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MONTEREY, CALIFORNIA

THESIS

FREQUENCY MAPPING FOR THE OPERATIONAL FREQUENCY MANAGER

by

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13. ABSTRACT (maximum 200 words)

The Department of Defense (DoD) has placed great emphasis on the networking and connectivity of forces over the last several years. Programs include the Global Information Grid (GIG), Force Net, and Net Centric Warfare to name a few. These programs emphasize and stress the warfighter's need to stay connected to their appropriate operational command and control structure during operations. The value of this connectivity is crucial to both the individual warfighter and the command structure as a force multiplier in modern warfare. One solution to this problem of connectivity is giving our operating forces the tools and knowledge of existing network infrastructure that details the information regarding the location, frequency and power out of existing nodes and spectrum analysis. The knowledge and ability of a trained Frequency Manager will allow our forces to use the full electromagnetic spectrum to maintain connectivity with their command structure.

The goal of this research is to provide a systematic approach to detecting existing network and telecommunication frequencies and mapping their positions. This information can then used by a Frequency Manager for planning operational test exercises and for operational forces that may operate in an area that is frequency saturated. In these situations and with the knowledge of existing frequencies these forces will be better able to manage, configure, and exploit existing network communications. The experimental study will encompass the collection, data processing, modeling and mapping of existing networks and their electromagnetic effects in both a rural and urban environment using the TNT 802.16 OFDM test bed in the San Francisco Bay area and Camp Roberts.

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ABSTRACT

The Department of Defense (DoD) has placed great emphasis on the networking and connectivity of forces over the last several years. Programs include the Global Information Grid (GIG), Force Net, and Net Centric Warfare to name a few. These programs emphasize and stress the warfighter's need to stay connected to their appropriate operational command and control structure during operations. The value of this connectivity is crucial to both the individual warfighter and the command structure as a force multiplier in modern warfare. One solution to this problem of connectivity is giving our operating forces the tools and knowledge of existing network infrastructure that details the information regarding the location, frequency and power out of existing nodes and spectrum analysis. The knowledge and ability of a trained Frequency Manager will allow our forces to use the full electromagnetic spectrum to maintain connectivity with their command structure.

The goal of this research is to provide a systematic approach to detecting existing network and telecommunication frequencies and mapping their positions. This information can then used by a Frequency Manager for planning operational test exercises and for operational forces that may operate in an area that is frequency saturated. In these situations and with the knowledge of existing frequencies these forces will be better able to manage, configure, and exploit existing network communications. The experimental study will encompass the collection, data processing, modeling and mapping of existing networks and their electromagnetic effects in both a rural and urban environment using the TNT 802.16 OFDM test bed in the San Francisco Bay area and Camp Roberts.

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LIST OF ACRONYMS

AMPS – Advanced Mobile Phone System

ARPANET – Advanced Research Project Agency Network

C2 – Command and Control

CDMA – Code Division Multiple Access

DARPA – Defense Advanced Research Projects Agency

DBM – Decibel Referenced to One Milliwatt

DSI – Decision Support Interface

ESRI – Environmental System Research Institute

FCC – Federal Communications Commission

FDMA – Frequency Division Multiple Access

FM – Frequency Manager

GHZ - Gigahertz

GIG – Global Information Grid

GPS – Global Positioning System

GWOT – Global War on Terrorism

HF – High Frequency

IMTS – Improved Mobile Telephone System

L2TP – Layer Two Tunnel Protocol

LBNL – Lawrence Berkeley National Lab

MHZ – Megahertz

MIO – Maritime Interdiction Operations

NOC – Network Operation Center

OFDM – Orthogonal Frequency Division Modulation

PCS – Personal Communication Services

PDA – Personal Data Assistant

RF – Radio Frequency

SAOFDM – Self Aligning Orthogonal Frequency Division Modulation

SOF – Special Operations Force

TCP – Transport Control Protocol

TDMA – Time Division Multiple Access

TNC – Terminal Node Controller

TNT- Tactical Network Topology

TOC - Tactical Operation Center

UAV - Unmanned Ariel Vehicle

UHF – Ultra-High Frequency

VPN – Virtual Private Network

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I. INTRODUCTION

A. BACKGROUND

Over the last several years Department of Defense (DoD) has placed great emphasis on the networking and connectivity of forces. These programs include the Global Information Grid (GIG), Force Net, and Net Centric Warfare to name a few. These programs emphasize and stress the warfighter's need to stay connected to their appropriate operational command and control structure during operations. The importance of this connectivity is important to both the individual warfighter and the command structure as well. Both of these entities through the use of network connectivity share intelligence, execute orders which result in real time decisions being made that may determine life or death as well as mission success.

Over the last several years, primarily since the attacks of 9/11, DoD has been shifting its operational focus from fighting the Cold War to fighting terrorism. The Global War On Terrorism (GWOT) has brought about many new challenges. Instead of organizing forces to fight state sponsored militaries on the field of battle we are faced with fighting non-state actors, non-uniformed individuals that operate in small groups or cells. This change from state sponsored to non-state sponsored enemies has changed the focus of the U.S. military's doctrine and tactics. This change has resulted in the U.S. military focusing on smaller units, quicker decision cycles and increasing operator awareness. This is being accomplished though the use of networks and the networking of these small operating units with their appropriate command structure.

Over the last several years military forces have found themselves operating military forces in support of GWOT in both remote locations and in urban environments. In remote locations the development of ad-hoc networks to support the operating forces can be resolved due to the open terrain and ability to maintain line of sight with various nodes for the connectivity and relay of data. However, in the urban environment this is not as easy due to the inability of forces to maintain line of sight because of the building structures that surround our operational forces. Another problem when working in an

urban environment is the interference from other systems that may be operating within this environment. These systems include radio, wireless networks, microwave, television and every other thing that operates in the electromagnetic spectrum that is close to the frequencies that our forces are attempting to utilize.

One solution to this problem is giving our operating forces a map of existing network infrastructure that details the information regarding the location, frequency and power out of existing network point - to - point antennas. In some urban areas this may not be possible therefore equipping our operating forces with the ability to quickly detect and map existing directional antenna's becomes critical to the success of or forces. This knowledge and ability will allow our forces to utilize these directional antenna's to maintain connectivity with their command structure.

B. STATEMENT OF PROBLEM

As networking and telecommunications technology develops and becomes more affordable various networking and telecommunications infrastructures are placed into operation in urban environments. These include wireless networks, cell phones, television and various other wireless communication devices. These wireless communication devices are placed in optimal locations to provide its customers continuous service. Therefore, when U.S. military units operate in these urban environments there is the potential for these forces to utilize this existing wireless network infrastructure.

The Global War on Terrorism has U.S. and coalition forces operating in these urban areas. However, these units often depend on line of sight communications and networking to link them to their Command and Control (C2) node. Often these units are required to operate in areas where they are unable to maintain these links with their C2 node do to the various interferences found while operating in an urban environment to include both electromagnetic interference as well as structural interference.

If these forces had the ability to know the location and use of existing networks and telecommunications infrastructures already in place they may be able to use these point - to - point antennas to regain connectivity with their C2 node.

The goal of this research is to provide a systematic approach to detecting existing network and telecommunication wireless point - to - point antennas and map these positions. This information will then be available in planning by forces that may operate in an area that will place them in a position to loose connectivity with their C2 node. In these situations and with the knowledge of existing wireless point - to - point antennas these units will be able to exploit the existing networks to maintain communications. However, this mapping of existing networks applies to all available wireless services in an urban environment. These include AM/FM radio antennas, microwave directional antennas, television and any wireless service operating in the area. The information needed to exploit these services will include antenna location, frequency being utilized, type of use, power out. With this information available to forces operating in an urban environment it will allow them to adapt to any mission they are presented with and be able to have an understanding of the electromagnetic spectrum that they may be able to exploit and utilize to maintain connectivity with their appropriate command and control node. This information will be vital to both the mission planning and mission adaptation for forces that operate in any urban environment.

C. ASSUMPTIONS

- A systematic approach will be conducted for this research, guided by Dr. Bordetsky and Eugene Bourakov.
- Testing will begin at Camp Roberts using a test plan developed by Lauro Luna and Scott Walker, approved by Dr. Bordetsky and Eugene Bourakov.
- Each follow on test will be accomplished in a similar manner and will be based on the findings of the previous test.
- All required equipment will be provided by the Naval Postgraduate School (NPS) through Dr. Bordetsky and Eugene Bourakov.
- All required equipment will be made available for scheduled tests.
- All funding will be provided through NPS.
- This thesis work will be used for future planning and thesis work and projects.
- Atmospherics will support testing.

- The thesis students under the direction and advice of thesis advisors will accomplish the interpretation of test results.
- The Camp Roberts facility and San Francisco Bay TNT OFDM networks will be used as the test bed for this thesis.

D. METHODOLOGY

This will be an experimental study, which will encompass the collection, data processing, modeling and mapping of electromagnetic effects in both a rural and urban environment using the TNT 802.16 OFDM test bed in the San Francisco Bay area and Camp Roberts.

The initial research will be conducted using the TNT 802.16 OFDM test bed in Camp Roberts. This test site was chosen for the initial research because it is for the most part a benign environment with minimal electromagnetic interference in the area. A specific test plan will be developed and used to conduct specific research to gain understanding of the measurement and electromagnetic effects on 802.16 point - to - point antennas.

Another very important issue that will be looked at is the Self Aligning Orthogonal Frequency Division Multiplexing (SAOFDM) antennas. These antennas self align through the use of a 900 MHz control frequency. In an urban environment this frequency may be congested and the control frequency may not operate. In this situation it is imperative for the correct operation of these antennas for them to be adaptive to the environment they are operating in. During the tests at Camp Roberts these antennas will be looked at with further testing in the San Francisco Bay are during the MIO TNT tests.

The results of the testing in Camp Roberts will be applied to the second portion of testing to take place on the San Francisco Bay area TNT 802.16 OFDM test bed. A similar test plan to Camp Roberts experimentation will be used, however the San Francisco Bay area is considered to be a more challenging environment to test in due to the amount of electromagnetic energy being used in an urban environment.

Upon completion of the San Francisco Bay area testing a specific area in San Francisco will be chosen for the third portion of testing. The chosen area will be scanned using a mobile spectrum analyzer and the location of detected point - to - point antennas will be documented and mapped. Throughout the experimentation process specific test plans will be developed and spectrum analyzers will be required to analyze the electromagnetic spectrum. The use of other equipment such as GPS receivers, specialized software and portable computer may be required.

This thesis will attempt to answer the following questions:

1. What Interferes With 802.16?

- What are the Electromagnetic Effects on 802.16 Network Connectivity?
- How Does Antenna Placement Compensate for Electromagnetic Effects on Network Connectivity?
- Can Electromagnetic Interference Be Compensated for Based on Adjusting Antenna Position and Or Adjusting Power Out?
- Can A Model Be Developed to Take Electromagnetic Inputs and Provide Optimal Antenna Placement to Support 802.16 Wireless Connectivity?
- Will This Provide a Framework to Support 802.16 Wireless Network Rapid Deployment?
- Can The Electromagnetic Effects Be Documented And Planned in 802.16 Network Development and Placement to Optimize Performance?

2. How can 802.16 Point - to - Point Antennas be Mapped?

- Can 802.16 Network Point - to - Point Antennas Be Detected, Located And Mapped?
- Can Other Wireless Services in the Area Be Mapped?
- How Does Multi Path Propagation Affect The Ability to Locate And Map Network Point - to - Point Antennas?

3. How Can 802.16 OFDM Be Exploited or Interfered with?

- Can the Knowledge of Location and the Mapping of Existing Network Point - to - Point Antennas Allow for Its Exploitation in an Urban Environment?

- How Easily Can 802.16 Be Jammed or Interfered with?
- Can the Side Lobes And Back Lobes of 802.16 OFDM Backbone Be Exploited?

This thesis research and testing will attempt to follow the below outlined structure:

4. Electromagnetic Effects on 802.16 Network Connectivity

- Testing Conducted on OFDM
- Affects Of Adjusting Antenna Placement or Power Out on Interference
- Testing Results
- Test Conclusions

5. The Mapping of 802.16 OFDM Point - to - Point Antennas

- Tests to Attempt to Detect And Map 802.16 Point - to - Point Antennas In An Urban Environment
- Ability to Map Other Networking Services in An Urban Environment
- How Did Multi-Path Propagation Affect Our Ability to Locate And Map 802.16 Point - to - Point Antennas in an Urban Environment?

6. The Exploitation and Ability to Interfere With 802.16 OFDM

- Once Point - to - Point Antennas Are Located Can They Be Exploited and How?
- Were We Able to Interfere with 802.16 OFDM Point - to - Point Antennas?
- Were Side Lobes and Back Lobes, Once Located, Able to Be Exploited and How?

E. ORGANIZATION OF THE THESIS

- Chapter I (Introduction): This will be the introduction to the thesis and will identify the methodology behind the research to be conducted. Chapter I will contain the first test plan to be executed at Camp Roberts using the TNT OFDM 802.16 test bed.
- Chapter II (Wireless Networking History): This chapter will discuss the history of 802.16 and the potential future of wireless technology.

- Chapter III (Mapping Research): This chapter will discuss current mapping examples and requirements needed for a Frequency Manager.
- Chapter IV (Camp Roberts Test Plan One and Results): This chapter will discuss the results and lessons learned from the tests conducted at Camp Roberts. From this information, the next test plan will be developed and executed in the San Francisco Bay area using the TNT test bed.
- Chapter V (Mapping Research Applied Based on Camp Roberts Experiments): This chapter will discuss and evaluate frequency management websites based on Camp Roberts Exercise.
- Chapter VI (San Francisco Bay Test Plan Two and Results): This chapter will discuss the results and lessons learned from the test conducted in the San Francisco Bay area. If required, the next test plan will be developed based on required testing as determined by the thesis students and advisors.
- Chapter VII (Mapping Research Applied Based on San Francisco Experiments): This chapter will discuss and evaluate frequency management websites based on San Francisco Exercise.
- Chapter VIII (Additional Mapping Considerations Focused on Livermore California Emergency Service Exercise):
- Chapter IX (Recommendations and Conclusion): This chapter will discuss the recommendations and conclusion made by the thesis students on any future work on this project.

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II. HISTORICAL OVERVIEW OF WIRELESS TECHNOLOGY

A. INTRODUCTION

The purpose of this chapter is to provide a history of wireless and or radio technologies. Both terms are interchangeable but often used in different contexts. Amazingly wireless technology is more than a century old. From Tesla's 1893 transmission of radio waves to today's Wi-MAX standard it has been the continuous push for new ideas in scientific research that little by little has given rise to the wireless technology industry. The following table provides a chronological description of key events in the wireless technology area from inception to today's cellular and computer technology.

B. HISTORICAL OVERVIEW

1883	First detection of radio waves by Heinrich Hertz. Created radio waves using a Spark Gap Transmitter.
1893	Nikolai Tesla transmits radio waves.
1896	Guglielmo M. Marconi develops the first wireless telegraph system.
1898	Tesla demonstrates a remote control boat. But because of the lack of knowledge about radio waves the crowd thinks Tesla is controlling the boat with his mind.
1906	Reginald Fessenden broadcast his voice over the North Atlantic using AM (Amplitude Modulation).
1913	Harold D. Arnold creates the first Amplifying Vacuum Tube October 18, 1913 used on long line telephone lines.
1915	First Trans Atlantic transmission conducted from Arlington Virginia to Paris France achieved by AT&T. The Eiffel Tower was used to hold the receiving antenna.
1927	First commercial radiotelephone service operated between Britain and the US
1931	FM (Frequency Modulation) developed by Edward H. Armstrong. FM is a key to transmission of digital information across RF.
1946	First car-based mobile telephone set up in St. Louis, using 'push-to-talk' technology
1948	Claude Shannon publishes two benchmark papers on Information Theory, containing the basis for data compression (source encoding) and error detection and correction (channel encoding)

1950	TD-2, the first terrestrial microwave telecommunication system, installed to support 2400 telephone circuits.
1950s	Late in the decade, several 'push-to-talk' mobile systems established in big cities for CB-radio, taxis, police, etc.
1950s	Late in the decade, the first paging access control equipment (PACE) paging systems established
1960s	Early in the decade, the Improved Mobile Telephone System (IMTS) developed with simultaneous transmit and receive, more channels, and greater power
1962	The first communication satellite, Telstar, launched into orbit
1964	The International Telecommunications Satellite Consortium (INTELSAT) established, and in 1965 launches the Early Bird geostationary satellite
1968	Defense Advanced Research Projects Agency – US (DARPA) selected BBN to develop the Advanced Research Projects Agency Network (ARPANET),the father of the modern Internet
1970s	Packet switching emerges as an efficient means of data communications, with the X.25 standard emerging late in the decade
1972	Ethernet is created. Transmission of 2.94 Mbits/s.
1977	The Advanced Mobile Phone System (AMPS), invented by Bell Labs, first installed in the US with geographic regions divided into 'cells' (i.e. cellular telephone)
1983	January 1, TCP/IP selected as the official protocol for the ARPANET, leading to rapid growth.
1992	One-millionth host connected to the Internet, with the size now approximately doubling every year
1993	Internet Protocol version 4 (IPv4) established for reliable transmission over the Internet in conjunction with the Transport Control Protocol (TCP).
1994–5	FCC licenses the Personal Communication Services (PCS) spectrum (1.7 to 2.3 GHz) for $7.7 billion.
1998	Ericsson, IBM, Intel, Nokia, and Toshiba announce they will join to develop Bluetooth for wireless data exchange between handheld computers or cellular phones and stationary computers.
1990s	Late in the decade, Virtual Private Networks (VPNs) based on the Layer 2 Tunneling Protocol (L2TP) and IPSEC security techniques become available.
1997	IEEE 802.11 is created, also known as Wi-Fi. The original specification had a maximum bandwidth of 2 Mbits/s.
2000	802.11(b)-based networks are in popular demand
2000-2001	Wired Equivalent Privacy (WEP) Security is broken. The search for greater security for 802.11(x)-based networks increases
2001	IEEE 802.16 standard is created also known as WiMax.
2003	IEEE 802.11g is added to the 802.11 standard allowing transmission up to 54 Mbits/s.

Table 1. History of Wireless Technology (From: [1]).

C. CELLULAR TECHNOLOGIES

Cellular technology has evolved tremendously over the past several decades. What individuals fail to remember is that cellular technology is simply a very sophisticated radio. Cellular technology can trace it roots to two very pioneering inventors Nokolai Tesla and Guglielimo Marconi. The first generation of cell phones was introduced using analog technology, which uses one seventh of the available duplex voice channels. The second generation of cell phones was introduced using digital technology which can carry three times the number of calls compared to using an analog system. There are a number of factors that have facilitated the spread the cellular technology but only a few that spawn the industry and those include transmission power, frequency reuse, and power consumption. Figure 1 depicts how frequencies reuse and power transmissions have been cultivated to improve cellular technology.

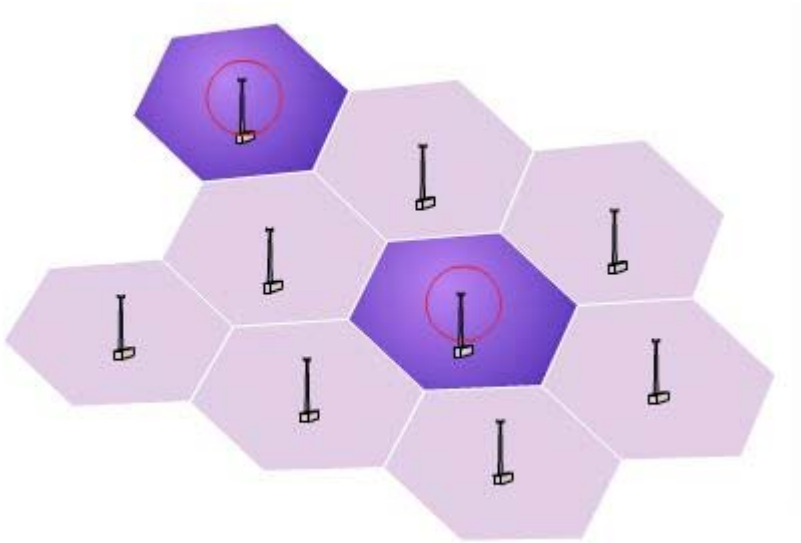


Figure 1. Frequency Reuse Cell Cluster (From: [2]).

The figure above illustrates when cell phones and base stations use low-power transmitters, the same frequencies can be reused in non-adjacent cells. Therefore, the two purple cells can reuse the same frequencies.

The second generation of cell phones uses three common technologies Frequency division multiple access (FDMA), Time division multiple access (TDMA), and Code division multiple access (CDMA). FDMA separates the spectrum into distinct voice channels by splitting it into uniform chunks of bandwidth. To better understand FDMA, think of radio stations: Each station sends its signal at a different frequency within the available band. FDMA is used mainly for analog transmission.

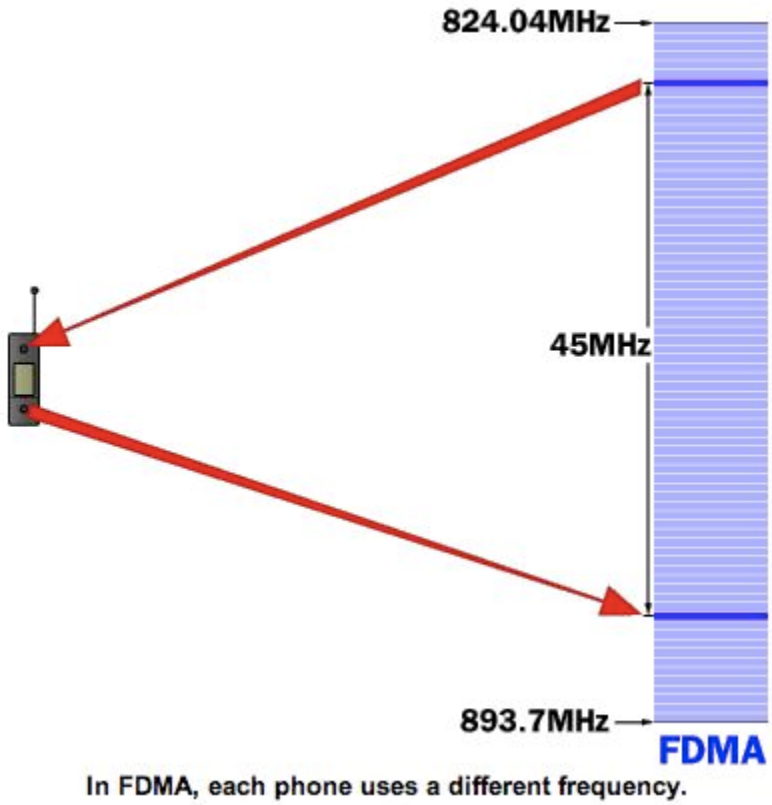


Figure 2. FDMA (From: [2]).

TDMA has three times the capacity of an analog system using the same number of channels. This is achievable because voice data has been converted to digital information and compressed so that it takes up significantly less transmission space.

