leaves a switch, the call contends for limited connectivity availability with other calls.

A second metric was also developed to give sensitivity to the grade of service the voice network provided. The second metric was computed by modifying the first by a

grade of service weight. Grade of Service (GOS) is a standard metric used in telephone network engineering. It is a value between 0 and 1, with 0 representing no blocked calls and 1 indicating that all calls placed are blocked. GOS is determined by dividing the total number of blocked telephone calls by the total of blocked telephone calls and completed calls. The GOS for each experiment was determined computed using data generated by the Extend model. The GOS weight was determined by raising 10 to the GOS power. The final quality metric is obtained by dividing the first metric by the GOS weight results. The resulting metric penalizes the performance of a particular experiment if either bandwidth is unavailable or if voice subscribers cannot access the voice network. The metric's mathematical form is:

$$Q_T = BW_T / 10^{GOS}$$

## **C. NETWORK SIMULATION EXPERIMENTS**

### **1. Simulation Scenarios**

Experiment simulations were conducted using Extend, according to the variable factor conditions determined using the Taguchi method of experiment design. Architecture variability was controlled by manipulating available link resources. To model Architecture 1, resources available for voice traffic were set to the planned Desert Knight availability of bandwidth to support the TRI-TAC switched voice network. For Architecture 3, resource availability was set to be equivalent to the transmission system total capacity, as planned during Desert Knight. Mean call time and network load were varied by changing the value of a control block for each noise factor, appropriate for the



required value of the noise factor. Network condition was controlled by setting particular resource availability over designated segments, representing transmission devices, to zero. Each experiment was conducted for a simulated 24-hour period. Table 2, below, summarizes the experiment scenarios.

Using Extend, 18 experiments were conducted. Architecture 1 experiment data was modified for Architecture 2 data analysis. This was done because Architecture 2 differs from Architecture 1 only by the availability of excess bandwidth for other services. In essence, Architecture 2 modeling became a spreadsheet data computation.

Experiment	Experiment Designation	Architecture	Network Condition	Length of Mean Call	Network Loading
1	C1E1	1	Ideal	2 Minutes	Nominal
2	C1E2	1	Ideal	5 Minutes	+100%
3	C1E3	1	Ideal	10 Minutes	+200%
4	C1E4	1	2 Links Down	2 Minutes	+100%
5	C1E5	1	2 Links Down	5 Minutes	+200%
6	C1E6	1	2 Links Down	10 Minutes	Nominal
7	C1E7	1	4 Links Down	2 Minutes	+200%
8	C1E8	1	4 Links Down	5 Minutes	Nominal
9	C1E9	1	4 Links Down	10 Minutes	+100%
10	C2E1	2	Ideal	2 Minutes	Nominal
11	C2E2	2	Ideal	5 Minutes	+100%
12	C2E3	2	Ideal	10 Minutes	+200%
13	C2E4	2	2 Links Down	2 Minutes	+100%
14	C2E5	2	2 Links Down	5 Minutes	+200%
15	C2E6	2	2 Links Down	10 Minutes	Nominal
16	C2E7	2	4 Links Down	2 Minutes	+200%
17	C2E8	2	4 Links Down	5 Minutes	Nominal
18	C2E9	2	4 Links Down	10 Minutes	+100%
19	C3E1	3	Ideal	2 Minutes	Nominal
20	C3E2	3	Ideal	5 Minutes	+100%
21	C3E3	3	Ideal	10 Minutes	+200%
22	C3E4	3	2 Links Down	2 Minutes	+100%
23	C3E5	3	2 Links Down	5 Minutes	+200%
24	C3E6	3	2 Links Down	10 Minutes	Nominal
25	C3E7	3	4 Links Down	2 Minutes	+200%
26	C3E8	3	4 Links Down	5 Minutes	Nominal
27	C3E9	3	4 Links Down	10 Minutes	+100%

Table 2. Experiment Scenarios

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## IV. DATA ANALYSIS

### A. EXPERIMENT RESULT DATA ELEMENT INPUT

An Excel spreadsheet was built to facilitate data analysis and organized so that data for each experiment was captured on a separate worksheet. Data elements are derived from planning documents and from Extend experiment results, and are used to compute experiment statistics. Inputted data elements are Total Link Bandwidth, Bandwidth Reserved for Voice, Model Bandwidth Utilization, Completed Calls, and Blocked Calls and are described below:

#### 1. Total Link Bandwidth

Total Link Bandwidth is derived from Desert Knight '00 planning documents. Each DTG is carried by a particular transmission system, which may carry other services in addition to the DTG. For example, DTG 1 is carried by a Ground Mobile Forces (GMF) satellite link, designated as SZP01016 in the planning documents. This link has an aggregate of 576 kbps, with 288 kbps dedicated to DTG 1. The total link bandwidth availability is used to determine Total Link Bandwidth. When the system is degraded under Network Condition Levels 1 and 2, simulating loss of a link, the bandwidth for the appropriate links are set to zero.

#### 2. Bandwidth Reserved for Voice

The Bandwidth Reserved for Voice data element for Architecture 1 is equivalent to the bandwidth of the TRI-TAC DTGs planned in the Desert Knight '00

communications system planning documents. Architecture 2's value for this data element is the same as for Architecture 1, but the use of this element in experiment statistics computation is different for the two architectures. In Architecture 2, this value is used to grant a maximum bandwidth for voice use, but allows bandwidth unused by voice services to be made available for other services. Architecture 3's value for this data element was set to zero, reflecting this architecture does not reserve any bandwidth exclusively for voice.

### **3. Model Bandwidth Utilization**

Model Bandwidth Utilization was determined from the results of each Extend simulation experiment. For each DTG in the network, Extend generates a utilization statistic for the simulated 24-hour period modeled. The statistic is based on a decimal usage factor for each DTG where a value of zero indicates no usage and a value of 1 indicates total usage for the modeled period. For Architecture 1, this statistic was not necessary, as any "excess" bandwidth in the voice network is not available for other services to use, however, Architecture 2 does use the Model Bandwidth Utilization statistic that was generated in Architecture 1 experiments.

### **4. Completed Calls**

Completed calls were determined from the results of each Extend simulation experiment. Experiment results showed the total number of calls completed during the simulated 24-hour period for each node. For example, experiment results for the 1<sup>st</sup> MEB node showed the total number of calls that were completed to each of the other nodes in the network. The completed calls statistic does not correlate to a particular DTG path; it

reflects satisfied demand on the voice network, based on the routing that is “hardwired” into the model.

### 5. Blocked Calls

Blocked calls were determined from the results of each Extend simulation experiment in the same manner as completed calls. Again, the statistic does not correlate to a particular DTG path; it reflects demand that was not serviced by the voice network, based on the “hardwired” routing of the model. Table 3 below, summarizes the data elements that were inputted to the spreadsheet.

<b>Data Element</b>	<b>Architecture 1</b>	<b>Architecture 2</b>	<b>Architecture 3</b>
Total Link Bandwidth	Planning Documents	Planning Documents	Planning Documents
Bandwidth Reserved for Voice	Planning Documents	Modified from Planning Documents	Modified from Planning Documents
Model Bandwidth Utilization	Extend Simulation Result	Extend Simulation Result	Extend Simulation Result
Completed Calls	Extend Simulation Result	Extend Simulation Result	Extend Simulation Result
Blocked Calls	Extend Simulation Result	Extend Simulation Result	Extend Simulation Result

Table 3. Inputted Data Element Sources

### B. EXPERIMENT STATISTICS COMPUTATION

Each worksheet computes statistics for that experiment run, resulting in a qualitative measure of performance for that experiment. There are eight statistics computed for each experiment run. These statistics are grouped into two broad categories: Bandwidth Utilization and Grade of Service. The experiment metrics described earlier are determined using these computed statistics; the Bandwidth metric is a summary of the Bandwidth Utilization category, and the Grade of Service sensitive metric is computed using both categories.

## 1. **Bandwidth Utilization Statistics**

The Bandwidth Utilization statistics computed are Bandwidth Used for Voice, Bandwidth Available for Other Services, and Total System Available Bandwidth. A short description of each statistic and how it is derived is provided below:

### *a. Bandwidth Used for Voice*

Bandwidth Used for Voice determines how much bandwidth is necessary to carry all completed calls made in the experiment. For Architecture 1, this statistic did not have to be computed. Architecture 1's Bandwidth Used for Voice statistic is equal to the DTG planned bandwidth. TRI-TAC switches reserve all DTG bandwidth for voice services regardless of the actual voice traffic load. For Architecture 2, this statistic is computed by multiplying the Model Bandwidth Utilization statistic by the Bandwidth Reserved for Voice data element. This computation in effect, measures how much bandwidth the voice services actually demanded, within the restriction of not exceeding the planned voice bandwidth of Architecture 1. For Architecture 3, this statistic is computed by multiplying the Model Bandwidth Utilization statistic by the Total Link Bandwidth data element. This computation measures how much bandwidth was actually demanded by voice services, with no restriction, within the carrying capacity of the network transmission systems.

### *b. Bandwidth Available for Other Services*

Bandwidth Available for Other Services determines how much bandwidth is available for services other than voice on the transmission network after completed calls are carried. For Architecture 1, Bandwidth Available for Other Services is

computed by subtracting the Bandwidth Reserved for Voice data element from the Total Link Bandwidth data element. For Architecture 2, the statistic is computed by subtracting the Bandwidth Used for Voice statistic from the Total Link Bandwidth data element. Carrying out the computation in this manner allows for unused bandwidth in the voice network to be available for other services. For Architecture 3, the statistic is computed in the same manner as for Architecture 2, but the Bandwidth Used for Voice statistic is computed differently, as described in the previous paragraph.

*c. Total System Available Bandwidth*

This metric is computed by summing each DTGs Bandwidth for Other Services statistic. This indicates the bandwidth throughout the system that has not been used by voice services. This statistic is equivalent to the first experiment metric, based on bandwidth performance, described earlier.

**2. Grade of Service Statistics**

The Grade of Service statistics computed are Aggregate Completed Calls, Aggregate Blocked Calls, Node Grade of Service, Aggregate Grade of Service, and the Grade of Service Sensitive Experiment Metric.

*a. Aggregate Completed Calls and Aggregate Blocked Calls*

The Aggregate Completed Calls and Aggregate Blocked Calls are sums of each node's experiment results for Completed Calls and Blocked Calls. The aggregates show the total network results for each experiment.



*b. Node Grade of Service*

Node Grade of Service is computed for each network node by dividing the number of blocked calls at that node by the sum of completed calls and blocked calls at that node. The statistic results in a value between zero and 1, where zero indicates no blocked calls, and 1 indicates all calls are blocked. Node Grade of Service is not used directly in the experiment metrics, but is used to compare traffic loads at different nodes against observed Desert Knight '00 data.

*c. Aggregate Grade of Service*

Aggregate Grade of Service is computed in the same manner as Node Grade of Service, but uses the Aggregate Completed Calls and Aggregated Blocked Calls statistics to compute the overall statistic. This statistic reflects the total voice network performance in terms of call completion.

*d. Grade of Service Sensitive Experiment Metric*

This metric is the primary metric used to compare different Architecture experiment results. The mathematical form of this metric was described earlier in this thesis. The Total System Available Bandwidth statistic is weighted using the Aggregate Grade of Service Metric in the previously discussed formula.

**3. Experiment Summary Statistics**

For each experiment, two metric statistics are generated; Total System Available Bandwidth, and the Grade of Service Sensitive Experiment Metric. These metrics are taken into their own summary workbook in the Excel spreadsheet for further analysis. Experiment result metrics are placed into tables summarizing either the Total System

Available Bandwidth or the Grade of Service Sensitive Experiment Metric. The tables are organized in rows reflecting each of the three architectures, and columns, representing the conditions conducted for that experiment. The Taguchi method of experiment analysis provides many different statistical analysis tools to assist in determining the overall results. In addition to the previously described experiment metrics that express overall performance, it is desirable to capture the interactions between the control factors, or architectures, and the experiment noise factors.

*a. Control Factor-to-Noise Factor Interaction*

Taguchi provides a method of organizing the overall experiment metrics so that interactions between experiment factors can be analyzed. This is accomplished by extracting from the main experiment summary table metric results that are related and performing additional calculations. In this thesis, comparison is made between the architectures, which are control factors in the experiment design, and the noise factors, which are Network Condition, Length of Call, and Network Loading. In the summary table, observed results are grouped into sets described by Architecture and one of the Noise Factors by level. In the experiment design used in this thesis, each set consists of three metric values. A Control Factor-to-Noise Factor Interaction table is built with three rows, representing each of the three architectures, and three columns, representing the average value of the three metric observations for each experiment that tested that Noise Factor at a particular level. The resulting 3 x 3 table summarizes the effects of each noise factor in the experiments conducted. Spreadsheet data is provided in Appendix D.

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## V. ANALYSIS RESULTS AND FINDINGS

### A. EXPERIMENT RESULTS

The two exercise metrics used to determine performance of the three modeled architectures provided consistent results overall, with variation over the results of particular experiment conditions.

Using the Total System Available Bandwidth metric, Architecture 2 was overall the best architecture, performing 1.7 % better than Architecture 3 and 145.8 % better than Architecture 1. Using this metric, the experiment results were not significantly sensitive to particular experiment conditions. Rather, the bandwidth available on all architectures degraded when more voice service was demanded on the network, but not dramatically.

When the Grade of Service Sensitive Metric is used to quantify the experiment results, a different order of performance is observed. Architecture 3 performs 17.4 % better than Architecture 2, and 196.4 % better than Architecture 1. This metric revealed the sensitivity of the system to high levels of two noise factors: Length of Mean Call and Network Loading. Experiments where these noise factors were high resulted in a dramatic decrease in performance for each of the three architectures as a result of large numbers of blocked calls driving up the computed Aggregate Grade of Service. In all experimental conditions, Architecture 3 outperformed the other architectures.

Simulation and data analysis show that Architecture 3 provides significant improvement in the efficiency of the tactical transmission system network when

compared to Architecture 1, and provides higher grade of service performance for voice services than Architecture 2.

## **B. EXPERIMENT ANALYSIS**

The conclusion drawn from the previous section is supported by the information provided in the remainder of this chapter and in appendices at the end of this thesis.

### **1. Total System Bandwidth Available Metric Analysis**

#### ***a. Experiment Results***

The experiment metric results for the Total System Bandwidth Available Metric are depicted below in Table 4. The experiment results are summarized visually with the radar plot in Figure 9. The radar plot depicts experiment results by architecture. The axes of the radar plot represent each of the nine experiment conditions under which each of the architectures was modeled. These axes correspond to the last digit of the experiment designation found in Table 4. The plots on each of the experiment condition axes are based on the value of the Total System Bandwidth Available Metric for that simulation. The experiment metric values for each of the architectures are connected, giving a visual area representation of the experiment results.

Experiment	Experiment Designation	Architecture	Network Condition	Length of Mean Call	Network Loading	Experiment Metric Result
1	C1E1	1	Ideal	2 Minutes	Nominal	7040
2	C1E2	1	Ideal	5 Minutes	+100%	7040
3	C1E3	1	Ideal	10 Minutes	+200%	7040
4	C1E4	1	2 Links Down	2 Minutes	+100%	5312
5	C1E5	1	2 Links Down	5 Minutes	+200%	5312
6	C1E6	1	2 Links Down	10 Minutes	Nominal	5312
7	C1E7	1	4 Links Down	2 Minutes	+200%	5024
8	C1E8	1	4 Links Down	5 Minutes	Nominal	5024
9	C1E9	1	4 Links Down	10 Minutes	+100%	5024
10	C2E1	2	Ideal	2 Minutes	Nominal	18479.385
11	C2E2	2	Ideal	5 Minutes	+100%	16075.397
12	C2E3	2	Ideal	10 Minutes	+200%	14449.296
13	C2E4	2	2 Links Down	2 Minutes	+100%	14975.269
14	C2E5	2	2 Links Down	5 Minutes	+200%	12243.834
15	C2E6	2	2 Links Down	10 Minutes	Nominal	13427.963
16	C2E7	2	4 Links Down	2 Minutes	+200%	12982.087
17	C2E8	2	4 Links Down	5 Minutes	Nominal	13509.525
18	C2E9	2	4 Links Down	10 Minutes	+100%	11992.218
19	C3E1	3	Ideal	2 Minutes	Nominal	18647.777
20	C3E2	3	Ideal	5 Minutes	+100%	16172.488
21	C3E3	3	Ideal	10 Minutes	+200%	13815.609
22	C3E4	3	2 Links Down	2 Minutes	+100%	15199.450
23	C3E5	3	2 Links Down	5 Minutes	+200%	11684.877
24	C3E6	3	2 Links Down	10 Minutes	Nominal	13382.675
25	C3E7	3	4 Links Down	2 Minutes	+200%	12687.621
26	C3E8	3	4 Links Down	5 Minutes	Nominal	13621.147
27	C3E9	3	4 Links Down	10 Minutes	+100%	10819.810

Table 4. Experiment Results for Total System Bandwidth Available Metric

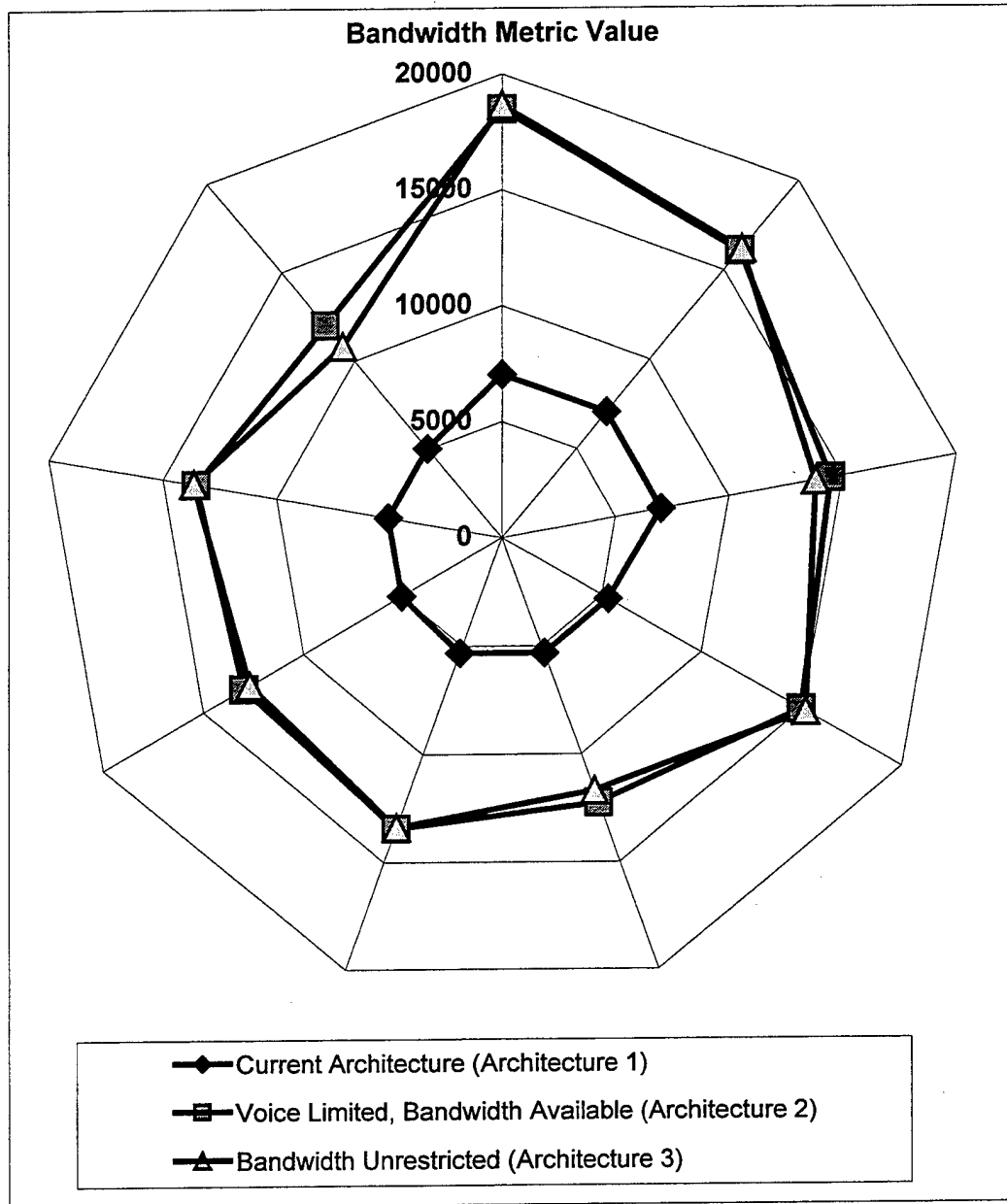


Figure 9. Radar Graph of Total System Available Bandwidth Metric Results

***b. Control Factor-to-Noise Factor Interaction***

The experiment results were manipulated according to the process described in Chapter IV. For the Total System Available Bandwidth Metric, Noise

