ANALYSIS OF OVER-THE-HORIZON TACTICAL COMMUNICATIONS IN AN IMMATURE THEATER

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14. ABSTRACT

This qualitative research in the field of over-the-horizon (OTH) voice communications, for maneuver forces at echelons below division, aims to use grounded theory and axial coding to address feasibility for increasing the military's tactical OTH capabilities. Using the variables of frequency bands, capacity, costs, and mobility, the research examines both alternate portions of the electromagnetic spectrum and rising technologies in order to develop an emerging theory for how OTH capabilities will increase in the future.

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ABSTRACT

ANALYSIS OF OVER-THE-HORIZON VOICE COMMUNICATIONS IN AN IMMATURE THEATER, by Major Samuel Eugene Sinclair, 75 pages.

This qualitative research in the field of over-the-horizon (OTH) voice communications, for maneuver forces at echelons below division, aims to use grounded theory and axial coding to address feasibility for increasing the military's tactical OTH capabilities. Using the variables of frequency bands, capacity, costs, and mobility, the research examines both alternate portions of the electromagnetic spectrum and rising technologies in order to develop an emerging theory for how OTH capabilities will increase in the future.

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TABLE OF CONTENTS

ACRONYMS

BLOS	Beyond Line of Sight
CS	Capability Set
DAMA	Demand Assigned Multiple Access
DOD	Department of Defense
EHF	Extremely High Frequency
EMS	Electromagnetic Spectrum
FAS	Federation of American Scientists
GHz	Gigahertz
HNR	Highband Networking Radio
JTRS	Joint Tactical Radio System
LOS	Line of Sight
MILSTAR	Military Strategic Tactical Relay
NCW	Net-Centric Waveform
NSA	National Security Agency
OTH	Over-the-Horizon
PM DCATS	Project Manager, Defense Communications and Army Transmission Systems
SATCOM	Satellite Communications
SCAMP	Single Channel Anti-jam Manportable
SHF	Super High Frequency
SMART-T	Secure Mobile Anti-Jam Reliable Tactical Terminal
SRW	Soldier Radio Waveform
TR	Transmitted Reference

UHF	Ultra High Frequency
UWB	Ultra Wideband
VHF	Very High Frequency

ILLUSTRATIONS

TABLES

CHAPTER 1

INTRODUCTION

This research is organized into five chapters: 1. Introduction, 2. Literature Review, 3. Methodology, 4. Analysis, 5. Conclusions and Recommendations. This chapter, the introduction, is organized using the deficiencies model from Creswell.[1] The sub-headings for this model are: (1) The Research Problem and Research Question, (2) Studies That Have Addressed the Problem, (3) Deficiencies in the Studies, (4) The Importance of the Study, and (5) The Purpose Statement. The intent of using the deficiencies model for organizing the introduction is to provide the reader with an appreciation for the chosen research method explained in Chapter 3, Methodology. Additionally, the deficiencies model will help focus the reader on the researcher's understanding of the problem and the study's importance.

During Operation Anaconda, March 2002, CH-47s from 7th Aviation Battalion of the 101st Airborne Division moved an assaulting force to the Shahi Kot valley in the Paktia province from their staging field at Bagram airbase in the Parwan. The distance was approximately 110 statute miles or 185 kilometers (km). No Line of Sight (LOS) tactical radio in the Very High Frequency (VHF) band could range that distance. Communication between the maneuver forces near the landing zones and aircraft flying to and from Bagram was limited to tactical Satellite Communications (SATCOM). These communications were only available to select groups of special operations forces. Conventional maneuver companies could not effectively communicate the situation to aviation assets and command posts, which were tens or hundreds of miles away.[2]

Following the battle, the after action reviews stressed the demand for improving Over-the-Horizon (OTH) communications capabilities.[3]

In response to Anaconda and the Global War on Terrorism, the Army placed increased emphasis on the Joint Tactical Radio System (JTRS) program launched in the late 1990s. However, the program, due to budget constraints and a failure to meet expectations within a select time frame, was discontinued in late 2011.[4] Although the Department of Defense (DOD) officially cancelled this program of record, it represents the most recent research and development for increased voice and data communications capabilities.

The essence of JTRS was the understanding that the war fighter's receiver-transmitter would be integrated as a node to create a mobile ad hoc network capable of OTH communications in an austere environment.[5] In simpler terms, communication between radios A and B would be enhanced by radio C, even if radio C was not actively receiving or transmitting. Furthermore, the receiver-transmitter would be reliant on software for processing signals. It could be updated like a computer, using programs without having to change the hardware.[6]

Future endeavors to increase tactical communications capabilities will build on the work completed for JTRS over a 15 year period; the most recent military communications purchases have been of products developed for JTRS. Many of these acquisitions are highlighted in Chapter 2, Literature Review. Among them are a series of software programmable radios that are capable of transmitting and receiving both SATCOM and terrestrial radio waveforms in the VHF and Ultra High Frequency (UHF) portions of the electromagnetic spectrum (EMS). The PRC 155 and 154A are two examples of such radios and are currently being integrated into the system designs for communications at echelons below division.[7]

The Research Problem

Although OTH voice communications capabilities for maneuver forces in an immature theater at echelons lower than division have made significant advancements since 2002, there are still several deficiencies and challenges involving the low number of formations that can utilize these capabilities simultaneously. According to the Deputy Chief of Naval Operations for Networking, only 20 percent of the military's demands for OTH communications, through SATCOM, have been met during the Global War on Terrorism.[8] The Chief's report made sense to the researcher who experienced a Combat Aviation Brigade in 2009, with five maneuver task forces, limited to one SATCOM channel. This limitation was representative of the Chief's estimate of 20 percent - one out of five - demands met.

Five channels per brigade, however, do not represent a published minimum requirement. According to the Capability Set (CS) 14 for communications architecture, each brigade, by design, should expect no more than one channel.[9] Approximately 34 users should have access to this channel.[10] Allocating one channel per brigade is not an ideal, however, just a realistic expectation based on the limit of UHF SATCOM frequencies available.[11] So what is the right number of channels per brigade and how many users should expect access to those channels? More importantly, without fixating on UHF SATCOM, how does the military increase its OTH voice communications capabilities through other, less restrictive, means?

Since signal requirements depend heavily on mission and operational variables, it is difficult to find exact figures for the required number of channels and users in a brigade. For the purposes of this research, the gap between current capabilities and demands for OTH voice communications is defined as: The preponderance of maneuver forces below division are without OTH voice capabilities when the demand is for every tracked operational entity to have them. The size of this demand seems, at first, unreasonable. In actuality, the demand mirrors one of the stated goals for the CS 14 communications architecture, “Beyond Line of Sight (BLOS) data and voice capability is provided to the dismount at platoon and company.”[12] To develop approximations for numbers of channels and users per brigade, one can use the CS 14 architecture for current LOS capabilities. On average, 900 systems with one command net per battalion sized maneuver task force capable of OTH voice transmissions should meet the brigade’s requirements.[13]

While the military has OTH voice communications capabilities by several means, it cannot advertise that the preponderance of maneuver forces on the ground have those capabilities available. Recognizing this gap between the military’s demands and what they are capable of producing inspires several questions: What hardware, software, and space vehicle appliqués are available currently, and what portions of the EMS do they use? How much is the military in competition with commercial interests for the use of certain portions of the EMS? Is the gap between the demand and the allocation due to costs associated with the capability? What are the prospective products and methods for the future of OTH voice communications? Finally, is a solution to use different portions of the EMS or is increasing the capacity, within portions of the EMS already used, a more viable option? These questions represent several variables for the research problem which require exploration. Paring down these questions, however, it appears that feasibility for increasing the availability of OTH voice capabilities is the overarching theme; and therefore, the researcher formed the following research question and sub-research questions.

The Research Question

What is the feasibility of increasing OTH voice communications capabilities in an immature theater to meet the demand for maneuver forces, both air and ground, by using portions of the electromagnetic spectrum that are not already utilized or maximized? Could these developments increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them? Furthermore, how susceptible to communications interference and jamming are each of the alternatives?

Studies That Have Addressed the Problem

Not every study included in Chapter 2, Literature Review, is included here. The researcher provides some brief explanations, however, for four recent research studies, which address at least some portion of the research question. The intent for this section is to support the following discussion of deficiencies found in OTH voice communications research. An acknowledgment of the deficiencies aids in developing a starting point for either revising the research question or building a method to answer it.

First study: In 2010 the U.S. Army Research Office in partnership with North Carolina State University produced a summary titled, “Ultra-Wideband Impulse Radio for Tactical Ad-Hoc Military Communications: Final Report." This study looked at Transmitted Reference (TR) techniques (techniques for placing reference signals before data signals developed in the 1960s) as a means of lowering the costs and increasing the capacity of Super High Frequency (SHF) receivers. These SHF receivers are designed to capture Ultra-Wideband (UWB) waves in the 3.1 to 10.6 gigahertz (GHz) range. The report stated that TR UWB would be a great improvement over UWB in the categories of costs and capacity.[14]

The significance of this study is that most OTH voice communications for the military are accomplished using some portion of the UHF band, which is more congested and contested than SHF. If methods for receiving and transmitting SHF waves improve, there is potential for increasing the military's OTH voice communications capabilities by utilizing alternate portions of the EMS.

Second study: Prior to the military cancelling the JTRS program of record in 2011, the Congressional Budget Office, in 2009, reported on a study from the MITRE Corporation concerning wireless communications acquisitions. The MITRE study, dated 2007, outlined the Army of 2030's demands for software programmable radios to replace legacy radios by developing an approximation of total vehicles, aircraft, and dismounts. The figure was just over 580,000 units, and the cost associated with this volume was over 100 billion. This cost was based on the Army's estimate of 15 billion for the purchase of 86,000 units. Since the software programmable radios developed using the JTRS framework are compatible with legacy LOS radios, like the Single Channel Ground and Airborne Radio System (SINCGARS), the Army can acquire new radios incrementally.[15] Still, the preponderance of maneuver forces at echelons below division are potentially without OTH voice communications capabilities if the Army does not equip them with something more capable than SINCGARS. This statement is especially true in scenarios similar to the first Gulf War in which more than two corps have to maneuver simultaneously.