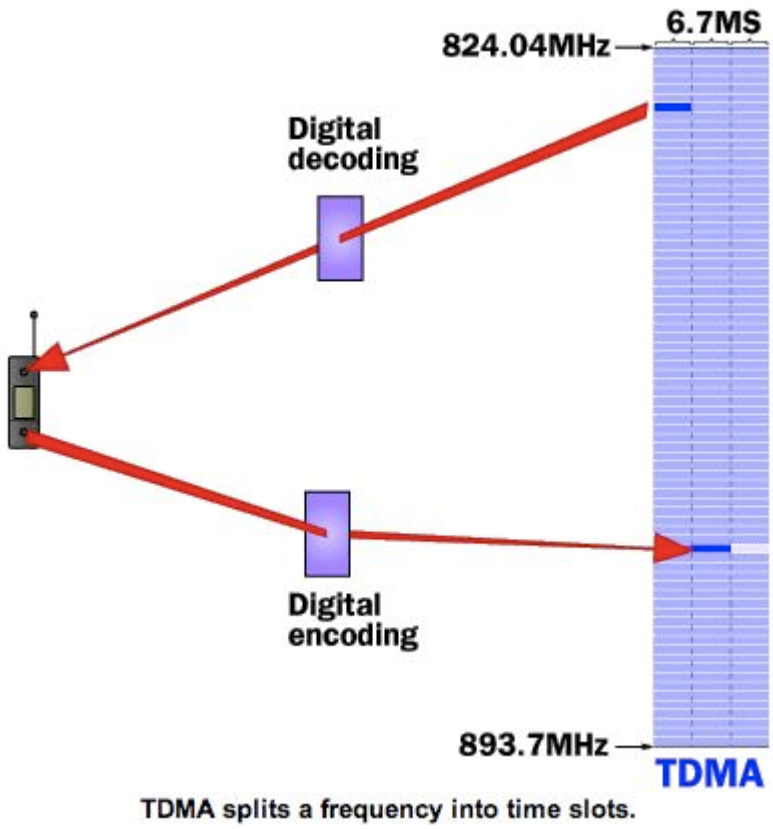


Figure 3. TDMA (From: [2]).

CDMA, after digitizing data, spreads it out over the entire available bandwidth. Multiple calls are overlaid on each other on the channel, with each assigned a unique sequence code. CDMA is a form of spread spectrum, which simply means that data is sent in small pieces over a number of the discrete frequencies available for use at any time in the specified range.

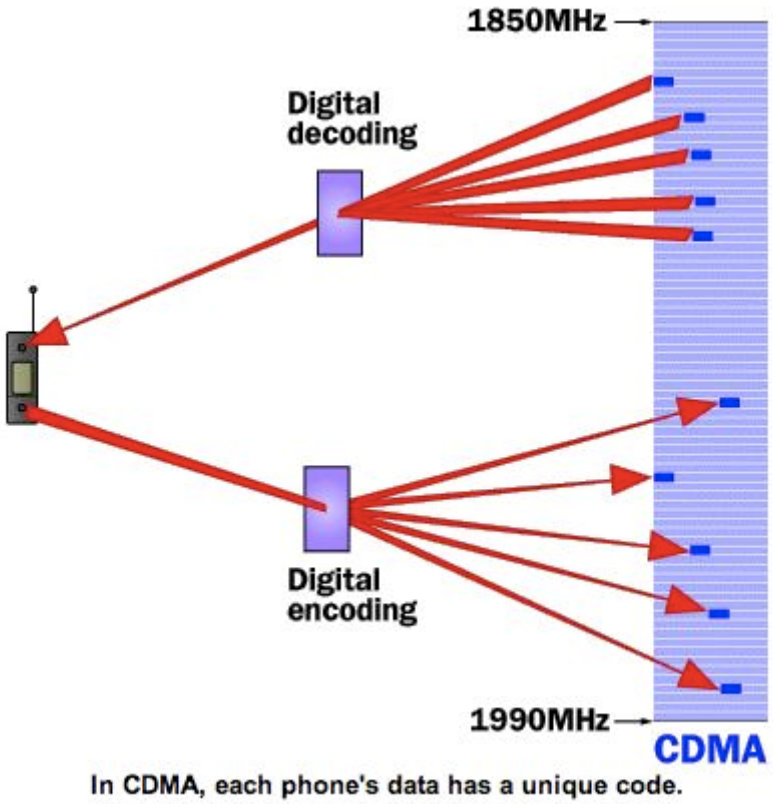


Figure 4. CDMA (From: [2]).

The third generation cellular technology has networks with the potential transfer speeds of up to 3 Mbps and more (about 15 seconds to download a 3-minute MP3 song). The third generation technology is planned for the true multimedia cell phone customer – also called smart phones. These include features of increased bandwidth and transfer rates to accommodate Web-based applications and phone-based audio and video files. Third generation phones are like mini-laptops that accommodate video conferencing, streaming video, and instantly downloading email messages with attachments.

D. PACKET DATA

Everything on the Internet revolves and involves packets. What is a packet? A packet is information broken into smaller parts of a certain size. Each packet carries the information that will help it get to its destination that includes the sender's IP address, the receiver's IP address, the number that tells the network how many packets this e-mail

message has been broken into and the number of this specific packet. Each packet can contain from 1000 to 1500 bytes of information that may contain the body of the message. In order to make the network more efficient each packet is sent out to its destination by the best available route depending on the protocol used. This also allows the network to balance the transmission load and to by pass any problems in the network. A packet carries the data in a particular protocol that the Internet uses. Networks that transmit data in small packets are called packet switching networks.

Packet Data technology was developed in the mid-1960s and was put into functional application in ARPANET. The ALOHANET was initiated in 1970 and established at the University of Hawaii as the first large-scale packet radio project.

Packet has three great advantages over other digital modes: transparency, error correction, and automatic control. The operation of a packet station is transparent to the end user. Connect to the other station, type in your message, and it is sent automatically. The Terminal Node Controller (TNC) automatically divides the message into packets, keys the transmitter, and then sends the packets. While receiving packets, the TNC automatically decodes, checks for errors, and displays the received messages. Packet radio provides error-free communications due to the built-in error detection schemes. If a packet is received, it is checked for errors and will be displayed only if it is correct. In addition, any packet TNC can be used as a packet relay station, sometimes called a digipeater. This allows for greater range by stringing several packet stations together. Another advantage of packet over other modes is the ability for many users to be able to use the same frequency channel simultaneously. Most packets are split into three parts the header, the body, and the trailer. As explained above the header contains instructions about the data carried by the packet. The body or payload has the data the packet is actually delivering. The trailer or footer contains bits that tell the receiving device it has reached the end of the packet and an error correction bit.

Packet - E-mail Example		
Header	Sender's IP address Receiver's IP address Protocol Packet number	96 bits
Payload	Data	896 bits
Trailer	Data to show end of packet Error correction	32 bits

Figure 5. Packet Description (From: [2]).

E. CONCLUSION

While the wireless industry may have a long history of scientific development it is still in its infancy when it comes to its potential. As Isaac Newton once wrote “If I have seen further it is by standing on ye shoulders of Giants,” in a famous letter of his to Robert Hooke. All those who press forward on new wireless possibilities do so on the shoulders of Tesla, Marconi and many others that are unnamed. The technology included above, cellular technology and packet data are key components of any future wireless technologies. The research and testing conducted for this thesis is but a small part of a growing need for frequency management in any testing or operational environment.

III. MAPPING RESEARCH

A. BACKGROUND

Upon doing initial research regarding available mapping programs available on the Internet it was discovered there is a wide range of programs available for different consumers. However, upon review of a couple of programs and looking through pictorials on various company websites it seemed that none of them quite met the needs of the thesis research. It then became obvious that specific requirements had not been defined. Therefore, the next step was to think of the user requirements as well as the operating environment the program would be used in.

B. VISION

An example scenario explaining how the program would be used will help to envision the operating environment and the requirements outlined below.

A Special Operations Force (SOF) is deploying on a specific mission in an urban environment. The specific type of mission is not important but it is essential for this group to maintain communications with their command node wherever in the world it is located. These communications can be voice or data (e-mails, pictures, etc.). During the mission they lose primary communications due to casualty, environmental effects, system operating range or for whatever reason. This program would help operating forces regain communications with their command node by using the existing infrastructure within the urban environment they are working in.

This program would allow planners as well as operators the ability to look at a detailed map of their operating environment to include building types, streets and GPS inputs mapping where the team was located. There would be various overlays, depending on the equipment being used by the team that would give detailed data on the location

and configuration of the telecommunication infrastructure (antennas, use, frequency range, etc.). From these overlays, the operating forces are able to take advantage of this information to re-establish communications with their command node.

C. OPERATING ENVIRONMENT

The operating environment envisioned for the mapping program would be two fold. It would support operational planners as well as the operator in the field. It will be important that the program be able to transition from the planner to the operator with all planning notes saved and key infrastructure points highlighted for the operator. The program must be simplistic and flexible to use allowing both planners and operators to access overlays, tailor the display and have the ability to quickly query various databases of information.

D. REQUIREMENTS

The program requirements are broken into planner requirements and operator requirements. Some of the requirements will overlap to show that commonality of requirements does exist and also allow ease in requirement prioritization if required.

1. Planner

- Must operate on portable computers (Lap Top).
- Positional data of telecommunication infrastructure (Antennas) in latitude and longitude.
- Operating frequencies.
- Usage of antennas.
- Power out.
- Type of antenna (Omni, directional, OFDM)
- Have ability to make notes as attachments to various overlays.
- Strategic understanding of services available.

2. Operator

- Must operate on portable computers (PDA).
- Positional data of telecommunication infrastructure (Antennas) in latitude and longitude that can be converted to a bearing and range.
- Operating frequencies.
- Usage of antennas.
- Power out.
- Type of antenna (Omni, directional, OFDM)
- Have ability to display notes made by planners.
- Knowledge of specific services available in the area of operations that could be tied into.

3. Mapping Programs Reviewed

- FCC.ORG

The first site reviewed was the Federal Communication Commission home page at www.fcc.org. Once in the site and with a little navigation wireless communications was discovered under the bureau section. Then navigating to the geographic information systems link where downloads were accessible and offered by the FCC [3].

The mapping program download offered by the FCC is ArcExplorer from ESRI (http://www.esri.com/software/ArcExplorer/download.html). The software can be downloaded once an individual is registered with ESRI. The file that was downloaded and saved was aejee_231_windows_zip. Once the ArcExplorer software was installed one must return FCC web page to access available licensing data base extracts that included market boundaries and US boarders and features.

The following downloads were available from the FCC:

- AM
  - Data Source: FCC Media Bureau
- Antenna Structure Registration
  - Data Source: FCC Wireless Telecommunications Bureau

- Cellular
    - Data Source: FCC Wireless Telecommunications Bureau
- Cellular Service Area Boundaries
    - Data Source: FCC Wireless Telecommunications Bureau
- FM
    - Data Source: FCC Media Bureau
- Land Mobile – Commercial
    - Data Source: FCC Wireless Telecommunications Bureau
- Land Mobile – Private
    - Data Source: FCC Wireless Telecommunications Bureau
- Land Mobile – Broadcast
    - Data Source: FCC Wireless Telecommunications Bureau
- MDS/ITFS
    - Data Source: FCC Wireless Telecommunications Bureau
- Microwave
    - Data Source: FCC Wireless Telecommunications Bureau
- Paging
    - Data Source: FCC Wireless Telecommunications Bureau
- TV – NTSC
    - Data Source: FCC Media Bureau
- TV – Digital
    - Data Source: FCC Media Bureau
- TV – Contours NTSC and Digital
    - Data Source: FCC Media Bureau

E. EXAMPLES

The following are examples of the displays provided by using ArcExplorer and downloading the available data from the FCC website as described above.

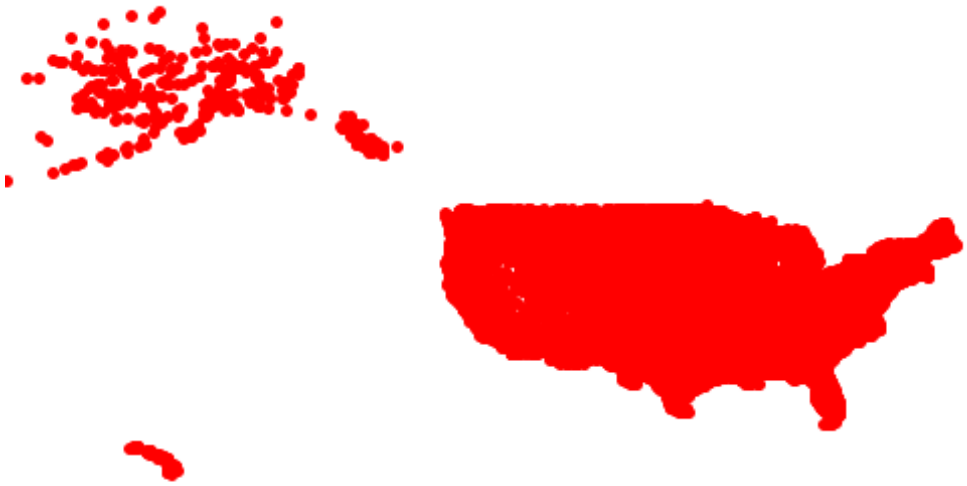


Figure 6. Small-scale view of the city and town information.

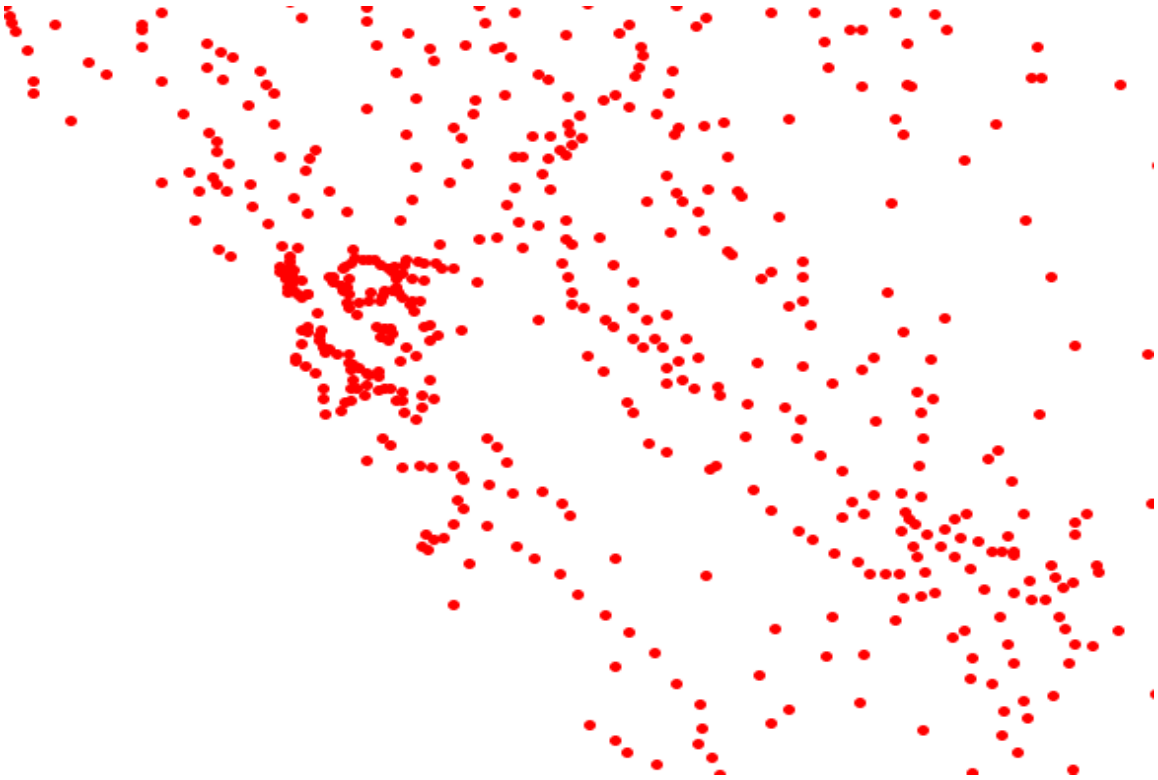


Figure 7. Large-scale view of the city and town representation of the San Francisco Bay Area.

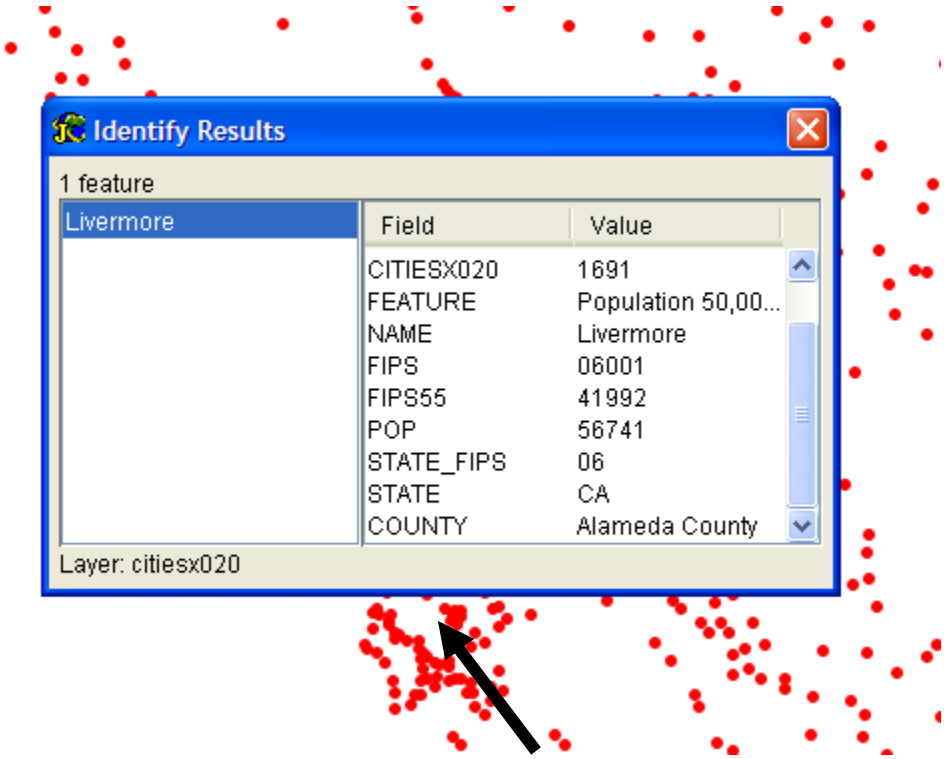


Figure 8. Displays amplifying data on a selected town or city. In the example above, Livermore is being displayed.

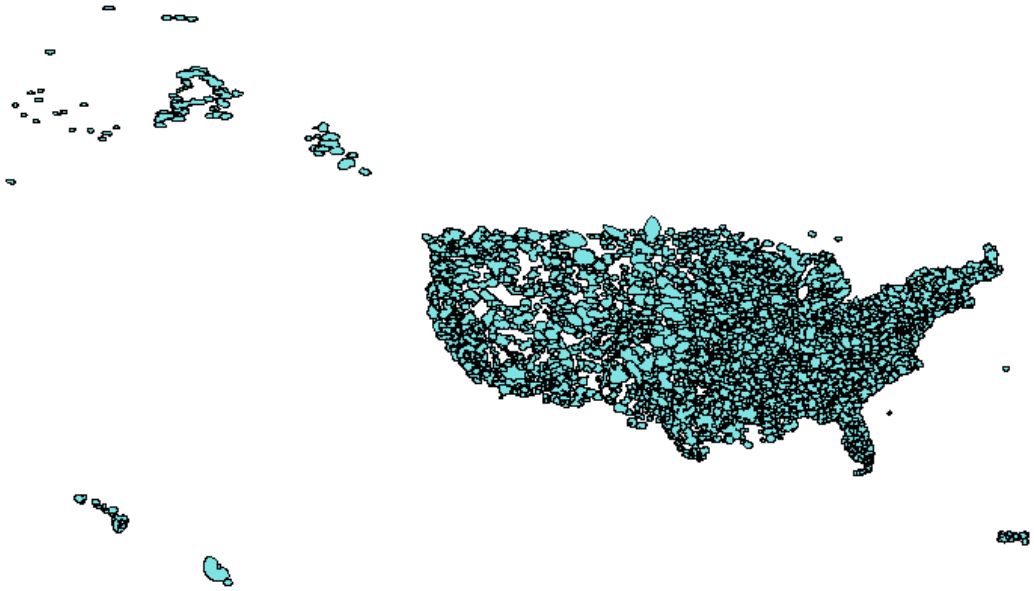


Figure 9. Small-scale view of the cellular aggregates by call sign.

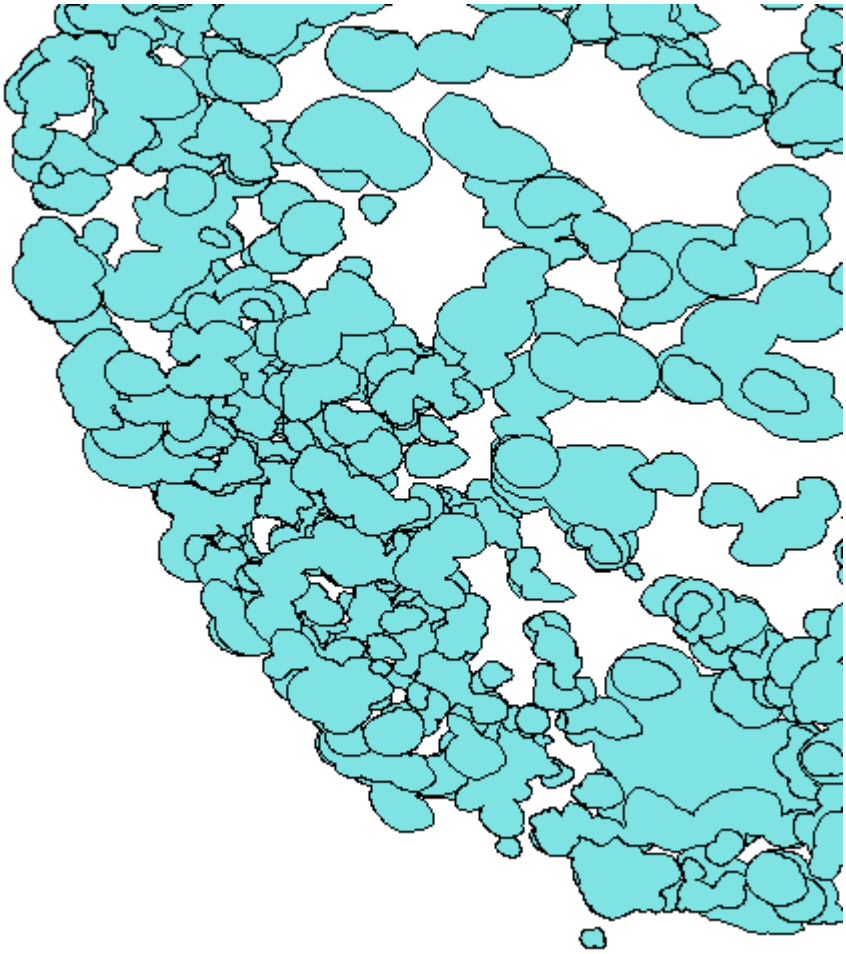


Figure 10. Larger-scale view of the cellular aggregates by call sign.

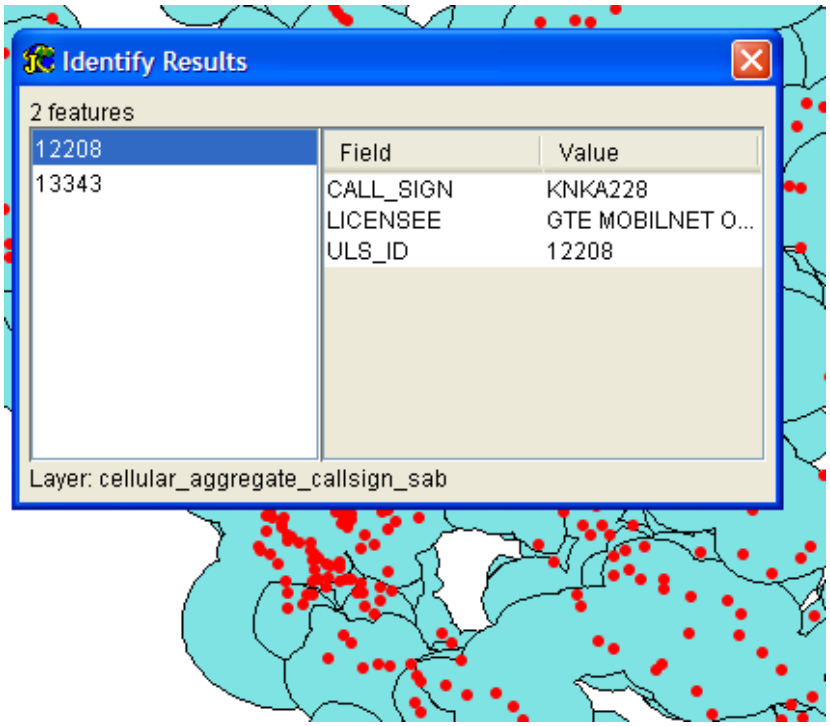


Figure 11. Information provided by the cellular aggregates by call sign overlaid with cities, 12208 is one of two cell licensees in Livermore.