Factor interactions with the three architectures were generally linear; with no one factor causing a dramatic decrease in performance. The Noise Factor with the greatest interaction with the three systems in the extreme experiment condition was Network Condition. When four transmission links were lost, the effect was a decrease in performance of 28.6 % for Architecture 1, as compared to the ideal network condition. Architectures 2 and 3 experiment metrics decreased 21.7 % and 23.7 % respectively. A graphical summary of this interaction is displayed in Figure 10. The Length of Mean Call Noise Factor interaction caused an 18.3 % reduction in the experiment metric for Architecture 3 when comparing the 2-minute level to the 10-minute level; Architecture 2's interaction resulted in a decrease of 14.1 % when compared to the same Noise Factor levels. Architecture 1 did not change, as bandwidth available to other services in the current system is not dependent on bandwidth reserved for voice services. A graphical summary of this interaction is displayed in Figure 11. The Network Loading Noise Factor interaction had the least interactive effect, with Architecture 3's experiment metric being reduced by 16.3 % when the nominal condition is compared to the +200 % condition. Architecture 2's performance was reduced by 12.6 %, and Architecture 1 was unaffected by Network Loading, for the same reason as the previous Noise Factor. A graphical summary of this interaction is displayed in Figure 12.



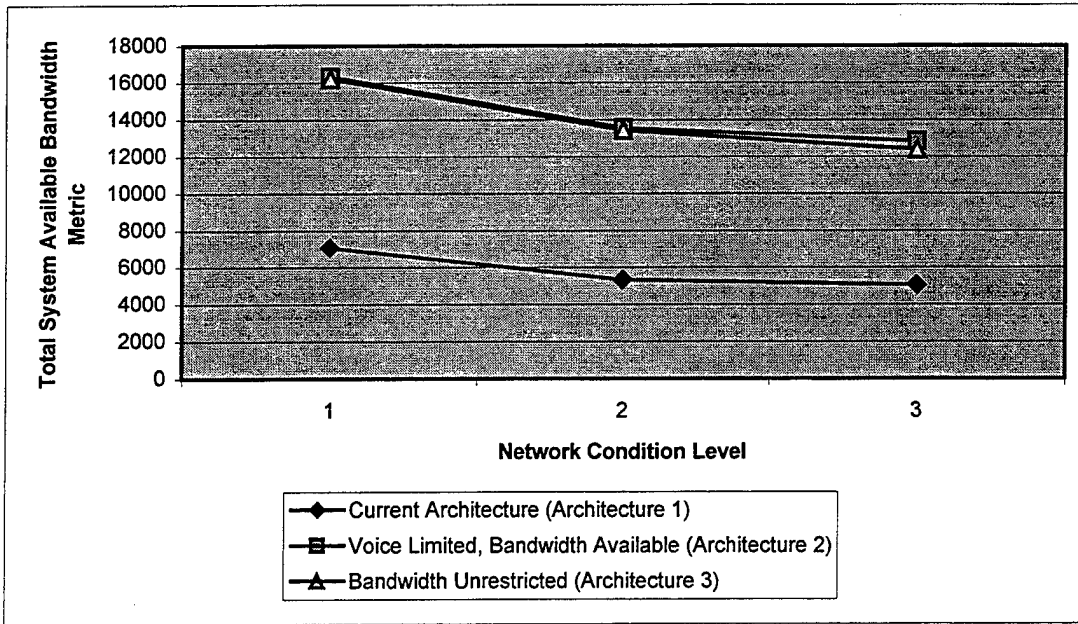


Figure 10. Network Condition Interaction Graph for Total System Available Bandwidth Metric

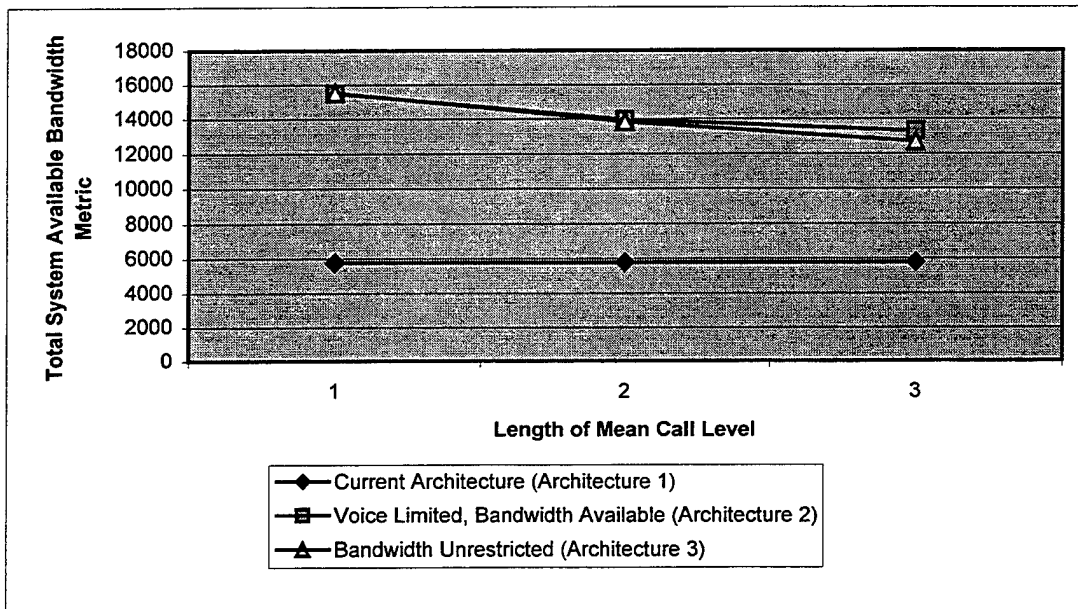


Figure 11. Length of Mean Call Interaction Graph for Total System Available Bandwidth Metric

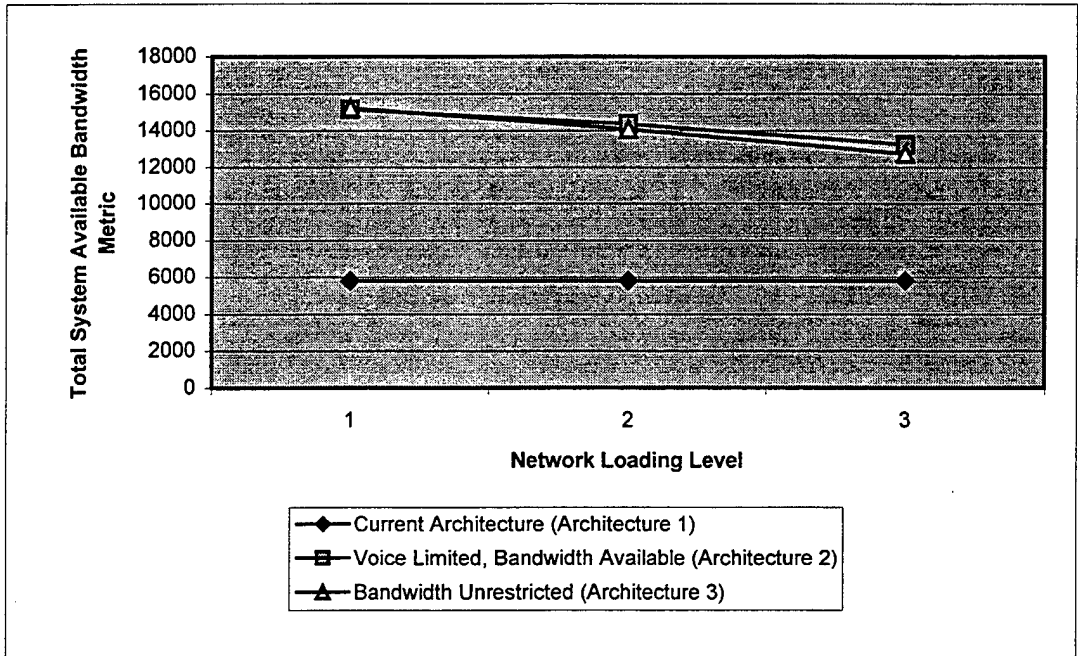


Figure 12. Network Loading Interaction Graph for Total System Available Bandwidth Metric

## 2. Grade of Service Sensitive Metric Analysis

### a. Experiment Results

The experiment metric results for the Grade of Service Sensitive Metric are depicted below in Table 5. The experiment results are summarized visually with the radar plot in Figure 13. The radar plot is organized in the same manner as the radar plot for the Total System Available Bandwidth Metric. The last digit of the experiment designator found in Table 5 corresponds to the radar plot axis of the same number. Again, the experiment metric values for each of the architectures are connected, giving a visual area representation of the experiment results.

Experiment	Experiment Designation	Architecture	Network Condition	Length of Mean Call	Network Loading	Experiment Metric Result
1	C1E1	1	Ideal	2 Minutes	Nominal	6964.306
2	C1E2	1	Ideal	5 Minutes	+100%	5449.560
3	C1E3	1	Ideal	10 Minutes	+200%	1865.026
4	C1E4	1	2 Links Down	2 Minutes	+100%	4895.665
5	C1E5	1	2 Links Down	5 Minutes	+200%	2371.348
6	C1E6	1	2 Links Down	10 Minutes	Nominal	3806.759
7	C1E7	1	4 Links Down	2 Minutes	+200%	3332.186
8	C1E8	1	4 Links Down	5 Minutes	Nominal	3929.130
9	C1E9	1	4 Links Down	10 Minutes	+100%	2015.894
10	C2E1	2	Ideal	2 Minutes	Nominal	1820.694
11	C2E2	2	Ideal	5 Minutes	+100%	12443.727
12	C2E3	2	Ideal	10 Minutes	+200%	3827.886
13	C2E4	2	2 Links Down	2 Minutes	+100%	13801.563
14	C2E5	2	2 Links Down	5 Minutes	+200%	5465.812
15	C2E6	2	2 Links Down	10 Minutes	Nominal	9621.416
16	C2E7	2	4 Links Down	2 Minutes	+200%	8610.415
17	C2E8	2	4 Links Down	5 Minutes	Nominal	10565.423
18	C2E9	2	4 Links Down	10 Minutes	+100%	4811.910
19	C3E1	3	Ideal	2 Minutes	Nominal	18582.426
20	C3E2	3	Ideal	5 Minutes	+100%	15896.532
21	C3E3	3	Ideal	10 Minutes	+200%	4101.705
22	C3E4	3	2 Links Down	2 Minutes	+100%	14357.629
23	C3E5	3	2 Links Down	5 Minutes	+200%	6971.872
24	C3E6	3	2 Links Down	10 Minutes	Nominal	12503.999
25	C3E7	3	4 Links Down	2 Minutes	+200%	11652.322
26	C3E8	3	4 Links Down	5 Minutes	Nominal	12583.892
27	C3E9	3	4 Links Down	10 Minutes	+100%	5985.138

Table 5. Experiment Results for Grade of Service Sensitive Metric

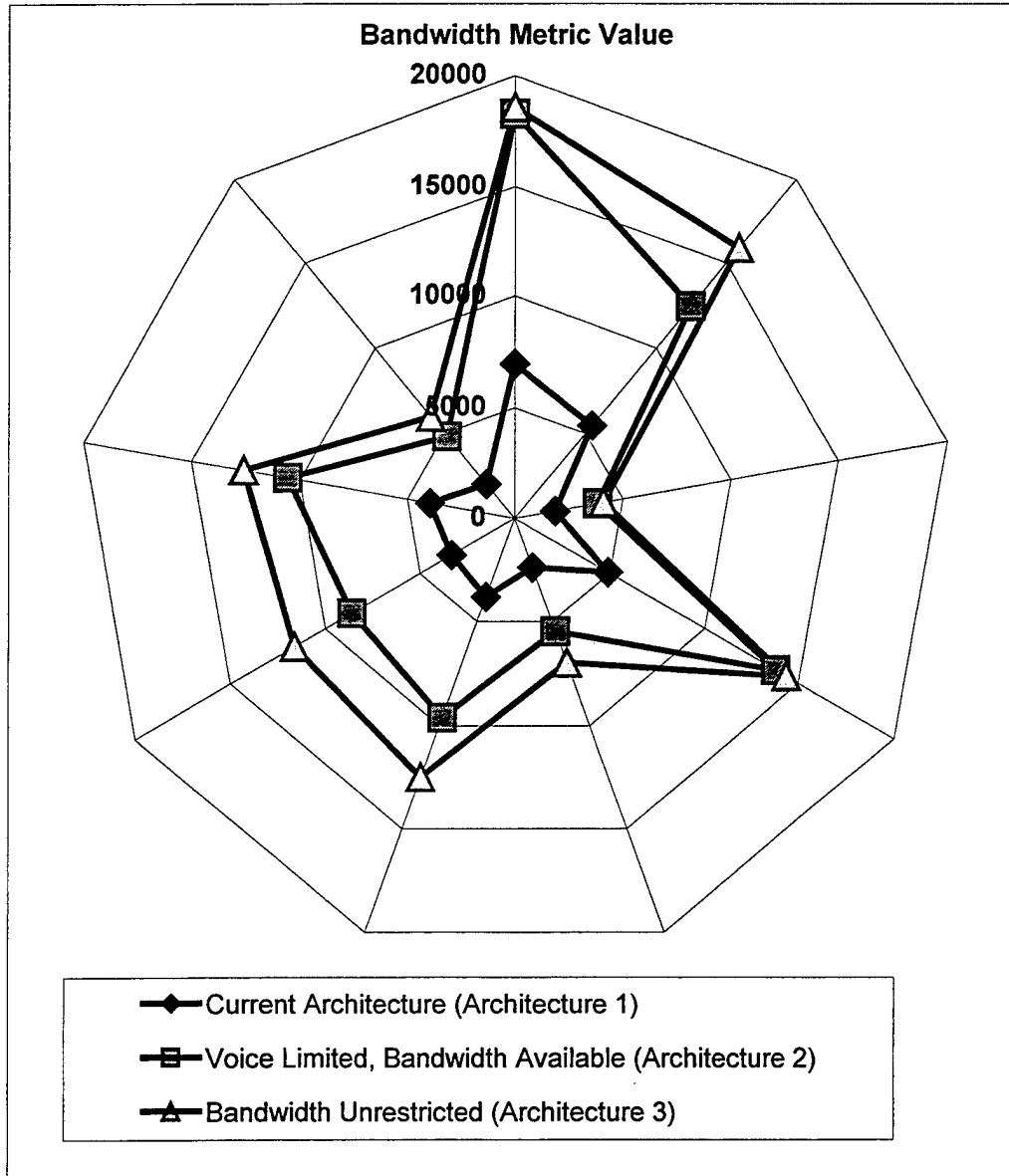


Figure 13. Radar Graph of Grade of Service Sensitive Metric Results

***b. Control Factor-to-Noise Factor Interaction***

The experiment results were manipulated according to the process described in Chapter IV. For the Grade of Service Sensitive Metric, Noise Factor interactions were more pronounced than with the Total System Available Bandwidth

Metric. The Noise Factor with the greatest interaction with the three systems in the extreme experiment condition was Length of Mean Call. At the 10-minute level, Architecture 2's performance was decreased 55.1 % as compared to the 2-minute level. Architecture 1 decreased 49.4 % and Architecture 3 decreased 49.3 % over the same Noise Factor levels. A graphical summary of this interaction is displayed in Figure 14. The Network Condition Noise Factor, which had the strongest interaction with the Total System Available Bandwidth Metric had a strong interaction, but was lower than the other two Noise Factors. Architecture 1 decreased in performance 35.0 %, Architecture 2 decreased 30.6 %, and Architecture 3 decreased 21.7 % comparing the network condition with 4 transmission links removed to the ideal condition with all links in service. A graphical summary of this interaction is displayed in Figure 15. The Network Loading Noise Factor had a different interaction than any other encountered during the experiment. Where all other interactions observed followed a nearly linear relationship, this Noise Factor indicates the beginning of a system failure at the experiment extreme. For Architecture 2, system performance decreases 19.2 % as the Network Load increases from nominal to +100%, but decreases 53.5 % when the nominal load is compared to the +200% level. Architectures 1 and 3 display similar characteristics, with the former decreasing 16.0 % and 48.5 % and the latter decreasing 17.0 % and 48.0 %. A graphical summary of this interaction is displayed in Figure 16.