The significance of this study is that the researcher gains an approximation of the number of units required to field a software programmable radio that has the potential to increase OTH voice communications capabilities to the preponderance of maneuver forces below division. Additionally, the researcher has an estimate on the costs associated with this approximation. Both figures provide a baseline for exploring feasibility with regards to costs, and will aid in answering the first sub-research question: Could these developments increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them?

Third study: In 2012 the University of California, Davis under the supervision of the US Army Research Office conducted research to develop theories for networking cognitive radios. Cognitive radios, without direct input from the user, sense, track, and exploit the most efficient waveforms[*] for transmitting voice and data. When networked together, they create an ad-hoc mobile network, capable of OTH communications, most similar to the JTRS main concept explained earlier. This type of network is significant as it does not depend on a large and previously established infrastructure of towers and/or satellites.

[*]Waveforms, for example the Soldier Radio Waveform (SRW), refer to waves along select portions of the EMS known as bands of operation. Most radios using waveforms are capable enough to move seamlessly between large variations in frequency along these bands.

One of the emerging theories, developed by this research, advocated the use of "sequential estimation strategy."[16] Sequential estimation strategy is a software protocol that allows the radio to estimate how much a particular waveform is used by the primary user and subsequently use that waveform more efficiently without interrupting the primary user's transmissions. Additionally, the operator does not have to coordinate with other users for time sharing.

This research on cognitive radio applications is significant because, without advocating a particular waveform or alternate portion of the EMS, it demonstrates feasibility for software programmable radios to increase the efficiency of portions already in use. This study relates to the primary research question concerning the EMS - portions already utilized or maximized. The researcher is not just looking for theories which support alternate bands of the EMS but also theories which advocate maximizing the efficiency of current bands to increase capabilities for OTH voice communications.

Fourth study: In 2008, two students from the Naval Postgraduate School developed the term "Tactical Private Satellite Network." These students conducted research in increasing satellite communications capabilities by actively managing the available military and commercial bandwidths from a single control node at the operational level. The Tactical Private Satellite Network would increase efficiency by dynamically directing the timeshare of bandwidths based on the individual needs of the tactical users. The network would assess those individual needs given the most current set of mission and operational variables from the common operational picture.[17] This research represented a theory for timesharing more advanced and dynamic than using a list of predetermined and inflexible timeslots. As situations develop, such a predetermined list would never match changes to the threat or the operational environment.

This research is significant because it shows that without technology, for example software programmable cognitive radios, or moving to another portion of the EMS, like SHF or Extremely High Frequency (EHF), there are emerging theories for increasing efficiency for OTH voice communications. An increase in efficiency has the potential to increase capabilities through current SATCOM means. This emerging theory, however, while addressing efficiency for the current set of users, does not provide a material solution for creating more users at echelons below division. Therefore, this theory does not help with the first sub-research question which concerns the preponderance of maneuver forces possessing OTH voice communications capabilities.

Deficiencies in the Studies

The recent research attention for OTH voice communications is best characterized as pragmatic, compartmentalized, and quantitative in nature. Researchers place little emphasis on exploration of the problem. They fail to begin with a wider view that examines, without prejudice for a select method, feasibility for future OTH voice communications capabilities. It appears there has been a need to introduce potential solutions without developing an overarching theory which governs thought concerning the problem.

In the first study, researchers reviewed methods to improve the efficiency of SHF carrier waves. SHF is a less saturated portion of the EMS and therefore is one example of an alternate. Still, the research had a narrow focus: the quantitative performance of a select band of SHF carrier waves. The second study was also quantitative in nature: the volume of more capable radios necessary to potentially increase OTH voice communications capabilities for the preponderance of maneuver forces and the associated costs. The third study on networking cognitive radios explored sequential estimation strategy as a means of introducing more users to a select band and therefore increasing capabilities. This study developed emerging theories but was still compartmentalized, pragmatic, and quantitative, as it focused on the performance of a single solution. The fourth study was also constrained by the predetermined need to test the performance of a proposed solution: a signal node equipped with both military and commercial SATCOM assets. This study was made in an effort to advocate a more dynamic method for frequency allocation and management.

All the above studies, and most of the literature from chapter 2, are important to the researcher and have merit. If deficiencies must be found, however, one is easily recognized: All the studies are quantitative. All the studies have a relatively narrow focus that is anchored on a predetermined method. Finally, all the studies seek a potential solution or direction for further research without presenting a more objective analysis resultant from exploration of the problem in its totality.

Therefore, it is the researcher’s intent to design a qualitative study, atypical of physical science research, to examine the problem from the perspective of a capability as opposed to the merits of a predetermined method. This study should result in the development of a substantive theory for future testing. The particulars of the qualitative method for this research are explained in detail in Chapter 3, Methodology.

Importance of the Study

As explained in the deficiencies portion of this chapter, in conducting a review of literature, the researcher quickly discovered a large volume of compartmentalized data, articles highlighting specific capabilities and operational characteristics for select developments. There was very little to read about theory or emerging practices that explained, from start to finish, how a large volume of maneuver forces in an austere environment would have OTH voice capabilities. There were very few studies that compared numerous methods of wave propagation. Typically, the performance of an emerging method was compared to a previous similar method; for example, TR UWB compared to UWB, as explained in the first study. This trend seemed to emerge because of the researcher's desire to be pragmatic, to present a specific, rigid, and easily explained solution for OTH voice capabilities, as opposed to exploring theory.

Clearly not enough is known about the problem, and the problem needs exploration. This research is important because scientists, researchers, and military leaders - especially ones involved in acquisitions - can use it to better understand the problem of the gap between demands for increased OTH voice capabilities and the current capabilities. With this understanding, interested readers can make informed decisions for future research. In addition to the studies currently available, readers will have research that represents an objective understanding of feasibility for increasing OTH voice capabilities for the preponderance of maneuver forces in an austere environment. Furthermore, readers will have a qualitative analysis of a wider variety of select systems and methods. Usually, researchers report on just one or two systems.

The Purpose Statement

The purpose of this research is to conduct a qualitative analysis, using grounded theory design (explained in chapter 3), of documents relating to improved OTH voice communications capabilities for maneuver forces in an immature theater at echelons lower than division. This analysis will aid in determining the feasibility of increasing OTH voice capabilities for maneuver forces to meet their current demands, and will examine the following: portions of the EMS used, capacity of that EMS portion, costs, and mobility. Mobility is defined by the size of the terminal and the power required in an austere environment. Selectively examining these four different categories will help determine where to focus the military's research and development efforts since the JTRS program has ended, but the demand for the preponderance of military forces to have OTH voice capabilities remains. As a result of this research, readers will have a substantive theory that links emerging technologies and techniques to a possible increase in OTH voice communications capabilities. Additionally, readers will have recommendations for testing this theory and conducting further research. Chapter 2 is the literature review and is organized by the four categories.

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[1]John W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*, ed. Lauren Habib (Thousand Oaks, CA: Sage Publications, 2013), 130-136.

[2]Richard B. Andres and Jeffrey B. Hukill, "Anaconda: A Flawed Joint Planning Process," *Joint Forces Quarterly* 47 (4th Quarter 2007): 137-139.

[3]Richard L. Kugler, Michael Baranick, and Hans Binnendijk, "Operation Anaconda: Lessons for Joint Operations" (Report, Center for Technology and National Security Policy, National Defense University, March 2009), http://www.dtic.mil/docs/citations/ADA496469 (accessed 13 May 2014), 20-22.

[4]Carlo Munoz, "Army Kills JTRS, Goes 'Platform Agnostic' With Network Plan," *Breaking Defense*, 12 October 2011, http://breakingdefense.com/2011/10/army-kills-jtrs-goes-platform-agnostic-with-network-plan (accessed 8 November 2013).

[5]Kris Osborne, "JTRS Advances 'Cognitive Radio' Concept," Army.mil, 2 May 2012, http://www.army.mil/article/79102/ (accessed 17 April 2013).

[6]Congressional Budget Office, *The Army's Wireless Communications Programs* (Washington, DC: Congressional Budget Office, 2009), http://www.dtic.mil/get-tr-doc/pdf?AD=ADA494523 (accessed 8 November 2013), 2-3.

[7]Department of the Army, *CS 14 Network Design Book* (Washington, DC: Government Printing Office, June 2013), 2-4.

[8]Department of the Army, *Army SATCOM Architecture Book* (Washington, DC. Government Printing Office, August 2013), 5-2.

[9]Department of the Army, *CS 14 Network Design Book*, 10-8.

[10]Ibid., 2-18.

[11]Ibid., 10-8.

[12]Ibid., 2-1.

[13]Ibid., 2-15

[14]L. Li, J. K. Townsend.US Army Research Office, "Ultra-Wideband Impulse Radio for Tactical Ad-Hoc Military Communications" (Final Report, North Carolina State University, Raleigh, NC, 2010), http://www.dtic.mil/dtic/tr/fulltext/u2/a534155.pdf (accessed 10 November 2013), 1-5.

[15]Congressional Budget Office, 14-15.

[16]Qing Zhao, "Networking Cognitive Radios for Tactical Communications" (Research Project, University of California-Davis and US Army Research Office, 2012), http://www.dtic.mil/docs/citations/ADA582905 (accessed 12 November 2013), 1-7.

[17]Brian H. Conrad and Ioannis Tzanos, "A Conceptual Framework for Tactical Private Satellite Networks" (Thesis, Navy Post Graduate School, Monterey, CA, September 2008), http://www.dtic.mil/dtic/tr/fulltext/u2/a488784.pdf (accessed 14 November 2013), 165-170.

CHAPTER 2

LITERATURE REVIEW

As stated in chapter 1, the purpose of this research is to conduct a qualitative analysis, using grounded theory design, of documents relating to improved OTH voice communications capabilities for maneuver forces in an immature theater at echelons lower than division. This research does not presume to discover a solution to the demand for this capability. Instead, the research is intended to discover enduring themes found through different sources in an effort to communicate meaning, develop an emerging theory, and help direct future research and development efforts. Ultimately, the research will serve to answer the question of feasibility for increasing OTH voice communications capabilities to meet the current demand, as outlined in chapter 1, by using different portions of the EMS or improving the efficiency of the portions already in use.