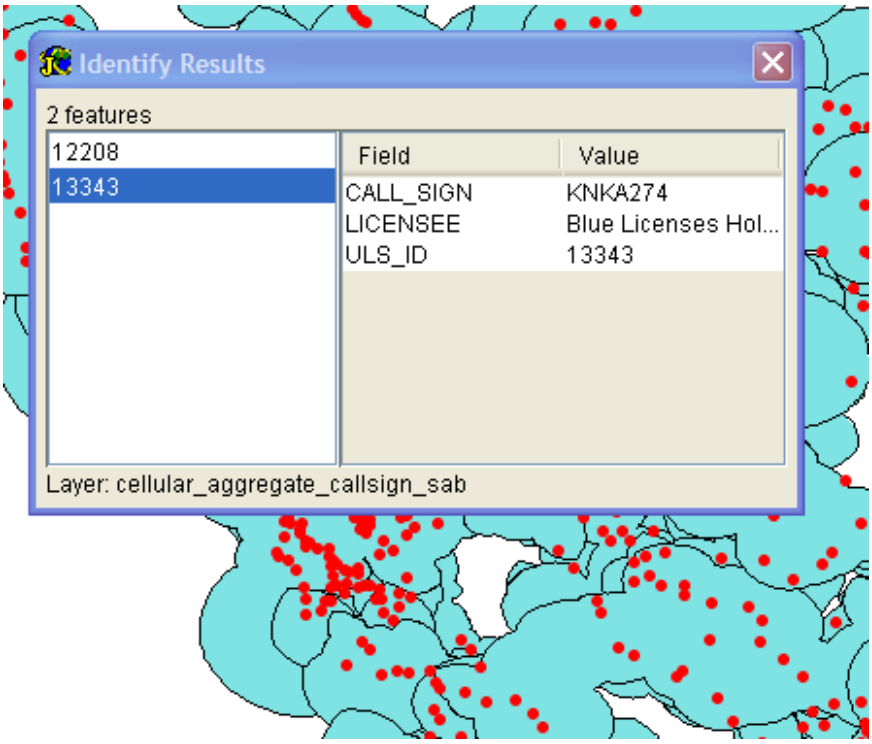


Figure 12. Information provided by the cellular aggregates by call sign overlaid with cities, 13343 is one of two cell licensees in Livermore.

Figure 13. Small-scale view of the antenna registration.

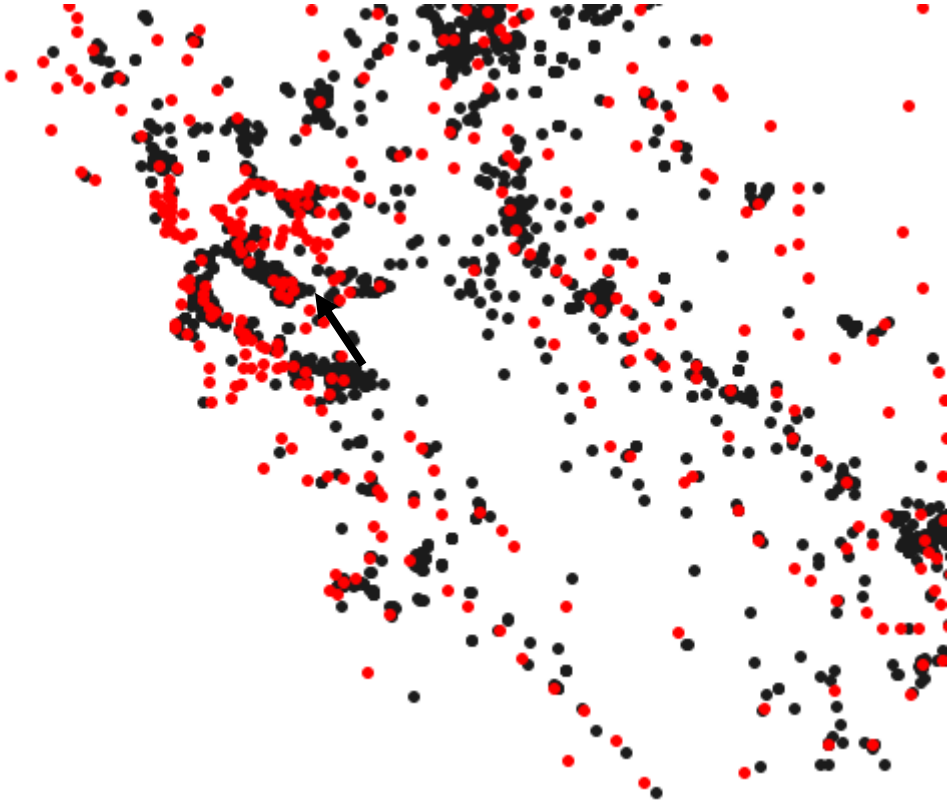


Figure 14. Larger scale view of the antenna registration overlaid with the city data.

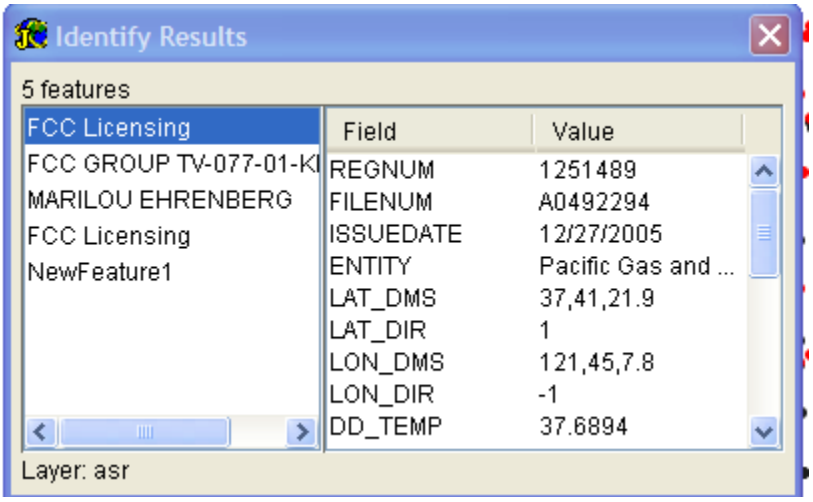


Figure 15. Identity results are the results of a single query of antenna registration data in the Livermore area.

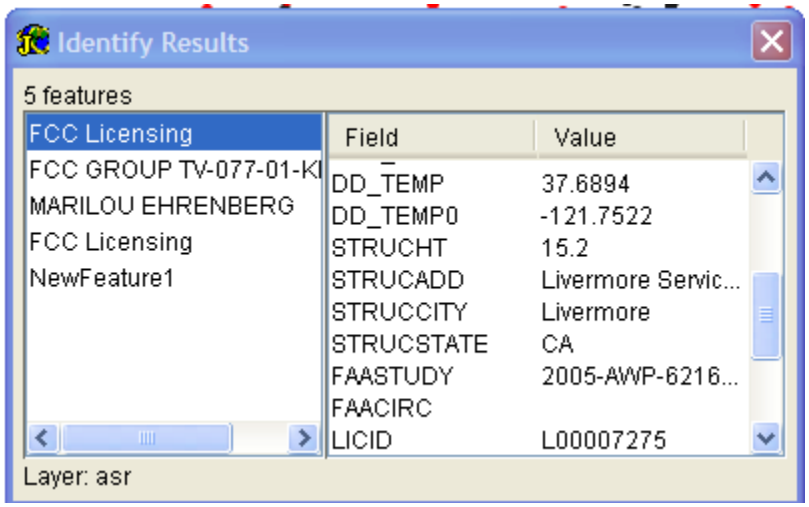


Figure 16. Identity results are the results of a single query of antenna registration data in the Livermore area.

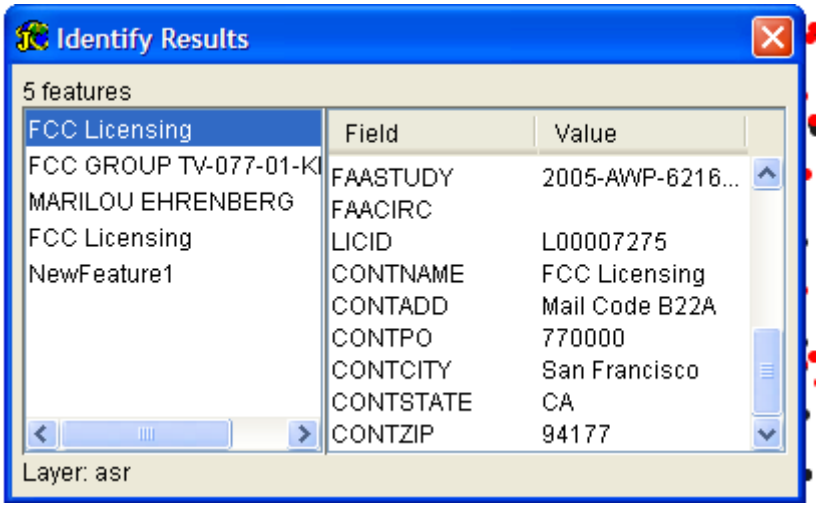


Figure 17. Identity results are the results of a single query of antenna registration data in the Livermore area.

Figure 18. Small-scale view of airports.

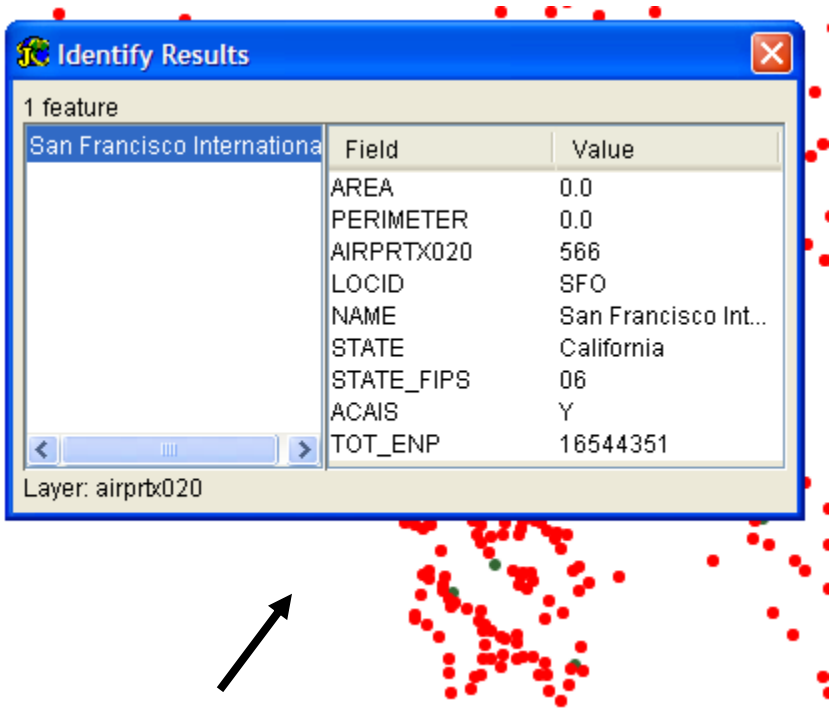


Figure 19. Displays the city overlays along with airports. San Francisco International Airport is displayed.

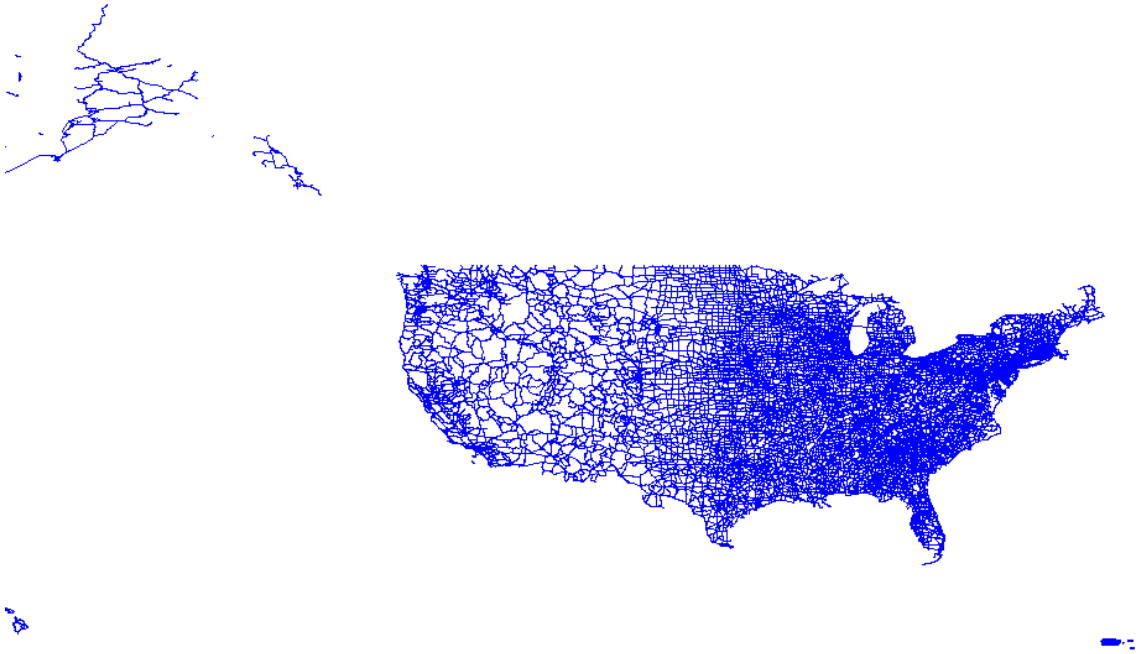


Figure 20. Small-scale view of the roads.

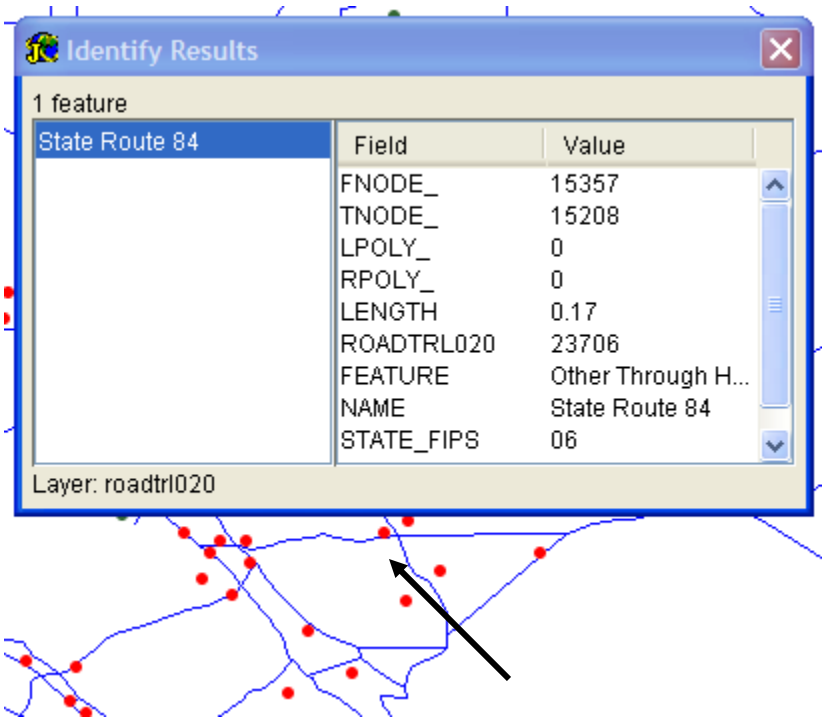


Figure 21. Displays State Route 84 in the vicinity of Livermore.

Evaluation: The above figures made available by using the tools at the FCC website display a sample of the mapping information available there. The good thing about the data provided is the overview of licensed FCC antennas along with a variety of information. However, there was no data dictionary available that broke down the meaning of all the fields of information displayed when information was queried.

For the mapping that is being researched for this thesis it is determined that the information from the FCC may be able to be used in conjunction with another mapping program or may be useful if used by another application that can access and manipulate the FCC's data. The FCC gives location of licensed services that could potentially be incorporated into overlays for operations planning and execution.

K5EHX Repeater Mapping Web Site - http://k5ehx.net/repeaters/qrepeater.php is a website that is used by amateur radio operators to document and update the location of repeater sites that can be used by radio operators. The main page uses Google earth for

the mapping and allows views to include map (default), satellite and hybrid. It allows the user to search for repeaters based on call sign, geography, tag and state. The home page is shown below [5].

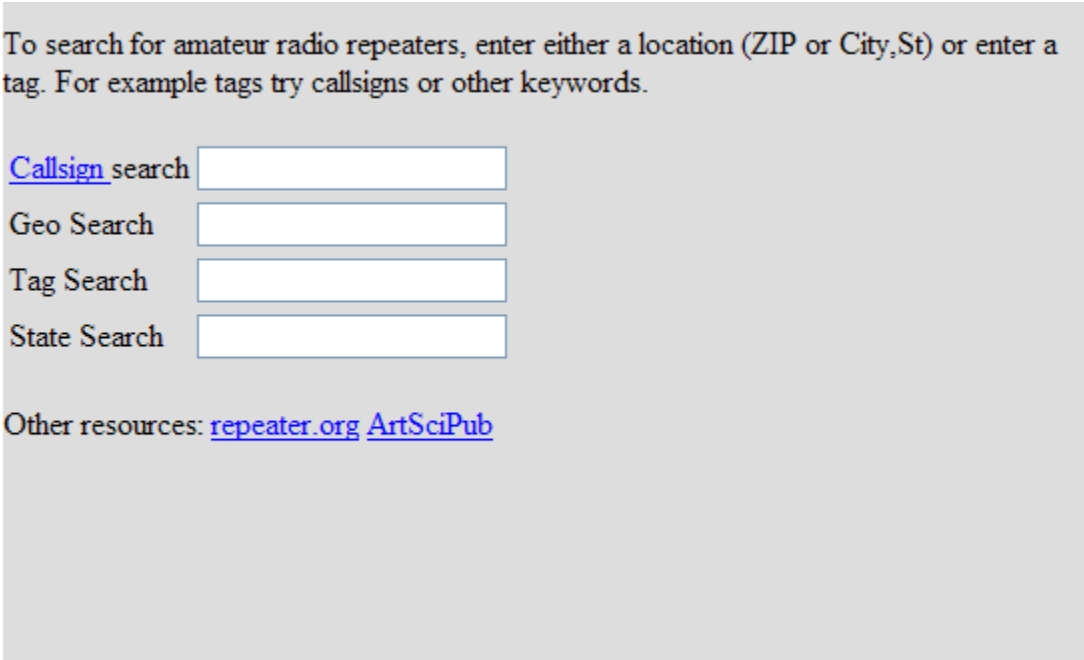


Figure 22. Query Page to Locate Registered Repeaters (From: [5]).

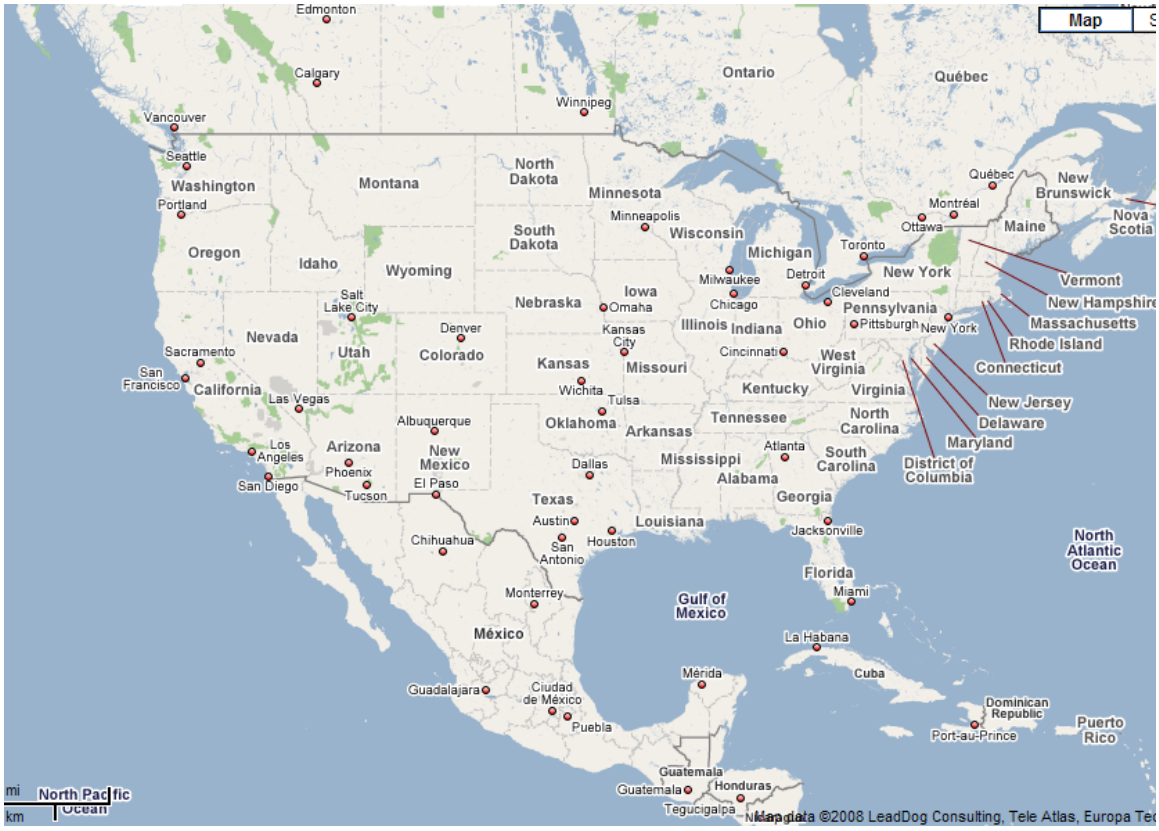


Figure 23. Small Scale Map Used on Repeater Locator Page (From: [5]).

Showing amateur radio repeaters with coverage of 37.682032, -121.768363. *(Not what you expected?)*

*Query returns 68 repeaters.**

(Only 30 drawn on map, for all use download.)

Repeater #530 edit zoom (1 of 68)

Freq	442.2500	Trustee	KD6QDW
Desc		Club	
Shift		OfstFrq	5
PL	103.5	DCS	
Range	20	Last Upd	0000-00-00 00:00:00
Lat	37.681944	Long	-121.766944
City	Livermore	State	CA
ZIP		Dist	0.08 mi

Notes:

Tags: KD6QDW Livermore CA 70cm

Nearby: 1 10 20 50

Figure 24. Repeater Location and Identity Data in the Vicinity of Livermore (From: [5]).

Figure 25. Range Rings that Provides Ranging Information at a Glance Using Google Earth (From: [5]).