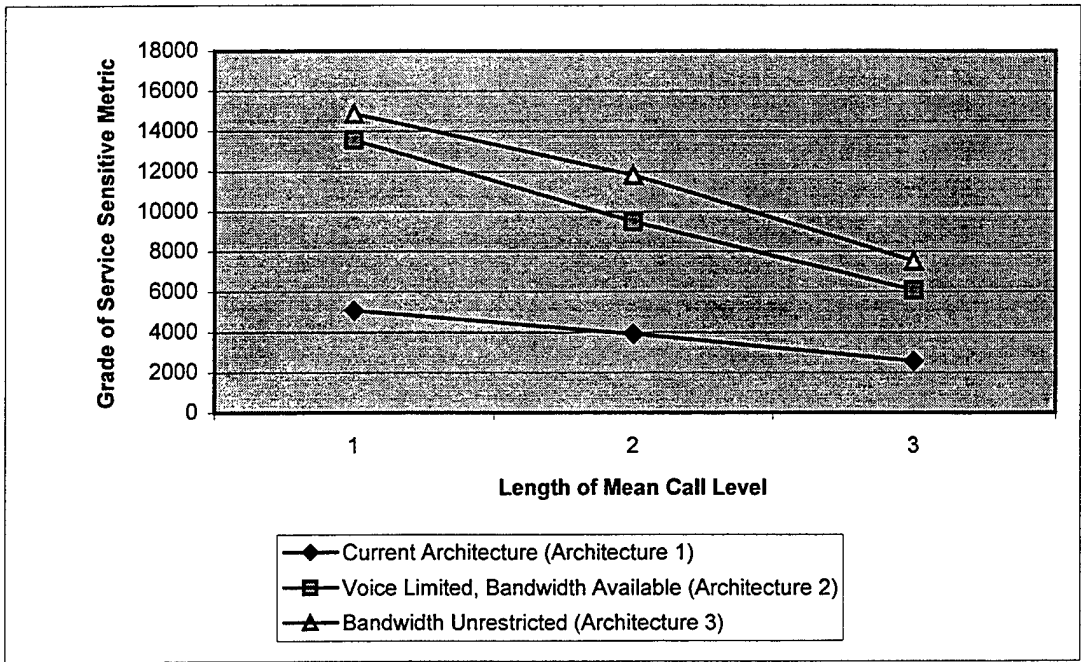


Figure 14. Length of Mean Call Interaction Graph for Grade of Service Sensitive Metric

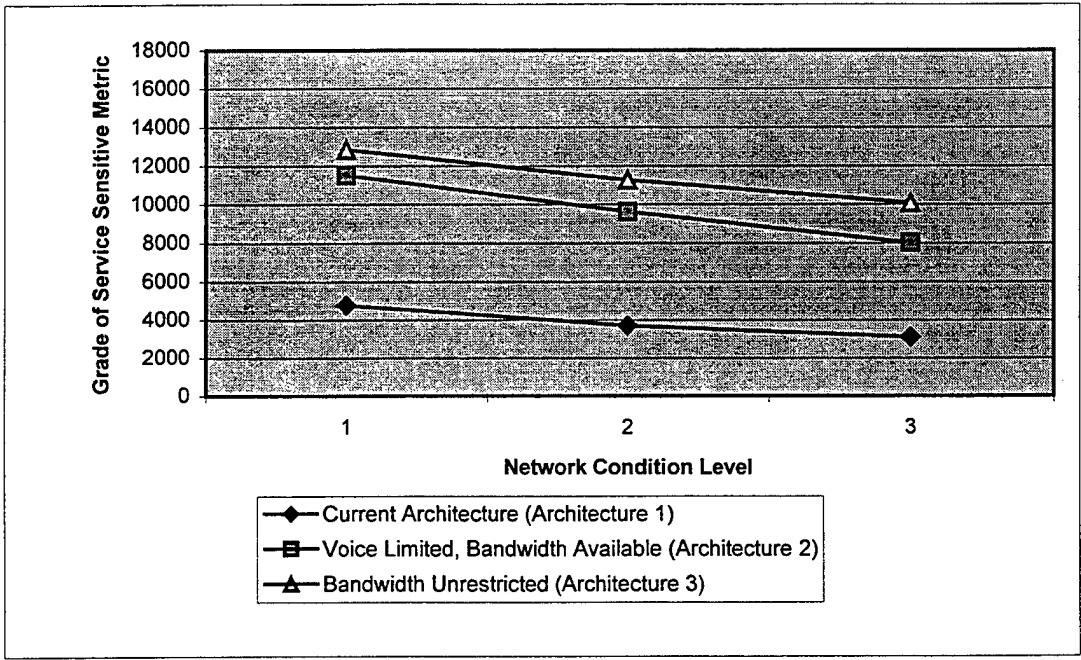


Figure 15. Network Condition Interaction Graph for Grade of Service Sensitive Metric

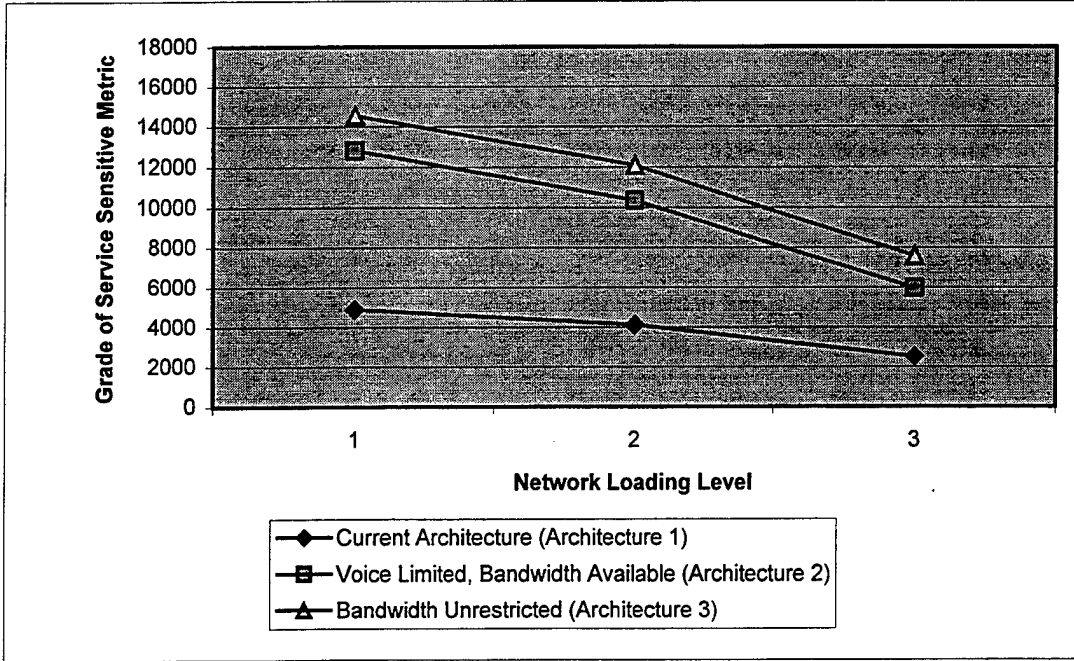


Figure 16. Network Loading Interaction Graph for Grade of Service Sensitive Metric

## **VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH**

### **A. CONVERGENCE IN THE TACTICAL ENVIRONMENT**

Commercial telecommunications carriers are moving towards a converged network based on a ubiquitous digital backbone designed to carry all forms of communication seamlessly and efficiently. In the commercial world, convergence is causing traditional service providers, such as local telephone and long distance carrier companies to rethink their business strategy in order to survive. In the commercial environment, convergence results in better customer service and efficient use of the installed network, as well as potentially greater profits for service providers.

In the tactical environment, and in particular as it relates to the Marine Corps, convergence can provide a more efficient digital command and control network that provides greater capacity and flexibility, given the same transmission system. The experiment results of a hypothetically converged network based on a real-world scenario presented in this thesis clearly show that greater bandwidth efficiency and better service can be achieved by combining all digital traffic onto the common transmission backbone. Reserved bandwidth for any service dramatically reduces a network's ability to carry the total network demand. Current projections about future tactical networks all assume greater bandwidth demands made by the network's users. This increased demand will be partially met through the fielding of additional transmission systems, but all have an upper limit of bandwidth throughput. The gains made by converging the tactical network



would make the network more adaptable to user demand, as well as simpler to plan and obtain service.

One modeling assumption made in this thesis makes the simulation results conservative. When looking at literature on Voice over IP, such as Bjarne Munch's white paper, "IP Telephony – Today/Tomorrow/Ever?," it is clear that most commercial solutions will implement a converged network with voice channel compression to gain additional efficiency on the network. The International Telecommunications Union (ITU) has authored agreements, such as the G.726 Adaptive Differential Pulse Code Modulation (ADPCM) standard which supports voice compression to 16 kbps per channel; and the G.729 Conjugate-Structure Algebraic Code Excited Linear Prediction (CS-ACELP) standard which supports 8 kbps per channel. Either standard could be implemented in a tactical system. For the simulations run in this thesis, all voice channels were assumed to be 32 kbps, the same as was implemented in the Desert Knight '00 network.

Bjarne Munch points out in his white paper that the ITU standards can be implemented in a number of ways. Vendors are developing converged networks that support voice services as Voice over Internet Protocol (VoIP), Voice over Frame Relay (VoFR), and Voice over Asynchronous Transfer Mode (VoATM) networks. Using any one of these implementations can result in a highly efficient network that is resistant to node failures.

Commercially developed technologies have been increasingly used in the tactical environment. Personal computers, routers, video conferencing suites, client-server

networks and web-based intranets all were developed in the commercial environment and have been successfully employed by Marine forces in the tactical environment. Converging voice and data networks onto a common transportation network not only will result in service and efficiency improvements, but it is a logical next step from a technological standpoint.

## **B. RECOMMENDED AREAS FOR FUTURE RESEARCH**

Several areas of research can be carried forward relating to this thesis, grouped into two areas, supported by a third. The first area is technology implementations, the second area cryptography, both supported by additional modeling and simulation.

Research should be conducted into determining the best technological solution to implement a converged network in a tactical environment. There are many implementations of voice services in a converged network, such as VoIP, VoFR, and VoATM, as well as emerging technologies being developed in the commercial sector. The unique characteristics of tactical transmission systems would impact the choice of technology chosen for implementation. Factors such as relatively high bit error rates, limited transmission system bandwidth, field generated power sources, electromagnetic interference, network robustness, and the ability to hold up and provide reliable service in rough field environments must be considered. Research conducted with these and other pertinent factors in mind could aid the intelligent choice of network solution.

All military command and control networks must be protected by cryptographic systems. Voice systems should be compatible with current systems to as great an extent

as possible. Implementing this form of cryptography in a packet-based network, with multiple levels of classification flowing across it, with multiple addressees, is a challenging problem, worthy of several thesis projects.

Both these areas of research should be supported by additional modeling and simulation projects. Modeling and simulation provides great insight into problems otherwise unavailable. When considering technological and cryptographical solutions to implement a converged network, simulation can provide answers to overhead requirements, and expected performance under combat conditions without the investment involved in building a physical prototype.

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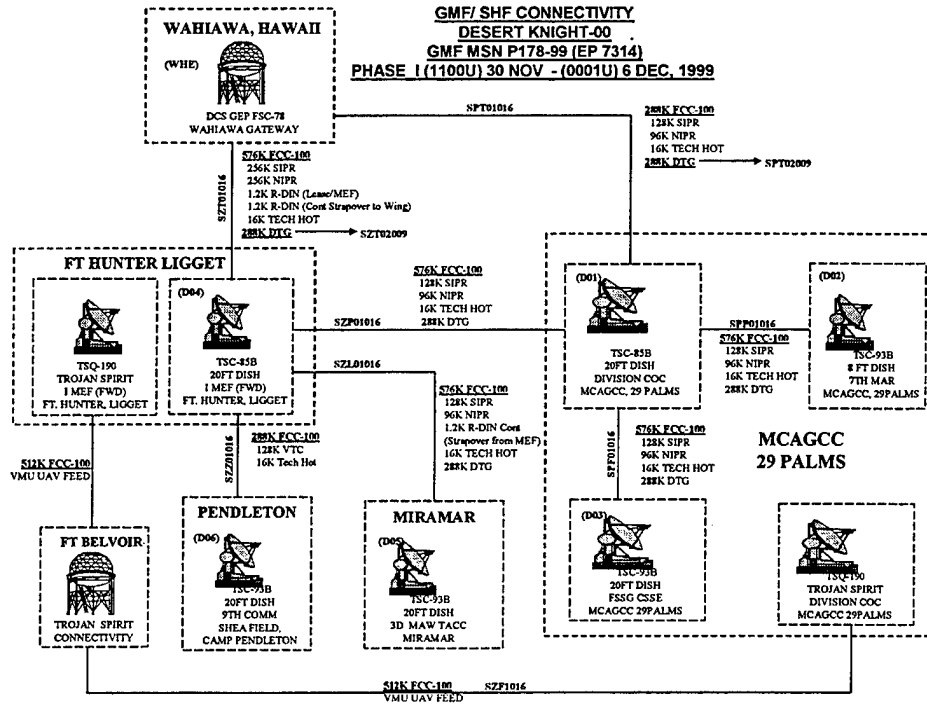
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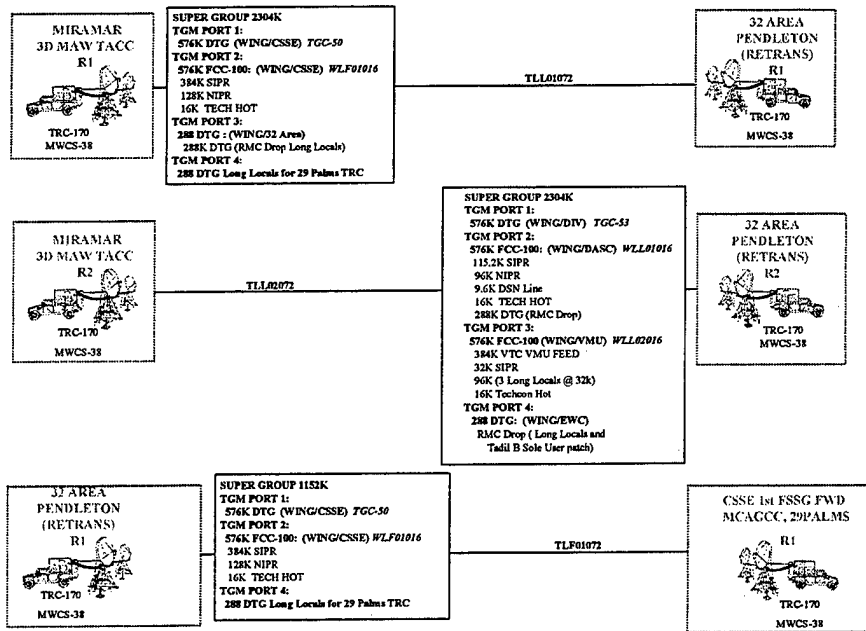
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# APPENDIX A. DESERT KNIGHT '00 COMMUNICATIONS PLANNING DOCUMENTS

This appendix contains the high-level communications network planning documents generated by the 1<sup>st</sup> MEB G-6 and 9<sup>th</sup> Communication Battalion.

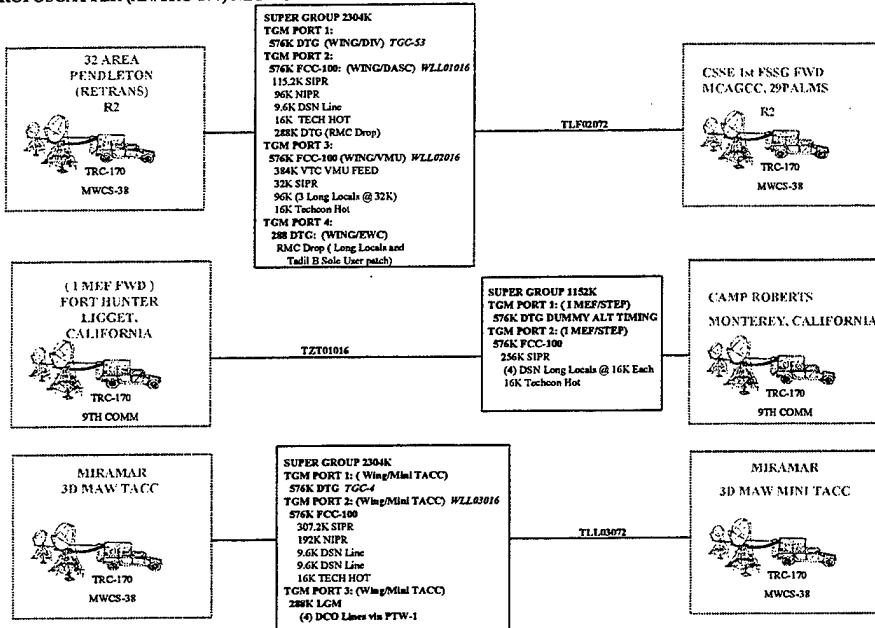


TROPOSCATTER (AN/TRC-170) NETWORK FOR DESERT KNIGHT-00



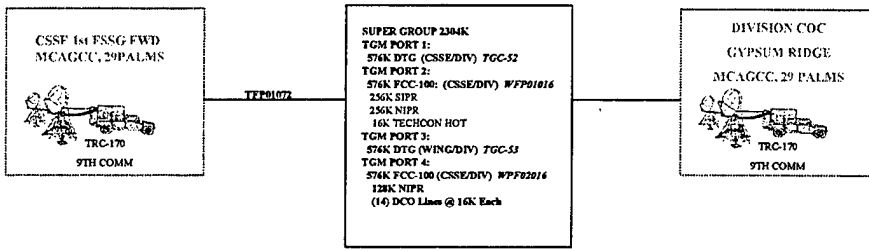
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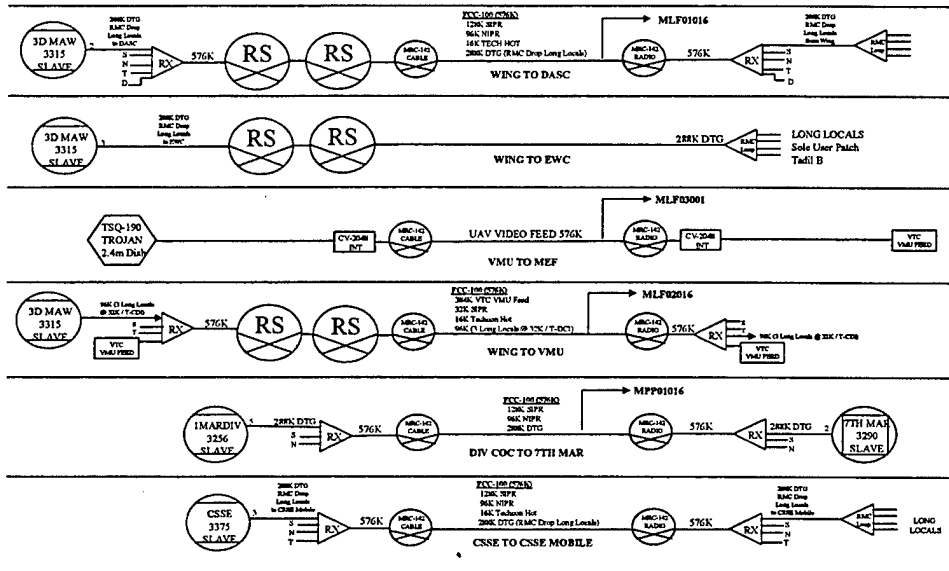
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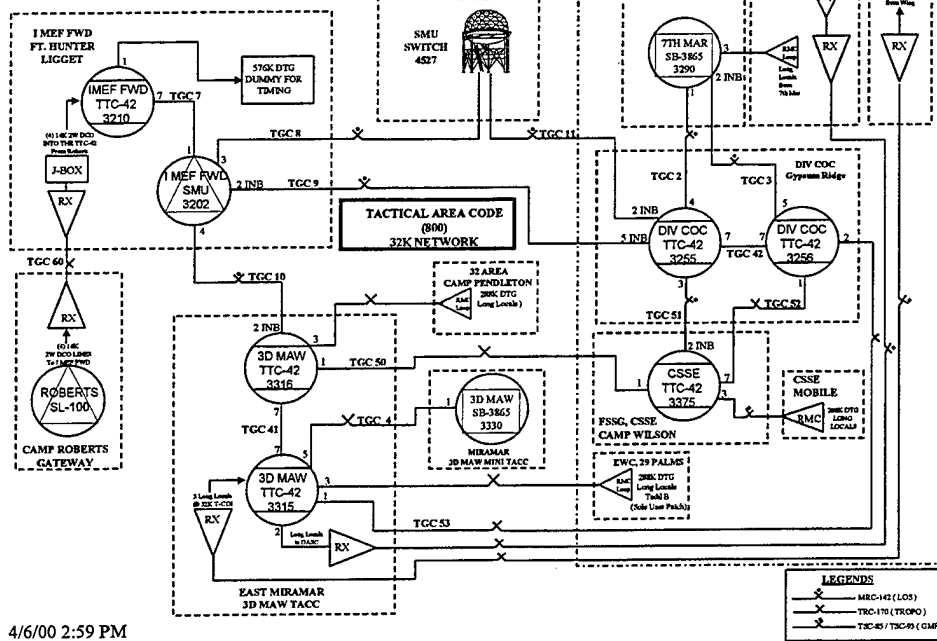
LINE OF SITE (AN/MRC-142) NETWORK FOR DESERT KNIGHT-00