This chapter is organized by the four categories or sub-headings listed in the Purpose Statement of chapter 1: portions of the electromagnetic spectrum used, capacity of that EMS portion, costs, and mobility. Figure 1 is a graphic from the Federation of American Scientists (FAS) that illustrates an analysis for all four categories across the Ultra High Frequency (UHF), Super High Frequency (SHF), and Extremely High Frequency (EHF) military portions of the EMS.[1] This graphic and some initial information for defining variables in the research question are presented at the beginning of the chapter. This initial information provides a base of knowledge for better understanding the literature which relates to the four sub-headings.

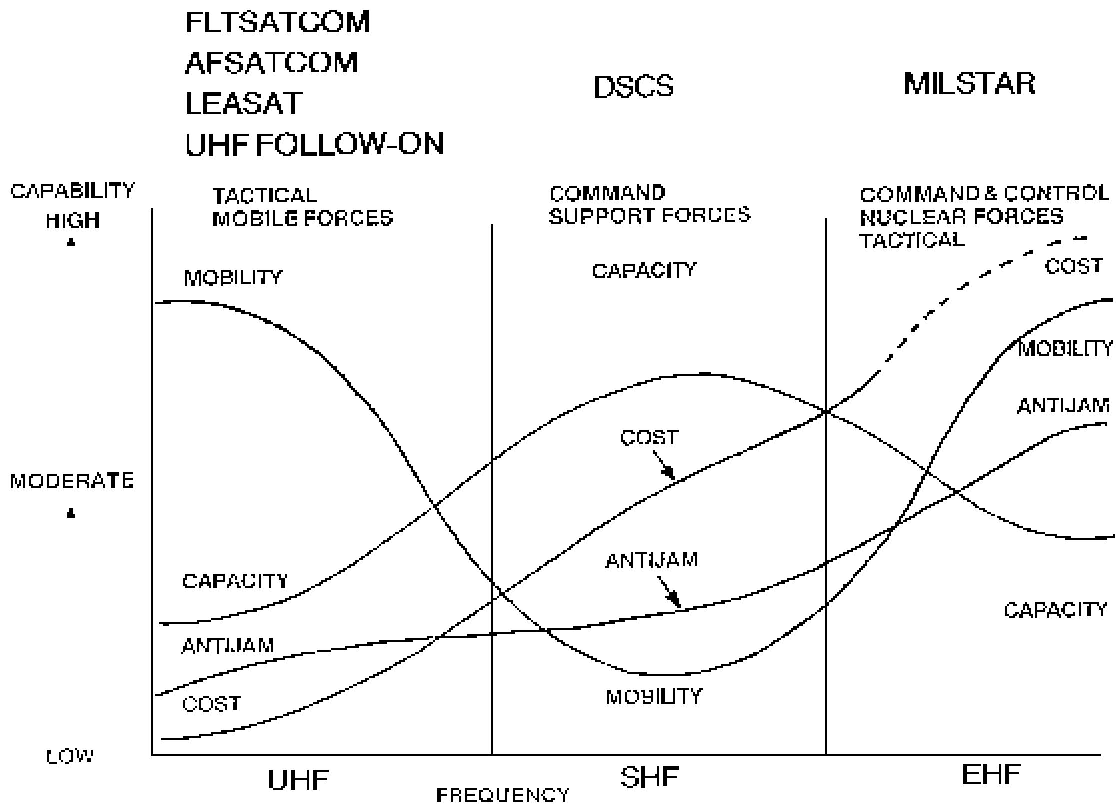

Figure 1. Category Analysis for UHF, SHF, and EHF

Source: Federal Administration of Scientists, *Army Space Reference Text* (Washington, DC: Federal Administration of Scientists, 2013), 1.

Disregarding the actual terminals or satellite systems used to communicate on one of these three portions, the lines show a convergence in the EHF spectrum where mobility, capacity, and anti-jam capabilities are relatively high compared to SHF and UHF, where either mobility or anti-jam suffer. Unfortunately, EHF is also characterized by a significant rise in costs. Costs are important, since the research question focuses on radio systems that the DOD will field to the majority of maneuver forces. Although this figure asserts that EHF has the potential to be highly mobile, there are no current EHF systems that are any more mobile than SHF applications. There are lighter, arguably manportable EHF systems, but they all have to remain immobilized to receive the dense, focused, and directional EHF signals. Additionally, anti-jam, while not one of the four categories for organizing this chapter, is important, as addressing the vulnerability to jamming is a sub-research question. Finally, the heading, "Tactical Mobile Forces," listed above the UHF column, indicates that the current practice for echelons lower than division - the smallest tactical unit - is to use UHF, while command support and control forces at division or higher use SHF and EHF.

The primary question this graphic inspires: Why is the EHF (30 to 300 GHz) portion of the EMS, which represents waves more dense than SHF but less dense than infrared light, so costly? The answer is that the technical complexities of designing both the satellite payloads and the receiver terminals capable of sending and receiving EHF carrier waves is extremely high. This is because EHF is more susceptible to obstacles, weather, and atmospheric interference, especially while on the move. These challenges with EHF increase the cost associated with it by 100 percent or more as compared to UHF alternatives.[2] Atmospheric absorption and reflection properties of the EMS are explained in further detail under the sub-section, Other Portions of the EMS.

Additional Information for Defining the Research Question

OTH defined: To answer the research questions one must address the distance associated with OTH voice communications. This is difficult to define since the distance to the horizon for a soldier on the ground varies depending on atmospheric conditions and his height above the earth's surface. A good approximation of the distance to the horizon for a soldier who stands at two meters is five km. This approximation is based on the formula - distance in km is approximately 3.57 times the square root of the observer's height in meters.[3] For rotary wing at 200 meters the horizon is 50 km away. Any voice communications beyond such approximations, where a LOS radio is no longer of use, should be considered OTH. For the purposes of this research, OTH voice communications capability will focus on distances from 5 to 200 km. Capabilities beyond 200 km are usually not a demand for maneuver forces at echelons lower than division. A distance of over 200 km is too reaching for the control and sustainment of subordinate units and therefore impractical.

Current Capabilities: For echelons lower than division, the war fighter is usually equipped with a LOS radio that performs frequency modulation in the VHF range of the EMS. The legacy LOS radio has been some form of the SINCGARS. Relay towers and stations can enhance these LOS radios giving them some BLOS capability synonymous with OTH, but with limited performance. According to the most recent Army technical manual for SINCGARS systems, max ranges for planning purposes are 5 to 10 km for dismounts and 10 to 40 km for vehicles or command posts equipped with power amplifiers.[4] These max ranges represent some OTH capability up to 40 km, but still fail to cover the above mentioned distances from 5 to 200 km.

Recent acquisitions, however, have increased the small unit's capability; with the PRC-155 and PRC-154A, soldiers can transmit and receive both VHF and UHF signals, to include UHF signals for SATCOM. Because of the expense of these systems, not every operational unit is fully equipped, and there are performance limitations caused by interference, which lead to fewer channels.[5] Still, these radios are an excellent improvement over the systems available in the past.

Bands of Frequencies: Throughout this research radios that use the UHF, SHF, or EHF portions of the EMS are analyzed. These portions are defined by frequency sets of waves. It is important to include a table that lists the frequencies in Hz for each of the three portions, plus waves that are lower in frequency than UHF and used by the military. UHF is 300-3000MHz, SHF is 3000MHz-30GHz, and EHF is 30-300GHz.[6]

Table 1. Radio Frequencies and Wavelengths

Band		Frequency	Wavelength
LF	Low Frequency	30-300kHz	10–1 km
MF	Medium Frequency	300-3000kHz	1000–100 m
HF	High Frequency (Short Wave)	3-30 MHz	100–10 m
VHF	Very High Frequency	30-300MHz	10–1 m
UHF	Ultra High Frequency	300-3000MHz	100–10 cm
SHF	Super High Frequency	3-30 GHz	10–1 cm
EHF	Extremely High Frequency	30-300GHz	10–1 mm

Source: M. P. M. Hall and L. W. Barclay, ed., *Radiowave Propagation* (London, UK: Peter Peregrinus, 1989), 1.

The bands in table 1 are broken down even further by separate standards or systems for labeling frequency ranges, such as the International Telecommunications Union (ITU) and the European Union, North Atlantic Treaty Organization, United States

Electronic Counter Measures Frequency Designations (EU, NATO, US ECM).[7] It is not in the scope of this chapter to list all the different standards as tables. However, it is important to recognize that there are several different methods, throughout the globe, for labeling frequency sets as bands. Often in literature concerning radio voice communications there are references to these bands: for example, the NATO L band or the Ku and Ka Waveguide Frequency Bands. For this research, when the author cites a specific band, of a specific standard for labeling bands, he will list the frequencies associated with the band in hertz and the band from table 1 in which it resides.

Other portions of the EMS: While this research is not limited to any specific portion of the EMS, it is important to note the physical characteristics of carrier waves that make communications with frequencies less than 30 kHz and more than 300 GHz impracticable. Figure 2 is a graphic depicting the atmospheric reflection and absorption properties of frequencies outside the normal bands for wave propagation.[8] Using EMS frequencies outside these normal communication bands is difficult, as the carrier waves are unable to reach their destination due to the atmosphere, weather, or other physical obstacles; an exception is laser and light communications between satellites in orbit. These communications do not need to reach the earth's surface by penetrating the atmosphere.

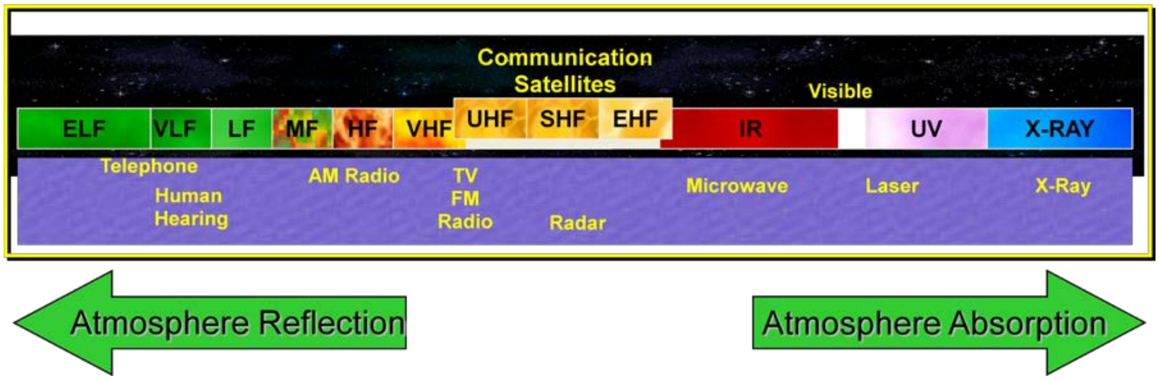

Figure 2. Atmospheric Reflection and Absorption Properties for EMS

Source: Department of Joint Interagency and Multinational Operations, "A537 Space Orientation" (Lesson 6 Slide Presentation, Command and General Staff College, Fort Leavenworth, KS, 2014), 11.