Repeater #530 edit zoom (1 of 5)

Freq	442.2500	Trustee	KD6QDW
Desc		Club	
Shift		OfstFrq	5
PL	103.5	DCS	
Range	20	Last Upd	0000-00-00 00:00:00
Lat	37.681944	Long	-121.766944
City	Livermore	State	CA
ZIP		Dist	0 mi

Notes:

Tags: KD6QDW Livermore CA 70cm

Nearby: 1 10 20 50

Figure 26. Sample of Repeater Data Provided (From: [5]).

Repeater #7389 edit zoom (2 of 5)

Freq	145.3500	Trustee	AB6CR
Desc		Club	
Shift		OfstFrq	-0.6
PL	100	DCS	
Range	30	Last Upd	0000-00-00 00:00:00
Lat	37.681944	Long	-121.766944
City	Livermore	State	CA
ZIP		Dist	0 mi

Notes:

Tags: AB6CR Livermore CA 2m

Nearby: 1 10 20 50

Figure 27. Sample of Repeater Data Provided (From: [5]).

Repeater #7391 edit zoom (4 of 5)

Freq	146.7750	Trustee	WA6YHJ
Desc		Club	
Shift		OfstFrq	-0.6
PL	100	DCS	
Range	30	Last Upd	0000-00-00 00:00:00
Lat	37.681944	Long	-121.766944
City	Livermore	State	CA
ZIP		Dist	0 mi

Notes:

Tags: WA6YHJ Livermore CA 2m

Nearby: 1 10 20 50

Figure 28. Sample of Repeater Data Provided (From: [5]).

When the city of Livermore is tagged the repeater selection was reduced to 5 as displayed in Figure 29. This site provides specifically frequency and location information, which is very useful to the frequency manager. Then by selecting Trustee KD6QDW the Google Earth display provides ranging information on that specific repeater as shown in Figure 30.

Repeater #7392 edit zoom (5 of 5)

Freq	147.1200	Trustee	AD6KV
Desc		Club	
Shift		OfstFrq	0.6
PL	100	DCS	
Range	30	Last Upd	0000-00-00 00:00:00
Lat	37.681944	Long	-121.766944
City	Livermore	State	CA
ZIP		Dist	0 mi

Notes:

Tags: AD6KV Livermore CA 2m

Nearby: 1 10 20 50

Figure 29. Sample of Repeater Data Provided (From: [5]).

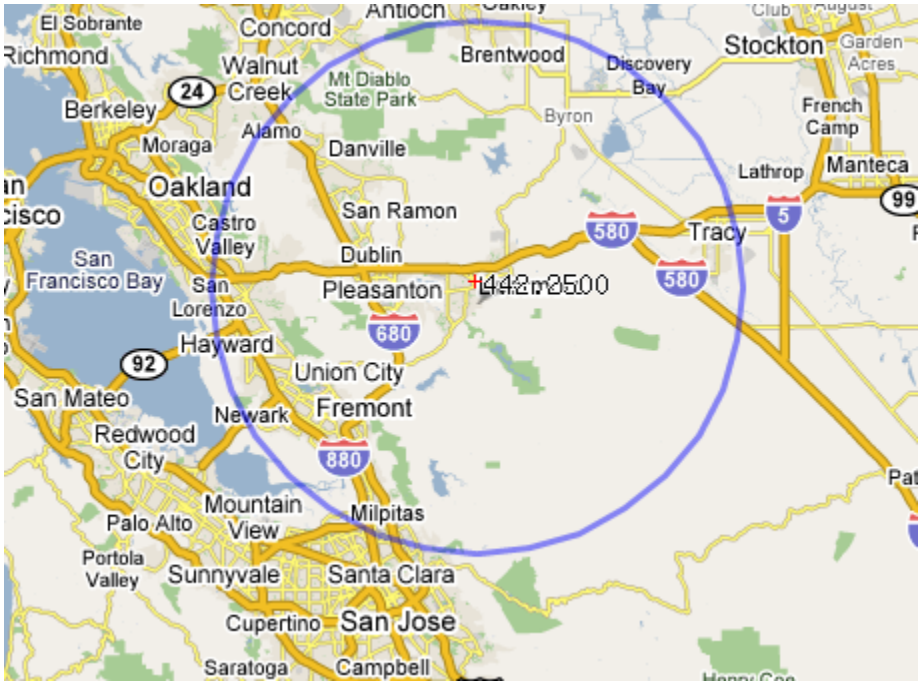


Figure 30. Google Earth Display of Selected Repeater Site (From: [5]).

F. FIRST EVALUATION

This website offers similar information as the FCC website, except on repeater antennas utilized by radio operators vice FCC licensed antennas. This site takes advantage of Google Earth and is much more used friendly than the FCC website. Also, the FCC website only posts FCC licensed antennas where this site provides a collaborative tool for radio operators to post the repeaters that they operate or that operate in their area along with pertinent amplifying information to include frequency and positional information.

- NPS Frequency Management Web Site:

  http://cenetix.nps.edu/FrqManager/ (or http://192.168.99.155/FrqManager/ to run it from within the TNT network). The NPS Frequency Management Web Site is included in the thesis as a developing and evolving tool in conjunction with the thesis research. A review and critique of this site will be conducted to improve the thesis research product as a function of operational frequency management.

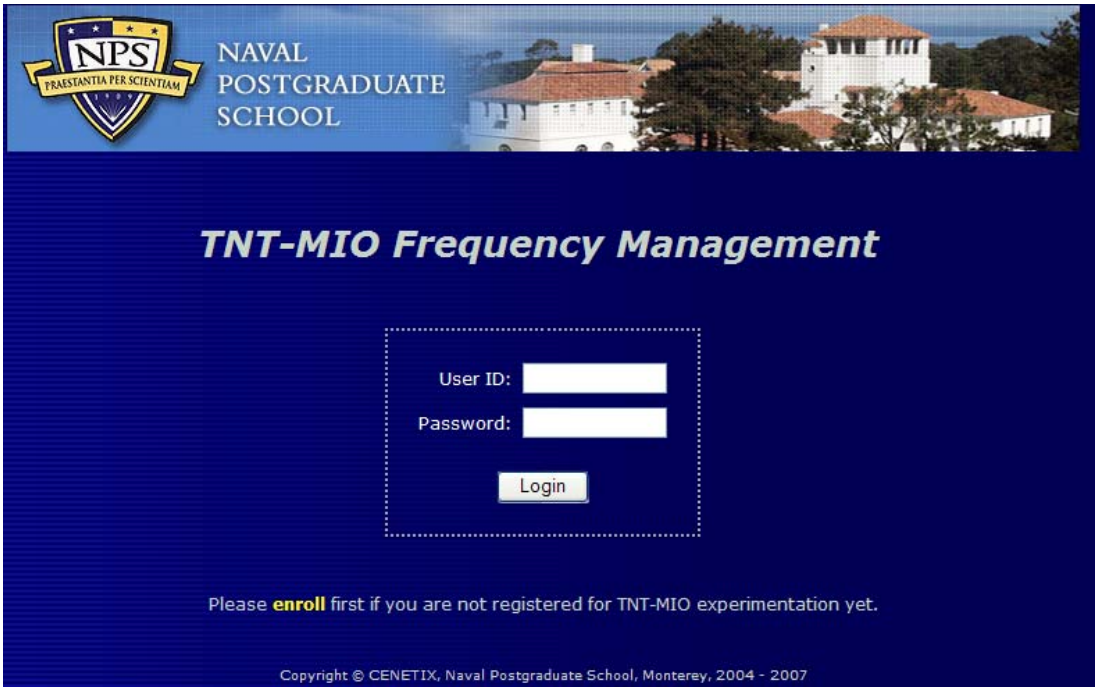


Figure 31. First page the user will see when the individual navigates to this web site. All users of this web site must be a registered (From: [4]).

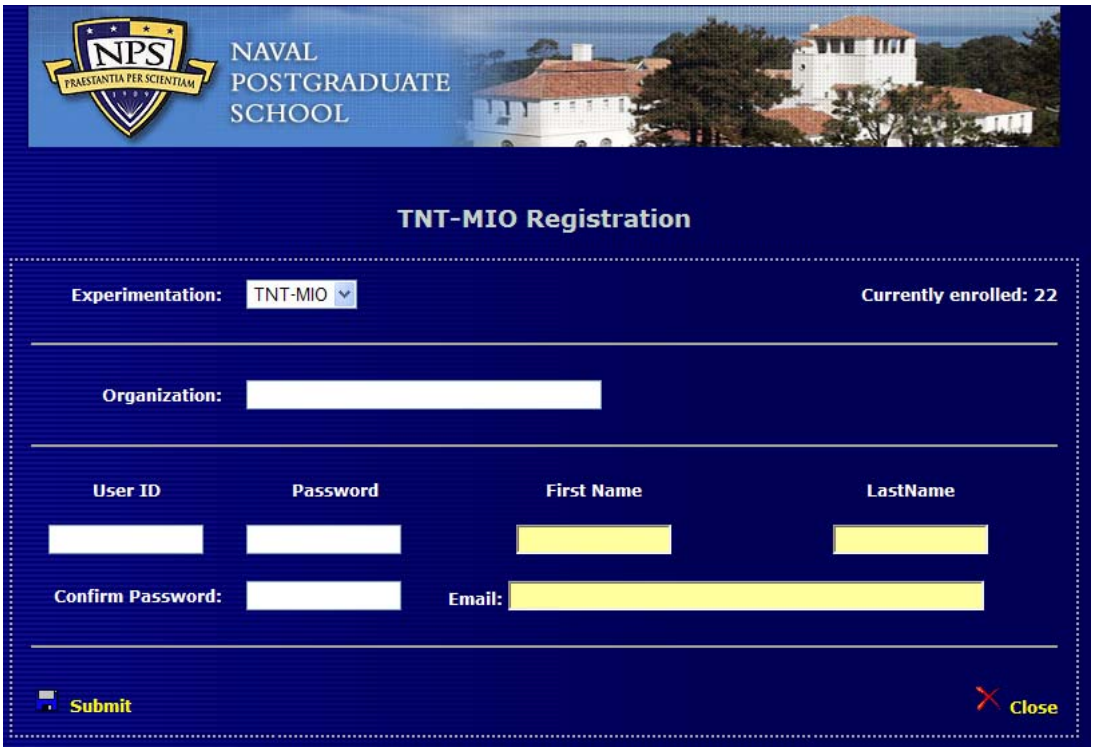


Figure 32. The registration page to log set up an account for a specific experiment. The rest of the required information is self-explanatory (From: [4]).

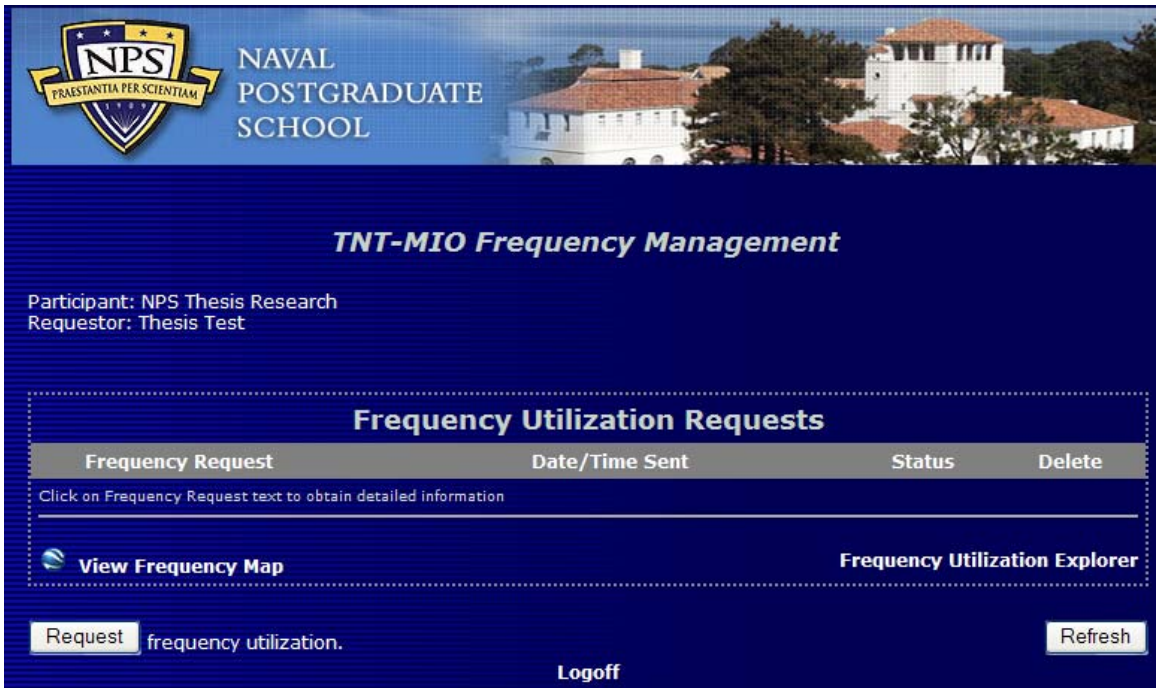


Figure 33. Allows the user to request frequency utilization for the equipment the user is requesting to operate during the TNT experimentation (From: [4]).

Figure 34 allows the user to input specifics about the equipments operational frequencies for the upcoming experimentation. The technology tab allows the user to select 802.11 (a, b, g), 802.16 OFDM, UHF, HF, Mesh or Other. The Customizable Frequency tab and Adjustable Power tabs allow the user to select Yes or No. The Usage tab is for the user to select either On-Demand or Uninterruptible. The Antenna Type allows the user to select Omni, Sector or Directional. The rest of the fields are self-explanatory and this page allows the user to describe briefly the purpose for the frequency being requested.

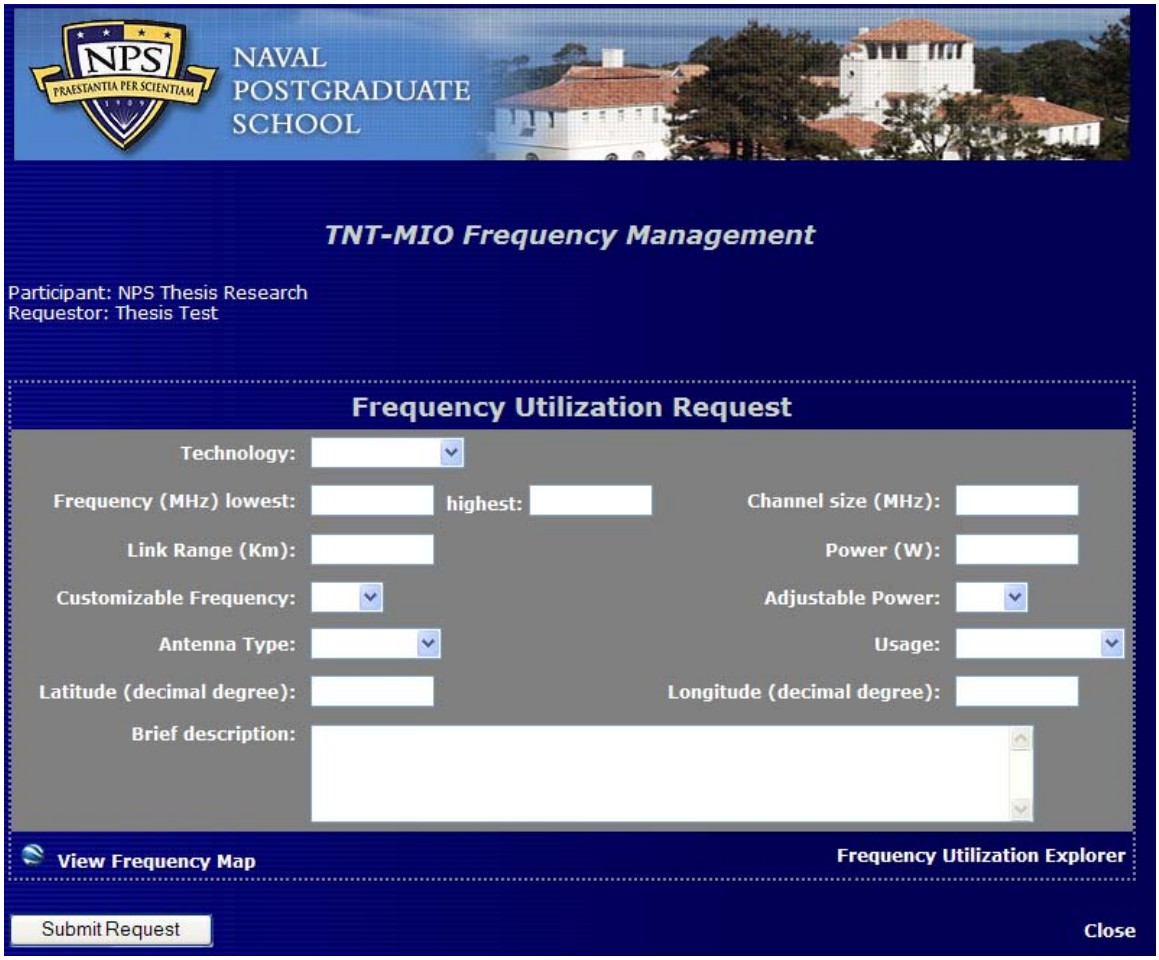


Figure 34. Frequency Utilization Request (From: [4]).

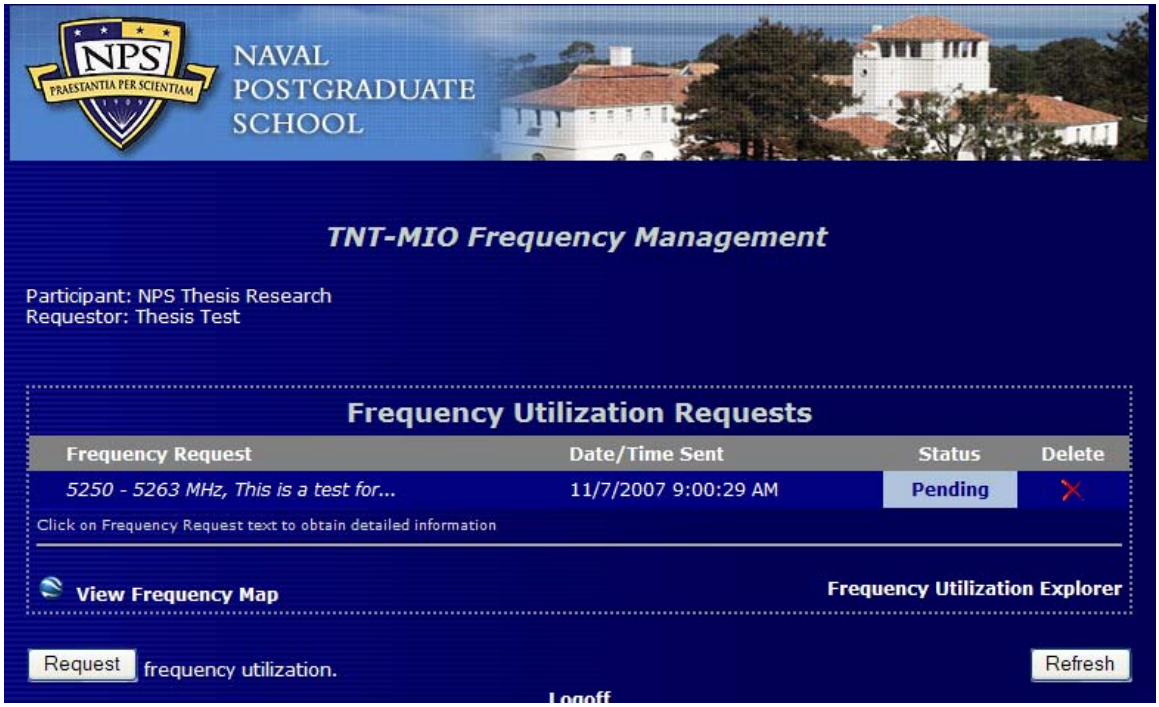
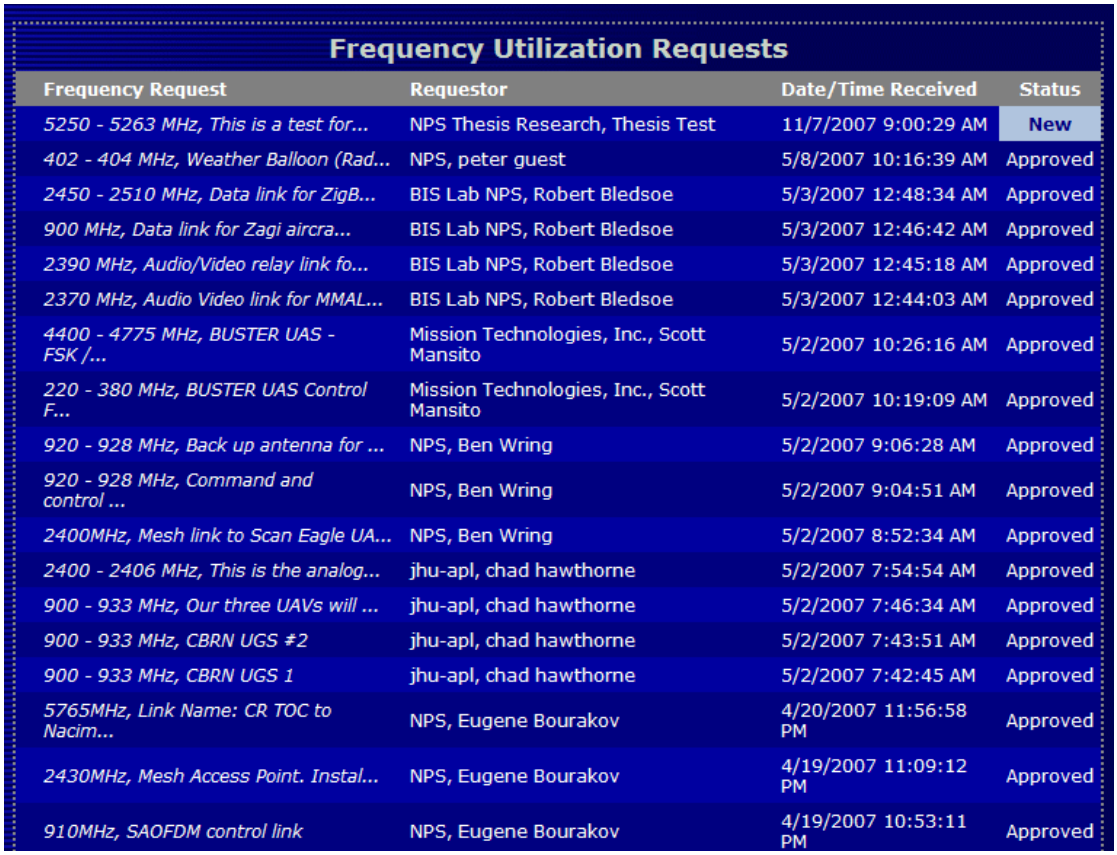


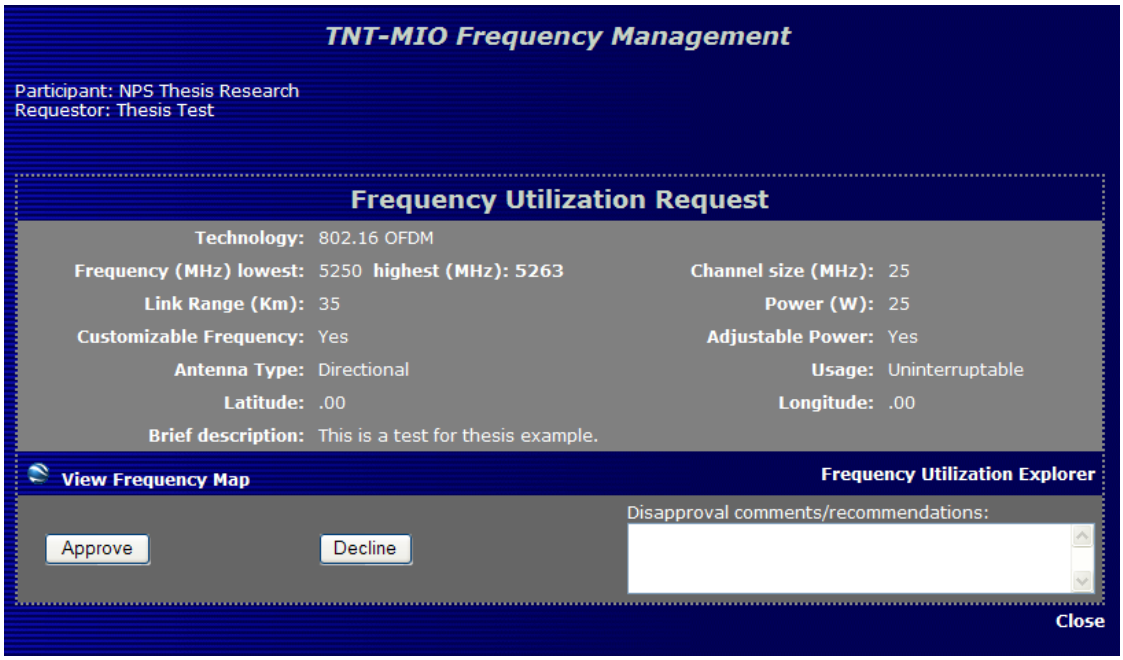
Figure 35. Displays the request is pending approval from the events frequency manager (From: [4]).