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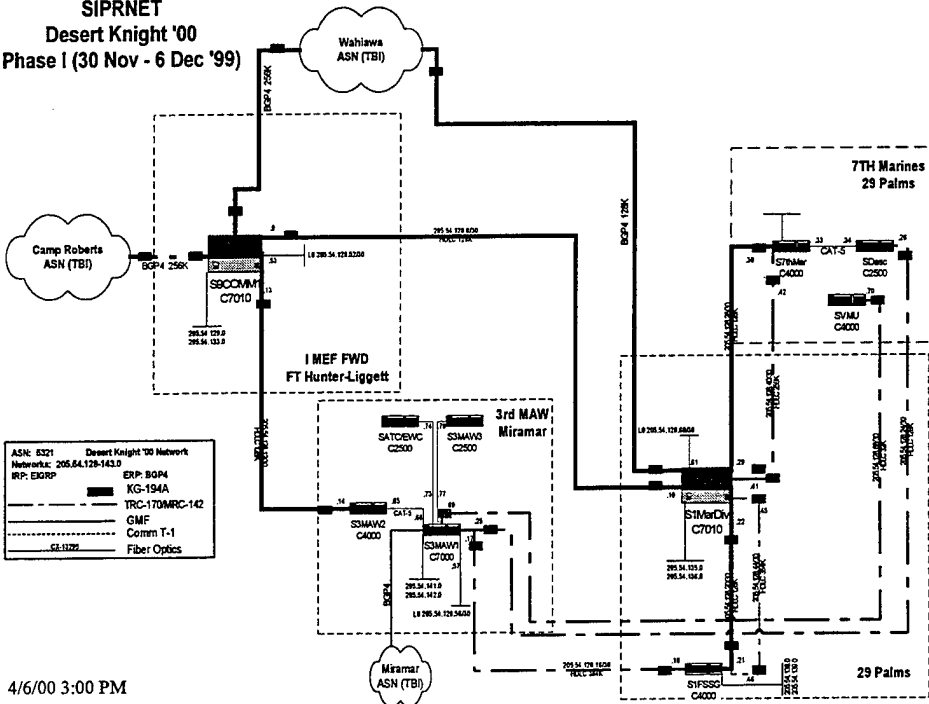


**SWITCHING CONNECTIVITY**  
**DESERT KNIGHT - 00**  
**PHASE I (1100U) 30 NOV - (0001U) 6 DEC 1999**



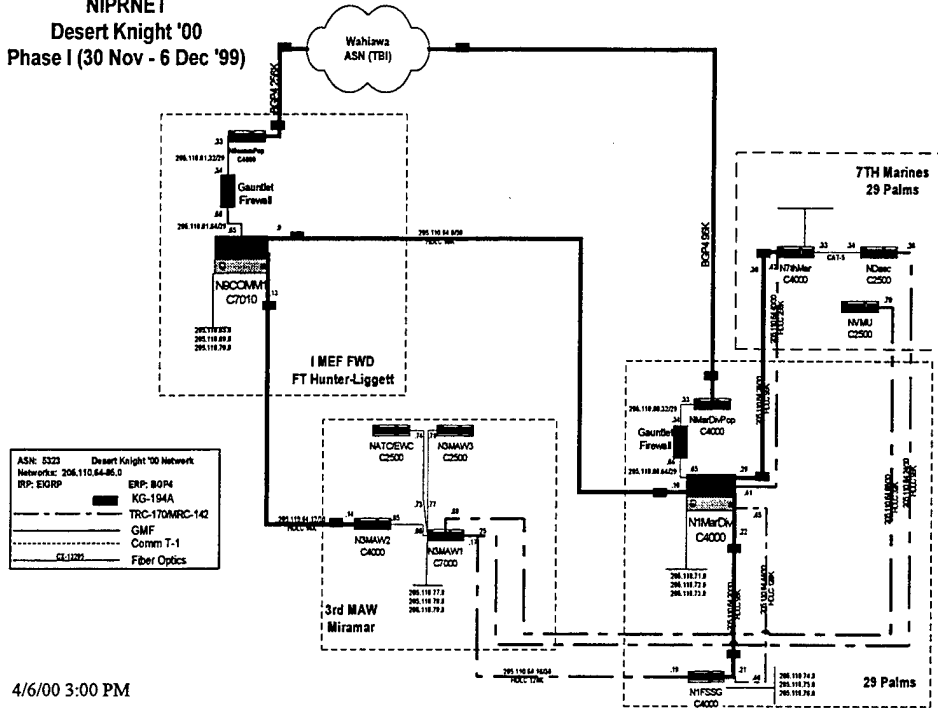
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**SIPRNET**  
**Desert Knight '00**  
**Phase I (30 Nov - 6 Dec '99)**



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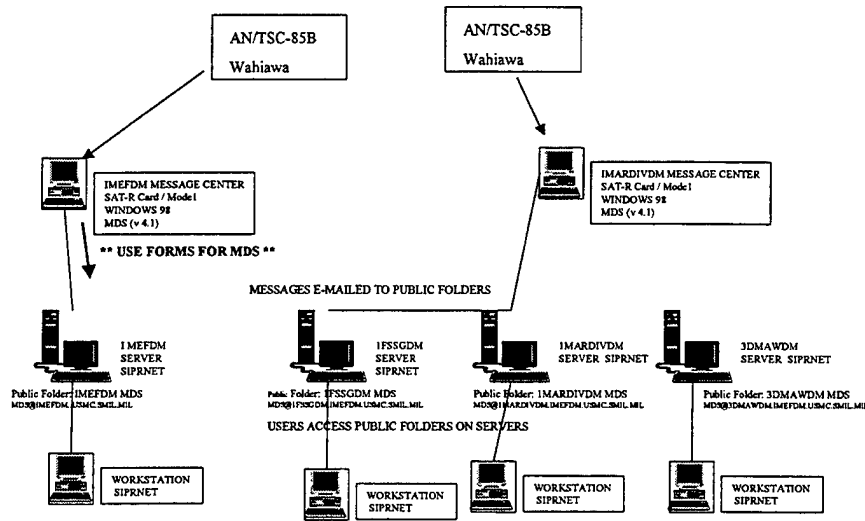
**NIPRNET  
Desert Knight '00  
Phase I (30 Nov - 6 Dec '99)**



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**I MEF MESSAGE TRAFFIC DISSEMINATION PLAN  
Desert Knight '00**

Messages for all PLAs sent to AN/TSC-96A.  
MDS software e-mails messages to proper PLA via SIPRNET. E-mails received by NT Server and stored in public folders where users can access via workstation.



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# I MEF MESSAGE TRAFFIC COLLECTION PLAN

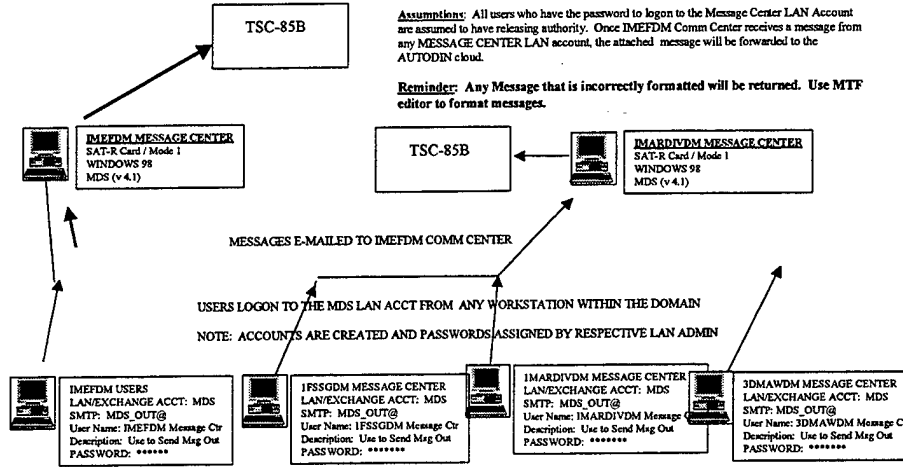
Desert Knight '00

## Procedures for MDS Collection

- LAN Administrators create MDS LAN account in their respective Domains.
- MSCs will determine who has releasing authority and who will receive the password to the MDS Lan Account.
- Users login to their respective MDS LAN account. Use MS Outlook to send e-mail to IMEFDM Comm Center (attach DRAFT MTF message). IMEFDM Comm Center will forward the message out to the AUTODIN cloud.

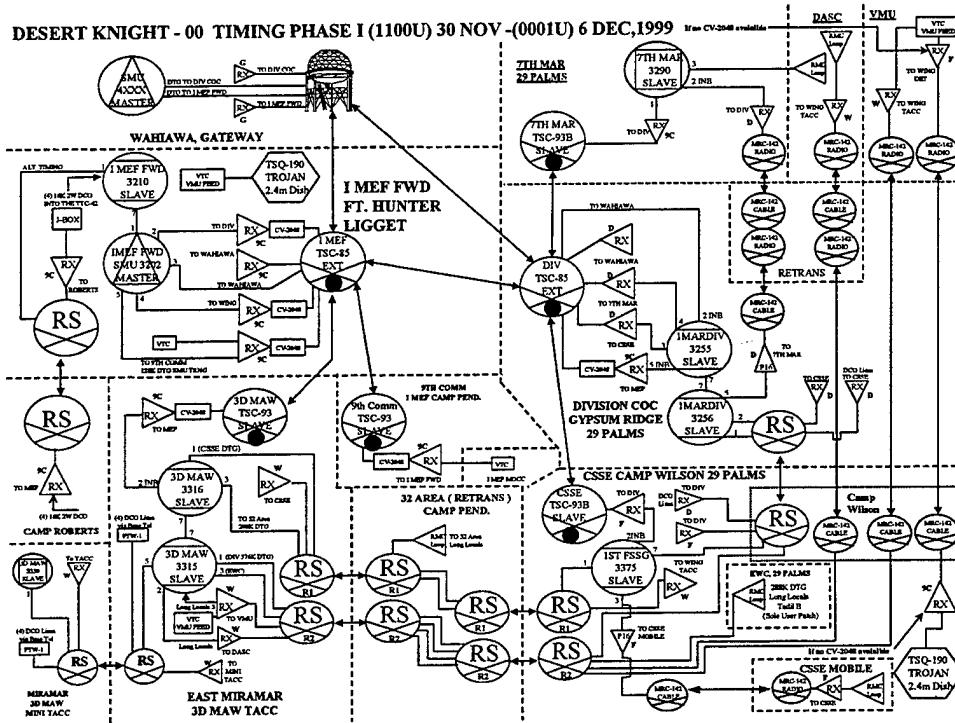
**Assumptions:** All users who have the password to login to the Message Center LAN Account are assumed to have releasing authority. Once IMEFDM Comm Center receives a message from any MESSAGE CENTER LAN account, the attached message will be forwarded to the AUTODIN cloud.

**Reminder:** Any Message that is incorrectly formatted will be returned. Use MTF editor to format messages.



4/6/00 3:01 PM

## DESERT KNIGHT - 00 TIMING PHASE I (1100U) 30 NOV - (0001U) 6 DEC, 1999



## APPENDIX B. EXTEND MODEL BLOCKS

This Appendix describes the composition of the Extend model blocks used in this thesis. The first portion of this appendix describes the individual blocks used in the construction of the model. The second portion provides a partial example of a modeled node.



**Activity, Multiple.** Holds many items and passes them out based on the delay and arrival time for each item. The item with the smallest delay and earliest arrival time is passed out first. The delay time for each item is set through the D connector or, if nothing is connected there, can be specified in the dialog.



**Activity, Service.** Passes an item only when the demand connector is connected and certain conditions exist at the demand input (either demand's value is true [greater than 0.5] or it pulls in an item). Depending on the type of output connector (item or value) attached to demand, this block passes single items or passes a specified number of items. This block allows service on demand. You can think of this block as a path with a gate that opens on demand, where demand can accumulate.



**Combine.** Combines the items from two different sources into a single stream of items. This is different from the batch blocks which join items from several sources into one item. The items in the Combine block retain their separate identities and are not batched together. Examples of use are: merging traffic, customers coming from two entrances to form a single line.



**Constant Block.** Generates a constant value at each step. You specify the constant value in the dialog (the default constant is 1). If the input is connected, the input value is added to the constant in the dialog. This block is typically used for setting the

value for the inputs to other blocks. For example, you can use it for a steady flow of fluid, cash, or a delay time value.



**Count Items.** Passes items through and reports the total number of items passed in its dialog and at the # connector.



**Divide.** Divides the top input by the bottom input. You can choose whether a bottom input of 0 yields an output of noValue or stops the simulation with an error message.



**Executive.** This block is the heart of each discrete event model and must be placed to the left of all other blocks in the model. It allows the duration of the simulation to be controlled by the end time or by another number specified in the dialog. Generally you will have no reason to change the default values in the dialog.



**Completed Calls Exit.** Passes items out of the simulation. The total number of items absorbed by this block is reported in its dialog and at the # connector.



**Demanded Calls Generator.** Provides items for a discrete event simulation at specified interarrival times. Choose either a distribution on the left, or choose the empirical distribution and enter probabilities in the table. Items can be created with a random distribution or at a constant rate of arrival. You can also specify the number of items output at each event in the dialog or at the V connector. This block provides items at specified interarrival rates. Since it always pushes items, this block should usually be followed by a Queue or Resource block when used to provide items for the model. Otherwise, you may lose some items that are generated. If an arrival rate of 0 or less

occurs, items are generated immediately (at the time the 0 or less value occurs). The parameters for the distribution arrival times are set in the dialog. The random distributions include: beta, binomial, constant, empirical, Erlang, exponential, gamma, hyperexponential, log normal, normal, Pearson type V, Pearson type VI, Poisson, Triangular, uniform integer, uniform real, and Weibull. The empirical distribution may have up to 20 points and may be interpreted as a discrete, stepped, or interpolated distribution. The input connectors 1, 2, and 3 allow you to change the parameters of the random distribution as the simulation progresses.



Call Hold Time

**Input Random Number.** Generates random integers or real numbers based on the selected distribution. You can use the dialog or the three inputs, 1, 2, and three to specify arguments for the distributions. You can select the type of distribution: Uniform (integer or real), Beta, Binomial, Erlang, Exponential, Gamma, Geometric, HyperExponential, LogLogistic, LogNormal, Neg. Binomial, Normal, Pearson type V, Pearson type VI, Poisson, Triangular, Weibull, and Empirical. The Empirical distribution uses a table of up to 50 values to generate a discrete, stepped, or interpolated empirical distribution.



Avail Circuits?

**Logical And.** Performs logical AND operation on the inputs. If each of the two inputs is greater than 0.5, the output is 1; if none or only one of the inputs is greater than 0.5, the output is 0.



**Multiply.** This block multiplies the inputs.

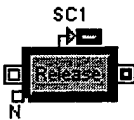


**Plotter, Discrete Event.** This plotter is to be used only in discrete event models. It is used to plot values such as information about items (queue length, attribute values, number of items exited, etc). Both the value and the time the value was recorded

(event time) are shown in the data table for each input. You can specify in the dialog whether to plot values only when they change (the default) or to plot all values (this last choice plots slower and uses more memory).



**Queue, Resource Pool.** A queue for resource pool units. Items wait until the specified number of resource pool units become available. The order of items in the queue is determined by the ranking rule in the dialog of the Resource Pool block. The maximum length, which determines how many items the queue can hold, can be set in the dialog. You can also see the average queue length, average wait time, and utilization of the queue in the dialog.



**Release Resource Pool.** This block releases a resource pool as the item passes through. This pool of resource units can be released by either:

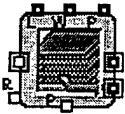
- Choosing the "Release Resource Pool by name" radio button and entering the name of the Resource Pool block and the number of units to be released.
- Choosing the "Release resource pool by attribute" radio button and specifying an attribute which has been set by a Queue, Resource Pool block.

The Resource Pool is immediately released and will check its list of items requesting the resource pool to see if it can be allocated to a different item.