Figure 2 is helpful for understanding why 30 kHz to 300 GHz for communications and radar applications is desirable. Anywhere else along the EMS there is too much reflection or absorption. This figure, however, is an oversimplification of the reflection and absorption properties concerning the EMS and the atmosphere. Visible light, for example, is barely absorbed by the atmosphere. Figure 3, from NASA, further illustrates the discrete absorption properties of certain frequencies and wavelengths.[9]

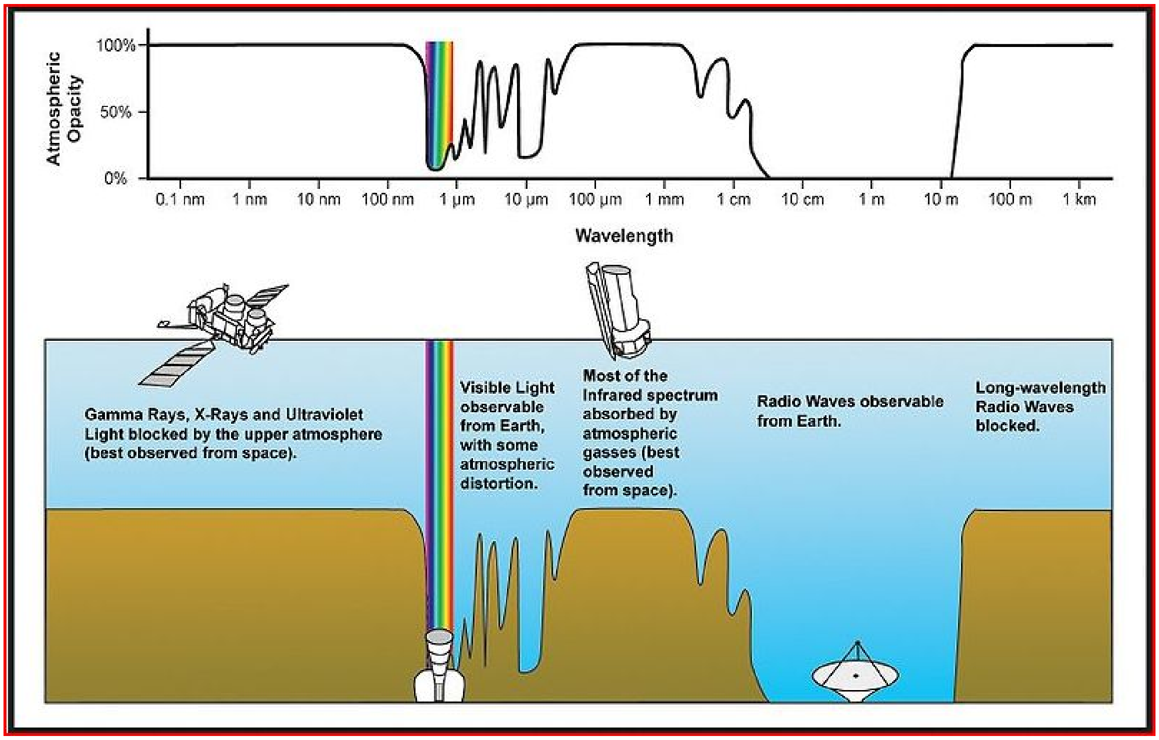

Figure 3. Atmospheric Opacity for Wavelengths

Source: Wikimedia Commons, "Atmospheric Electromagnetic Transmittance or Opacity Graphic" (Online NASA Graphic, Wikimedia Commons, 2014).

Note that figure 3 is organized by wavelength and not frequency. Therefore, as it reads from left to right, light is on the left side and radio waves, such as EHF, SHF, and UHF, are on the right side. As depicted in table 1, lower frequencies correlate to larger wavelengths. The significance of this figure is the understanding that increasing frequency or reducing wavelength does not increase capabilities, as every type of wave has discrete absorption properties.

Portions of the Electromagnetic Spectrum Used

At the start of this chapter was a brief overview of subjects concerning OTH voice communications which included: the four categories for organizing this research - EMS, capacity, cost, and mobility - OTH defined, current capabilities, bands of frequencies, and alternate portions of the EMS. This section catalogs the literature for the first category, portions of the EMS used.

Study 1: Study 1 is the military's current and near future communication demands on the EMS for echelons beneath division. Table 2 outlines the basic spectrum requirements for the radio waveforms and hardware applications used in the CS 14 communications architecture. The bands of operation, listed in the second column, use the Electrical and Electronics Engineers' (IEEE) standard for labeling frequency sets. Beneath the table is a brief explanation of where the IEEE bands correlate to the basic bands explained in table 1.

Table 2. CS14 Spectrum/Satellite Requirements

	Bands of Operation *	Initial Observations
SINCGARS	VHF (30-88 MHz)	Already employed in scale. Further analysis not performed.
SRW	UHF (225-450 MHz) and L-band (1350-1390, 1755-1850 MHz)	Many nets per BCT will be challenging. ***Investigation needed.***
HNR	C-band (4400-4900 MHz)	Requires one 22 MHz channel per DIV. Directional antennas facilitate reuse. However, C-band availability in some locales is limited. ***Investigation needed.***
NCW	Ku-band and Ka-band SATCOM	Many additional on the move platforms will be challenging. ***Investigation needed.***
BFT	L-band SATCOM	PM analysis to date indicates BFT resource needs do not change dramatically (improved efficiency in BFT-2 increases capacity and enables CS14 quantities)
UHF SATCOM	UHF	It is understood that this resource is limited; its role within CS14 Network Design reflects that.

Source: Department of the Army, *CS 14 Network Design Book* (Washington, DC: Government Printing Office, June 2013), 4-3.

SINCGARS, legacy radios, explained earlier in the chapter, use the very low end of VHF, 30-88 MHz. SRW is primarily three separate portions of UHF: 225-450 MHz, 1350-1390 MHz and 1755-1850 MHz. Note that L-band, when using IEEE, is a UHF subset. The Highband Networking Radio (HNR) uses the C-band, 4-8 GHz, which is in the SHF portion of the spectrum. HNR, however, is an application currently limited to the division or higher. Net-Centric Waveform (NCW), which is limited to company command posts or higher, uses the Ku band, 12-18 GHz, which is SHF and the Ka band, 27 to 40 GHz, which is both SHF and the low end of EHF. SHF and EHF waveforms, as explained in the first part of chapter 2, lack mobility. NCW is interesting because it is an example of SHF waveforms used at echelons below division, but not while on the move. Finally, BFT is a UHF SATCOM application.

This table makes the point that most tactical radio capabilities that can provide OTH voice communications at echelons lower than division rely heavily on the UHF band for either the SRW or satellite communications. Of all the systems available to echelons lower than division, only the Net-Centric Waveform (NCW) uses the SHF and EHF portions of the EMS. Additionally, the table states that introducing multiple on the move platforms for NCW presents a challenge. Lastly, one should recognize that the CS 14 represents solutions and goals for the near future using equipment that may only be available to three or four brigades at a time. By no means is the data from table 2 representative of what the preponderance of maneuver forces is currently capable.

UHF - Study 1: In 2004, two marines attending the Navy Post Graduate School tested systems for improved voice and data communications. Although they may not have intended, almost every system used some portion of UHF, and could be divided into two subcategories, satellite dependent or no satellite required. The three that could be used for OTH voice communications all used satellites receiving and transmitting data with UHF.[10] Interestingly, all three used the same portion of UHF, approximately 1525 to 1646.5 MHz, representative of the IEEE L band.

Using figure 1, it is reasonable to assume that in 2004 the UHF IEEE L band's moderate capacity, low costs, and high mobility contributed to the development of several UHF satellite communications systems; these were the systems available for testing. Susceptibility to jamming was not tested. However, figure 1 shows UHF wave propagation is more susceptible to jamming than SHF and EHF waves. The significance of this study is that it confirms a reliance and possibly fixation on UHF and, more specifically, UHF SATCOM for OTH voice communications capabilities.

SHF - Study 1: Note, the following study was one of the examples reviewed in chapter 1 to support the deficiencies model. In 2010, the U.S. Army Research Office, in partnership with North Carolina State University, produced a summary titled, "Ultra-Wideband Impulse Radio for Tactical Ad-Hoc Military Communications: Final Report." This study looked at Transmitted Reference (TR) techniques (techniques for placing reference signals before data signals developed in the 1960s) as a means of lowering the costs and increasing the capacity of Super High Frequency (SHF) receivers. These SHF receivers are designed to capture Ultra-Wideband (UWB) waves in the 3.1 to 10.6 gigahertz (GHz) range. The report stated that TR UWB would be a great improvement over UWB in the categories of costs and capacity.[11]

Although a study outlining SHF receivers as opposed to UHF is significant, the reader should remember the analysis from figure 1. SHF receivers and transmitters are extremely heavy, lack mobility, and are more costly than VHF or UHF. Therefore, feasibility, with regards to the preponderance of maneuver forces below division having some form of SHF voice communications, is an issue.

EHF - Studies 1 and 2: Most of the literature found on EHF highlights the U.S. Air Force and Lockheed Martin's Advanced EHF (AEHF) satellite programs. In 2010, the first AEHF satellite payload was delivered for launch. The system, if fully operational, has the potential to increase the military's EHF satellite capabilities by five times as much as the current Military Strategic Tactical Relay (MILSTAR) system, which also uses EHF.[12] Note that for maneuver forces below division there are currently no EHF resources in the planned communications architecture. In fact, one of the only EHF receivers available is the Single Channel Anti-jam Manportable (SCAMP), AN/PSC-11. At approximately 40 pounds, this system is barely man portable and requires a 10 minute set up and tear down time. It has no on-the-move capabilities.[13] An additional EHF system is the Secure Mobile Anti-Jam Reliable Tactical Terminal (SMART-T). This system is a more prolific, vehicle mounted piece of hardware, which closely resembles the hardware used in SHF applications. It is the primary system used by division or higher to communicate with MILSTAR and AEHF. While it is mobile, it has little or no on-the-move capabilities.[14]

An understanding of current and projected EHF capabilities is significant for outlining the feasibility to use EHF as an alternative to UHF at echelons below division. As explained in the first section of this chapter, there are many challenges relating to EHF carrier waves. These challenges are primarily their susceptibility to weather, the extreme costs for payload and receiver production, and their current size and lack of mobility. Still, this research recognizes the military's commitment to both the MILSTAR constellation and the new AEHF satellites for strategic and operational demands as neither program has been cancelled.