Frequency Utilization Requests

Frequency Request	Requestor	Date/Time Received	Status
5250 - 5263 MHz, This is a test for...	NPS Thesis Research, Thesis Test	11/7/2007 9:00:29 AM	New
402 - 404 MHz, Weather Balloon (Rad...	NPS, peter guest	5/8/2007 10:16:39 AM	Approved
2450 - 2510 MHz, Data link for ZigB...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:48:34 AM	Approved
900 MHz, Data link for Zagi aircra...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:46:42 AM	Approved
2390 MHz, Audio/Video relay link fo...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:45:18 AM	Approved
2370 MHz, Audio Video link for MMAL...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:44:03 AM	Approved
4400 - 4775 MHz, BUSTER UAS - FSK /...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:26:16 AM	Approved
220 - 380 MHz, BUSTER UAS Control F...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:19:09 AM	Approved
920 - 928 MHz, Back up antenna for ...	NPS, Ben Wring	5/2/2007 9:06:28 AM	Approved
920 - 928 MHz, Command and control ...	NPS, Ben Wring	5/2/2007 9:04:51 AM	Approved
2400MHz, Mesh link to Scan Eagle UA...	NPS, Ben Wring	5/2/2007 8:52:34 AM	Approved
2400 - 2406 MHz, This is the analog...	jhu-apl, chad hawthorne	5/2/2007 7:54:54 AM	Approved
900 - 933 MHz, Our three UAVs will ...	jhu-apl, chad hawthorne	5/2/2007 7:46:34 AM	Approved
900 - 933 MHz, CBRN UGS #2	jhu-apl, chad hawthorne	5/2/2007 7:43:51 AM	Approved
900 - 933 MHz, CBRN UGS 1	jhu-apl, chad hawthorne	5/2/2007 7:42:45 AM	Approved
5765MHz, Link Name: CR TOC to Nacim...	NPS, Eugene Bourakov	4/20/2007 11:56:58 PM	Approved
2430MHz, Mesh Access Point. Instal...	NPS, Eugene Bourakov	4/19/2007 11:09:12 PM	Approved
910MHz, SAOFDM control link	NPS, Eugene Bourakov	4/19/2007 10:53:11 PM	Approved

Figure 36. Displays the frequency managers page with the pending request (From: [4]).



TNT-MIO Frequency Management

Participant: NPS Thesis Research
Requestor: Thesis Test

Frequency Utilization Request

Technology: 802.16 OFDM
Frequency (MHz) lowest: 5250 **highest (MHz):** 5263 **Channel size (MHz):** 25
Link Range (Km): 35 **Power (W):** 25
Customizable Frequency: Yes **Adjustable Power:** Yes
Antenna Type: Directional **Usage:** Uninterruptable
Latitude: .00 **Longitude:** .00
Brief description: This is a test for thesis example.

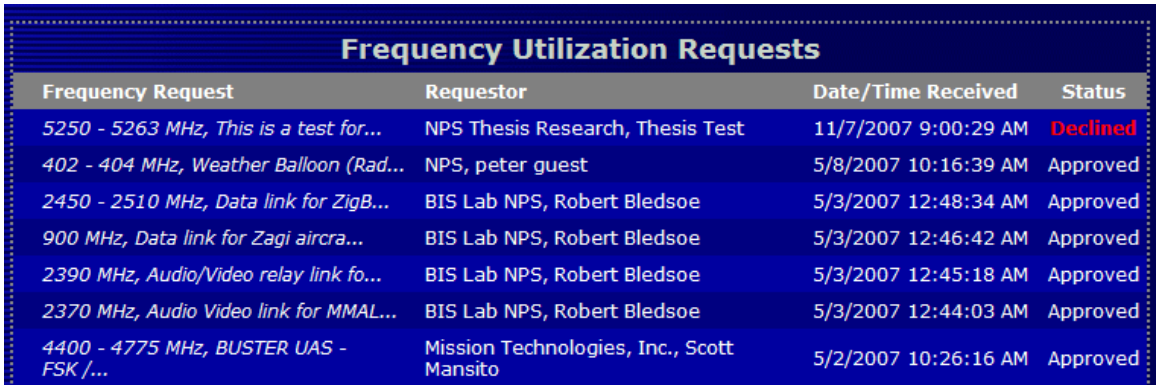
View Frequency Map **Frequency Utilization Explorer**

Disapproval comments/recommendations:

Approve Decline

Close

Figure 37. Allows the frequency manager to either approve or decline the request and to provide the user feedback if the request is denied (From: [4]).



Frequency Utilization Requests

Frequency Request	Requestor	Date/Time Received	Status
5250 - 5263 MHz, This is a test for...	NPS Thesis Research, Thesis Test	11/7/2007 9:00:29 AM	Declined
402 - 404 MHz, Weather Balloon (Rad...	NPS, peter guest	5/8/2007 10:16:39 AM	Approved
2450 - 2510 MHz, Data link for ZigB...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:48:34 AM	Approved
900 MHz, Data link for Zagi aircra...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:46:42 AM	Approved
2390 MHz, Audio/Video relay link fo...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:45:18 AM	Approved
2370 MHz, Audio Video link for MMAL...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:44:03 AM	Approved
4400 - 4775 MHz, BUSTER UAS - FSK /...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:26:16 AM	Approved

Figure 38. Displays the request as denied on the frequency managers utilization request page (From: [4]).

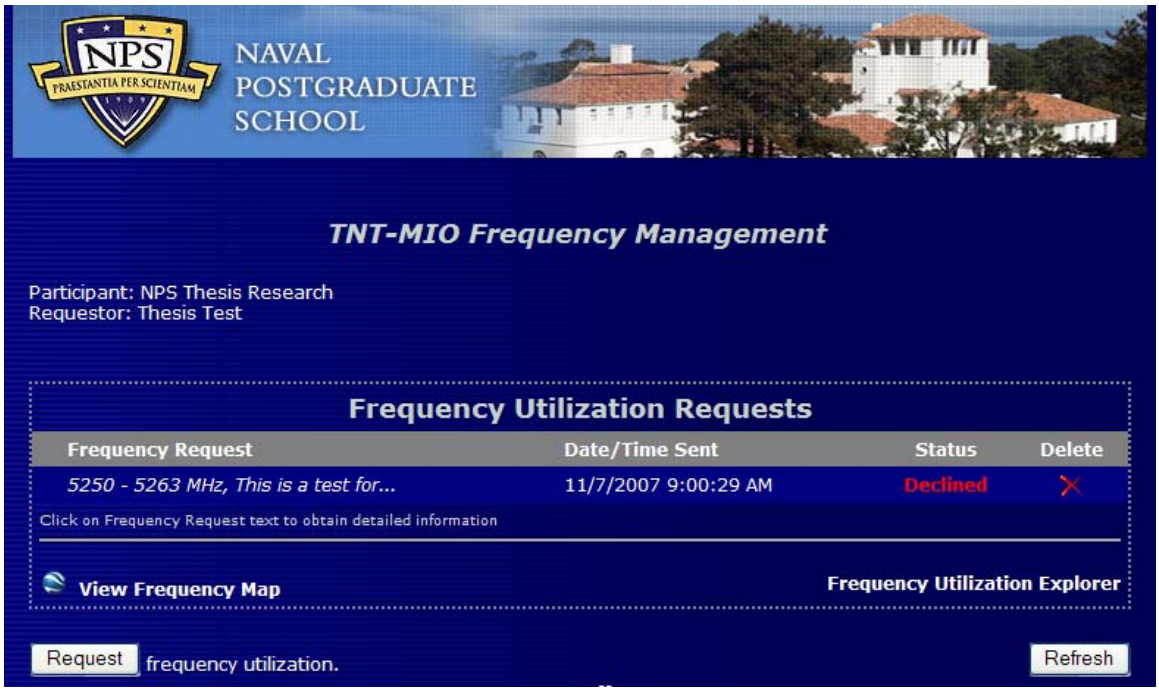


Figure 39. Displays the request denial to the requester (From: [4]).

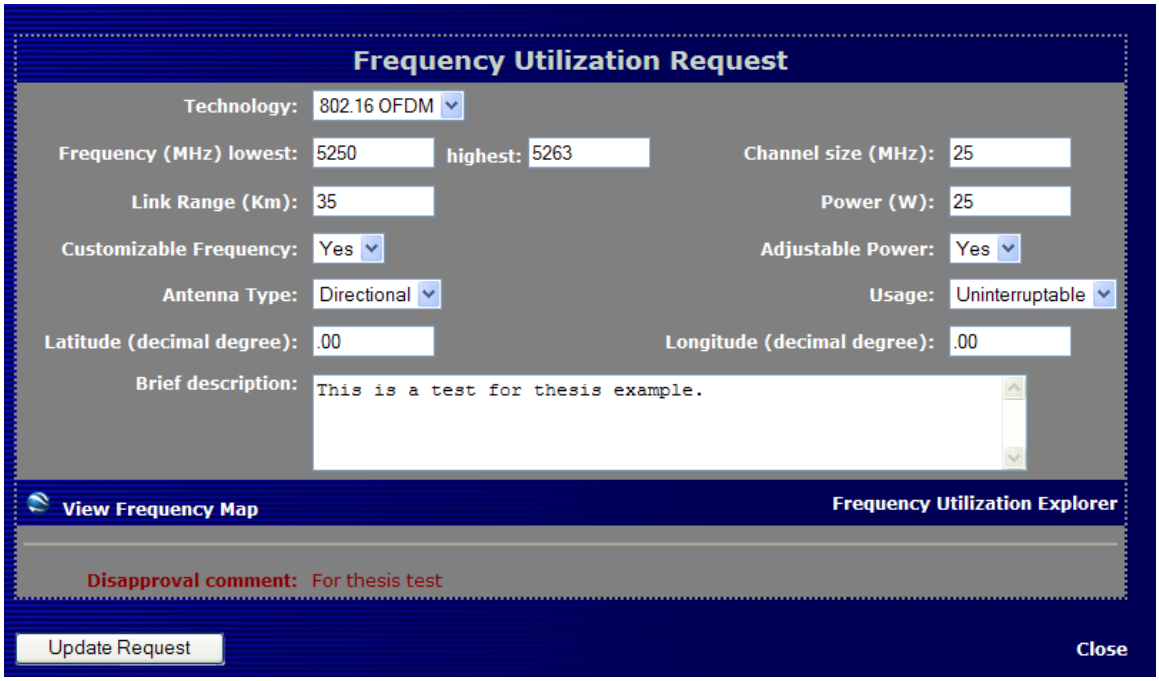


Figure 40. Displays the user the reason for denial and allows the user to update the request based on the disapproval comment provided by the frequency manager (From: [4]).

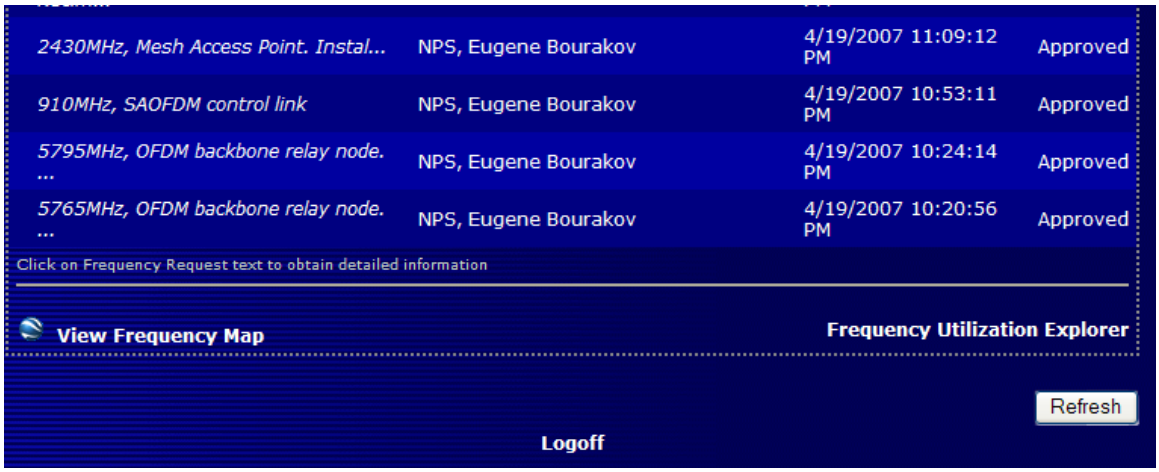


Figure 41. Allows the frequency manager to view the frequency map and frequency utilization explorer (From: [4]).

Figures 42 to 45 shows several pictures of the amplifying information available to the frequency manager by clicking of the various icons being used on the Google Earth display.

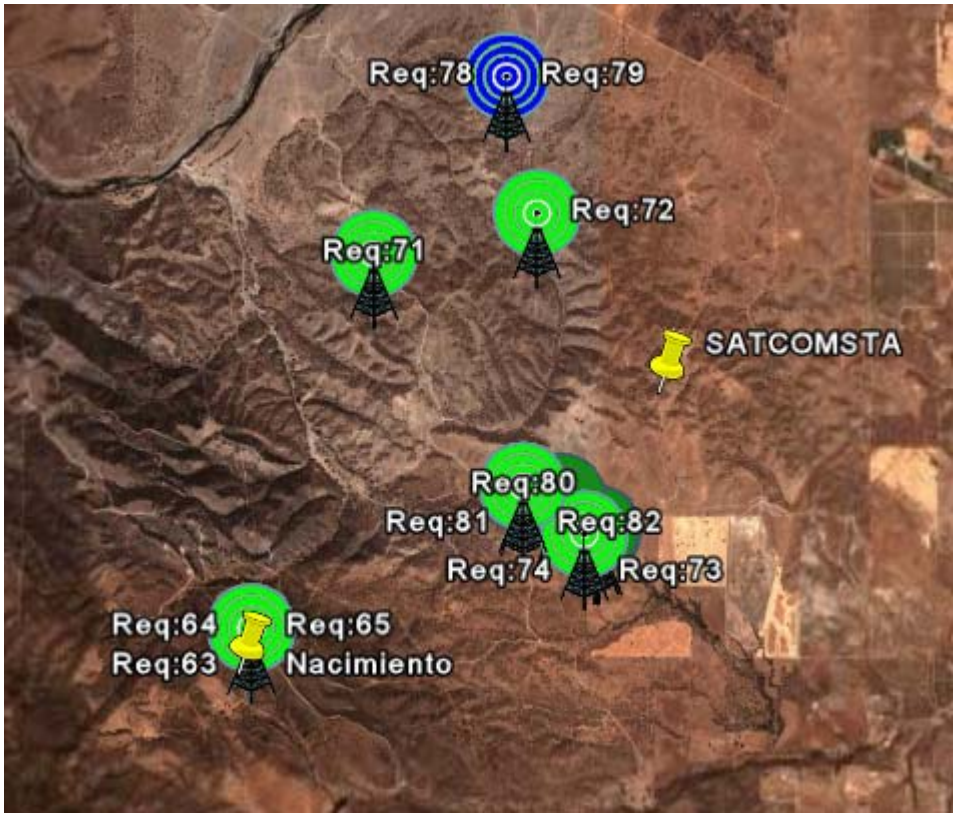


Figure 42. Allows the frequency manager to view the frequency map using Google Earth (From: [4]).

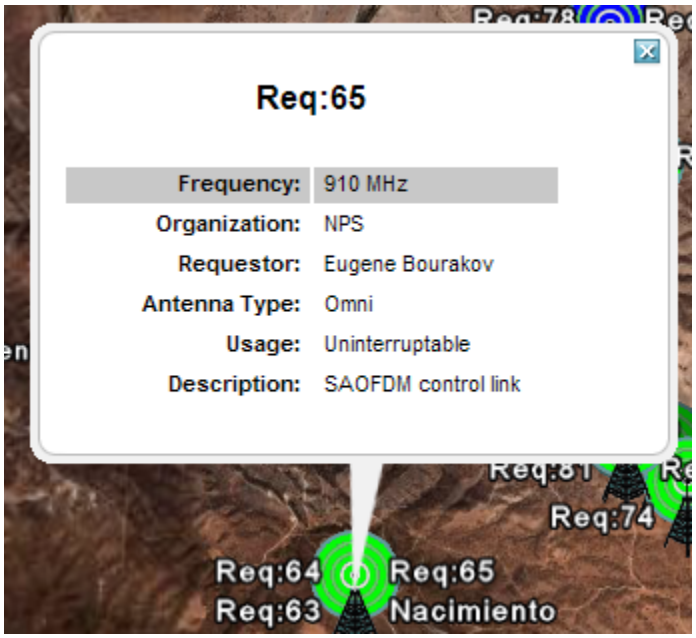


Figure 43. Shows amplifying information on designated site (From: [4]).

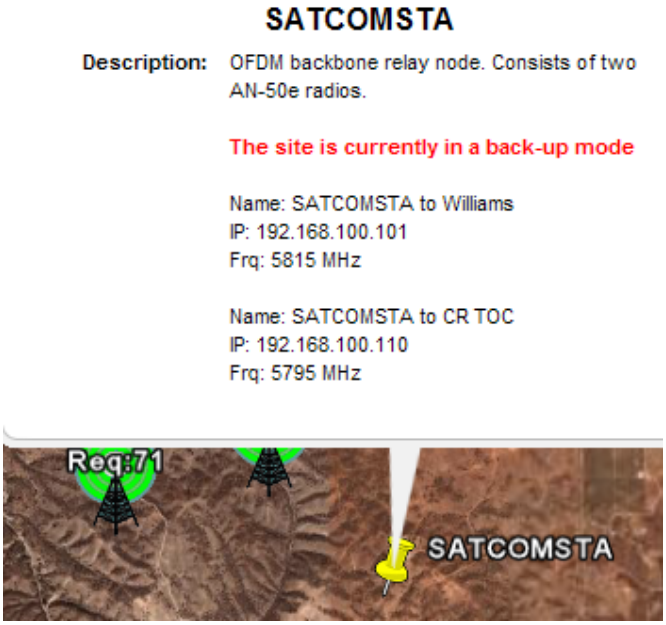


Figure 44. Amplifying data on SATCOM site (From: [4]).

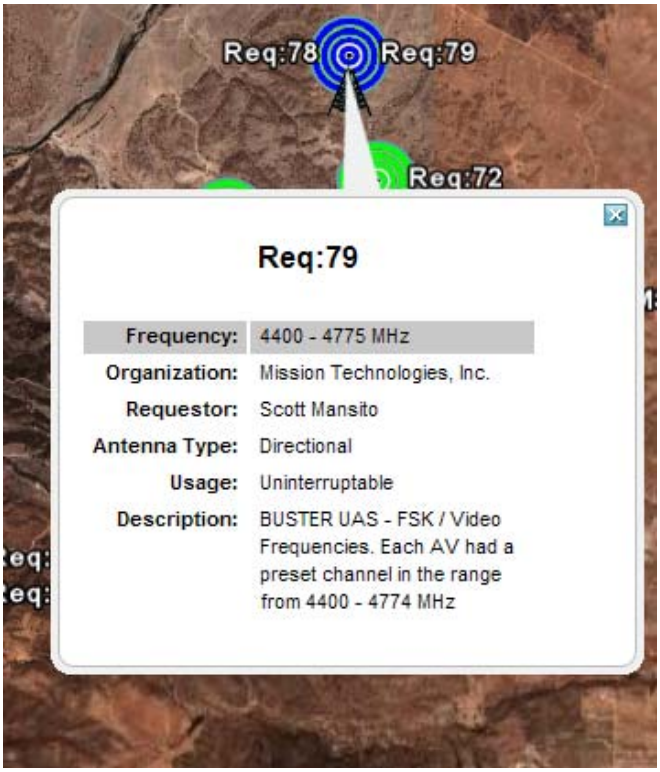


Figure 45. Amplifying information on designated site (From: [4]).

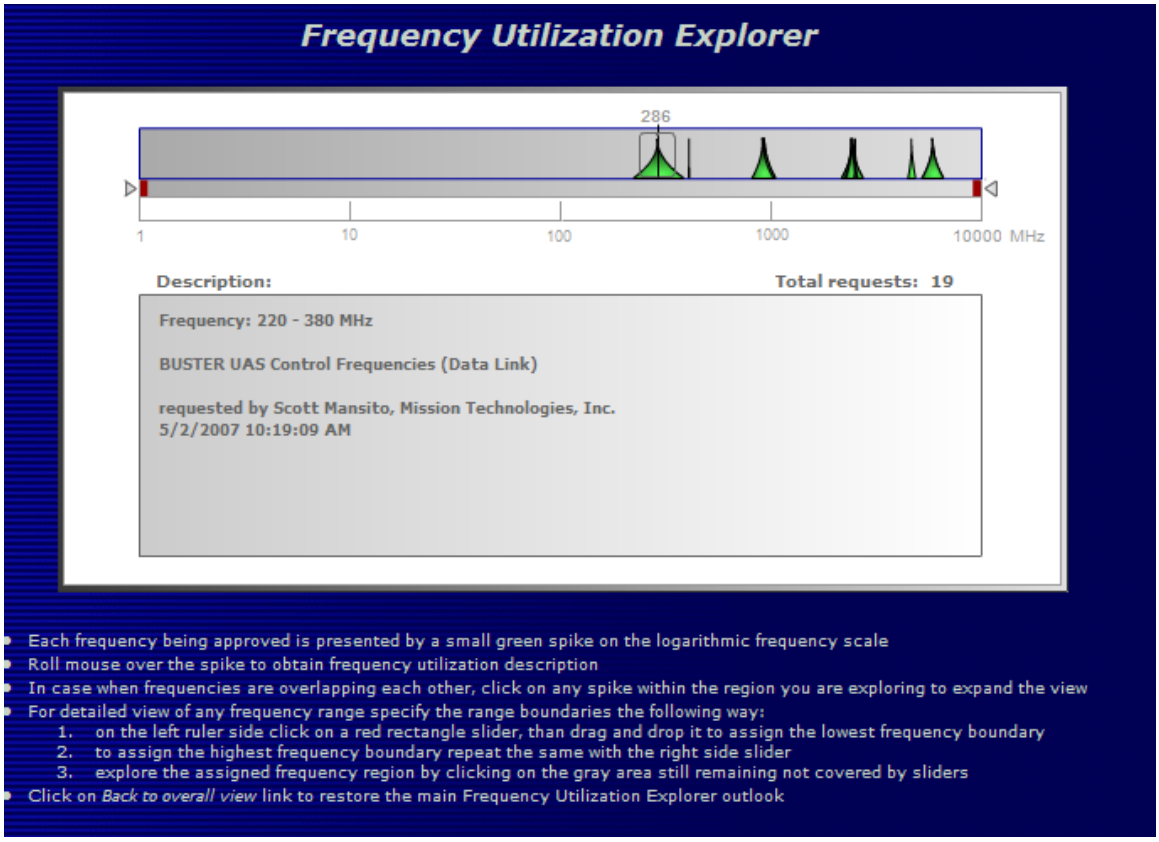


Figure 46. Frequency Utilization Explorer Focused on 286 MHZ (From: [4]).