**Resource Pool.** This block holds resource pool units to be used in a simulation. These units limit the capacity of a section of a model. For example, this could be used to represent a limited number of tables at a restaurant. Unlike the Resource block, the resource pool units are not items. They are variables which indicate how much of a constraining factor is available. The Resource Pool block works with the Queue, Resource Pool to allocate the pool of resources to items and it works with the Release

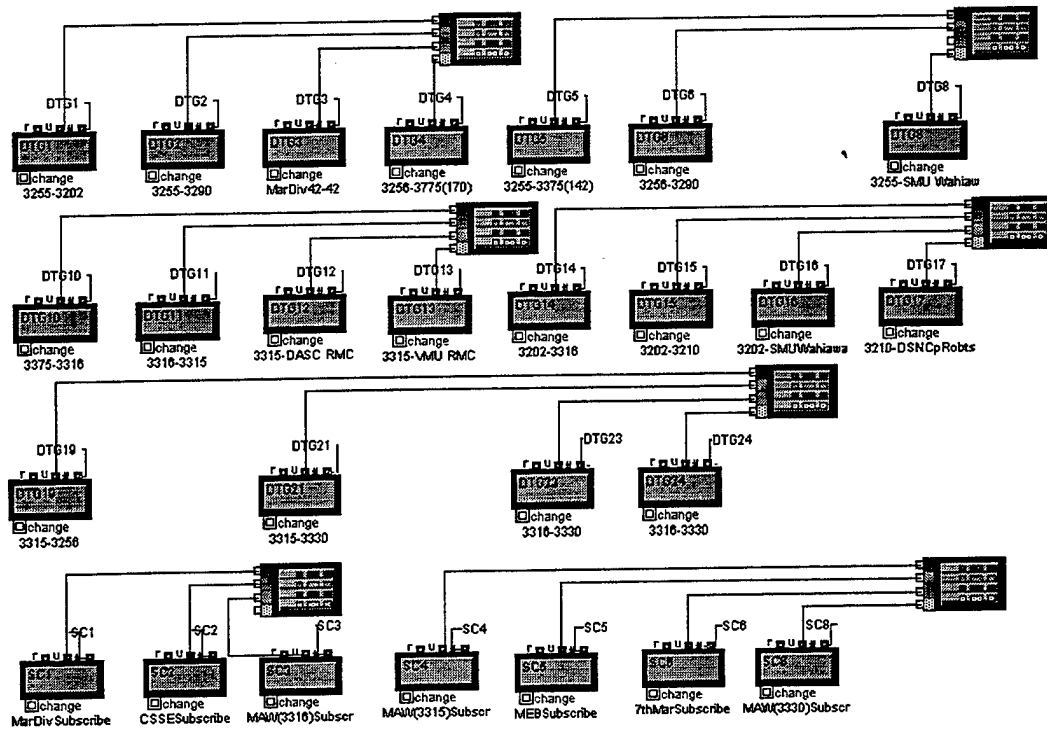
Resource Pool block to release the pool of resources. Items can wait for a resource pool from any number of Queue, Resource Pool blocks. The Resource Pool block determines the order in which the resource pool units are allocated. Units can be allocated to either the item which arrived first in the Queue, Resource Pool block or the item with the highest priority (the lowest numerical priority value). If the Only allocate to the highest ranked item option is checked, only one item will be considered when the resource pool allocation is attempted. If this is not checked, the pool will look through all of the items waiting until it finds both the first item which can leave the Queue, Resource Pool block and a sufficient number of available resource pool units. The change connector modifies the number of resource pool units available by the value of the item at change. (The main difference between the regular item input and the change input is that the input at change may be negative, reducing the number of units available in the block.)



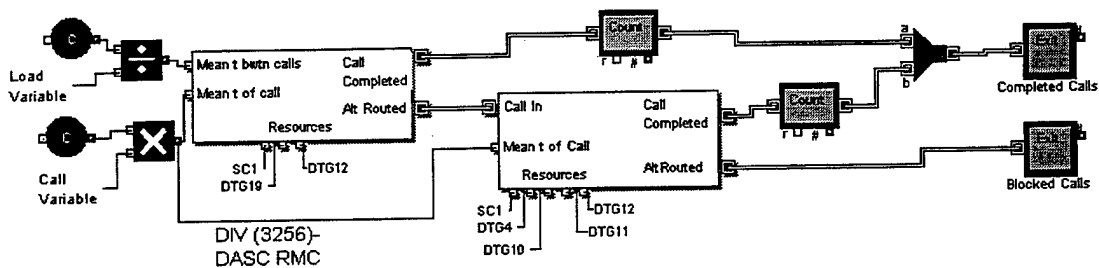
Stack Queue. Takes in items and holds them until they are requested by other blocks in the model. The stack holds items on a First-In-First-Out (FIFO), Last-In-First-Out (LIFO), Priority, or Reneging basis, as specified in the dialog. This block also provides the capability of setting the priority for each item that passes through.

These individual blocks are combined to form the structure of the model used for this thesis. Example structure of key portions of the model is provided below.





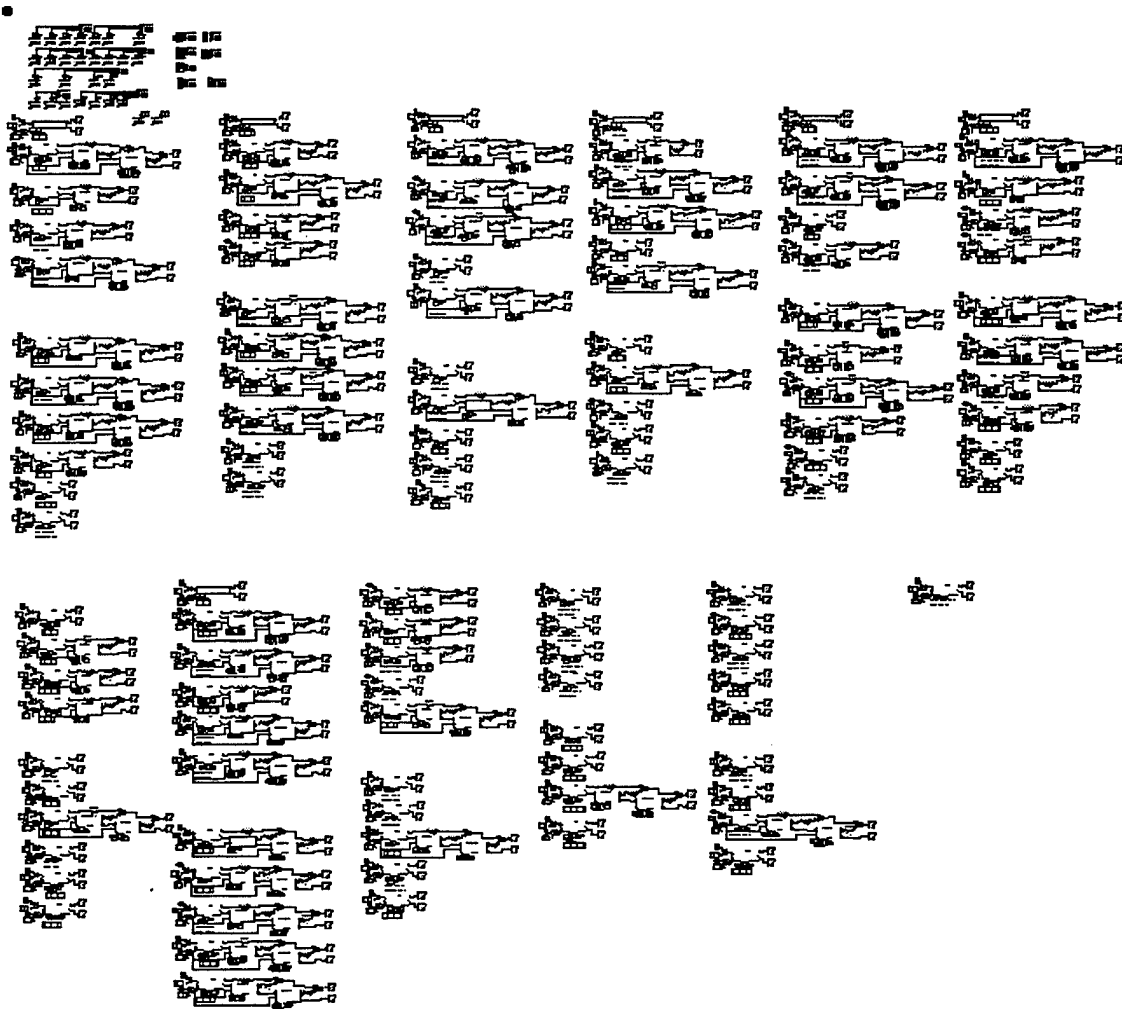
This diagram forms the resource pool of all required resources necessary to complete a telephone call in the model. Each modeled DTG is provided with a number of resources available to it in terms of 32 kbps channels. End user telephones at major switches are contained in the SC blocks. The maximum assignable number of instruments for the AN/TTC-42 is 150. The resource pool is where the utilization information for each DTG is gathered.

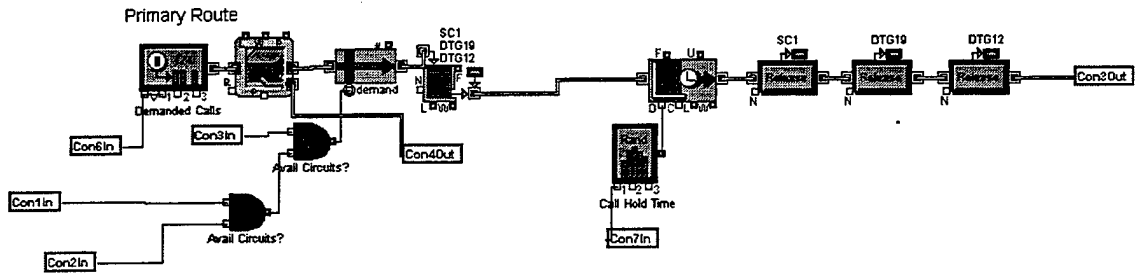


An individual connection, from one node to another is represented in the above diagram. The constant values to the left of the model were based on observed data from the Desert

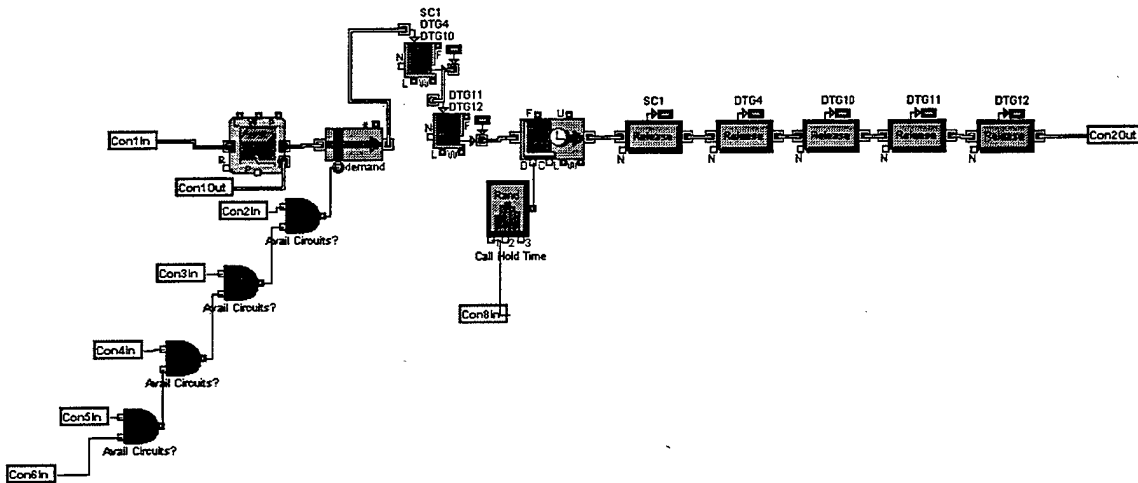
Knight '00 exercise. The first block represents the primary route of the call attempt, and the second the alternate route. Availability of resources in the resource pool are checked by the connectors shown below each of the routes. If a call cannot be completed, it is routed out the Blocked Calls exit block. If it is completed, it is routed out the Completed Calls exit block.

One block exists for each node to call another node in the network. As a result, the 1<sup>st</sup> Marine Division portion of the model consists of 11 connections, as shown above. The entire model contains 115 connections, as shown below. The upper left portion of the model is the resource pool, as depicted above.





The primary route block consists of the above diagram. The connector on the program block adjusts the traffic loading variable by increasing or decreasing the mean of the Erlang distribution, representing the time between calls placed. The call enters the Stack Queue, where the availability of resources are checked. If resources are available, the Activity, Service block "pulls" the call into the Resource Queue block, where the available resources are assigned to the telephone call. If no resources are available, the call is renege'd to the alternate route connector. The completed call will remain in the Activity, Multiple block for the randomly assigned time period of the call based on the decaying exponential distribution contained in the Input Random Number block, as modified by the time of call noise factor. When the call is "terminated," the call travels through the Release Resource Pool blocks where the resources used for that telephone call are made available for other demanded service.



The alternate route is configured in the same manner as the primary route, except that the attempted route taken is different. In this case, a telephone call that cannot be completed

is not sent to another alternate route, but is renegeed by the Stack Queue to the Blocked Call exit block.

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## APPENDIX C. MODEL PROGRAMMING SHEETS

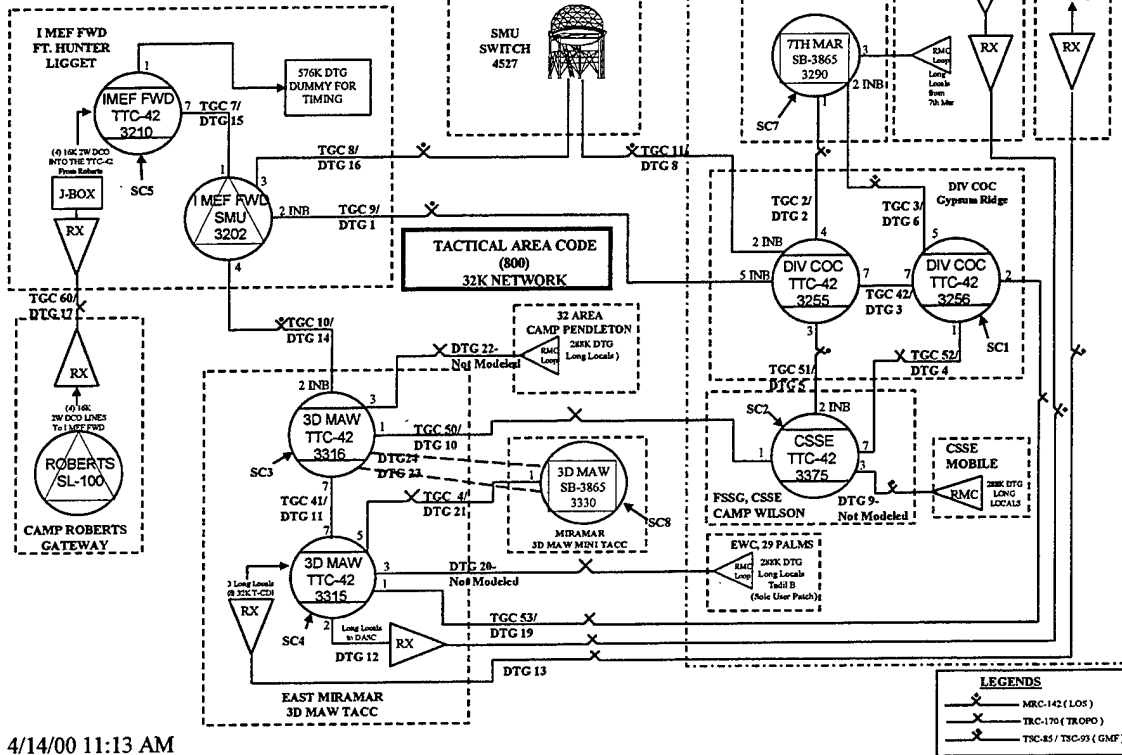
This appendix contains the programming sheets used to configure the model used in this thesis. Each sheet describes the connectivity from each node to every other node in the network, described in a sequence of resources that must be available for a call to be completed, and a percentage used to determine the percentage of total generated calls destined for a node in the network. For example, the first program line in the model is described below:

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
DIV (3256) – MEB (3210)	SC1-3-1-15-SC5	(1) SC1-4-10-14-15-SC5 (2) SC1-3-5-10-14-15-SC5	20%

The notation describes the connectivity between the 1<sup>st</sup> Marine Division switchboard and the 1<sup>st</sup> Marine Expeditionary Brigade switchboard, from the Division's perspective. A telephone call placed from the Division has a primary route that originates with one of the 150 available telephone instruments (SC1) and travels over DTG's 3, 1, 15, and terminates at one of the 150 available telephone instruments at the MEB (SC5). Alternate routes are programmed in the same manner. The percentage of generated calls to the called node is used to determine how many of the observed telephone calls generated during Desert Knight are placed by the model to the called node.

The following page displays the associated DTG numbers with the link established for the Desert Knight Exercise. To simplify the modeling process, three links were not modeled, but their traffic loads were treated as being carried by the nearest local switchboard, as if they were a local subscriber. The DTG numbering scheme was used, as some links modeled were not assigned Trunk Group Cluster (TGC) numbers by the automated planning tool.

**SWITCHING CONNECTIVITY  
DESERT KNIGHT - 00  
PHASE I (1100U) 30 NOV - (0001U) 6 DEC 1999**



4/14/00 11:13 AM

1<sup>st</sup> Marine Division Switch (3256)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
DIV (3256) – MEB (3210)	SC1-3-1-15-SC5	(3) SC1-4-10-14-15-SC5 (4) SC1-3-5-10-14-15-SC5	20%
DIV (3256) – 7 <sup>th</sup> Marines (3290)	SC1-6-SC6	(1) SC1-3-2-SC6	40%
DIV (3256) – DASC RMC	SC1-19-12	(1) SC1-4-10-11-12	2%
DIV (3256) – CSSE (3375)	SC1-4-SC2	(1) SC1-3-5-SC2 (2) SC1-3-1-14-10-SC2	13%
DIV (3256) – MAW (1) (3316)	SC1-4-10-SC3	(1) SC1-19-11-SC3 (2) SC1-3-1-14-SC3	6%
DIV (3256) – MAW (2) (3315)	SC1-19-SC4	(1) SC1-4-10-11-SC4 (2) SC1-3-1-14-11-SC4	6%
DIV (3256) – MAW (3) (3330)	SC1-19-21-SC8	(1) SC1-4-10-24-SC8 (2) SC1-3-1-14-23-SC8	6%
DIV (3256) – VMU FCC-100	SC1-19-13	(1) SC1-3-5-10-11-13	1%
DIV (3256) – DSN (1)	SC1-3-8		4%
DIV (3256) – DSN (2)	SC1-3-1-16		2%



CSSE Switch (3375)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
CSSE (3375) – MEB (3210)	SC2-5-1-15-SC5	(1) SC2-10-14-15-SC2	25%
CSSE (3375) – DIV (3256)	SC2-4-SC1	(1) SC2-5-3-SC1 (2) SC2-10-14-1-3-SC1	32%
CSSE (3375) – 7 <sup>th</sup> Marines (3290)	SC2-5-2-SC6	(1) SC2-4-6-SC6	32%
CSSE (3375) – DASC RMC	SC2-10-11-12	(1) SC2-4-19-12	1%
CSSE (3375) – MAW (1) (3316)	SC2-10-SC3	(1) SC2-5-1-14-SC3 (2) SC2-4-19-11-SC3	2%
CSSE (3375) – MAW (2) (3315)	SC2-10-11-SC4	(1) SC2-4-19-SC4 (2) SC2-5-1-14-11-SC4	1%
CSSE (3375) – MAW (3) (3330)	SC2-10-24-SC8	(1) SC2-4-19-21-SC8 (2) SC2-5-1-14-23-SC8	1.5%
CSSE (3375) – VMU FCC-100	SC2-10-11-13	(1) SC2-4-19-13 (2) SC2-5-1-14-11-13	0.5%
CSSE (3375) – DSN (1)	SC2-5-8		4%
CSSE (3375) – DSN (2)	SC2-10-14-16		1%

MAW (1) AN/TTC-42 Switch (3316)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
MAW (1) (3316) – MEB (3210)	SC3-14-15-SC5	(1) SC3-10-5-1-15-SC5 (2) SC3-11-19-3-1-15-SC5	17%
MAW (1) (3316) – DIV (3256)	SC3-10-4-SC1	(1) SC3-11-19-SC1 (2) SC3-14-1-3-SC1	12.5%
MAW (1) (3316) – 7 <sup>th</sup> Marines (3290)	SC3-10-5-2-SC6	(1) SC3-11-19-6-SC6 (2) SC3-14-1-2-SC6	12.5%
MAW (1) (3316) – DASC RMC	SC3-11-12		3%
MAW (1) (3316) – CSSE (3375)	SC3-10-SC2	(1) SC3-14-1-5-SC2 (2) SC3-11-19-4-SC2	8%
MAW (1) (3316) – MAW (2) (3315)	SC3-11-SC4		28%
MAW (1) (3316) – MAW (3) (3330)	SC3-24-SC8	(1) SC3-23-SC8 (2) SC3-11-21-SC8	16%
MAW (1) (3316) – VMU RMC	SC3-11-13		3%
MAW (1) (3316) – DSN (1)	SC3-10-5-8		40%*
MAW (1) (3316) – DSN (2)	SC3-14-16		60%*

\* DSN Connectivity percentages reflect observed DSN traffic for Desert Knight, and are treated separately from non-DSN traffic.