Capacity

Study 1: Note, the following study was one of the examples reviewed in chapter 1 to support the deficiencies model. In 2012, the University of California, Davis conducted research to develop theories for networking cognitive radios. Cognitive radios, without direct input from the user, sense, track, and exploit the most efficient waveforms for transmitting voice and data. When networked together, they create an ad-hoc mobile network, capable of OTH communications. This type of network is significant, as it does not depend on a large and previously established infrastructure of towers and/or satellites. One of the emerging theories, developed by this research, advocated the use of "sequential estimation strategy." [15] Sequential estimation strategy is a software protocol that allows the radio to estimate how much a particular waveform is used by the primary user, and, subsequently, to use that waveform more efficiently without interrupting the primary user's transmissions. Therefore, without coordinating for time sharing, the military user increases the capacity of an established waveform.

Study 2: Note, the following study was one of the examples reviewed in chapter 1 to support the deficiencies mode1. In 2008, two students from the Naval Postgraduate School developed the term "Tactical Private Satellite Network." These students conducted research in increasing satellite communications capabilities by actively managing the available military and commercial bandwidths from a single control node at the operational level. The Tactical Private Satellite Network would increase efficiency by dynamically directing the timeshare of bandwidths based on the individual needs of the tactical users.[16] This research represented a theory for timesharing more advanced and dynamic than using a list of predetermined and inflexible timeslots. It is significant because it shows that, without technology, for example software programmable cognitive radios, or moving to another portion of the EMS, like SHF or EHF, there are emerging theories for increasing efficiency, and thus capacity, for OTH voice communications.

Studies 3 and 4: Mobile User Objective System (MUOS) is an initiative to use internet protocols, similar to the cell phone 3G network, to increase the capacity of what would otherwise be legacy, single channel, UHF SATCOM. This increase is tenfold, raising the current volume of users from 600 to just over 7000. The military accomplishes this by building four ground stations that will process the UHF signals. The satellites, five in total, will act like cell phone towers supporting both the user and the ground stations.[17] This advancement is even greater than the Demand Assigned Multiple Access (DAMA) system. DAMA is a slightly older system than MUOS which increases the efficiency of traditional UHF SATCOM by as much as four to twenty times. It accomplishes this by recognizing unused space on a UHF carrier wave and then dynamically changing the priority user for segments of that wave.[18] DAMA is most similar to the sequential estimation strategy discussed in study 1.

The significance of MUOS and DAMA is that they can interface with many of the software programmable radios developed for JTRS. This makes either system attractive, as there is no demand to have a completely different terminal to receive or transmit signals. MUOS and DAMA represent two means by which OTH voice communications capabilities can increase without utilizing a different portion of the EMS.

Costs

Study 1: Note, the following study was one of the examples reviewed in chapter 1 to support the deficiencies model. Prior to the military cancelling the JTRS program of record in 2011, the Congressional Budget Office, in 2009, reported on a study from the MITRE Corporation concerning wireless communications acquisitions. The study introduced a figure of just over 580,000 units, at a total cost of 100 billion dollars, to replace legacy radios with software programmable radios. Since the software programmable radios are compatible with legacy LOS radios, the Army can acquire new radios incrementally.[19]

The significance of this study is that the researcher gains an approximation of the number of units required to field a software programmable radio that has the potential to increase OTH voice communications capabilities to the preponderance of maneuver forces below division. Additionally, the researcher has an estimate on the costs associated with this approximation.

Study 2: In 2013, the U.S. Army Defense Logistics Agency, under the provisions of the Multi-mode Airborne Radio Set program, purchased 13 million dollars worth of equipment from Raytheon for rotary wing assets. The contract overall is worth 370 million dollars and approximately 5600 radio sets. The preponderance of the equipment is the ARC-231, designed for improved range, improved capacity for voice, video and data, and improved encryption capabilities, National Security Agency (NSA) type 1. The system covers OTH communications, air to air, and air to ground[20] Raytheon is known for their UHF communications with satellites using a mobile unit that can also perform VHF/UHF LOS communications.

The significance of this article is that it lists, for division rotary wing assets, both the military's commitment to, and the recent costs associated with, UHF/DAMA satellite communications and UHF terrestrial communications. The ARC-231 and other acquisitions related to the UHF/DAMA design may not have the capability to use a different portion of the EMS. This limitation affects feasibility to introduce alternate portions of the EMS as a means of increasing OTH voice communications capabilities; hundreds of millions of dollars are already committed to a specific solution.

Study 3: The Project Manager, Defense Communications and Army Transmission Systems (PM DCATS) awarded AT&T a $ 4.1 billion contract for services in October 2013. The contract is for an indefinite quantity and delivery of services over a five year period. Included in the service package are "satellite, microwave, fiber-optic, OTH, radio, and wireless capabilities, as well as all ancillary support services."[21] These support services are not directly a part of the CS 14 design for echelons lower than division. However, this article is significant, as it highlights the costs associated with ancillary services designed to support the Army's communication needs at all three levels of war for a five year period.

Study 4: The Army, in an effort to lower costs for communications development post the JTRS program, is asking commercial enterprises to develop off-the-shelf technologies. These technologies will focus on hardware which incorporates the military's advancements in software programmable radios.[22] Like commercial enterprises competing to launch space vehicles, the potential for both lowering costs and having several emerging technologies to choose from is extremely high. The military's commitment to commercial industries, as a method preferred over developing contracts for a program of record, is significant. It helps the researcher visualize a future in which several different but interoperable systems will dominate the military's communications architecture as opposed to a singular and dated systems solution.

Mobility

As explained at the beginning of this chapter, because of the nature of carrier waves, UHF applications are more mobile than SHF and EHF. Equipment for SHF and EHF applications requires larger amounts of hardware to transmit and receive the waves. SHF waves are denser than 3000 MHz, but not yet as close to infrared light as EHF waves. EHF waves have the potential for mobility, however, current applications are just as cumbersome as most SHF systems. The discrete properties of waveforms in these two bands lead to the necessity for heavier equipment that is less mobile. Such is the case with the NCW and HNR which are limited to command posts.

Studies 1 and 2: Most of the literature that discusses mobility of communication systems, exclusive of discussing a particular system in its entirety or discussing the EMS, deals with advancements in batteries and antennas. Power density, as defined by watt hours per kilogram of weight carried, is very important, as the power supply for a radio accounts for over 40 percent of the system's overall weight. Techniques such as Digital Pre-Distortion and Linearization, which involve dynamic changes to the response of a radio's power amplifier, greatly increase the overall power density of batteries in a radio system.[23]

In addition to power density, antenna efficiency is also important for creating radio systems that are more mobile. Some of the most current techniques for building better antennas involve ferrite loading.[24] Ferrites are usually ceramic materials that increase the efficiency of an antenna and allow it to be shorter and lighter. Antennas which are smaller, more durable, lighter, and have increased efficiency contribute to greater mobility.

Studies concerning power density and improved antennas are significant, as they foster an appreciation for what it takes to make systems more mobile. Additionally, these studies are often limited to VHF and UHF communications devices. This further demonstrates that SHF and EHF systems mobility is relatively underdeveloped.

Summary

The studies in the four sub-categories of EMS, Capacity, Costs, and Mobility represent the end of Chapter 2, Literature Review. The following chapter, Chapter 3, Methodology, explains in detail the model for conducting a qualitative analysis of both the studies in this chapter and additional documents relating to OTH voice communications. Chapter 3 begins with restating the purpose of this research introduced in chapter 1.

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CHAPTER 3

RESEARCH METHODOLOGY

Introduction

Purpose of Research:

The purpose of this research is to determine the feasibility of increasing OTH voice communications capabilities in an immature theater to meet the demand for maneuver forces, both air and ground, by using portions of the electromagnetic spectrum that are not already utilized or maximized. Furthermore, this research seeks to answer the questions: (1) can developments in OTH voice communications increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them, and (2) how susceptible to communications interference and jamming are each of the systems? Derived of these questions are the four categories of EMS, capacity, mobility and cost. Selectively examining the four categories will help determine where to focus the military's research and development efforts since the JTRS program has ended, but the demand for the preponderance of military forces to have OTH voice capabilities remains. As a result of this research, readers will have a substantive theory that links emerging technologies and techniques to a possible increase in OTH voice communications capabilities. Additionally, readers will have recommendations for testing this theory and conducting further research.

Organization

This chapter is organized into four parts: design, method, analysis, and summary. Design is the steps taken by the researcher to answer the primary research question and secondary research questions listed above. Method is about the criteria used to determine the credibility of sources and the feasibility and suitability of examples. Analysis is a more detailed description of how the design is applied to the research and what the standards for significance are. Finally, the summary will further expound on the argument for qualitative versus quantitative research in dealing with this problem, and list the outputs for Chapter 4, Analysis.

Design

Having experienced in Afghanistan in 2009 what Vice Admiral Harry B. Harris, Deputy Chief of Naval Operations for Networking, described as only 20% of our narrowband communications (OTH SATCOM*)* demands being met during the Global War on Terror, the researcher was curious to learn about the possibilities of increasing OTH capability.[1] What hardware, software, and space vehicle appliqués are available currently, and what portions of the EMS do they use? What are the prospective products and methods for the future of OTH voice communications? What the researcher quickly discovered was a large volume of compartmentalized data, articles highlighting specific capabilities and operational characteristics for select developments. There was very little to read about theory or emerging practices that explained, from start to finish, how a large volume of maneuver forces in an austere environment would have OTH voice capabilities. Clearly not enough was known about the problem, and the problem needed exploration.