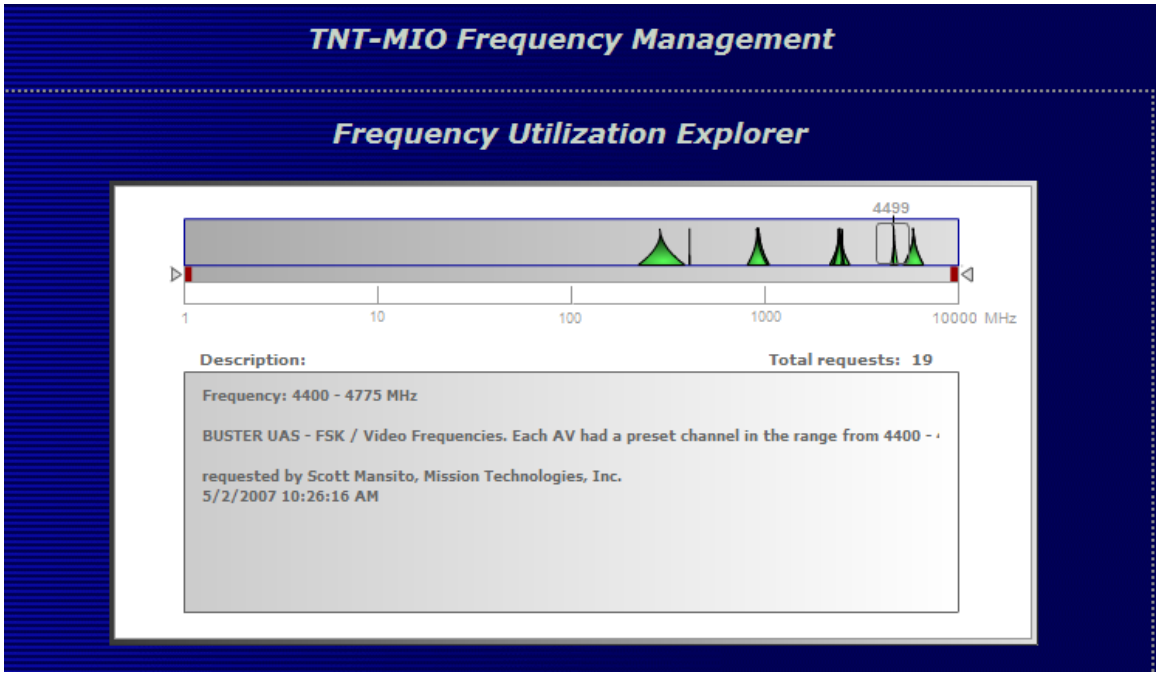


Figure 47. Frequency Utilization Explorer Focused on 4499 MHZ (From: [4]).

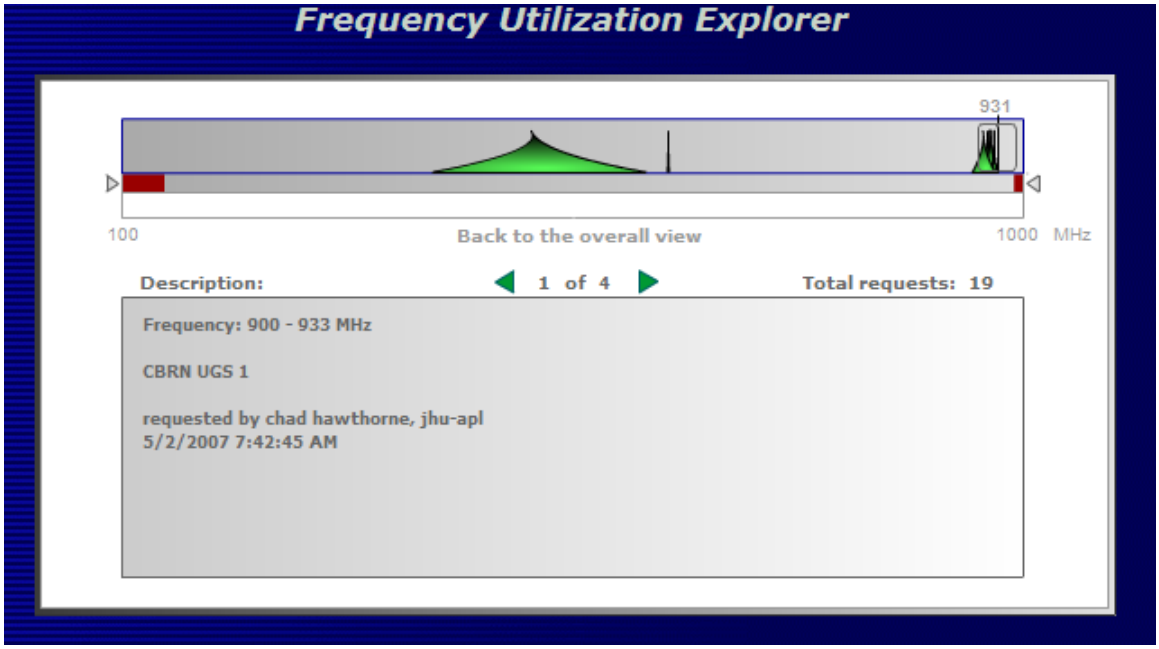


Figure 48. Frequency Utilization Explorer Focused on 931 MHZ (From: [4]).

Figure 49 shows the frequency utilization explorer that allows the frequency manager to view potential frequency conflicts. It displays the equipment operating within a specific frequency range by passing the cursor above various frequencies on the bar. Note: The bar allows the frequency manager to drill down into specific frequency ranges.

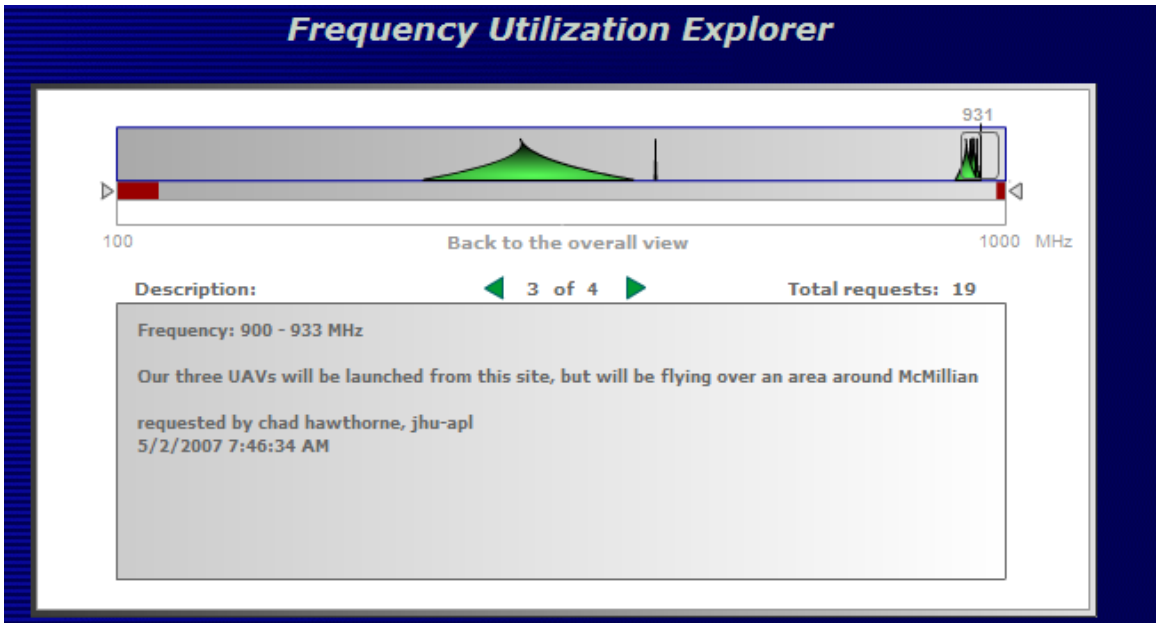


Figure 49. Frequency Utilization Explorer (From: [4]).

Figure 50 shows the frequency utilization map available to the frequency manager by clicking the link from the frequency utilization explorer page.

Note: Frequencies are listed in numerical order vice random to allow the frequency manager ease for locating specific equipment operating at specific frequencies.

Frequency Utilization List

#	Frequency (MHz)	Utilization Description	Requestor
1	220-380	BUSTER UAS Control Frequencies (Data Link)	Scott Mansito Mission Technologies, Inc. 5/2/2007 10:19:09 AM
2	402-404	Weather Balloon (Radiosonde) data transfer communication	peter guest NPS 5/8/2007 10:16:39 AM
3	900	Data link for Zagi aircraft.	Robert Bledsoe BIS Lab NPS 5/3/2007 12:46:42 AM
4	900-933	CBRN UGS 1	chad hawthorne jhu-apl 5/2/2007 7:42:45 AM
5	900-933	CBRN UGS #2	chad hawthorne jhu-apl 5/2/2007 7:43:51 AM
6	900-933	Our three UAVs will be launched from this site, but will be flying over an area around McMillian Field. This is the autonomy link between UAVs and the UGS.	chad hawthorne jhu-apl 5/2/2007 7:46:34 AM
7	910	SAOFDM control link	Eugene Bourakov NPS 4/19/2007 10:53:11 PM
8	920-928	Command and control Link to Scan Eagle UAV.	Ben Wring NPS 5/2/2007 9:04:51 AM
9	920-928	Back up antenna for command and control link to Scan Eagle.	Ben Wring NPS 5/2/2007 9:06:28 AM
10	2370	Audio Video link for MMALV and MiniWhegs vehicles.	Robert Bledsoe BIS Lab NPS 5/3/2007 12:44:03 AM

Figure 50. Frequency Utilization List in numerical order (From: [4]).

G. SECOND EVALUATION

After review of the NPS TNT - Frequency Management website tools there are a few things to note. First, the ability for organizations or individuals to enter specifics regarding frequency operations of equipment the user would like to operate during TNT test events is a great collaboration tool that could be applied to frequency management for any organization to use for any operation that involved one or multiple organizations

supporting specific operations. The latitude and longitude function would not be required though on the user input page. For specific frequency management and de-confliction the software requires a better input/output display to help the frequency manger de-conflict frequencies. The web page must allow for inputs of measured background noise to determine potential interference. Also, software necessitates the addition of the available service architecture.

The NPS Frequency Manager Website with the additions of some aspects of the FCC and Radio Operator websites documented along with some adjustments and additions as described above could become the tool needed to meet the requirement described at the beginning of this chapter.

H. CONCLUSION

Upon review of these websites, it is apparent none of them meet the entire need of the frequency manager in an operational environment. However, the NPS website provides the best working tool closest to the requirements and with some changes to the site can be a complete Decision support interface (DSI) for the frequency manager.

Both the FCC and the Radio Repeater websites offer information that is valuable and useful to a frequency manager. The positional and frequency data can be extracted from these sites and placed into the NPS Frequency Manager Geographic Mapping portion of the website to help de-conflict the existing electromagnetic environment prior to any test or operational equipment is activated.

For example, the Frequency Manager (FM), knowing the area of an upcoming test or operation, could map geographically and in the frequency spectrum the existing known antenna infrastructure. After that the FM can take measurements in the operational or test area using a spectrum analyzer. If these measurements can be associated with existing antennas then they too can be plotted both geographically and within the frequency spectrum it is operating in. However, frequencies that are detected and can not be associated with existing infrastructure still need to be mapped within the frequency spectrum it was detected in. By doing this the Frequency Manager will have a complete idea of the electromagnetic arena the equipment will be operating in. The FM then can

look through the listing of equipment that is to be used and see what conflicts potentially exist with the electromagnetic environment and a determination as to whether to use the equipment can be made. Then the Frequency Manager can de-conflict any of the equipment that is to be used that operates on similar or the same frequencies. This can be done by either time, distance, or possibly adjusting the frequencies or the power out.

By accomplishing these items prior to executing any event or test will minimize the frustration and the loss of time of operators and test directors. Events will be conducted with minimal to no loss of time due to interference. Or all participants know in advance that there may be interference when operating certain equipment and if the interference is detected everyone already knows the probable cause and decisions can be rapidly made as to terminate or continue the operation of said equipment with little to no loss of time troubleshooting the problem.

IV. TEST PLAN ONE AND RESULTS

A. INTRODUCTION

This is the first test plan for our thesis is for frequency mapping to support successful operation of 802.16 wireless networks (TNT Test Bed) and will be the basis for follow on test plans and experiments. Test Plan One will be incorporated into this thesis and will be amplified and/or modified by thesis advisors as needed. The purpose of this test is for the thesis researchers (Scott Walker and Lauro Luna) to become familiar with an 802.16 wireless network, the operation of a spectrum analyzer and the beginning of data collection in an electro-magnetic benign environment.

This test will be conducted over a 2-3 day period using the TNT test bed established at Camp Roberts. Equipment to be used for the test will be as follows:

- The 802.16 network test bed at Camp Roberts.
- Fixed spectrum analyzer at Camp Roberts.
- Portable spectrum analyzer to be provided by Dr. Bordetsky.
- Directional antenna for direction finding to be provided by Dr. Bordetsky.
- Lap top computer to run analyzer software as required to be provided by Dr. Bordetsky.
- Lap top computer for research and notes to be provided by research students.
- Administrative supplies (paper, pencils and pens, folders) to be provided by research students.
- Keys and combinations to trailers, gates, and facilities at Camp Roberts as appropriate for successful completion of the test to be provided by Dr. Bordetsky.
- Map of Camp Roberts and 802.16 antenna locations to be provided by Dr. Bordetsky.
- GPS Receiver to be provided by Dr. Bordetsky.

B. CURRENT BACKBONE CONFIGURATION

The current TNT OFDM 802.16 fixed backbone network is what will be used to accomplish our tests and experiments. Test Plan one will be conducted at Camp Roberts and will complete the first phase of our tests and experiments. The TNT OFDM 802.16 backbone is the test bed for this project and has the following composition:

- CENETIX Lab is tied into and supported by the NPS NOC.
- NPS NOC to Spanagel Hall Tower 2
- Tower 2 to Mount Toro (24.32 KM)
- Mount Toro to Bryant Hill Tower (29.27 KM)
- Bryant Hill Tower to Williams Hill Tower (60 KM)
- Williams Hill Tower to Camp Roberts SATCOMSTA (32.87 KM)
- Camp Roberts SATCOMSAT to Camp Roberts TOC at McMillian Airfield (2.29 KM)

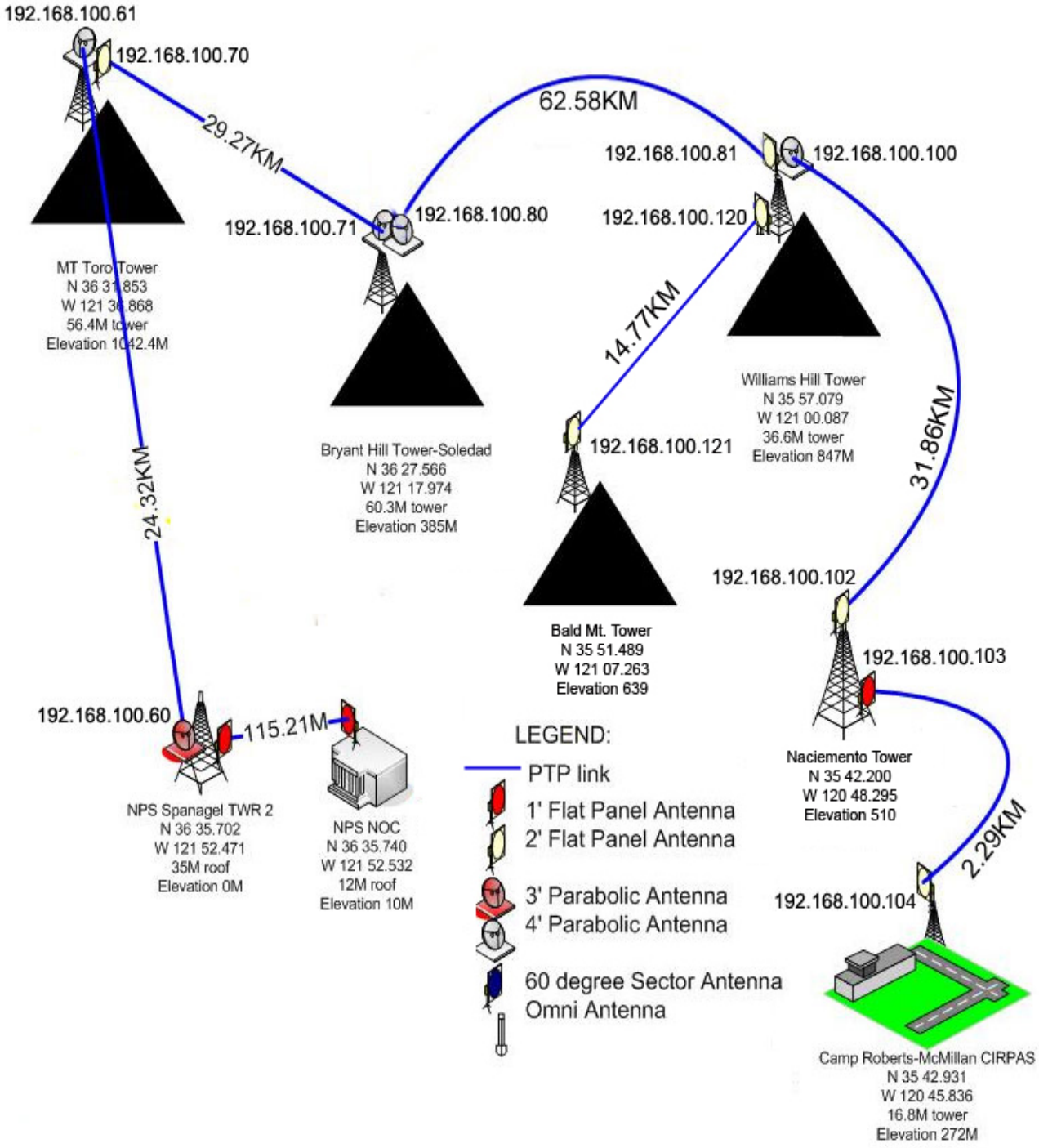


Figure 51. TNT TEST BED Architecture.

C. TEST PLAN ONE SPECIFIC STEPS

1. Ensue equipment is available to run test.
2. Determine dates for the test.
    a. De-conflict other Camp Robert events
    b. De-conflict classes
    c. Obtain Dr. Bordetsky's approval on test dates
3. Once dates are approved
    a. Submit request for thesis travel
    b. Through student services arrange lodging
    c. Acquire orders and approval for POV
4. Prior to departure
    a. Familiarization with equipment set-up and operation to include software and hardware of specific systems to be used during the experiment.
    b. Learn how to set up the 802.16 network at Camp Roberts (see Mike Clement).
    c. Ensure all equipment is in hand to include this test plan.
5. Day One at Camp Roberts
    a. Utilizing the fixed and portable spectrum analyzers look for existing radio frequencies (RF) that are in the area and document this data. Readings from spectrum analyzers will be in the location of test bed AP's. Note: This is prior to initializing the 802.16 TNT test bed network at Camp Roberts.
    b. Initialize 802.16 network and verify network is up and operational. This may require computer set-up to transmit data.
    c. Once network is verified as up and operating utilizing both the fixed and portable spectrum analyzers take readings again.
    d. Document differences and lessons learned.
6. Day Two at Camp Roberts
    a. Conduct RF scans using spectrum analyzers to see is there are any changes from Day 1. Document any noted differences.
    b. Ensure 802.16 network TNT test bed is up and operational.
    c. Conduct experiment attempting to use a directional antenna to see if by signal strength and frequency the AP's of the 802.16 TNT test bed can be located and isolated.
    d. Document lessons learned and begin to outline test plan two.
7. Day Three at Camp Roberts
    a. Will be used as a back-up day for events unable to be accomplished from day's one and two.
    b. Used to test ideas and theories gained from the previous two days of testing.
8. Return from Camp Roberts.
    a. File travel claim
    b. Conduct briefing with Dr. Bordetsky of results and lessons learned from experiment.

c. Get direction from Dr. Bordetsky on next test plan and thesis direction.
d. Write the test results up as part of the thesis.

D. TEST PLAN ONE RESULTS

Test Plan One was executed 05 November 2007 to 09 November 2007 at the Camp Roberts Test Site using the TNT Experiment as a base line. We are using an Anritsu MS2721B spectrum analyzer with the following antennas:

806 – 869 MHZ

896 – 941 MHZ

1.71 – 1.88 GHZ

1.85 – 1.99 GHZ

2.4 – 2.5 GHZ

5.725 – 5.825 GHZ

Wideband Antenna

The purpose of this test is to become familiar with the use of the frequency analyzer and best ways to operate it in support of mapping the frequency environment in the vicinity of the TOC at Camp Roberts. The objectives are to become familiar with the procedures to detect and document the frequency environment and to provide a basis for frequency management. The information gathered will be documented in this document and displayed on a spreadsheet using Microsoft Excel.

Weather Conditions: 05 November 2007

UV Index: 1
Low Wind: From SSW at 11 mph
Humidity: 29%
Pressure: 29.96 in. ↓
Dew Point: 42°F
Visibility: 10.0 miles
Temperature: High 78 Low 42

E. SCANNING RESULTS

806 – 869 MHZ Results: Noise to about -86dBm. No obvious signals.
896 – 941 MHZ Results: From 870 MHZ to 950 MHZ various spikes that went slightly below -84 dBm, which was above the rest of the noise at about -65 dBm.

Note: On readings taken 02/24/07 it was noted that 925 MHZ to 940 MHZ was dirty and it was believed that the source of the interference was the local METOC station that has a link back to the TNT compound.
1.71 – 1.88 GHZ Results: Picked up a distinct spike at 1.89 GHZ to – 55 dBm.
1.85 – 1.99 GHZ Results: Picked up a distinct spike at 1.89 GHZ to – 55 dBm.
2.4 -2.5 GHZ Results: When using this antenna on the spectrum analyzer in the vicinity of the Camp Roberts TOC trailers we were receiving a signal at approximately 2.445 GHZ at – 59 dBm.
5.725 – 5.825 GHZ Results: Noise to about -84 dBm. No obvious signals.
Wideband Antenna: Using the wideband antenna we validated the 2.445 GHZ spikes however, we also detected spikes at 2.4 GHZ and 2.49 GHZ. The high noise level and the various spikes from 870 MHZ to 950 MHZ were validated. When attempting to validate the 1.89 GHZ spike at the north end of the TNT Compound we were unable to detect the signal. However, when we moved to the south end of the compound we detected the 1.89 GHZ spike.