MAW (2) AN/TTC-42 Switch (3315)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
MAW (2) (3315) – MEB (3210)	SC4-11-14-15-SC5	(1) SC4-19-3-1-15-SC5	33%
MAW (2) (3315) – DIV (3256)	SC4-19-SC1	(1) SC4-11-10-4-SC1 (2) SC4-11-14-1-3-SC1	10%
MAW (2) (3315) – 7 <sup>th</sup> Marines (3290)	SC4-19-6-SC6	(1) SC4-11-10-4-6-SC6 (2) SC4-11-14-1-2-SC6	10%
MAW (2) (3315) – DASC RMC	SC4-12		3%
MAW (2) (3315) – CSSE (3375)	SC4-11-10-SC2	(1) SC4-19-4-SC2 (2) SC4-11-14-1-5-SC2	8%
MAW (2) (3315) – MAW (1) (3316)	SC4-11-SC3		28%
MAW (2) (3315) – MAW (3) (3330)	SC4-21-SC8	(1) SC4-11-23-SC8 (2) SC4-11-24-SC8	5%
MAW (2) (3315) – VMU FCC-100	SC4-13		3%
MAW (2) (3315) – DSN (1)	SC4-11-10-5-8		40%*
MAW (2) (3315) – DSN (2)	SC4-11-14-16		60%*

\* DSN Connectivity percentages reflect observed DSN traffic for Desert Knight, and are treated separately from non-DSN traffic.

MEB Switch (3210)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
MEB (3210) – DIV (3256)	SC5-15-1-3-SC1	(1) SC5-15-14-10-4-SC1 (2) SC5-15-14-10-5-3-SC1	20%
MEB (3210) – 7 <sup>th</sup> Marines (3290)	SC5-15-1-2-SC6	(1) SC5-15-1-3-6-SC6 (2) SC5-15-14-10-4-6-SC6	20%
MEB (3210) – DASC RMC	SC5-15-14-11-12		1%
MEB (3210) – CSSE (3375)	SC5-15-1-5-SC2	(1) SC5-15-14-10-SC2	10%
MEB (3210) – MAW (1) (3316)	SC5-15-14-SC3	(1) SC5-15-1-5-10-SC3 (2) SC5-15-1-3-19-11-SC3	16%
MEB (3210) – MAW (2) (3315)	SC5-15-14-11-SC4	(1) SC5-15-1-3-19-SC4	16%
MEB (3210) – MAW (3) (3330)	SC5-15-14-11-21-SC8	(1) SC5-15-1-3-19-21-SC8 (2) SC5-15-14-24-SC8	16%
MEB (3210) – VMU FCC-100	SC5-15-14-11-13	(1) SC5-15-1-3-19-13	1%
MEB (3210) – Camp Roberts DSN	SC5-17		N/A**
MEB (3210) – Waihaiwa DSN	SC5-15-16		N/A**

\*\* MEB DSN connectivity was direct to the servicing gateway, and traffic levels were accurately captured.

7<sup>th</sup> Marines Switch (3290)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
7 <sup>th</sup> Marines (3290) – MEB (3210)	SC6-2-1-15-SC5	(1) SC6-6-3-1-15-SC5 (2) SC6-6-4-10-14-15-SC5	30%
7 <sup>th</sup> Marines (3290) – DIV (3256)	SC6-6-SC1	(1) SC6-2-3-SC1	27%
7 <sup>th</sup> Marines (3290) – DASC RMC	SC6-6-19-12	(1) SC6-2-3-19-12	5%
7 <sup>th</sup> Marines (3290) – CSSE (3375)	SC6-2-5-SC2	(1) SC6-6-4-SC2	10%
7 <sup>th</sup> Marines (3290) – MAW (1) (3316)	SC6-2-5-10-SC3	(1) SC6-6-19-11-SC3 (2) SC6-2-1-14-SC3	10%
7 <sup>th</sup> Marines (3290) – MAW (2) (3315)	SC6-6-19-SC4	(1) SC6-6-4-10-11-SC4 (2) SC6-2-1-14-11-SC4	5%
7 <sup>th</sup> Marines (3290) – MAW (3) (3330)	SC6-6-19-21-SC8	(1) SC6-2-1-14-24-SC8	5%
7 <sup>th</sup> Marines (3290) – VMU FCC-100	SC6-6-19-13	(1) SC6-2-1-14-11-13	2%
7 <sup>th</sup> Marines (3290) – DSN 1	SC6-2-8		4%
7 <sup>th</sup> Marines (3290) – DSN 2	SC6-2-1-16		2%

DASC RMC

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
DASC RMC – MEB (3210)	12-11-14-15-SC5		16%
DASC RMC – DIV (3256)	12-19-SC1	(1) 12-11-10-4-SC1	16%
DASC RMC – 7 <sup>th</sup> Marines (3290)	12-19-6-SC6	(1) 12-19-3-2-SC6	16%
DASC RMC – CSSE (3375)	12-11-10-SC2	(1) 12-19-4-SC2	2%
DASC RMC – MAW (1) (3316)	12-11-SC3		15%
DASC RMC – MAW (2) (3315)	12-SC4		15%
DASC RMC – MAW (3) (3330)	12-21-SC8	(1) 12-11-24-SC8 (2) 12-11-23-SC8	15%
DASC RMC – VMU FCC-100	12-13		3%
DASC RMC – DSN 1	12-11-10-5-8		1%
DASC RMC – DSN 2	12-11-14-16		1%

MAW (3) Switch (SB-3865) (3330)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
MAW (3) (3330) – MEB (3210)	SC8-21-11-14-15-SC5	(1) SC8-21-19-3-1-15-SC5 (2) SC8-24-14-15-SC5	17%
MAW (3) (3330) – DIV (3256)	SC8-21-19-SC1	(1) SC8-24-10-4-SC1 (2) SC8-23-14-1-3-SC1	17.5%
MAW (3) (3330) – 7 <sup>th</sup> Marines (3290)	SC8-21-19-6-SC6	(1) SC8-24-14-1-2-SC6	12.5%
MAW (3) (3330) – DASC RMC	SC8-21-12	(1) SC8-24-11-12 (2) SC8-23-11-12	3%
MAW (3) (3330) – CSSE (3375)	SC8-24-10-SC2	(1) SC8-21-19-4-SC2 (2) SC8-23-14-1-5-SC2	8%
MAW (3) (3330) – MAW (1) (3316)	SC8-24-SC3	(1) SC8-23-SC3 (2) SC8-21-11-SC3	22%
MAW (3) (3330) – MAW (2) (3315)	SC8-21-SC4	(1) SC8-23-11-SC4 (2) SC8-24-11-SC4	22%
MAW (3) (3330) – VMU FCC-100	SC8-21-13	(1) SC8-24-11-13 (2) SC8-23-11-13	3%
MAW (3) (3330) – DSN 1	SC8-24-10-5-8	(1) SC8-23-10-5-8 (2) SC8-21-11-10-5-8	40%*
MAW (3) (3330) – DSN 2	SC8-24-14-16	(1) SC8-23-14-16 (2) SC8-21-11-14-16	60%*

\* DSN Connectivity percentages reflect observed DSN traffic for Desert Knight, and are treated separately from non-DSN traffic.

VMU FCC-100

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
VMU FCC-100 – MEB (3210)	13-11-14-15-SC5	(1) 13-19-3-1-15-SC5	16%
VMU FCC-100 – DIV (3256)	13-19-SC1	(1) 13-11-10-5-3-SC1	16%
VMU FCC-100 – 7 <sup>th</sup> Marines (3290)	13-19-6-SC6	(1) 13-11-14-1-2-SC6	16%
VMU FCC-100 – DASC RMC	13-12		3%
VMU FCC-100 – CSSE (3375)	13-11-10-SC2	(1) 13-19-4-SC2 (2) 13-11-14-1-5-SC2	2%
VMU FCC-100 – MAW(1) (3316)	13-11-SC3		15%
VMU FCC-100 – MAW(2) (3315)	13-SC4		15%
VMU FCC-100 – MAW(3) (3330)	13-21-SC8	(1) 13-11-24-SC8 (2) 13-11-23-SC8	15%
VMU FCC-100 – Wahiawa DSN 1	13-11-10-5-8		1%
VMU FCC-100 – Wahiawa DSN 2	13-11-14-16		1%



DSN (1) (Wahaiwa)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
Wahaiwa DSN – DIV (3256)	8-3-SC1		60%
Wahaiwa DSN – 7 <sup>th</sup> Marines (3290)	8-2-SC6		5%
Wahaiwa DSN – DASC RMC	8-5-10-11-12		1%
Wahaiwa DSN – CSSE (3375)	8-5-SC2		10%
Wahaiwa DSN – MAW(1) (3316)	8-5-10-SC3		9%
Wahaiwa DSN – MAW(2) (3315)	8-5-10-11-SC4		9%
Wahaiwa DSN – MAW(3) (3330)	8-5-10-24-SC8	(1) 8-5-10-23-SC8 (2) 8-5-10-11-21-SC8	5%
Wahaiwa DSN – VMU FCC-100	8-5-10-11-13		1%

DSN (2) (Wahaiwa)

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
Wahaiwa DSN – MEB (3210)	16-15-SC5		70%
Wahaiwa DSN – DIV (3256)	16-1-3-SC1		5%
Wahaiwa DSN – 7 <sup>th</sup> Marines (3290)	16-1-2-SC6		5%
Wahaiwa DSN – DASC RMC	16-14-11-12		0.5%
Wahaiwa DSN – CSSE (3375)	16-14-10-SC2		0.5%
Wahaiwa DSN – MAW(1) (3316)	16-14-SC3		4.5%
Wahaiwa DSN – MAW(2) (3315)	16-14-11-SC4		4.5%
Wahaiwa DSN – MAW(3) (3330)	16-14-24-SC8	(1) 16-14-23-SC8 (2) 16-14-11-21-SC8	4.5%
Wahaiwa DSN – VMU FCC-100	16-14-11-13		0.5%

Camp Roberts DSN

Link	Primary Route	Alternate Route(s)	Percentage of Generated Calls to Node
Camp Roberts DSN – MEB (3210)	17-SC5		100%

## APPENDIX D. MODEL SPREADSHEET DATA

Appendix D contains experiment result data, by experiment. Experiment designators are contained in Table 2 of the thesis.

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	1728	576	N/A	N/A	1152
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	1152	576	N/A	N/A	576
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0
Total BW in System:		19296 Total System Available Bandwidth:		7040	
Computed System Grade of Service for Voice (System Aggregate):					0.004694836
					Experiment Metric: 6964.305654
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	3589	5	0.001391208		
CSSE	798	3	0.003745318		
MAW 3316 Switch	799	2	0.002496879		
MAW 3315 Switch	802	2	0.002487562		
MEB	2847	3	0.001052632		
7th Marines	776	4	0.005128205		
DASC	76	8	0.095238095		
MAW 3330 Switch	370	6	0.015957447		
VMU	67	9	0.118421053		
Wahiawa DSN (1)	458	4	0.008658009		
Wahiawa DSN (2)	204	6	0.028571429		
Camp Roberts DSN	238	0	0		
Aggregates:	11024	52			
Aggregate GOS:	0.004694836				

Spreadsheet 1, Experiment C1E1

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	1728	576	N/A	N/A	1152
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	1152	576	N/A	N/A	576
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0
Total B'W in System:		19296 Total System Available Bandwidth:		7040	
Computed System Grade of Service for Voice (System Aggregate):					0.111211207
					Experiment Metric: 5449.560174
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	6981	193	0.026902704		
CSSE	1527	63	0.039622642		
MAW 3316 Switch	1420	157	0.099556119		
MAW 3315 Switch	1396	181	0.114774889		
MEB	4411	1376	0.237774322		
7th Marines	1432	118	0.076129032		
DASC	112	32	0.222222222		
MAW 3330 Switch	637	109	0.146112601		
VMU	145	26	0.152046784		
Wahiawa DSN (1)	890	39	0.041980624		
Wahiawa DSN (2)	369	63	0.145833333		
Camp Roberts DSN	412	112	0.213740458		
Aggregates:	19732	2469			
Aggregate GOS:	0.111211207				

Spreadsheet 2, Experiment C1E2

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	1728	576	N/A	N/A	1152
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	1152	576	N/A	N/A	576
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total BW in System: 19296 Total System Available Bandwidth: 7040

Computed System Grade of Service for Voice (System Aggregate): 0.576887671

Experiment Metric: 1865.026417

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	5135	9321	0.644784173
CSSE	2423	818	0.252391237
MAW 3316 Switch	1423	1740	0.550110654
MAW 3315 Switch	1856	1405	0.430849433
MEB	4232	7252	0.631487287
7th Marines	1616	1449	0.472756933
DASC	113	210	0.650154799
MAW 3330 Switch	620	860	0.581081081
VMU	132	188	0.5875
Wahiawa DSN (1)	632	1156	0.646532438
Wahiawa DSN (2)	397	491	0.552927928
Camp Roberts DSN	266	804	0.751401869

Aggregates: 18845 25694

Aggregate GOS: 0.576887671

Spreadsheet 3, Experiment C1E3

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	0	0	N/A	N/A	0
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	0	0	N/A	N/A	0
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total BW in System: 16416 Total System Available Bandwidth: 5312

Computed System Grade of Service for Voice (System Aggregate): 0.035446336

Experiment Metric: 4895.665425

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	7068	30	0.004226543
CSSE	1570	32	0.019975031
MAW 3316 Switch	1483	131	0.081164808
MAW 3315 Switch	1510	129	0.078706528
MEB	5658	115	0.019920319
7th Marines	1548	17	0.01086262
DASC	153	17	0.1
MAW 3330 Switch	730	57	0.072426938
VMU	149	10	0.062893082
Wahiawa DSN (1)	675	228	0.252491694
Wahiawa DSN (2)	399	16	0.038554217
Camp Roberts DSN	527	7	0.013108614

Aggregates: 21470 789

Aggregate GOS: 0.035446336

Spreadsheet 4, Experiment C1E4

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	0	0	N/A	N/A	0
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	0	0	N/A	N/A	0
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total BW in System: 16416 Total System Available Bandwidth: 5312

Computed System Grade of Service for Voice (System Aggregate): 0.350262737

Experiment Metric: 2371.348205

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	9834	4422	0.310185185
CSSE	2744	448	0.140350877
MAW 3316 Switch	2249	973	0.301986344
MAW 3315 Switch	2196	902	0.291155584
MEB	5994	5658	0.485581874
7th Marines	2402	724	0.231605886
DASC	197	116	0.370607029
MAW 3330 Switch	942	559	0.372418388
VMU	216	113	0.343465046
Wahiawa DSN (1)	944	787	0.454650491
Wahiawa DSN (2)	595	250	0.295857988
Camp Roberts DSN	497	579	0.538104089

Aggregates: 28810 15531

Aggregate GOS: 0.350262737

Spreadsheet 5, Experiment C1E5



Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	0	0	N/A	N/A	0
DTG5	576	288	N/A	N/A	288
DTG6	576	288	N/A	N/A	288
DTG8	576	288	N/A	N/A	288
DTG10	0	0	N/A	N/A	0
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	576	576	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total BW in System: 16416 Total System Available Bandwidth: 5312

Computed System Grade of Service for Voice (System Aggregate): 0.144771154

Experiment Metric: 3806.158877

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3476	123	0.03417616
CSSE	749	66	0.080981595
MAw 3316 Switch	687	133	0.162195122
MAw 3315 Switch	643	136	0.174582798
MEB	2086	756	0.266009852
7th Marines	689	84	0.108667529
DASC	70	20	0.222222222
MAw 3330 Switch	325	75	0.1875
VMU	65	14	0.17721519
Wahiawa DSN (1)	339	106	0.238202247
Wahiawa DSN (2)	184	36	0.163636364
Camp Roberts DSN	198	61	0.235521236

Aggregates: 9511 1610

Aggregate GOS: 0.144771154

Spreadsheet 6, Experiment C1E6

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	0	0	N/A	N/A	0
DTG5	576	288	N/A	N/A	288
DTG6	0	0	N/A	N/A	0
DTG8	576	288	N/A	N/A	288
DTG10	0	0	N/A	N/A	0
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	0	0	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total BW in System: 15264 Total System Available Bandwidth: 5024

Computed System Grade of Service for Voice (System Aggregate): 0.178320418

Experiment Metric: 3332.185825

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	13188	1199	0.083339126
CSSE	3014	221	0.068315301
MAW 3316 Switch	2417	730	0.231966953
MAW 3315 Switch	2374	840	0.261356565
MEB	8487	2962	0.258712551
7th Marines	2466	624	0.201941748
DASC	181	141	0.437888199
MAW 3330 Switch	1169	371	0.240909091
VMU	192	111	0.366336634
Wahiawa DSN (1)	1359	457	0.251651982
Wahiawa DSN (2)	746	101	0.119244392
Camp Roberts DSN	883	159	0.152591171

Aggregates: 36476 7916

Aggregate GOS: 0.178320418

Spreadsheet 7, Experiment C1E7

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	N/A	N/A	288
DTG2	576	288	N/A	N/A	288
DTG3	2304	2304	N/A	N/A	0
DTG4	0	0	N/A	N/A	0
DTG5	576	288	N/A	N/A	288
DTG6	0	0	N/A	N/A	0
DTG8	576	288	N/A	N/A	288
DTG10	0	0	N/A	N/A	0
DTG11	2304	2304	N/A	N/A	0
DTG12	576	288	N/A	N/A	288
DTG13	576	96	N/A	N/A	480
DTG14	576	288	N/A	N/A	288
DTG15	2304	2304	N/A	N/A	0
DTG16	864	288	N/A	N/A	576
DTG17	576	64	N/A	N/A	512
DTG19	0	0	N/A	N/A	0
DTG21	2016	576	N/A	N/A	1440
DTG23	576	288	N/A	N/A	288
DTG24	288	288	N/A	N/A	0