When a research problem needs exploration to develop a substantive theory or determine meaning, qualitative research is most helpful.[2] Therefore the design of this research is qualitative, not quantitative or a mix of the two. Why a qualitative research methodology? Why is quantitative research not a better way to answer the question of feasibility for OTH voice communications in an austere environment? There are many quantitative studies on radio systems done for the purposes of making comparisons, measuring performances, and advertising discrete capabilities. However, such studies by their nature are limiting. The deductive and inductive reasoning the researcher uses to develop theory and create a framework are removed by the predetermined constraints of the quantitative research method.

According to Creswell, there are fewer limitations with qualitative research because the researcher employs an emerging approach to both inquiry and data analysis in an effort to discover patterns and themes.[3] Since the goals of this research require synthesis of the prescribed meanings for OTH voice communications in order to share overall feasibility and direct future research, a qualitative methodology is more appropriate. A simple explanation for choosing qualitative over quantitative is, “we conduct qualitative research because a problem or issue needs to be explored.”[4] This problem needs exploration beyond what an isolated set of variables in a quantitative study can provide.

But how is a qualitative research method designed? Creswell argues that there are five distinct approaches: narrative, phenomenon, grounded theory, ethnographic, and case study. Describing all five is not in the scope of this chapter, but the grounded theory approach was picked for its suitability to researching problems with several unknowns. Defining features of the grounded theory approach include: focusing on processes, developing theories for those processes, memoing ideas during data collection, and axial coding of categories.[5] These features, in conjunction with categories of analysis, which will be explained in the method part of this chapter, helped the researcher shape the four axial nodes listed in chapters 1 and 2: EMS, EMS capacity, cost, and mobility. As far as data collection, most data collection for the grounded theory approach is done by administering interviews. For this problem, however, the written thoughts, analysis, and quantitative results which experts share in articles seemed more appropriate than the opinions military signal experts have about OTH communications.

The process of collecting qualitative data by mining it from documents and articles as opposed to administering interviews came from the Merriam guide to qualitative research. Like Creswell, Merriam advocates the use of qualitative research for exploration and to develop theory and meaning. She also uses the same five approaches Creswell does, and her explanation of the grounded theory approach is synonymous with Creswell's, as both are citing the 1967 Glaser and Strauss book, *The Discovery of Grounded Theory*.[6] Merriam differs from Creswell, however, in that she advocates written documents and articles as forms of data used in qualitative research.[7] These forms are in addition to Creswell's forms of observations and interviews. Merriam's assertion that documents represent a type of data for qualitative analysis is further supported by Davies' explanation of content analysis.[8] Both argue that research using written documents is not just for historians but, as Davies elucidates, "can also be monumentally ambitious,"[9] at least as ambitious as other qualitative studies which pull data from interviews or observations. Davies and Merriam's criterion for selecting documents is the primary focus for developing the method section of this chapter.

Method

As stated in the introduction for this chapter, method, separate from design, concerns the criteria used to determine the credibility of sources and the feasibility and suitability of examples. Merriam's work makes it difficult to develop criteria for feasibility and suitability as she states that "documents include just about anything in existence prior to the research at hand."[10] Merriam does, however, citing Clark (1967), assist the researcher with questions about the authenticity of documents, which are helpful in determining the credibility of sources. Not all the questions are listed here (see appendix A for complete list), but examples include: who was/is the author, what was he trying to accomplish, and what was/is the author's bias?[11] The first part of the method for this research is to use the Clark questions to screen every prospective article. If the screening indicates that the author used little or no sources, has a gross bias, or that there are no other documents that can shed further light on what the author is attempting to communicate, then the researcher will exclude the document.

While the researcher will exclude documents with a gross bias, some bias is allowable. Since the U.S. is a consumer society, one can expect more literature on hardware and software systems, developed by corporations for potential sales, to be available as compared to impartial studies of the EMS. Recognizing this potential bias before conducting the research and analysis will save the researcher from making bad generalizations which are not representative of objective expertise in communications.

The second part of the method for this research is to determine the feasibility and suitability of the examples. After the Clark questions help the researcher screen articles for credibility, as recommend by Merriam, the researcher must have a set of criteria for determining if the articles are suitable. Suitability is defined as relevance to the research problem. Simply put, does the written document allow for further exploration and assist in answering the research question? To complete this task, the researcher used the Davies model to develop criteria for choosing documents in qualitative research.

In the Davies model for developing selection criteria of documents, step one is to determine the research question. This step was obviously completed prior to chapter 3's composition. Step two is to determine a sampling method, either whole units or parts of the whole. In this case, the researcher chose parts of the whole. Since the research question has a narrow focus concerning OTH voice communications capabilities for maneuver forces in an immature theater, the researcher needs to pull select articles from military, scholastic, and commercial publications without examining the entire source. Step three is to determine the category of analysis that will govern the researcher's coding process.[12] The axial coding process nodes of EMS, EMS capacity, cost, and mobility have already been discussed; however, as mentioned in the design portion of this chapter, there is a category of analysis that helped the researcher define those process nodes.

The three categories of analysis to choose from in step three are: the extraction and interpretation of meaning within a block of text, the counting of words, and the counting of repetitions of phrases. The researcher chose extraction and interpretation of meaning. This category seemed better suited for exploration of a problem than the more rigid categories of word and phrase counting.

Finally, step four is to create the axial coding frame that is suitable to the purpose of the research and can evolve and change during exploration. The axial coding frame which incorporates the nodes, EMS, EMS capacity, cost, and mobility is the subject of the analysis portion of this chapter.

Analysis

As stated in the introduction for chapter 3, analysis is a more detailed description of how the design is applied during the research and what standards for significance are used. In the design portion of this chapter, grounded theory is characterized as focusing on processes, developing theories for those processes, memoing ideas during data collection, and axial coding of categories.[13] This was Creswell's characterization, which is further supported and expounded upon by Bohm. Bohm explains that when text analysis is used in grounded theory, axial coding should be preceded by both memoing and open coding. Open coding is the analytical break down of written documents to form a succession of concepts that may or may not be used as axial codes. Axial coding is then followed by selective coding, which is the process of picking axial nodes as categories that are most closely related to the emerging theory.[14] This research uses the Bohm procedure for grounded theory because the open coding helps to further evaluate the documents before they are assigned to an axial node. Document evaluation, in addition to the steps listed in the method section of this chapter, aids in exploration and inductive reasoning, which are both necessary to develop an emerging theory.

If memoing ideas and using axial coding to organize data into categories and form an emerging theory are part of the process for grounded theory approach, what are the outputs for analysis? The primary output is a pliable logic model, with nodes and connections that is saturated with data and continually evolves into a substantive-level theory for further testing.[15] One can imagine a detective, with several pieces of dissimilar evidence, charting pictures, official records, and receipts together on a corkboard in an effort to induce cause or predict a future outcome. The process is the same in this research. The four axial codes for OTH voice communications become buckets of information. Those buckets then become nodes on a poster sheet with pieces of relevant evidence connecting them. At the end of the analysis the poster should reveal a direction for research and development and thus feasibility for achieving increased OTH capabilities in the future.

When conducting grounded theory research using documents in which a pliable model and resulting emerging theory are the primary outputs for analysis, how then does the researcher apply standards for significance? Usually, standards for significance are statistical in nature and apply to quantitative research that uses sampling.[16] Simply put, when testing a hypothesis in a quantitative study, the researcher assigns a p-value or percentage value that represents a standard for significance in his sample. If findings for that sample are outside the prescribed standard for significance then they are irrelevant; because they do not represent the population the sample was taken from. For example, if the p-value is five percent, but less than 95 percent of a sample asserts a prospective truth, then the findings for the research are inconclusive.

Davies writes, however, that in addition to probability and non-probability sampling methods used in quantitative research, in which the researcher assigns a standard for significance, there are strategic sampling methods for qualitative research, in which the researcher does not.[17] His explanation for strategic sampling is similar to his model for determining feasibility and suitability of examples described in the method portion of this chapter. Instead of a p-value, the researcher determines for himself the significance of the document in relation to his research question by asking, does the document assist with the exploration of the problem? Flick further elaborates on this loose standard for significance. In his explanation of degrees of standardization and control in qualitative design, Flick, citing Miles and Huberman, recommends a design with loose standards for significance when "new fields are being investigated and the theoretical constructs and concepts are relatively undeveloped."[18] Openness and flexibility are paramount to the exploratory nature of grounded theory research. However, to introduce some level of control for the documents and their resulting inputs to the pliable logic model, as stated in the method section, the researcher will use the Clark questions and the Davies selection criteria. Beyond those evaluation methods, the researcher will not apply a standard for significance to either the pliable logic model or the emerging theory once they are complete.

Summary

Qualitative research applied to a subject that is based mainly in the physical sciences is a hard sell; because typically quantitative studies are designed for testing physical hypotheses and qualitative studies are designed for history and sociology. This research, however, for increased OTH voice communications capabilities in an immature theater is better served by inductive reasoning and exploration because it focuses on emerging processes and procedures and the meanings assigned to them. The researcher found that to answer the questions of feasibility and to develop a theory for how OTH capabilities can increase in the future, quantitative research or a mix of quantitative and qualitative research methods were not sufficient. Testing a select set of variables in an effort to find some conclusive data for a report would not provide an overarching explanation of feasibility or a possible roadmap for increasing OTH capabilities.

A review of literature in research design and qualitative inquiry supported the decision to use qualitative research methods and aided the researcher in constructing a design and method for the project. First, the researcher committed to qualitative research after recognizing the necessity for exploration when dealing with several unknown variables. Second, he chose grounded theory research since it best focuses on processes and supports the use of documents for data mining. Third, the researcher found criteria for selecting documents based on their credibility and suitability to the research; namely, the Clark questions for credibility and the Davies design for suitability in sample selection. For suitability in sample selection, the researcher chose extraction and interpretation of meaning within select blocks of text from relevant articles which aid in the exploration of the problem. Furthermore, these meanings must be capable of coding into the axial nodes of EMS, EMS capacity, cost, and mobility, or capable of addressing communications interference and jamming. Potential for jamming is not one of the four axial nodes, but it is a sub-research question. Finally, the researcher, committed to grounded theory, will use open coding, memoing, axial coding, and selective coding to develop a pliable logic model and emerging theory for increased OTH voice capabilities.