Weather Conditions: 06 November 2007

UV Index: 0 Low
Low Wind: From W at 2 mph
Humidity: 32%
Pressure: 29.95 in.
Dew Point: 42°F
Visibility: 9.0 miles
Temperature: Low 42°F High 78°F

F. VALIDATION OF YESTERDAYS SIGNALS USING WIDEBAND ANTENNA

This morning verified that the signal from 875-950 MHZ still existed. However, this morning on the south end of the TNT Camp Roberts compound we detected spikes at 525 MHZ and 655 MHZ also. These two frequencies were not detected 05 November 2007 while taking measurements. Validated 1.89 GHZ signal still exists. While validating the 2.44 GHZ signal from yesterday it was noted that today, there were various signals from 2.4 GHZ to 2.5 GHZ, also picked up an occasional signal at 2.35 GHZ.

In conducting spectrum analysis from 0-7 GHZ we set the spectrum analyzer in 1 GHZ spread and if noting any signals we would decrease the scale as needed. This was accomplished by conducting measurements 0-7 GHZ at both the north and south ends of the TNT compound. Besides signals noted above the only other signal detected was a weak 5.76 GHZ signal at the south end of the compound.

Weather Conditions: 07 November 2007

UV Index: 3 Moderate
Low Wind: From E at 1 mph
Humidity: 54%
Pressure: 30.07 in.
Dew Point: 43°F
Visibility: 8.0 miles
Temperature: Low 42° F High 75° F

G. DETECTION OF SIGNALS USING WIDEBAND ANTENNA

To gain a further understanding of the frequency environment of the operation a HUMVEE was used as transportation along with a spectrum analyzer using a wideband antenna to take measurements around the local area. Measurements were taken on Naciemento Hill analyzing the readings from 0-7 GHZ. The following signals were detected:

- 1.15 GHZ signal that was intermittent from -55 to -65 dBm.
- 5.7 – 5.76 GHZ signal that was intermittent at – 51 dBm
- 875 MHZ signal that was solid at -69 dBm.
- 2.4 GHZ signal that appeared to be interfering with APL UAV's that were operating over the flight line by the TOC. Found a directional antenna that seemed to be the source of the signal that was interfering with the UAV's. This parabolic antenna is pointing about 10 degrees to the left of the SATCOM station when on Naciemento Hill facing SATCOM station.

In conducting a sweep of the TNT compound the following signals were detected.

- 425 MHZ very strong on both sides of the compound.
- 900-910 MHZ on both ends of the compound.
- 1.6 GHZ intermittent signal on the south end of the compound at – 69 dBm.
- 1.89 GHZ – 65 to -75 dBm
- 2.4 GHZ - 60 dBm.
- 5.75 GHZ – 65 dBm on the north end of the compound only.

H. CONCLUSIONS

In discussions with Dr. David Netzer and Dr. Alex Bordetsky prior to this TNT event it is apparent that frequency management is a key component to the success of the Camp Roberts experiments. Historically, at these events there have been delays and complications in conducting these test events because of frequency conflicts that prevented events from successfully executing on time. Frequently this problem is the effect of running different events where equipment operated on similar or the same frequency resulting in events being delayed until the conflict had been resolved.

The purpose of conducting a frequency spectrum analysis is to test and determine the frequency environment of the TNT test events at Camp Roberts. The Frequency Manager would use these measurements along with the identified and documented frequencies used to support the TNT events to manage potential interference and conflicts. It is apparent that the frequency manager must have knowledge of the frequency environment and a detailed understanding of the event timelines, frequencies used by various equipment and test scenarios. To help in the prevention of mutual interference preventing events from executing in accordance with the schedule each test group must not activate their equipment prior to receiving permission from the frequency manager.

It is important for the frequency manager to not only be knowledgeable about the frequencies the experimental equipment will operate on but also the specifics of the operations. For example, below is a list of information that the frequency manager needs to know prior to the start of events:

- Are the antennas being used omni-directional or directional?
- What power out is being used?
- Is the equipment fixed frequency or frequency hopping?
- Can the equipment frequency be adjusted?
- What location will they be operating in?
- What are the test objectives?
- What systems have priority during what events?

- Knowledge of the existing frequency environment prior to lighting off any test equipment to understand where there may be problems that are not caused by test equipment conflicting with each other.

Having a designated frequency manager that is involved from the beginning of exercise planning through completion of the test events is critical to the success of any test or operational event. Without a designated frequency manager there is a very serious potential for many wasted hours of frustration as test coordinators spend hours trying to de-conflict interference problems as they arise. The frequency manager removes this burden from the exercise coordinators and takes responsibility for the de-confliction of frequencies being used.

This test was conducted to validate the frequency environment for the frequency manager to be able to successfully do their job. The environment was measured and the readings were documented. All experimental equipment operational frequencies were documented along with specific notes as they would apply to frequency management. This information was laid out on a spreadsheet using Microsoft Excel so the frequency manager would be able to see potential interference issues based on the operating environment and conflicts between experimental equipment to be used.

I. TEST LESSONS LEARNED

Table 2 is used to supplement the excel spreadsheet documenting the frequencies used by the various test equipment and the frequencies detected in the area by the readings taken with a spectrum analyzer. This table in conjunction with the excel spreadsheet will answer the questions that we had prior to the test event and will help in analyzing the results.

What power is being used?	From a frequency manager's planning prospective power out is used to de-conflict equipment using similar or the same frequencies. If the conflicted equipment has a low enough power out and are operating in geographically different areas then they may be able to operate at the same time with no interference.
Is the equipment fixed frequency or frequency hopping?	If the equipment is capable of frequency hopping then wireless systems operating in the same geographic area can be used as long as the operating pattern and frequencies are not the same at the same time.
Can the equipment frequency be adjusted?	If the equipment frequency can be adjusted then systems can be de-conflicted by changing their operating frequencies.
What location will they be operating in?	Knowing the location where wireless equipment will be operating is important to de-conflict equipment that is operating on the same or similar frequencies. If interference occurs and it is determined that the interference is not caused by other test equipment operating then the cause of the interference must be determined to see if the interfering equipment can be shut down or if the event needs to be stopped or moved to another time or location.
What are the test objectives?	A clear understanding of the test objectives or mission help the frequency manager determine the priority of systems to be used and when. If it is apparent that there are more than one system that will interfere with each other than the frequency manager can authorize the use of the appropriate equipment based on objectives.
What systems have priority during what events?	Knowing what systems have priority for each event is important if interference occurs. Equipment that is operating on a similar frequency with a lower priority can be shut down prior to the higher priority equipment.
Knowledge of the existing frequency environment prior to lighting off any test equipment to understand where there may be problems that are not caused by test equipment conflicting with each other.	It is beneficial for the frequency manager to take measurements with a spectrum analyzer to see what frequencies are being used in the area prior to any test equipment radiating. This can alleviate problems if interference is detected on known test equipment frequencies then time will not be lost trying to de-conflict the operating system when the interference is being caused by an outside source. Also if you know certain frequencies are already being used and there are test systems on those same frequencies then you may be able to de-conflict by changing the systems frequency, if capable, or the geographic area of the test to minimize interference.

Table 2. Answers to Test Questions.

From 05 – 08 November 2007 we took readings with the spectrum analyzer and came up with the following results summarized (more specifics are outlined on the excel spreadsheet). Frequencies being used by non TNT participants seemed to be as follows: 870-975 MHZ, 1.89 GHZ, 2.4-2.5 GHZ, 5.75 GHZ. Of these the 2.4-2.5 GHZ had interference problems when conducting specific test events that operated in the same frequency range. When investigating the source it was discovered that a directional antenna on Naciemento Hill was transmitting in the general direction where the TNT test event was taking place. This interference caused delays and impacted the testing that was to take place in the designated test area. However, this was interference caused by a transmission not associated by the TNT participants and could not be terminated. If this signal had been detected prior to the days of the actual test events, then planning may have been conducted to limit or prevent the interference.

Based on these TNT experiments it appears a frequency manger with a decision support interface (DSI) would enable more effective de-confliction of experiments. This would save valuable testing time as well as the time it takes to de-conflict and identify the cause of interference. The DSI would have three portions to it. First, the DSI would have an input function where all the wireless test equipment with the appropriate information would be added. Then there would be a spreadsheet like the excel spreadsheet developed from the TNT experiment that is part of this thesis. Finally, there would be a mapping portion, similar to a Google earth type of display, where the location of known wireless antennas and repeaters could be mapped. This would have been useful in determining the interference problems encountered in the 2.5 GHZ range. One other important item, if possible the frequency manager should try to go to the test site prior to the test event to take readings with the spectrum analyzer. Readings should be documented like on the excel spreadsheet and any specific antennas should be mapped on the geographic plot with associated information. Then the frequency manager can discuss potential problems with the test director for early de-confliction to avoid wasting time and resources.

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V. MAPPING RESEARCH APPLIED BASED ON CAMP ROBERTS EXPERIMENTS

A. BACKGROUND

Based on the research conducted at Camp Roberts and the review of existing websites that offer a structure for frequency mapping, documented in Chapter III, a frequency management tool prototype linked to the TNT webpage has been collaboratively developed. This prototype will take into account the lessons learned from conducting individual test events, group exercises and the measurements gathered. This site will be the basis for a Frequency Manager Decision Support Interface (DSI).

In Chapter III, an evaluation was conducted of several existing software and websites to include the NPS frequency management website that is accessed through the NPS TNT Portal. In this chapter, the frequency manager website will be utilized as though a frequency manager is manipulating the site as a DSI. The registration or user requests aspects of the site will not be discussed or evaluated as accomplish during Chapter III. What will be illustrated is how the site can be used to manage and map frequencies, using the Camp Roberts TNT experiments as the environment or model. However, these same principles can be used for any test or operation.

B. THE TOOLS AND PROCESS

The first task a frequency manager must accomplish is to take measurements in the operating area for the TNT event. Due to schedule conflicts, no readings were taken prior to the event. However, measurements were taken everyday to document trends and to evaluate and locate the basis of any potential sources of interference for the TNT events. If the location of the source is ascertained then the source will be mapped geographically as well as within the frequency spectrum.

As the experimentation portion of the thesis is discussed all aspects of what was experienced and learned as de facto Frequency Managers will be explained. A brief example may be used and explained but moving on to the next step would do injustice to the complications that were encountered while conducting the frequency mapping and de-confliction. Therefore, to give a complete understanding of the process all aspects of the frequency management, de-confliction and mapping tasks will be examined and explained. Recommendations will also be discussed to help improve the frequency manger DSI, the mapping, and the de-confliction process.

The following is a list of the measurements that were recorded at Camp Roberts:

05 November 2007 measurements using a spectrum analyzer:

870-950 MHZ
1.89 GHZ
2.445 GHZ

06 November 2007 measurements using a spectrum analyzer:

525 MHZ at the south end of the TNT compound only.
655 MHZ at the south end of the TNT compound only.
875-950 MHZ
1.89 GHZ
2.35 GHZ was weak and intermittent, but measurable.
2.4-2.5 GHZ
5.76 GHZ this signal was weak and detected only at the south end of the TNT compound.

07 November 2007 measurements using a spectrum analyzer:

425 MHZ
900-910 MHZ
1.6 GHZ signal intermittent at the south end of the TNT compound.
1.89 GHZ at the north end of the TNT compound.
2.4-2.5 GHZ
5.75 GHZ at the north end of the TNT compound.

These measurements will be added to the frequency manager's notes that are accessed at the TNT website.

Figure 52 is the frequency manager notepad within the TNT frequency manager website. The above example lists the measurements taken at Camp Roberts during the last TNT experimentation. The measurements were taken and entered 05-07 November 2007 along with any amplifying notes. As Frequency Manager the next step that needs to be accomplished is to take note of any specific trends in the measurements that have been taken. When determining trends it must be noted that frequency readings on the spectrum analyzer are subject to some interpretation.

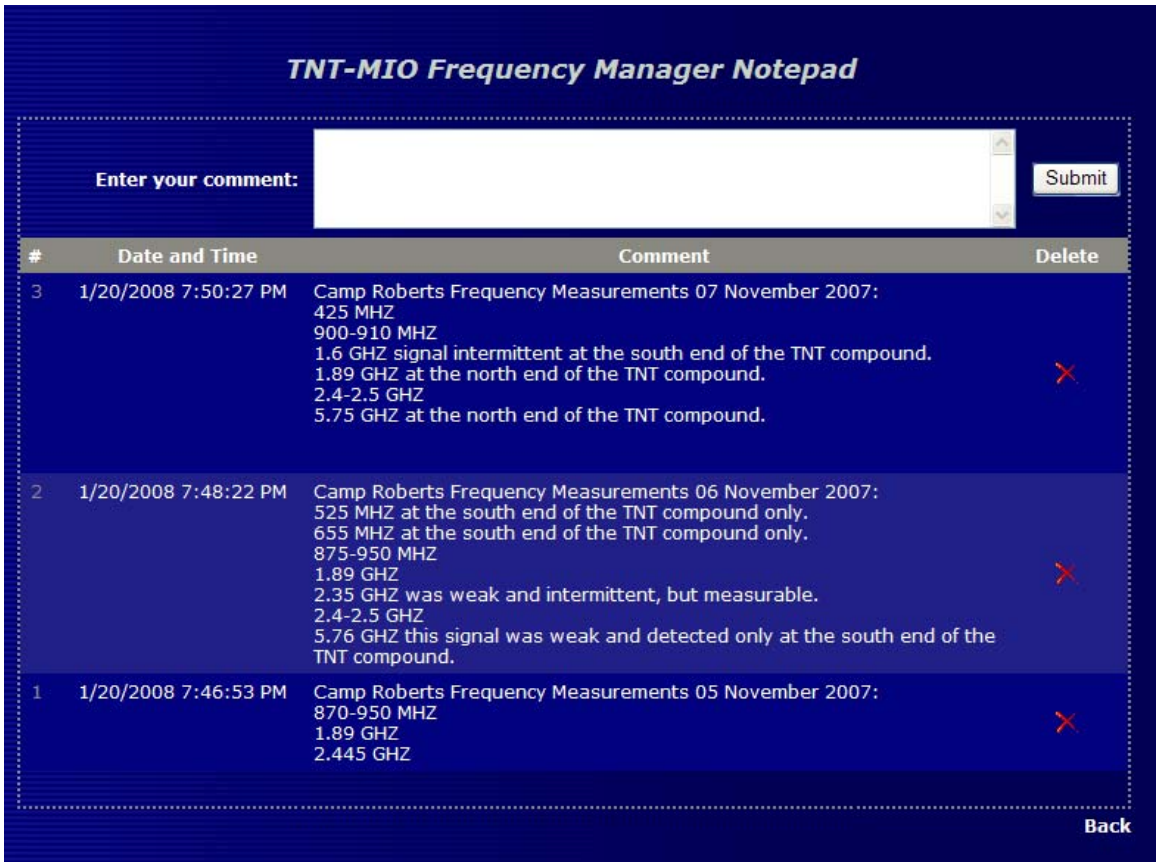

Figure 52. Frequency Notepad (From: [4]).

Below are the noted trends from the TNT experiment November 2007:

- 870-950 MHZ was detected everyday measurements were taken.
- 1.89 GHZ was detected everyday measurements were taken.
- 2.4-2.5 GHZ was detected everyday measurements were taken.

The frequencies listed above were detected everyday measurements were taken and will examined first for the purpose of mapping and de-confliction. The other measured frequencies will also be examined but because these were detected everyday measurements were taken it is very likely that they may be proven to a source of interference with the scheduled TNT test events.

The next thing that must be examined is the approved list of frequencies to be used during the test events. Figure 53 is a display of the list and there are several items that must be noted. First, there are several wavelengths listed on the frequency utilization page that operate in the low end of the 900 MHZ range. There is nothing noted specifically in the 1.89 GHZ range. Finally, there are several items that operate around the 2.4-2.5 GHZ range. The only other frequency range that needs to be examined for possible de-confliction is the 5.75 GHZ that was detected with the spectrum analyzer.

Frequency Utilization Requests

Frequency Utilization Request	Requestor	Date/Time Received	Status
402 - 404 MHz, Weather Balloon (Rad...	NPS, peter guest	5/8/2007 10:16:39 AM	Approved
2450 - 2510 MHz, Data link for ZigB...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:48:34 AM	Approved
900 MHz, Data link for Zagi aircra...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:46:42 AM	Approved
2390 MHz, Audio/Video relay link fo...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:45:18 AM	Approved
2370 MHz, Audio Video link for MMAL...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:44:03 AM	Approved
4400 - 4775 MHz, BUSTER UAS - FSK /...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:26:16 AM	Approved
220 - 380 MHz, BUSTER UAS Control F...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:19:09 AM	Approved
920 - 928 MHz, Back up antenna for ...	NPS, Ben Wring	5/2/2007 9:06:28 AM	Approved
920 - 928 MHz, Command and control ...	NPS, Ben Wring	5/2/2007 9:04:51 AM	Approved
2400MHz, Mesh link to Scan Eagle UA...	NPS, Ben Wring	5/2/2007 8:52:34 AM	Approved
2400 - 2406 MHz, This is the analog...	jhu-apl, chad hawthorne	5/2/2007 7:54:54 AM	Approved
900 - 933 MHz, Our three UAVs will ...	jhu-apl, chad hawthorne	5/2/2007 7:46:34 AM	Approved
900 - 933 MHz, CBRN UGS #2	jhu-apl, chad hawthorne	5/2/2007 7:43:51 AM	Approved
900 - 933 MHz, CBRN UGS 1	jhu-apl, chad hawthorne	5/2/2007 7:42:45 AM	Approved
5765MHz, Link Name: CR TOC to Nacim...	NPS, Eugene Bourakov	4/20/2007 11:56:58 PM	Approved
2430MHz, Mesh Access Point. Instal...	NPS, Eugene Bourakov	4/19/2007 11:09:12 PM	Approved
910MHz, SAOFDM control link	NPS, Eugene Bourakov	4/19/2007 10:53:11 PM	Approved
5795MHz, OFDM backbone relay node. ...	NPS, Eugene Bourakov	4/19/2007 10:24:14 PM	Approved
5765MHz, OFDM backbone relay node. ...	NPS, Eugene Bourakov	4/19/2007 10:20:56 PM	Approved

Click on Frequency Request text to obtain detailed information

View Frequency Map **Frequency Utilization Explorer**

Figure 53. List Frequency Utilization Requests (From: [4]).

The next step the Frequency Manager must complete is examine and ensure that each of the scheduled Frequency Utilization Request Test items will not encounter interference with the other requests. First, we will look at all the 900 MHZ range items.

Figures 54 to 60 are all the test equipment that could potentially be interfered with in the lower 900 MHZ frequency range.

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	900 **highest (MHz):**	**Channel size (MHz):**	50
Link Range (Km):	20	**Power (W):**	.6
Customizable Frequency:	No	**Adjustable Power:**	No
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.72	**Longitude:**	-120.7738
Brief description:	Data link for Zagi aircraft.		

Figure 54. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	920 **highest (MHz): 928**	**Channel size (MHz):**	.20
Link Range (Km):	100	**Power (W):**	1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.718811	**Longitude:**	-120.768895
Brief description:	Back up antenna for command and control link to Scan Eagle.		

Figure 55. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	920 **highest (MHz): 928**	**Channel size (MHz):**	.20
Link Range (Km):	100	**Power (W):**	1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Directional	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.718811	**Longitude:**	-120.768895
Brief description:	Command and control Link to Scan Eagle UAV.		

Figure 56. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	802.11 (a,b,g)		
Frequency (MHz) lowest:	900 **highest (MHz): 933**	**Channel size (MHz):**	30
Link Range (Km):	5	**Power (W):**	.7
Customizable Frequency:	No	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.715	**Longitude:**	-120.766
Brief description:	Our three UAVs will be launched from this site, but will be flying over an area around McMillian Field. This is the autonomy link between UAVs and the UGS.		

Figure 57. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	802.11 (a,b,g)		
Frequency (MHz) lowest:	900 **highest (MHz): 933**	**Channel size (MHz):**	30
Link Range (Km):	5	**Power (W):**	.7
Customizable Frequency:	No	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.7482	**Longitude:**	-120.772
Brief description:	CBRN UGS #2		

Figure 58. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	802.11 (a,b,g)		
Frequency (MHz) lowest:	900 **highest (MHz): 933**	**Channel size (MHz):**	30
Link Range (Km):	5	**Power (W):**	.7
Customizable Frequency:	No	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.744	**Longitude:**	-120.7928
Brief description:	CBRN UGS 1		

Figure 59. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	UHF		
Frequency (MHz) lowest:	910 **highest (MHz):**	**Channel size (MHz):**	5
Link Range (Km):	20	**Power (W):**	1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.705566	**Longitude:**	-120.808197
Brief description:	SAOFDM control link		

Figure 60. Specific Frequency Request (From: [4]).

Figures 61 to 66 are all the test equipment that could potentially be interfered within the 2.4 to 2.5 GHZ frequency range.

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	2450 **highest (MHz): 2510**	**Channel size (MHz):**	5
Link Range (Km):	3	**Power (W):**	.4
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.72	**Longitude:**	-120.7738
Brief description:	Data link for ZigBee networking of MMALV.		

Figure 61. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	2390 **highest (MHz):**	**Channel size (MHz):**	10
Link Range (Km):	3	**Power (W):**	.5
Customizable Frequency:	Yes	**Adjustable Power:**	No
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.72	**Longitude:**	-120.7738
Brief description:	Audio/Video relay link for Zagi aircraft.		

Figure 62. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	2370 **highest (MHz):**	**Channel size (MHz):**	10
Link Range (Km):	3	**Power (W):**	.5
Customizable Frequency:	Yes	**Adjustable Power:**	No
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.72	**Longitude:**	-120.7738
Brief description:	Audio Video link for MMALV and MiniWhegs vehicles.		

Figure 63. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Mesh		
Frequency (MHz) lowest:	2400 **highest (MHz):**	**Channel size (MHz):**	20
Link Range (Km):	10	**Power (W):**	1
Customizable Frequency:	No	**Adjustable Power:**	Yes
Antenna Type:	Directional	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.718811	**Longitude:**	-120.768895
Brief description:	Mesh link to Scan Eagle UAV through tracking antenna at GCS.		

Figure 64. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Other		
Frequency (MHz) lowest:	2400 **highest (MHz): 2406**	**Channel size (MHz):**	6
Link Range (Km):	10	**Power (W):**	1
Customizable Frequency:	No	**Adjustable Power:**	No
Antenna Type:	Omni	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.715	**Longitude:**	-120.766
Brief description:	This is the analog video link on our UAVs. They will be launched from this lat/lon but will be flying around McMillian field.		

Figure 65. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	Mesh		
Frequency (MHz) lowest:	2430 **highest (MHz):**	**Channel size (MHz):**	60
Link Range (Km):	5	**Power (W):**	1
Customizable Frequency:	No	**Adjustable Power:**	Yes
Antenna Type:	Omni	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.715595	**Longitude:**	-120.764638
Brief description:	Mesh Access Point. Installed at NPS UAV VAN site Provides Mesh connectivity for domain 192.168.112.0		

Figure 66. Specific Frequency Request (From: [4]).

Figures 67 to 69 are all the test equipment that could potentially be interfered with in the lower 5.7 GHZ frequency range.

Frequency Utilization Request

Technology:	802.16 OFDM		
Frequency (MHz) lowest:	5765 **highest (MHz):**	**Channel size (MHz):**	20
Link Range (Km):	4	**Power (W):**	0.1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Directional	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.715519	**Longitude:**	-120.764251
Brief description:	Link Name: CR TOC to Nacimiento IP: 192.168.99.30		

Figure 67. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	802.16 OFDM		
Frequency (MHz) lowest:	5795 **highest (MHz):**	**Channel size (MHz):**	20
Link Range (Km):	8	**Power (W):**	0.1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Directional	**Usage:**	On-demand
Antenna polarization:		**Azimuth:**	0
Latitude:	35.705566	**Longitude:**	-120.808197
Brief description:	OFDM backbone relay node. Link: Nacimiento to LRV IP: 192.168.99.32		

Figure 68. Specific Frequency Request (From: [4]).