Total B/W in System: 15264 Total System Available Bandwidth: 5024

Computed System Grade of Service for Voice (System Aggregate): 0.106753223

Experiment Metric: 3929.130083

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3426	180	0.049916805
CSSE	769	33	0.041147132
MAW 3316 Switch	696	129	0.156363636
MAW 3315 Switch	676	130	0.161290323
MEB	2471	342	0.121578386
7th Marines	674	91	0.118954248
DASC	48	36	0.428571429
MAW 3330 Switch	317	72	0.185089974
VMU	51	27	0.346153846
Wahiawa DSN (1)	327	117	0.263513514
Wahiawa DSN (2)	207	20	0.088105727
Camp Roberts DSN	245	7	0.027777778

Aggregates: 9907 1184

Aggregate GOS: 0.106753223

Spreadsheet 8, Experiment C1E8

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576		288	N/A	N/A	288
DTG2	576		288	N/A	N/A	288
DTG3	2304		2304	N/A	N/A	0
DTG4	0		0	N/A	N/A	0
DTG5	576		288	N/A	N/A	288
DTG6	0		0	N/A	N/A	0
DTG8	576		288	N/A	N/A	288
DTG10	0		0	N/A	N/A	0
DTG11	2304		2304	N/A	N/A	0
DTG12	576		288	N/A	N/A	288
DTG13	576		96	N/A	N/A	480
DTG14	576		288	N/A	N/A	288
DTG15	2304		2304	N/A	N/A	0
DTG16	864		288	N/A	N/A	576
DTG17	576		64	N/A	N/A	512
DTG19	0		0	N/A	N/A	0
DTG21	2016		576	N/A	N/A	1440
DTG23	576		288	N/A	N/A	288
DTG24	288		288	N/A	N/A	0

Total BW in System: 15264 Total System Available Bandwidth: 5024

Computed System Grade of Service for Voice (System Aggregate): 0.396581965

Experiment Metric: 2015.893875

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	4669	2445	0.343688502
CSSE	1346	276	0.170160296
MAW 3316 Switch	1042	598	0.364634146
MAW 3315 Switch	1003	607	0.377018634
MEB	2750	2957	0.518135623
7th Marines	959	604	0.38643634
DASC	76	86	0.530864198
MAW 3330 Switch	435	331	0.432114883
VMU	80	81	0.50310559
Wahiawa DSN (1)	499	393	0.44058296
Wahiawa DSN (2)	314	133	0.29753915
Camp Roberts DSN	244	307	0.557168784

Aggregates: 13417 8818

Aggregate GOS: 0.396581965

Spreadsheet 9, Experiment C1E9

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1		576	288	0.283929	81.771552	494.228448
DTG2		576	288	0.134726	38.801088	537.198912
DTG3		2304	2304	0.018795	43.30368	2260.69632
DTG4		1728	576	0.026152	15.063552	1712.936448
DTG5		576	288	0.062232	17.922816	558.077184
DTG6		576	288	0.113184	32.596992	543.403008
DTG8		576	288	0.114092	32.858496	543.141504
DTG10		1152	576	0.045084	25.968384	1126.031616
DTG11		2304	2304	0.080185	184.74624	2119.25376
DTG12		576	288	0.087081	25.079328	550.920672
DTG13		576	96	0.060835	5.84016	570.15984
DTG14		576	288	0.282211	81.276768	494.723232
DTG15		2304	2304	0.057044	131.429376	2172.570624
DTG16		864	288	0.118098	34.012224	829.987776
DTG17		576	64	0.18615	11.9136	564.0864
DTG19		576	576	0.029522	17.004672	558.995328
DTG21		2016	576	0.0158	9.1008	2006.8992
DTG23		576	288	0	0	576
DTG24		288	288	0.096964	27.925632	260.074368

Total B/W in System: 19296 Total System Available Bandwidth: 18479.38464

Computed System Grade of Service for Voice (System Aggregate): 0.004694836

Experiment Metric: 18280.6936

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3589	5	0.001391208
CSSE	798	3	0.003745318
MAW 3316 Switch	799	2	0.002496879
MAW 3315 Switch	802	2	0.002487562
MEB	2847	3	0.001052632
7th Marines	776	4	0.005128205
DASC	76	8	0.095238095
MAW 3330 Switch	370	6	0.015957447
VMU	67	9	0.118421053
Wahiawa DSN (1)	458	4	0.008658009
Wahiawa DSN (2)	204	6	0.028571429
Camp Roberts DSN	238	0	0
Aggregates:	11024	52	
Aggregate GOS:	0.004694836		

Spreadsheet 10, Experiment C2E1

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.899354	259.013952	316.986048
DTG2	576	288	0.455041	131.051808	444.948192
DTG3	2304	2304	0.079228	182.541312	2121.458688
DTG4	1728	576	0.225653	129.976128	1598.023872
DTG5	576	288	0.287817	82.891296	493.108704
DTG6	576	288	0.650005	187.20144	388.79856
DTG8	576	288	0.555438	159.966144	416.033856
DTG10	1152	576	0.345383	198.940608	953.059392
DTG11	2304	2304	0.261954	603.542016	1700.457984
DTG12	576	288	0.340892	98.176896	477.823104
DTG13	576	96	0.29174	28.00704	547.99296
DTG14	576	288	0.906394	261.041472	314.958528
DTG15	2304	2304	0.200416	461.758464	1842.241536
DTG16	864	288	0.468925	135.0504	728.9496
DTG17	576	64	0.676351	43.286464	532.713536
DTG19	576	576	0.216045	124.44192	451.55808
DTG21	2016	576	0.097851	56.362176	1959.637824
DTG23	576	288	0	0	576
DTG24	288	288	0.26859	77.35392	210.64608

Total BW in System: 19296 Total System Available Bandwidth: 16075.39654

Computed System Grade of Service for Voice (System Aggregate): 0.111211207

Experiment Metric: 12443.72739

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	6981	193	0.026902704
CSSE	1527	63	0.039622642
MAW 3316 Switch	1420	157	0.099556119
MAW 3315 Switch	1396	181	0.114774889
MEB	4411	1376	0.237774322
7th Marines	1432	118	0.076129032
DASC	112	32	0.222222222
MAW 3330 Switch	637	109	0.146112601
VMU	145	26	0.152046784
Wahiawa DSN (1)	890	39	0.041980624
Wahiawa DSN (2)	369	63	0.145833333
Camp Roberts DSN	412	112	0.213740458

Aggregates: 19732 2469

Aggregate GOS: 0.111211207

Spreadsheet 11, Experiment C2E2

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.97511	280.83168	295.16832
DTG2	576	288	0.727841	209.618208	366.381792
DTG3	2304	2304	0.083511	192.409344	2111.590656
DTG4	1728	576	0.30446	175.36896	1552.63104
DTG5	576	288	0.521638	150.231744	425.768256
DTG6	576	288	0.77819	224.11872	351.88128
DTG8	576	288	0.834395	240.30576	335.69424
DTG10	1152	576	0.590355	340.04448	811.95552
DTG11	2304	2304	0.524548	1208.558592	1095.441408
DTG12	576	288	0.648334	186.720192	389.279808
DTG13	576	96	0.539559	51.737664	524.202336
DTG14	576	288	0.974193	280.567584	295.432416
DTG15	2304	2304	0.271496	625.526784	1678.473216
DTG16	864	288	0.871087	250.873056	613.126944
DTG17	576	64	0.940662	60.202368	515.797632
DTG19	576	576	0.327772	188.796672	387.203328
DTG21	2016	576	0.157599	90.777024	1925.222976
DTG23	576	288	4.50E-05	0.01296	575.98704
DTG24	288	288	0.312299	89.942112	198.057888

Total B/W in System: 19296 Total System Available Bandwidth: 14449.2961

Computed System Grade of Service for Voice (System Aggregate): 0.576887671

Experiment Metric: 3827.886211

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	5135	9321	0.644784173
CSSE	2423	818	0.252391237
MAW 3316 Switch	1423	1740	0.550110654
MAW 3315 Switch	1856	1405	0.430849433
MEB	4232	7252	0.631487287
7th Marines	1616	1449	0.472756933
DASC	113	210	0.650154799
MAW 3330 Switch	620	860	0.581081081
VMU	132	188	0.5875
Wahiawa DSN (1)	632	1156	0.646532438
Wahiawa DSN (2)	397	491	0.552927928
Camp Roberts DSN	266	804	0.751401869

Aggregates: 18845 25694

Aggregate GOS: 0.576887671

Spreadsheet 12, Experiment C2E3

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1		576	288	0.570261	164.235168	411.764832
DTG2		576	288	0.225937	65.069856	510.930144
DTG3		2304	2304	0.047271	108.912384	2195.087616
DTG4		0	576	0	0	0
DTG5		576	288	0.121902	35.107776	540.892224
DTG6		576	288	0.271561	78.209568	497.790432
DTG8		576	288	0.143277	41.263776	534.736224
DTG10		0	576	0	0	0
DTG11		2304	2304	0.162974	375.492096	1928.507904
DTG12		576	288	0.161477	46.505376	529.494624
DTG13		576	96	0.139571	13.398816	562.601184
DTG14		576	288	0.139571	40.196448	535.803552
DTG15		2304	2304	0.108959	251.041536	2052.958464
DTG16		864	288	0.218011	62.787168	801.212832
DTG17		576	64	0.353123	22.599872	553.400128
DTG19		576	576	0.109823	63.258048	512.741952
DTG21		2016	576	0.040781	23.489856	1992.510144
DTG23		576	288	0.008006	2.305728	573.694272
DTG24		288	288	0.162701	46.857888	241.142112

Total BW in System: 16416 Total System Available Bandwidth: 14975.26864

Computed System Grade of Service for Voice (System Aggregate): 0.035446336

Experiment Metric: 13801.56343

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	7068	30	0.004226543
CSSE	1570	32	0.019975031
MAW 3316 Switch	1483	131	0.081164808
MAW 3315 Switch	1510	129	0.078706528
MEB	5658	115	0.019920319
7th Marines	1548	17	0.01086262
DASC	153	17	0.1
MAW 3330 Switch	730	57	0.072426938
VMU	149	10	0.062893082
Wahiawa DSN (1)	675	228	0.252491694
Wahiawa DSN (2)	399	16	0.038554217
Camp Roberts DSN	527	7	0.013108614

Aggregates: 21470 789

Aggregate GOS: 0.035446336

Spreadsheet 13, Experiment C2E4



Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.957051	275.630688	300.369312
DTG2	576	288	0.623729	179.633952	396.366048
DTG3	2304	2304	0.140017	322.599168	1981.400832
DTG4	0	576	0	0	0
DTG5	576	288	0.34255	98.6544	477.3456
DTG6	576	288	0.789546	227.389248	348.610752
DTG8	576	288	0.512485	147.59568	428.40432
DTG10	0	576	0	0	0
DTG11	2304	2304	0.523743	1206.703872	1097.296128
DTG12	576	288	0.496346	142.947648	433.052352
DTG13	576	96	0.482411	46.311456	529.688544
DTG14	576	288	0.936895	269.82576	306.17424
DTG15	2304	2304	0.231829	534.134016	1769.865984
DTG16	864	288	0.722056	207.952128	656.047872
DTG17	576	64	0.871408	55.770112	520.229888
DTG19	576	576	0.470627	271.081152	304.918848
DTG21	2016	576	0.15585	89.7696	1926.2304
DTG23	576	288	0.007332	2.111616	573.888384
DTG24	288	288	0.326583	94.055904	193.944096
Total B/W in System:		16416	Total System Available Bandwidth:		12243.8336
Computed System Grade of Service for Voice (System Aggregate):					0.350262737
					Experiment Metric: 5485.811904
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	9834	4422	0.310185185		
CSSE	2744	448	0.140350877		
MAW 3316 Switch	2249	973	0.301986344		
MAW 3315 Switch	2196	902	0.291155584		
MEB	5994	5658	0.485581874		
7th Marines	2402	724	0.231605886		
DASC	197	116	0.370607029		
MAW 3330 Switch	942	559	0.372418388		
VMU	216	113	0.343465046		
Wahiawa DSN (1)	944	787	0.454650491		
Wahiawa DSN (2)	595	250	0.295857988		
Camp Roberts DSN	497	579	0.538104089		
Aggregates:	28810	15531			
Aggregate GOS:	0.350262737				

Spreadsheet 14, Experiment C2E5

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1		576	288	0.900227	259.265376	316.734624
DTG2		576	288	0.399928	115.179264	460.820736
DTG3		2304	2304	0.107264	247.136256	2056.863744
DTG4		0	576	0	0	0
DTG5		576	288	0.235438	67.806144	508.193856
DTG6		576	288	0.609283	175.473504	400.526496
DTG8		576	288	0.378599	109.036512	466.963488
DTG10		0	576	0	0	0
DTG11		2304	2304	0.326418	752.067072	1551.932928
DTG12		576	288	0.2933	84.4704	491.5296
DTG13		576	96	0.264095	25.35312	550.64688
DTG14		576	288	0.8497	244.7136	331.2864
DTG15		2304	2304	0.186537	429.781248	1874.218752
DTG16		864	288	0.46527	133.99776	730.00224
DTG17		576	64	0.677771	43.377344	532.622656
DTG19		576	576	0.274195	157.93632	418.06368
DTG21		2016	576	0.108923	62.739648	1953.260352
DTG23		576	288	0.005587	1.609056	574.390944
DTG24		288	288	0.27116	78.09408	209.90592

Total BW in System: 16416 Total System Available Bandwidth: 13427.9633

Computed System Grade of Service for Voice (System Aggregate): 0.144771154

Experiment Metric: 9621.415983

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3476	123	0.03417616
CSSE	749	66	0.080981595
MAW 3316 Switch	687	133	0.162195122
MAW 3315 Switch	643	136	0.174582798
MEB	2086	756	0.266009852
7th Marines	689	84	0.108667529
DASC	70	20	0.222222222
MAW 3330 Switch	325	75	0.1875
VMU	65	14	0.17721519
Wahiawa DSN (1)	339	106	0.238202247
Wahiawa DSN (2)	184	36	0.163636364
Camp Roberts DSN	198	61	0.235521236

Aggregates: 9511 1610

Aggregate GOS: 0.144771154

Spreadsheet 15, Experiment C2E6

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.848492	244.365696	331.634304
DTG2	576	288	0.695545	200.31696	375.68304
DTG3	2304	2304	0.120218	276.982272	2027.017728
DTG4	0	576	0	0	0
DTG5	576	288	0.210856	60.726528	515.273472
DTG6	0	288	0	0	0
DTG8	576	288	0.288746	83.158848	492.841152
DTG10	0	576	0	0	0
DTG11	2304	2304	0.225101	518.632704	1785.367296
DTG12	576	288	0.154665	44.54352	531.45648
DTG13	576	96	0.157156	15.086976	560.913024
DTG14	576	288	0.849246	244.582848	331.417152
DTG15	2304	2304	0.151597	349.279488	1954.720512
DTG16	864	288	0.385268	110.957184	753.042816
DTG17	576	64	0.594924	38.075136	537.924864
DTG19	0	576	0	0	0
DTG21	2016	576	0.027896	16.068096	1999.931904
DTG23	576	288	0.041166	11.855808	564.144192
DTG24	288	288	0.233616	67.281408	220.718592

Total BW in System: 15264 Total System Available Bandwidth: 12982.08653

Computed System Grade of Service for Voice (System Aggregate): 0.178320418

Experiment Metric: 8610.414951

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	13188	1199	0.083339126
CSSE	3014	221	0.068315301
MAW 3316 Switch	2417	730	0.231966953
MAW 3315 Switch	2374	840	0.261356565
MEB	8487	2962	0.258712551
7th Marines	2466	624	0.201941748
DASC	181	141	0.437888199
MAW 3330 Switch	1169	371	0.240909091
VMU	192	111	0.366336634
Wahiawa DSN (1)	1359	457	0.251651982
Wahiawa DSN (2)	746	101	0.119244392
Camp Roberts DSN	883	159	0.152591171

Aggregates: 36476 7916

Aggregate GOS: 0.178320418

Spreadsheet 16, Experiment C2E7

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.738923	212.809824	363.190176
DTG2	576	288	0.546967	157.526496	418.473504
DTG3	2304	2304	0.084661	195.058944	2108.941056
DTG4	0	576	0	0	0
DTG5	576	288	0.151335	43.58448	532.41552
DTG6	0	288	0	0	0
DTG8	576	288	0.194059	55.888992	520.111008
DTG10	0	576	0	0	0
DTG11	2304	2304	0.167736	386.463744	1917.536256
DTG12	576	288	0.124325	35.8056	540.1944
DTG13	576	96	0.136038	13.059648	562.940352
DTG14	576	288	0.72455	208.6704	367.3296
DTG15	2304	2304	0.113908	262.444032	2041.555968
DTG16	864	288	0.279612	80.528256	783.471744
DTG17	576	64	0.44327	28.36928	547.63072
DTG19	0	576	0	0	0
DTG21	2016	576	0.016875	9.72	2006.28
DTG23	576	288	0.031147	8.970336	567.029664
DTG24	288	288	0.192967	55.574496	232.425504

Total BW in System: 15264 Total System Available Bandwidth: 13509.52547

Computed System Grade of Service for Voice (System Aggregate): 0.106753223

Experiment Metric: 10565.42256

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3426	180	0.049916805
CSSE	769	33	0.041147132
MAW 3316 Switch	696	129	0.156363636
MAW 3315 Switch	676	130	0.161290323
MEB	2471	342	0.121578386
7th Marines	674	91	0.118954248
DASC	48	36	0.428571429
MAW 3330 Switch	317	72	0.185089974
VMU	51	27	0.346153846
Wahiawa DSN (1)	327	117	0.263513514
Wahiawa DSN (2)	207	20	0.088105727
Camp Roberts DSN	245	7	0.027777778