Due to the exploratory nature of the research, no standards for significance, beyond the evaluation methods for the documents, are applied to the logic model and emerging theory. There are three other shortfalls or challenges in conducting grounded theory research. First, some of the material in the literature review will already be based in theory. However, as the researcher forms an emerging substantive theory of his own, these preconceived theories cannot distract him.[19] Second, it is difficult to judge how much evidence is required to shape sufficiently the pliable theory model. Finally, the evidence must be from several different sources so that it is discriminate and without bias. The best way to overcome these challenges is to understand the outputs of the research. When the pliable logic model leads to an emerging theory with context, strategies, and consequences, the researcher will know he has achieved a desired end state.[20] This end state, a detailed explanation of the logic model and resulting emerging theory, is the subject of chapter 4.

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[1]Department of the Army, *Army SATCOM Architecture Book* (Washington, DC: Government Printing Office, August 2013), 5-2.

[2]Martin B. Davies, ed., *Doing a Successful Research Project: Using Qualitative or Quantitative Methods* (New York, NY: Palgrave Macmillian, 2007), 24.

[3]John W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*, ed. Lauren Habib (Thousand Oaks, CA: Sage Publications, 2013), 44.

[4]Ibid., 47.

[5]Ibid., 85.

[6]Sharan B. Merriam, ed., *Qualitative Research: A Guide to Design and Implementation* (San Francisco, CA: Jossey-Bass, 2009), 29.

[7]Ibid., 139.

[8]Davies, 181.

[9]Ibid., 182.

[10]Merriam, 139-140.

[11]Ibid., 151.

[12]Davies, 182-183.

[13]Creswell, 85.

[14]Andreas Bohm, "Theoretical Coding: Text Analysis in Grounded Theory," in *A Companion to Qualitative Research*, ed. Uwe Flick, Ernest Von Kardorff, and Ines Steinke (London, UK: Sage Publications, 2004), 271-273.

[15]Creswell, 89.

[16]Davies, 61-62.

[17]Ibid., 143-144.

[18]Uwe Flick, "Design and Process in Qualitative Research," in *A Companion to Qualitative Research*, ed. Uwe Flick, Ernest Von Kardorff, and Ines Steinke (London, UK: Sage Publications, 2004), 150-151.

[19]Creswell, 89.

[20]Ibid., 90.

CHAPTER 4

ANALYSIS

Introduction

As stated at the end of chapter 3, chapter 4 begins with a detailed description of the pliable logic model and an interpretation of the evidence within it. Secondly, chapter 4 - at the end - presents an emerging theory, resultant of the model, which can help focus the military's research and development efforts for OTH voice communications capabilities. In addition to these two outputs, chapter 4 helps explain the relationship of the pliable logic model to the research question and sub-research questions, and examines the impacts of unexpected discoveries and correlations on the research.

The Pliable Logic Model

Because the original pliable logic model is a progressive model on poster paper, with open, axial, and selective coding and memoing, as described in chapter 3, presenting the information from the model in a paper is challenging. To make the data more legible and present findings in a logical sequence, the researcher paired down the model into three tables: VHF/UHF, SHF, and EHF feasibility scores. The researcher picked this organization because the first layer of the model was three large columns representing those portions of the EMS. The researcher placed hardware and software applications, analyzed during the research, on the portions of the EMS they utilize.

In addition to seeing the applications in relation to both the EMS and one another, the researcher scored each application on a scale of one to ten along three of the four sub-categories - capacity, costs, and mobility - and, also, susceptibility to jamming. Note that these scores were not intended to be quantitative in nature. They are not the reported findings of an objective and quantitative experiment; however, during the process of inductive and deductive reasoning, the scores helped to track objectively notes for feasibility. Key to understanding both the individual sub-category scores and the system's total scores is knowing that, regardless of the category, 1 is least favorable and 10 is most favorable. For example, an inexpensive product receives a 10 for costs, not a 1, because costs are low. This system allows for the totals to make sense. A high total represents greater overall feasibility than a low one. Table 3 is the most congested table from the logic model, the VHF/UHF portion of the EMS.

Table 3. VHF/UHF Feasibility Scores

		Capacity	Costs	Mobility	Jamming	Totals	Notes
Frequency	2-2500 MHz (VHF&UHF)						
Products	PRC 155, 154A	8	4	9	4	25	Full replacement of legacy radios 100 billion
Frequency	30-88 MHz (VHF)						
Product	SINCGARS	3	9	8	3	23	LOS only, capabilities similar to BLOS up to 40 km dependent on antennae
Frequency	30-512 MHz (VHF%UHF)						
Products	AN/PAC-117, 148, PSC-5	5	4	9	3	21	Costs score low due to low volume in inventory large acquisitions needed
Frequency	1525-1646.5 MHz (UHF)						
Products	Commercial SAT phones	5	4	10	3	22	Costs score low due to low volume in inventory large acquisitions needed

		Capacity	Costs	Mobility	Jamming	Totals	Notes
Frequency	30-512 MHz (VHF&UHF)						Costs score low due to low volume in inventory large acquisitions needed
Products	CSEL, MBITR	3	4	10	3	20	
Frequency	225-450, 1350-1390, 1755-1850 MHz (VHF&UHF)						Radio waveform already developed, costs score high
Product	SRW	7	9	8	4	28	
Frequency	1000-2000 MHz (UHF)						Not an OTH voice product but in competition for UHF spectrum
Products	BFT-2	3	7	5	3	18	
Frequency	N/A						DAMA protocols can be developed in any band
Product	DAMA	6	9	8	3	26	
Frequency	300-3000 MHz (UHF)						7-10 billion to build 4 ground stations 5 satellites, replacing UFO
Product	MUOS	10	4	8	4	26	

Source: Created by author.

In table 3, established technologies and systems are highlighted in green. Emerging and future systems are amber. The products are organized from top to bottom by the frequencies they use, lowest to highest. The feasibility scores, all in the high teens and twenties - with very little variance - are not surprising. Remembering the FAS assessment of VHF/UHF communications from figure 1, one may logically assume that most applications using VHF/UHF carrier waves will be similar, along the lines of the sub-categories. The similarity is especially true for mobility and jamming, which have little variance in scores. The categories in which there are more variations are capacity - several emerging systems can improve upon capacity - and costs. Costs, for established technologies, like the SINCGARS, are characterized as sunk costs, and the score is high. For an emerging technology, however, an approximation of the estimated future costs is noted, and the score is low. Part of the reason the total scores are all similar, despite the capacity/cost variances, is there is an inverse relationship between capacity and costs. Simply stated, if an emerging technology scores high in capacity because of its efficiency, it will also cost more.

Lastly, by examining the table, one can see that the military VHF/UHF and UHF SATCOM portions of the EMS are saturated by many applications. This saturation creates congestion and contention for the band, which relates to the importance of research involving either alternate portions of the EMS or methods for increasing capacity and, thus, the volume of users for military OTH voice communications.

Relation to Research Questions VHF/UHF

To address how table 3's description and analysis relate to the research question - feasibility of increasing OTH voice communications capabilities in an immature theater to meet the demand for maneuver forces, both air and ground, by using portions of the electromagnetic spectrum that are not already utilized or maximized - the researcher will further explain three emerging technologies and one established technology from table 3, all of which have the potential to maximize the use of VHF/UHF bands. These technologies all scored the highest for feasibility and were designed to be paired together in an effort to increase efficiency and capacity. The four products are: MUOS, DAMA, SRW, and software programmable radios from the JTRS program like the PRC 155 and 154A.

Although MUOS and SRW do not work together directly, a software based radio can potentially utilize MUOS for UHF SATCOM and, when practicable and more efficient, transmit terrestrial UHF communications via SRW. In this sense, the cognitive, software programmable radios act like routers in computer systems. They will recognize the best and most efficient way to send voice and data signals without prejudice for a particular pathway or method. If the radio commits to SRW for terrestrial communications, the portions of UHF necessary to communicate with MUOS satellites is less congested. Additionally, DAMA, as explained in chapter 2, can help dynamically assign the priority of users when UHF SATCOM, via MUOS, is the only viable option for routing voice and data. The potential for pairing these systems is a tenfold increase in capacity and volume of users.

Unfortunately, this tenfold increase in capacity, brought primarily by the 3G like MUOS system and the receivers and transmitters which can use it, comes at a staggering cost: approximately 7-10 billion dollars for MUOS, 1 billion dollars a year upkeep, and anywhere from 25-100 billion dollars for a select amount of next generation software programmable radios to replace legacy radios. The grand total over the next ten years is no less than 45 billion dollars. This analysis relates to the second part of the research question - could these developments increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them?

Mobility is not an issue, as the software based radios are as mobile, if not more so, than most legacy radios. Secondly, costs, although high for this system, are not as big an issue as one would think. The military must replace legacy UHF SATCOM satellites due to service life issues, and is already committed to MUOS. It is halfway complete. Since the software based radios can be phased in and are interoperable with legacy radios, this researcher believes that the costs will not deter initiatives to bring this capability to the preponderance of maneuver forces below division.

The final part of the research question - how susceptible to communications interference and jamming are each of the alternatives - was addressed in table 3 and figure 1. There is no advantage when pairing MUOS, DAMA, SRW, and software programmable radios which affects the VHF/UHF bands susceptibility to jamming.

Before discussing the research impacts of unexpected discoveries and correlations for just the VHF/UHF portion of the logic model, below are tables 4 and 5, SHF and EHF, followed by their corresponding analysis and relation to the research question.

Table 4. SHF Feasibility Scores

		Capacity	Costs	Mobility	Jamming	Totals	Notes
Frequency	4.4-4.9 GHz (SHF)						Division only waveform discussed in chapter 2
Products	HNR	10	3	1	5	19	
Frequency	N/A						DAMA protocols can be developed in any band
Product	DAMA	6	9	8	3	26	
Frequency	12-18, 27-40 GHz (SHF&EHF)						EHF low end, CO level or above, immobile asset
Product	NCW	10	3	1	5	19	

Source: Created by author.

Table 5. EHF Feasibility Scores

		Capacity	Costs	Mobility	Jamming	Totals	Notes
Frequency	43-45 GHZ (EHF)						Division or above only asset for EHF communications with MILSTAR
Products	SMART-T	6	2	1	7	16	
Frequency	N/A						DAMA protocols can be developed in any band
Product	DAMA	6	9	8	3	26	
Frequency	43-45 GHZ (EHF)						Can be used at echelons lower than division
Product	PSC II SCAMP	6	4	2	7	19	

Source: Created by author.

Like table 3, there is no large variance in the total scores. This is due, in part, to the nature of products designed for these two portions of the EMS, as described in figure 1. Of note is that in these bands, there are significantly fewer products which affect OTH voice communications for maneuver forces below division. This is for three reasons. The first reason is that radar and remote sensing applications, either terrestrial or space based, dominate these bands. The second, as explained in chapter 2, is that the size of products necessary to receive or transmit SHF and EHF communications makes them less mobile. The third reason is that EHF frequencies are often blocked or scrambled by weather, atmosphere, or physical obstacles. The technology required to correct for this interference is extremely expensive, making EHF products cost twice that of their UHF alternatives.

Of the five SHF or EHF systems examined in these two tables, none represent a plausible solution to the OTH voice communications demands of the preponderance of maneuver forces below division. NCW is available at the company level, but is immobile, and the other four are immobile assets at division or above. However, higher echelons exchanging voice and data through these systems frees up space for UHF to be used at the tactical level. Therefore, one can view HNR and MILSTAR as ancillary support assets to the overall communications plan. This is advantageous since the capacity, especially for HNR in the SHF band, is extremely high.

Relation to Research Questions SHF and EHF

With regards to - using portions of the electromagnetic spectrum that are not already utilized - it is the researcher's opinion, after saturating the logic model using the methodology explained in chapter 3, that for maneuver forces below division there is no near future SHF or EHF alternative to either UHF terrestrial or UHF SATCOM. Furthermore, because of the atmospheric reflection and absorption properties of frequencies, which are outside the bands listed in table 1, there is no plausible alternative anywhere else along the EMS.

The amount of time, energy, and money necessary to develop such an alternative, just to free space in the UHF band in the hopes of becoming more capable, is prohibitive. This is especially true since there are so many emerging technologies designed to increase the efficiency and capacity of the UHF band. This point addresses the question - could these developments increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them? The answer for SHF and EHF, currently, is no. This is unfortunate, especially in the case of EHF, which rivals UHF along the sub-categories, with the exception of mobility. EHF mobility suffers, as products must be designed to counter the interference, inherit with EHF communications. Finally, with regards to - susceptibility to jamming - EHF, at least in the near term, would have an increased advantage over all other forms of carrier waves.

Unexpected Discoveries and Correlations

The most unexpected discovery that impacted this research was how quickly the outlook for alternate portions of the EMS became limited. With the scope of the research restricted to increasing capabilities for maneuver forces below division, there were many more documents concerning efficiency of UHF than there were documents explaining UHF alternatives. The EMS alternatives, for reasons explained, are often too costly and immobile. The second unexpected discovery was the high volume of emerging technologies and systems for increasing UHF efficiency. There are many to analyze and to choose. The pliable logic model was paramount to keeping the memoing and coding of these efficiency alternatives in a logical sequence. Finally, the correlation between the FAS characterization of bands, in figure 1, and the qualities of products, which researchers develop to use those bands, was very strong and helped guide the research.

Emerging Theory

The paired systems theory for increasing OTH voice communications capabilities in the VHF/UHF bands, which affect the preponderance of maneuver forces below division, is the result of analyzing the pliable logic model. Research and development efforts should place less emphasis on using other portions of the EMS to increase capabilities. Research should continue further developing the efficient use and increased capacity of the established military VHF/UHF bands. This emerging theory with recommendations for further research is the subject of the final chapter, Chapter 5, Conclusions and Recommendations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

As stated at the end of chapter 4, the paired systems theory for increasing OTH voice communications capabilities in the VHF/UHF bands, which affect the preponderance of maneuver forces below division, is the result of this qualitative research. The theory is that if the military pairs enough systems and technologies, which are designed to have interoperability with one another, then OTH voice communications capabilities will increase; the demands of maneuver forces will be met without requiring alternate portions of the EMS. The military should consider pairing the following systems: MUOS, DAMA, SRW, and cognitive, software programmable radios. Another candidate for systems pairing, from chapter 2, is “Tactical Private Satellite Networking” - control nodes at the operational level of war for the dynamic reallocation of frequency bands, both military and commercial.

The main discovery that emerged from interpreting the evidence in the pliable logic model was that using alternate portions of the EMS for OTH voice communications presents serious and nearly insurmountable issues. Extremely high costs and low mobility are the primary reasons that research in the area of alternate portions of the EMS for tactical communications is limited. Therefore, the answer to the research question - Is it feasible to increase OTH voice communications capabilities in an immature theater to meet the demand for maneuver forces, both air and ground, by using portions of the electromagnetic spectrum that are not already utilized or maximized? - is no and yes. Alternate portions of the EMS for OTH voice communications at the tactical level are not feasible, but increasing capabilities through the more efficient use of the established military VHF/UHF bands is feasible.

To answer the second part of the research question - could these developments increase the mobility and capacity of radio systems at a cost low enough for the preponderance of maneuver forces in the Army to acquire them? - mobility and capacity will increase by pairing the above mentioned systems, primarily MUOS and the radios that can use it. If the increase is tenfold, as the literature claims, then the ten year price tag of 45 to 120 billion dollars is acceptable. It is acceptable for two reasons. First, the military can phase in software programmable radios that have interoperability with both MUOS and legacy radios at a pace, and subsequent cost, of its choosing. Second, the MUOS capable satellites must replace older satellites which are near the end of their service. Therefore, one can view at least 20 billion dollars of the ten year price tag as committed spending.

Finally, the sub-research question - how susceptible to communications interference and jamming are each of the alternatives? - as explained in chapter 4, there is nothing about pairing the above mentioned systems that changes the jamming characteristics of VHF/UHF carrier waves. Susceptibility to jamming for VHF/UHF is much higher than any SHF or EHF form of communication.

The significance of these conclusions to the field of study - OTH voice communications at the tactical level of war - is that researchers can focus more attention on technologies that maximize the use of established bands and less attention on hardware that can receive and transmit other portions of the EMS. Technologies similar to cell phone networks or voice over internet protocols have a better chance of increasing capabilities in the near future than attempting to free up space in established bands by moving to another.

Recommendations

Based on the paired systems theory, any quantitative study developed to measure the performance of some combination of MUOS, DAMA, SRW, and cognitive, software programmable radios is recommended. In addition to this recommendation, research for the next generation of cognitive, software programmable radios should include tests for increasing the volume of frequencies from which a single system can choose. Since SHF products are so heavy, the researcher recommends developing a discrete radio waveform that jumps from VHF/UHF capabilities to EHF capabilities. Current EHF systems are also heavy; however, according to figure 1, there is the potential for increased mobility in EHF developments. Therefore, if future research pursues an alternate portion of the EMS, it should consider a discrete jump into the EHF band.

EHF may be the most plausible candidate for an alternate portion of the EMS; however, interference issues with EHF lead to high costs for producing the receiver/transmitters. A proposal for lowering these costs is to develop the discrete radio waveform so that only when the EHF signal is strong, due to clear weather and low mobility, will the radio even attempt to use it. Otherwise, the radio will use the VHF/UHF portions of the waveform. This has the potential to be cheaper than EHF radios which are designed with the hardware necessary to counteract interference and transmit exclusively on EHF. The advantage of discrete radio waveform is that when the radio is using EHF, the VHF/UHF bands will be less congested, and overall capabilities for OTH voice communications will increase.

In addition to quantitative research for paired systems and discrete waveforms, the researcher also recommends qualitative studies for further exploration of the topic along the four sub-categories. Beginning with portions of the EMS, the researcher recommends studying the impacts of software programmable radios on the current systems for joint frequency management. This paper investigated software programmable radios that would seamlessly change between various terrestrial waveforms and UHF SATCOM to increase efficiency and capabilities. However, current methods for procuring UHF SATCOM channels involve formal requests to the responsible service, for example the United States Navy. Qualitative research designed to produce an emerging theory for changing these formal and, arguably, more static systems to support newer technologies could help increase capabilities. Additionally, the research could be designed to determine if joint frequency management systems are hindrances to tactical OTH communications or if the problem is solely a function of capacity.

For the sub-categories of capacity and costs, the researcher recommends a qualitative study that examines the commercial portions of the VHF, UHF, SHF, and EHF bands. This study would address the feasibility of purchasing more bandwidth during periods of armed conflict. Acquiring additional frequencies has the potential to increase capabilities and be more cost effective than a commitment to new technologies. Many of the military's capabilities for OTH communications are already dependent on commercial assets; however, research that outlines how much the military currently purchases versus what is still available would be beneficial.

For an additional cost study, the researcher recommends examining the government's inability to pass budgets without dependence on continuation resolutions, and the long term impacts of these failed budgets on developing communications solutions. The JTRS program was conceived and resourced during a period of economic strength. After more than 10 years of development, its primary outputs are software programmable radios, waveforms with greater bandwidth, and increased interoperability. Given these accomplishments and an assumption that the government will not resolve its current budget issues, one can imagine long term progress in the field of military OTH voice communications as severely limited.

Finally, in the sub-category of mobility, the researcher recommends qualitative research that explores the difference in demands for OTH voice capabilities between combined arms maneuver and wide area security missions. Combined arms maneuver has the potential for a low demand, as the majority of maneuver assets will be in close proximity and satisfied with their LOS capabilities. Conversely, wide area security missions have smaller formations more dispersed and may require additional OTH communications. Furthermore, if OTH voice capabilities improve and subsequently increase the distances operational entities can separate and still remain effective, what are the impacts on the military's maneuver doctrine?

APPENDIX A

CLARK QUESTIONS FOR DETERMINING CREDIBILITY OF SOURCES AS LISTED BY MERRIAM

1. What is the history of the document?
2. How did it come into my hands?
3. What guarantee is there that it is what it pretends to be?
4. Is the document complete, as originally constructed?
5. Has it been tampered with or edited?
6. If the document is genuine, under what circumstances and for what purposes was it produced?
7. Who was/is the author?
8. What was he trying to accomplish? For whom was the document intended?
9. What were the maker's sources of information? Does the document represent an eyewitness account, a secondhand account, a reconstruction of an event long prior to the writing, an interpretation?
10. What was or is the maker's bias?
11. To what extent was the writer likely to want to tell the truth?
12. Do other documents exist that might shed additional light on the same story, event, project, program, context? If so, are they available, accessible? Who holds them?

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