Aggregates: 9907 1184

Aggregate GOS: 0.106753223

Spreadsheet 17, Experiment C2E8

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	288	0.92564	266.58432	309.41568
DTG2	576	288	0.869565	250.43472	325.56528
DTG3	2304	2304	0.170107	391.926528	1912.073472
DTG4	0	576	0	0	0
DTG5	576	288	0.342742	98.709696	477.290304
DTG6	0	288	0	0	0
DTG8	576	288	0.529238	152.420544	423.579456
DTG10	0	576	0	0	0
DTG11	2304	2304	0.354371	816.470784	1487.529216
DTG12	576	288	0.327155	94.22064	481.77936
DTG13	576	96	0.330305	31.70928	544.29072
DTG14	576	288	0.943786	271.810368	304.189632
DTG15	2304	2304	0.21656	498.95424	1805.04576
DTG16	864	288	0.704645	202.93776	661.06224
DTG17	576	64	0.87917	56.26688	519.73312
DTG19	0	576	0	0	0
DTG21	2016	576	0.059356	34.189056	1981.810944
DTG23	576	288	0.010932	3.148416	572.951584
DTG24	288	288	0.354164	101.999232	186.000768
Total B/W in System:		15264	Total System Available Bandwidth:		11992.21754
Computed System Grade of Service for Voice (System Aggregate):					0.396581965
					Experiment Metric: 4811.910406
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	4669	2445	0.343688502		
CSSE	1346	276	0.170160296		
MAW 3316 Switch	1042	598	0.364634146		
MAW 3315 Switch	1003	607	0.377018634		
MEB	2750	2957	0.518135623		
7th Marines	959	604	0.38643634		
DASC	76	86	0.530864198		
MAW 3330 Switch	435	331	0.432114883		
VMU	80	81	0.50310559		
Wahiawa DSN (1)	499	393	0.44058296		
Wahiawa DSN (2)	314	133	0.29753915		
Camp Roberts DSN	244	307	0.557168784		
Aggregates:	13417	8818			
Aggregate GOS:	0.396581965				

Spreadsheet 18, Experiment C2E9

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1		576	0	0.112564	64.836864	511.163136
DTG2		576	0	0.061238	35.273088	540.726912
DTG3		2304	0	0.019253	44.358912	2259.641088
DTG4		1728	0	0.010124	17.494272	1710.505728
DTG5		576	0	0.061298	35.307648	540.692352
DTG6		576	0	0.054809	31.569984	544.430016
DTG8		576	0	0.053734	30.950784	545.049216
DTG10		1152	0	0.022578	26.009856	1125.990144
DTG11		2304	0	0.019201	44.239104	2259.760896
DTG12		576	0	0.01421	8.18496	567.81504
DTG13		576	0	0.014093	8.117568	567.882432
DTG14		576	0	0.110639	63.728064	512.271936
DTG15		2304	0	0.056677	130.583908	2173.416192
DTG16		864	0	0.035505	30.67632	833.32368
DTG17		576	0	0.042809	24.657984	551.342016
DTG19		576	0	0.030316	17.462016	558.537984
DTG21		2016	0	0.004429	8.928964	2007.071136
DTG23		576	0	0	0	576
DTG24		288	0	0.089732	25.842816	262.157184

Total BW in System: 19296 Total System Available Bandwidth: 18647.77709

Computed System Grade of Service for Voice (System Aggregate): 0.001524664

Experiment Metric: 18582.42572

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3598	2	0.000555556
CSSE	790	2	0.002525253
MAW 3316 Switch	798	0	0
MAW 3315 Switch	783	0	0
MEB	2855	0	0
7th Marines	803	0	0
DASC	87	1	0.011363636
MAW 3330 Switch	393	7	0.0175
VMU	99	1	0.01
Wahiawa DSN (1)	446	1	0.002237136
Wahiawa DSN (2)	218	3	0.013574661
Camp Roberts DSN	263	0	0

Aggregates: 11133 17

Aggregate GOS: 0.001524664

Spreadsheet 19, Experiment C3E1

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576		0	0.535979	308.723904	267.276096
DTG2	576		0	0.299096	172.279296	403.720704
DTG3	2304		0	0.086764	199.904256	2104.095744
DTG4	1728		0	0.045039	77.827392	1650.172608
DTG5	576		0	0.300613	173.153088	402.846912
DTG6	576		0	0.263355	151.69248	424.30752
DTG8	576		0	0.241828	139.292928	436.707072
DTG10	1152		0	0.104119	119.945088	1032.054912
DTG11	2304		0	0.100009	230.420736	2073.579264
DTG12	576		0	0.072846	41.959296	534.040704
DTG13	576		0	0.060897	35.076672	540.923328
DTG14	576		0	0.547223	315.200448	260.799552
DTG15	2304		0	0.280205	645.59232	1658.40768
DTG16	864		0	0.17218	148.76352	715.23648
DTG17	576		0	0.198251	114.192576	461.807424
DTG19	576		0	0.153492	88.411392	487.588608
DTG21	2016		0	0.024814	50.025024	1965.974976
DTG23	576		0	0	0	576
DTG24	288		0	0.385596	111.051648	176.948352
Total BW in System:		19296	Total System Available Bandwidth:			16172.48794
Computed System Grade of Service for Voice (System Aggregate):						0.007474447
Experiment Metric:						15896.532
Node Aggregates						
Node	Completed Calls	Blocked Calls	Node GOS			
MarDiv	7153	48	0.006665741			
CSSE	1604	3	0.001866833			
MAW 3316 Switch	1602	7	0.004350528			
MAW 3315 Switch	1577	1	0.000633714			
MEB	5749	44	0.007595374			
7th Marines	1530	8	0.00520156			
DASC	151	2	0.013071895			
MAW 3330 Switch	704	41	0.055033557			
VMU	159	1	0.00625			
Wahiawa DSN (1)	897	6	0.006644518			
Wahiawa DSN (2)	411	5	0.012019231			
Camp Roberts DSN	506	0	0			
Aggregates:	22043	166				
Aggregate GOS:	0.007474447					

Spreadsheet 20, Experiment C3E2

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.796972	459.055872	116.944128
DTG2	576	0	0.499773	287.869248	288.130752
DTG3	2304	0	0.107616	247.947264	2056.052736
DTG4	1728	0	0.061568	106.389504	1621.610496
DTG5	576	0	0.714315	411.44544	164.55456
DTG6	576	0	0.301058	173.409408	402.590592
DTG8	576	0	0.545786	314.372736	261.627264
DTG10	1152	0	0.25407	292.68864	859.31136
DTG11	2304	0	0.189422	436.428288	1867.571712
DTG12	576	0	0.147029	84.688704	491.311296
DTG13	576	0	0.125965	72.55584	503.44416
DTG14	576	0	0.857957	494.183232	81.816768
DTG15	2304	0	0.456388	1051.517952	1252.482048
DTG16	864	0	0.426764	368.724096	495.275904
DTG17	576	0	0.543838	313.250688	262.749312
DTG19	576	0	0.268217	154.492992	421.507008
DTG21	2016	0	0.030893	62.280288	1953.719712
DTG23	576	0	0	0	576
DTG24	288	0	0.517675	149.0904	138.9096

Total BW in System: 19296 Total System Available Bandwidth: 13815.60941

Computed System Grade of Service for Voice (System Aggregate): 0.52740563

Experiment Metric: 4101.704942

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	4945	9487	0.657358647
CSSE	2327	819	0.260330579
MAW 3316 Switch	1468	1677	0.533227345
MAW 3315 Switch	2012	1085	0.350339038
MEB	5514	5947	0.518890149
7th Marines	1565	1501	0.489562948
DASC	179	135	0.429936306
MAW 3330 Switch	611	898	0.59509609
VMU	182	116	0.389261745
Wahiawa DSN (1)	868	959	0.524904215
Wahiawa DSN (2)	520	333	0.39038687
Camp Roberts DSN	692	348	0.334615385
Aggregates:	20883	23305	
Aggregate GOS:	0.52740563		

Spreadsheet 21, Experiment C3E3



Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.233675	134.5968	441.4032
DTG2	576	0	0.104959	60.456384	515.543616
DTG3	2304	0	0.046098	106.209792	2197.790208
DTG4	0	0	0	0	0
DTG5	576	0	0.118513	67.111488	508.888512
DTG6	576	0	0.118866	68.466816	507.533184
DTG8	576	0	0.063918	36.816768	539.183232
DTG10	0	0	0	0	0
DTG11	2304	0	0.041354	95.279616	2208.720384
DTG12	576	0	0.024028	13.840128	562.159872
DTG13	576	0	0.022589	13.011264	562.988736
DTG14	576	0	0.237802	136.973952	439.026048
DTG15	2304	0	0.113491	261.483264	2042.516736
DTG16	864	0	0.070176	60.632064	803.367936
DTG17	576	0	0.079867	46.003392	529.986608
DTG19	576	0	0.088638	51.055488	524.944512
DTG21	2016	0	0.009913	19.984608	1996.015392
DTG23	576	0	0.003409	1.963584	574.036416
DTG24	288	0	0.148142	42.664896	245.335104
Total BW in System:		16416	Total System Available Bandwidth:		15199.4497
Computed System Grade of Service for Voice (System Aggregate):					0.024745139
Experiment Metric:					14357.62896
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	7216	1	0.000138562		
CSSE	1596	20	0.012376238		
MAW 3316 Switch	1490	116	0.072229141		
MAW 3315 Switch	1505	107	0.066377171		
MEB	5756	0	0		
7th Marines	1584	1	0.000630915		
DASC	138	7	0.048275862		
MAW 3330 Switch	707	58	0.075816993		
VMU	146	4	0.026666667		
Wahiawa DSN (1)	657	233	0.261797753		
Wahiawa DSN (2)	412	4	0.009615385		
Camp Roberts DSN	509	0	0		
Aggregates:	21716	551			
Aggregate GOS:	0.024745139				

Spreadsheet 22, Experiment C3E4

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.861097	495.991872	80.008128
DTG2	576	0	0.405602	233.626752	342.373248
DTG3	2304	0	0.166643	383.945472	1920.054528
DTG4	0	0	0	0	0
DTG5	576	0	0.449507	258.916032	317.083968
DTG6	576	0	0.394472	227.215872	348.784128
DTG8	576	0	0.234438	135.036288	440.963712
DTG10	0	0	0	0	0
DTG11	2304	0	0.180421	415.689984	1888.310016
DTG12	576	0	0.109081	62.830656	513.169344
DTG13	576	0	0.10405	59.9328	516.0672
DTG14	576	0	0.86685	499.3056	76.6944
DTG15	2304	0	0.445575	1026.6048	1277.3952
DTG16	864	0	0.298714	258.088896	605.911104
DTG17	576	0	0.396722	228.511872	347.488128
DTG19	576	0	0.416949	240.162624	335.837376
DTG21	2016	0	0.037817	76.239072	1939.760928
DTG23	576	0	0.006227	3.586752	572.413248
DTG24	288	0	0.435548	125.437824	162.562176

Total BW in System: 16416 Total System Available Bandwidth: 11684.87683

Computed System Grade of Service for Voice (System Aggregate): 0.224274764

Experiment Metric: 6971.871511

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	9878	4462	0.311157601
CSSE	2927	269	0.08416771
MAW 3316 Switch	2379	751	0.239936102
MAW 3315 Switch	2747	468	0.145567652
MEB	9686	1905	0.164351652
7th Marines	2522	494	0.163793103
DASC	248	48	0.162162162
MAW 3330 Switch	935	558	0.373744139
VMU	269	53	0.164596273
Wahiawa DSN (1)	985	800	0.448179272
Wahiawa DSN (2)	742	97	0.115613826
Camp Roberts DSN	990	14	0.013944223

Aggregates: 34308 9919

Aggregate GOS: 0.224274764

Spreadsheet 23, Experiment C3E5

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.554734	319.526784	256.473216
DTG2	576	0	0.245888	141.631488	434.368512
DTG3	2304	0	0.115528	266.176512	2037.823488
DTG4	0	0	0	0	0
DTG5	576	0	0.300336	172.993536	403.006464
DTG6	576	0	0.315103	181.499328	394.500672
DTG8	576	0	0.15525	89.424	486.576
DTG10	0	0	0	0	0
DTG11	2304	0	0.104416	240.574464	2063.425536
DTG12	576	0	0.068309	39.345984	536.654016
DTG13	576	0	0.059121	34.053696	541.946304
DTG14	576	0	0.587629	338.474304	237.525696
DTG15	2304	0	0.282229	650.255616	1653.744384
DTG16	864	0	0.17702	152.94528	711.05472
DTG17	576	0	0.212666	122.495616	453.504384
DTG19	576	0	0.228117	131.395392	444.604608
DTG21	2016	0	0.021952	44.255232	1971.744768
DTG23	576	0	0.004112	2.368512	573.631488
DTG24	288	0	0.367739	105.908832	182.091168

Total BW in System: 16416 Total System Available Bandwidth: 13382.67542

Computed System Grade of Service for Voice (System Aggregate): 0.029494002

Experiment Metric: 12503.99937

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	3561	11	0.003079507
CSSE	750	10	0.013157895
MAW 3316 Switch	749	56	0.069565217
MAW 3315 Switch	739	51	0.064556962
MEB	2861	18	0.006252171
7th Marines	749	3	0.003989362
DASC	89	3	0.032608696
MAW 3330 Switch	338	50	0.128865979
VMU	80	5	0.058823529
Wahiawa DSN (1)	338	115	0.253863135
Wahiawa DSN (2)	220	5	0.022222222
Camp Roberts DSN	286	0	0

Aggregates: 10760 327

Aggregate GOS: 0.029494002

Spreadsheet 24, Experiment C3E6

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.614505	353.95488	222.04512
DTG2	576	0	0.422893	243.586368	332.413632
DTG3	2304	0	0.153733	354.200832	1949.799168
DTG4	0	0	0	0	0
DTG5	576	0	0.234522	135.084672	440.915328
DTG6	0	0	0	0	0
DTG8	576	0	0.114497	65.950272	510.049728
DTG10	0	0	0	0	0
DTG11	2304	0	0.078132	180.016128	2123.983872
DTG12	576	0	0.031389	18.080064	557.919936
DTG13	576	0	0.040328	23.228928	552.771072
DTG14	576	0	0.610435	351.61056	224.38944
DTG15	2304	0	0.224787	517.909248	1786.090752
DTG16	864	0	0.1342	115.9488	748.0512
DTG17	576	0	0.162835	93.79296	482.20704
DTG19	0	0	0	0	0
DTG21	2016	0	0.007742	15.607872	2000.392128
DTG23	576	0	0.029743	17.131968	558.868032
DTG24	288	0	0.313489	90.284832	197.715168

Total BW in System: 15264 Total System Available Bandwidth: 12687.61162

Computed System Grade of Service for Voice (System Aggregate): 0.036967404

Experiment Metric: 11652.32184

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	14035	166	0.011689318
CSSE	3184	29	0.009025833
MAW 3316 Switch	2985	227	0.070672478
MAW 3315 Switch	2886	239	0.07648
MEB	11456	85	0.007365046
7th Marines	2924	108	0.035620053
DASC	199	132	0.398791541
MAW 3330 Switch	1351	140	0.093896714
VMU	271	55	0.168711656
Wahiawa DSN (1)	1309	440	0.251572327
Wahiawa DSN (2)	865	11	0.012557078
Camp Roberts DSN	1050	0	0

Aggregates: 42515 1632

Aggregate GOS: 0.036967404

Spreadsheet 25, Experiment C3E7

Model Transmission Designator	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1	576	0	0.37203	214.28928	361.71072
DTG2	576	0	0.282424	162.676224	413.323776
DTG3	2304	0	0.096742	222.893568	2081.106432
DTG4	0	0	0	0	0
DTG5	576	0	0.140793	81.096768	494.903232
DTG6	0	0	0	0	0
DTG8	576	0	0.080673	46.467648	529.532352
DTG10	0	0	0	0	0
DTG11	2304	0	0.050848	117.153792	2186.846208
DTG12	576	0	0.021144	12.178944	563.821056
DTG13	576	0	0.023384	13.469184	562.530816
DTG14	576	0	0.397183	228.777408	347.222592
DTG15	2304	0	0.140656	324.071424	1979.928576
DTG16	864	0	0.089401	77.242464	786.757536
DTG17	576	0	0.107708	62.039808	513.960192
DTG19	0	0	0	0	0
DTG21	2016	0	0.005134	10.350144	2005.649856
DTG23	576	0	0.020947	12.065472	563.934528
DTG24	288	0	0.201671	58.081248	229.918752
Total BW in System:		15264	Total System Available Bandwidth:		13621.14662
Computed System Grade of Service for Voice (System Aggregate):					0.0343987
					Experiment Metric: 12583.89158
Node Aggregates					
Node	Completed Calls	Blocked Calls	Node GOS		
MarDiv	3575	36	0.009969538		
CSSE	788	9	0.011292346		
MAW 3316 Switch	733	58	0.073324905		
MAW 3315 Switch	711	56	0.073011734		
MEB	2891	2	0.000691324		
7th Marines	723	25	0.03342246		
DASC	55	25	0.3125		
MAW 3330 Switch	342	37	0.09762533		
VMU	57	16	0.219178082		
Wahiawa DSN (1)	350	114	0.245689655		
Wahiawa DSN (2)	212	3	0.013953488		
Camp Roberts DSN	258	0	0		
Aggregates:	10695	381			
Aggregate GOS:	0.0343987				

Spreadsheet 26, Experiment C3E8

Model Designator	Transmission Bandwidth (Kbps)	Total Link Bandwidth (Kbps)	Bandwidth Reserved (Voice) (Kbps)	Model Bandwidth Utilization	Bandwidth Used (Voice) (Kbps)	Bandwidth Available (Other) (Kbps)
DTG1		576	0	0.883843	509.093568	66.906432
DTG2		576	0	0.750079	432.045504	143.954496
DTG3		2304	0	0.231496	533.366784	1770.633216
DTG4		0	0	0	0	0
DTG5		576	0	0.477544	275.065344	300.934656
DTG6		0	0	0	0	0
DTG8		576	0	0.28087	161.78112	414.21888
DTG10		0	0	0	0	0
DTG11		2304	0	0.14639	337.28256	1966.71744
DTG12		576	0	0.07559	43.53984	532.46016
DTG13		576	0	0.086039	49.558464	526.441536
DTG14		576	0	0.914148	526.549248	49.450752
DTG15		2304	0	0.399383	920.178432	1383.821568
DTG16		864	0	0.288296	249.087744	614.912256
DTG17		576	0	0.399272	229.980672	346.019328
DTG19		0	0	0	0	0
DTG21		2016	0	0.014245	28.71792	1987.28208
DTG23		576	0	0.022774	13.117824	562.882176
DTG24		288	0	0.468142	134.824896	153.175104

Total B/W in System: 15264 Total System Available Bandwidth: 10819.81008

Computed System Grade of Service for Voice (System Aggregate): 0.25714545

Experiment Metric: 5985.138271

Node Aggregates

Node	Completed Calls	Blocked Calls	Node GOS
MarDiv	4772	2251	0.320518297
CSSE	1443	141	0.089015152
MAW 3316 Switch	1179	459	0.28021978
MAW 3315 Switch	1210	361	0.229789943
MEB	4428	1342	0.232582322
7th Marines	1233	283	0.186675462
DASC	93	70	0.429447853
MAW 3330 Switch	453	277	0.379452055
VMU	106	66	0.38372093
Wahiawa DSN (1)	514	377	0.42312009
Wahiawa DSN (2)	422	39	0.084598698
Camp Roberts DSN	521	2	0.003824092

Aggregates: 16374 5668

Aggregate GOS: 0.25714545

Spreadsheet 27, Experiment C3E9

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