Frequency Utilization Request

Technology:	802.16 OFDM		
Frequency (MHz) lowest:	5765 **highest (MHz):**	**Channel size (MHz):**	20
Link Range (Km):	4	**Power (W):**	0.1
Customizable Frequency:	Yes	**Adjustable Power:**	Yes
Antenna Type:	Directional	**Usage:**	Uninterruptable
Antenna polarization:		**Azimuth:**	0
Latitude:	35.705566	**Longitude:**	-120.808197
Brief description:	OFDM backbone relay node. Link: Nacimiento to CR TOC IP: 192.168.99.31		

Figure 69. Specific Frequency Request (From: [4]).

In the evaluation of whether there will be interference there are several affects that must be considered. This not only includes the frequency and whether or not the frequency can and may be customized (adjusted) but all of the following as well:

- Channel size.
- Power out and whether the power out is adjustable.
- Estimated range.
- Antenna type and polarization.
- Usage requirements and what the use requirements are.
- Location of system use.

Another tool to use that is offered by this website is the frequency utilization explorer. This tool does not take into account the background noise of measured frequencies by a spectrum analyzer, but the tool does help in the de-confliction of the TNT test systems.

Figures 70 and 71 display the information from the frequency utilization request page but in a graphical slide bar. The thickness of the cone green area directly relates to multiple frequencies being used in that frequency range of the spectrum. Figure 71 shows how the scale can be decreased to show the number of items within a specific area and to assist the Frequency Manager in de-conflicting potential interference between TNT test systems.

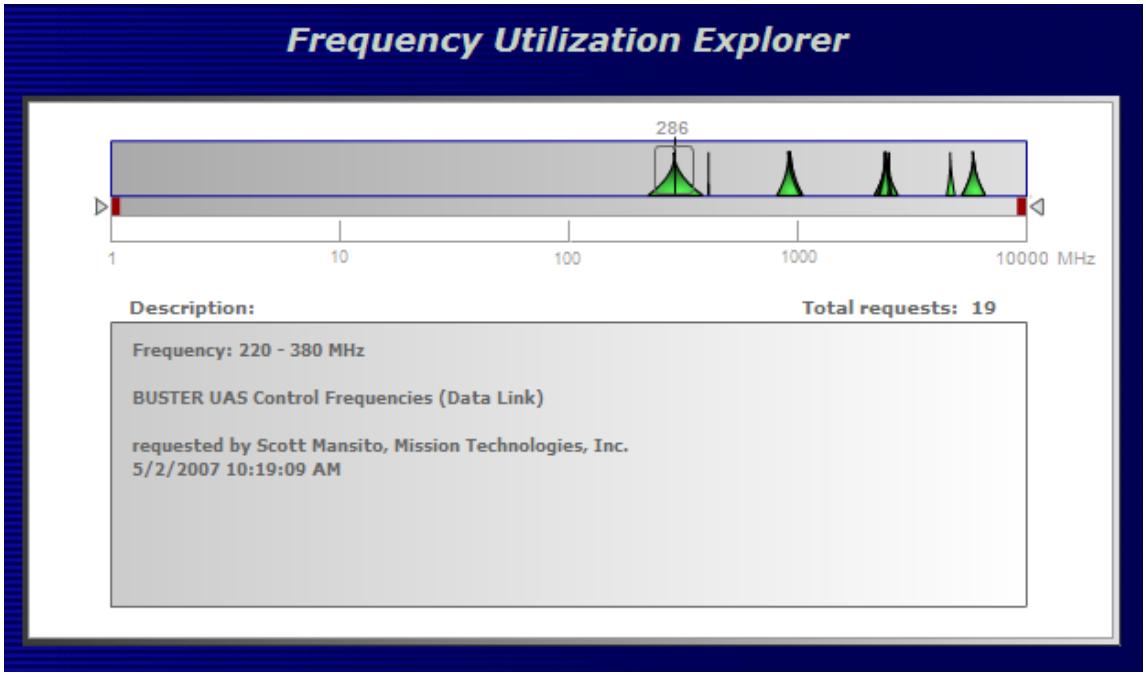

Figure 70. Frequency Utilization request page (From: [4]).

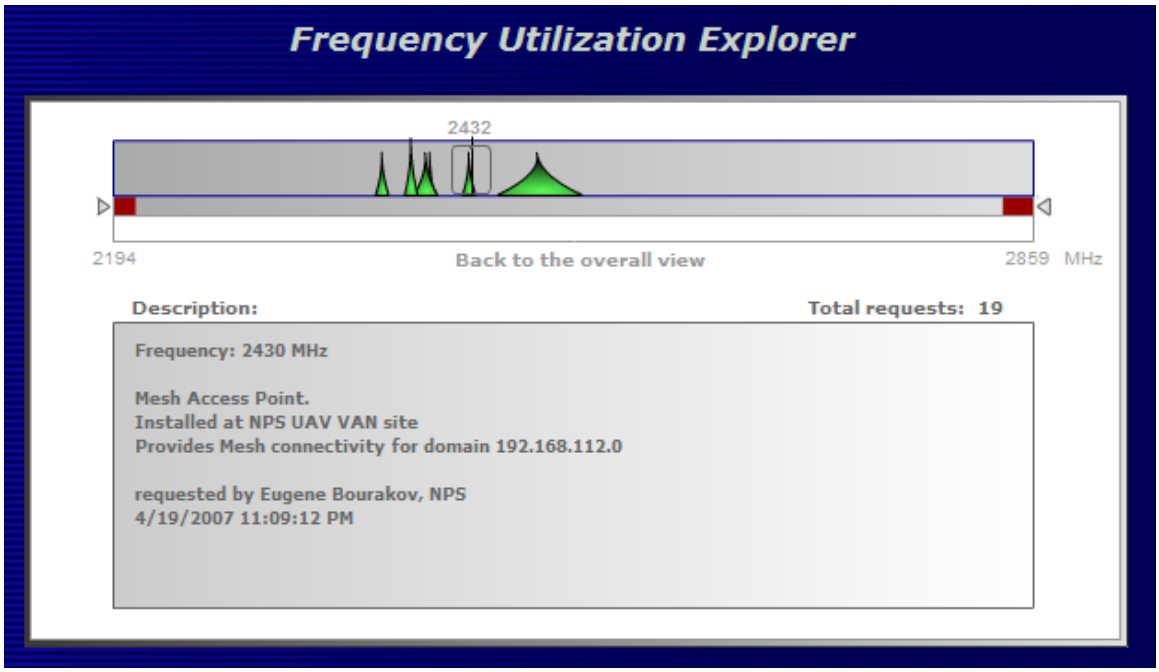

Figure 71. Frequency Utilization request page (From: [4]).

The last tool discussed for use on this website is the frequency map. This tool will help the Frequency Manger by providing a geographical map together with a layered display of the position of where the various test events are scheduled to take place. This tool also allows the Frequency Manager to map the location, if identified, of the source of potential interference that was identified while taking readings with the spectrum analyzer. This tool links to and uses Google Earth to display the frequency requests that are entered into the website.

Figure 72 shows a Google Earth representation of Camp Roberts and the area where the various tests have taken place. The test systems are listed by request number and the towers are color coded to represent whether the site is high power or low power. Figure 73 displays a more detailed view of Nacimiento Hill and requests 63, 64 and 65. Only request 64 had option to open and acquire the amplifying information. Figure 74 displays all the activity in the vicinity of the CR TOC (Camp Roberts Tactical Operations Center) and the airstrip that boarder's the TOC. Figures 75 to 78 provides a display of some of the locations of the systems that may have caused interference from the frequencies that we detected using the spectrum analyzer. Only the requests needed for consideration based on earlier measurements were opened.

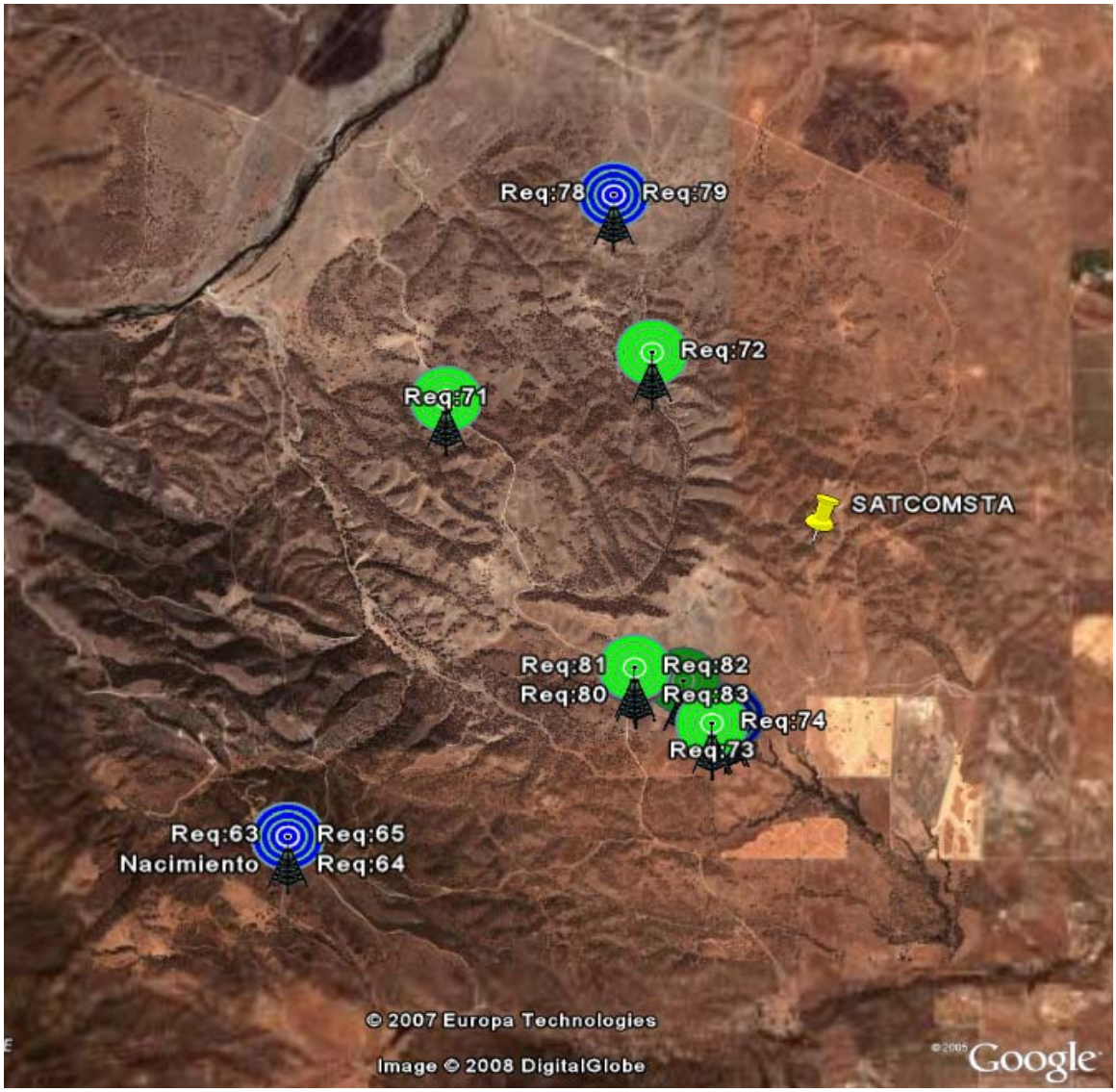

Figure 72. Google Earth Display of Camp Roberts (From: [4]).

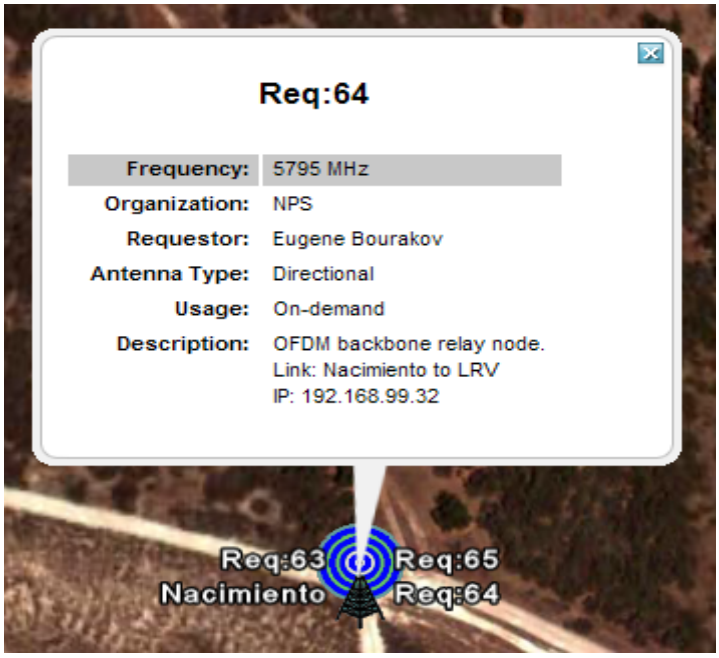

Figure 73. Nacimiento Hill with Request 64 displayed (From: [4]).

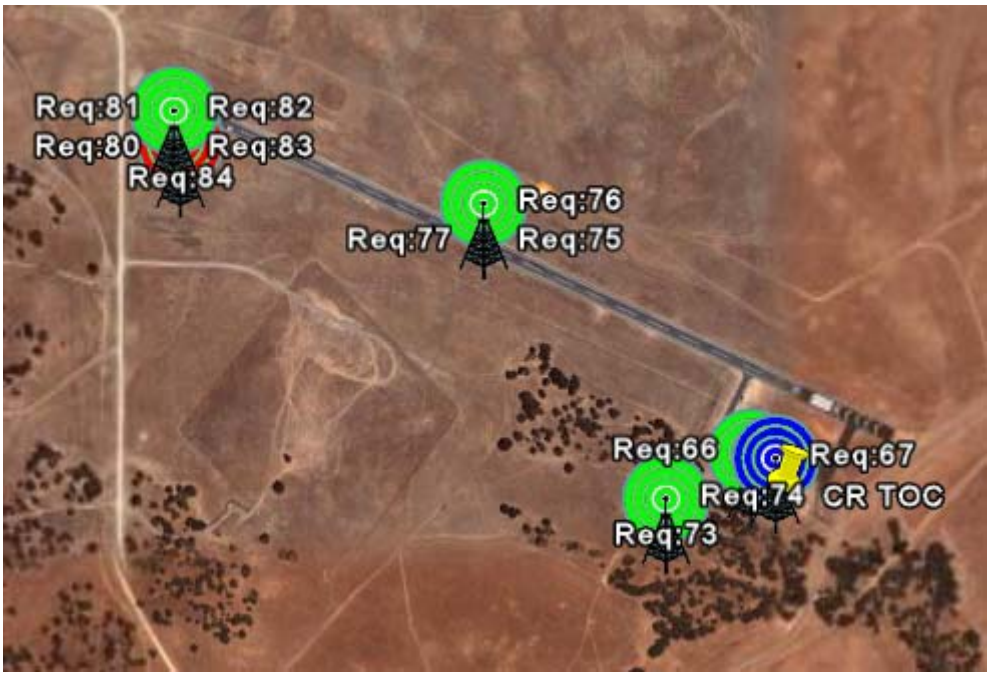

Figure 74. Camp Roberts Tactical Operations Center (From: [4]).

Figure 75. Amplifying Information on Request 75 (From: [4]).

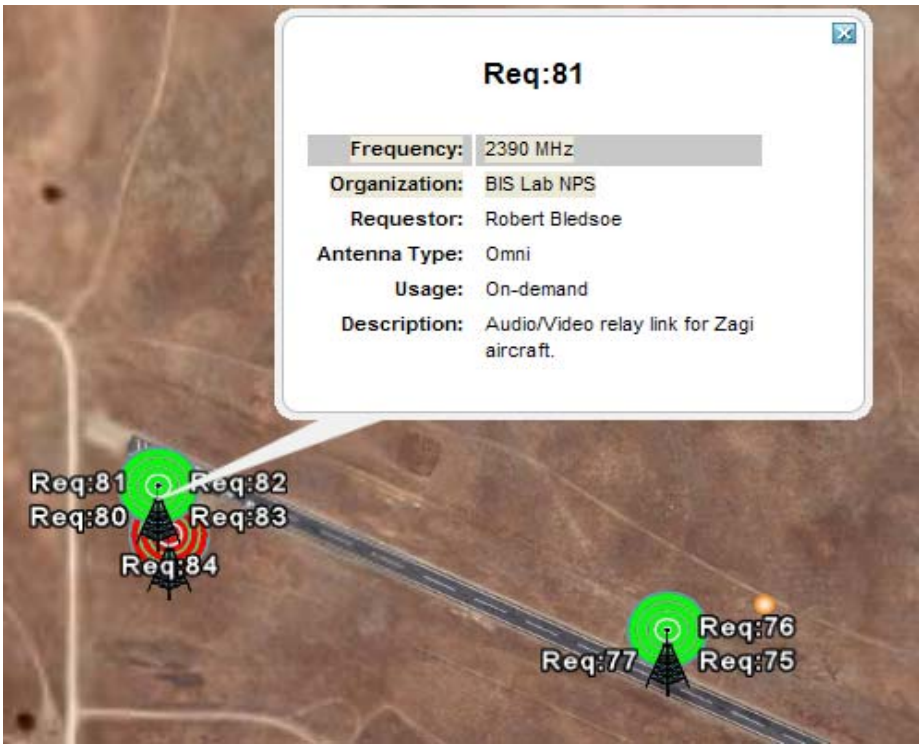

Figure 76. Amplifying Information on Request 81 (From: [4]).

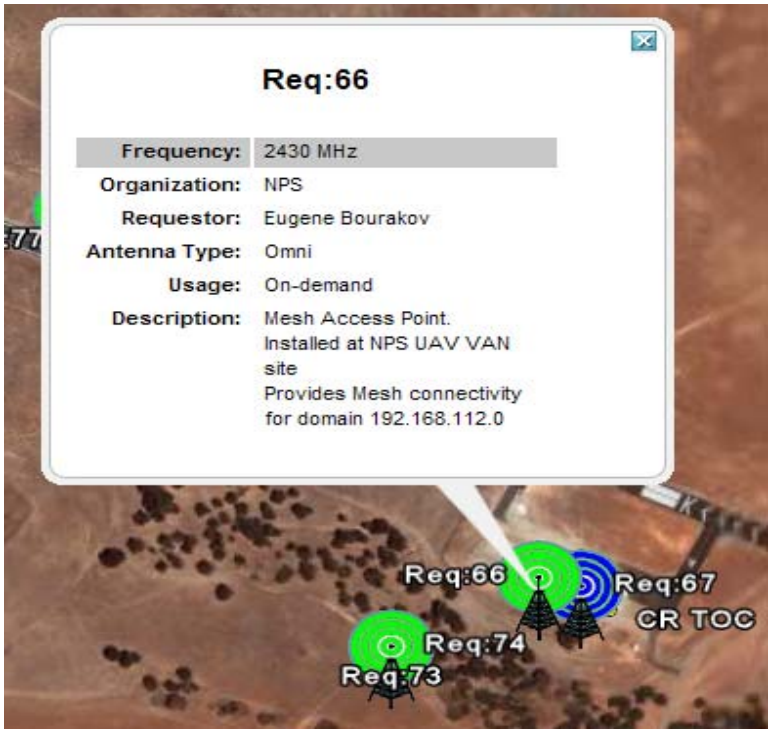

Figure 77. Amplifying Information on Request 66 (From: [4]).

Figure 78. Amplifying Information on Request 67 (From: [4]).

Now all the initial information to start the frequency management efforts has been acquired. Measurements have been taken, a list of systems that are to be tested during this TNT event have been gathered and the frequencies that may have caused interference have been identified. In addition, a mapping data displayed in both a frequency spectrum view and a geographic view has been generated. The three frequency areas that will be examined are the 900 MHZ, 2.4-2.5 GHZ and 5.75 GHZ.

First the 900 MHZ frequency arena will be examined. When measurements were taken potential problems were detected in the 870-950 MHZ range, this problem was detected everyday the measurements were taken (Note: Figure 52). When examining the systems that were operating in this range it was discovered that many systems were utilizing this frequency range (Note: Figures 54 to 60). These systems are as follows:

- Data link for Zagi aircraft. 900 MHZ, channel size 50 MHZ, power out .6 Watts.
- Command and control link and the back up antenna for command and control link for Scan Eagle. 920 – 928 MHZ, channel size .2 MHZ, power out 1 Watt.
- Autonomous (UAV) Unmanned Arial Vehicles link for 3 (UAV's) and the UGS and CBRN UGS numbers 1 and 2. 900-933 MHZ, channel size 30 MHZ, power out .7 Watts.
- SAOFDM control link. 910 MHZ, channel size 5 MHZ, power out 1 Watt.

As a Frequency Manager the following was noted from the website information. First, the number of possible interfering systems was narrowed down from seven to four. This was done by identifying three of the items listed as either backup systems or different parts to an overall system. Next, it is important to note from our frequency management experience that the 900 - 928 MHZ listed for use with the Scan Eagle UAV is set to operate in a selectable channel and frequency hop between 921-925 MHZ. This is important to note because unless there is another system that operates close enough to the Scan Eagle area of operation with a very large amount of power broadcasting and covering the whole 921 – 925 MHZ range or a system matches the hopping pattern that is used by the Scan Eagle system it may as well cause interference.

The Self Aligning OFDM antenna link is located and used to align our directional antennas that maintain the network. It is important to understand that if there is interference or a network issue this may cause a loss to the tactical network that is being utilized for all the TNT testing. Therefore, it is important to note that there is the potential for interference with these antennas that will cause measurements to be skewed.

When planning for the NPS UAV's and the Zagi UAV, which will be operating in the same general area around the airfield next to the TOC, it is important that they not interfere with each other. In fact the NPS UAV, Scan Eagle and Zagican be de-conflicted locally with the TNT test director. If any of these UAV's experience interference problems the first thing the frequency manager must discover is when the interference begin. The frequency manager can then request either shutting down or delaying operating equipment that may be causing the interference. But, it is also very important to note that background noise has been measured in this frequency range, which may be the cause. Due to limited time and resources, as well as the type of spectrum analyzer in use the location of the source of the signals being received was not ascertained.

Next, we will examine the 2.4 – 2.5 GHZ range. When the measurements were taken (Figure 52) a signal within this range was received everyday. Figures 61 to 66 list the systems that will use this frequency range for the TNT events. These are as follows:

- Data link for the ZigBee networking of MMALV. 2450-2510 MHZ.
- Audio/Video relay link for Zagi aircraft. 2390 MHZ.
- Audio/Video link for MMALV and MiniWhegs vehicles. 2370 MHZ.
- Mesh link to Scan Eagle UAV through tracking antenna at GCS. 2400 MHZ.
- Analog video link for UAV's. 2400-2406 MHZ.
- Mesh Access Point installed at NPS UAV VAN site. 2430 MHZ.

During the TNT test events, there was a number of interference issues for the UAV's operating in this frequency range in the vicinity of the airfield. In the process of taking frequency readings measurements were also taken on Nacimiento Hill. It was at this juncture that a 2.4 GHZ signal was discovered and appeared to be interfering with APL UAV's operated by the TOC over the flight. On Nacimiento Hill a directional

antenna was located that seemed to be the source of the signal that was interfering with the UAV's. This parabolic antenna is pointing from Nacimiento Hill about 10 degrees to the left of the SATCOM station. This was a prime example of the importance of understanding the electromagnetic environment and ensuring that it is properly mapped. If frequency measurement readings had not been taken and the antenna on Nacimiento Hill had not been ascertained as the culprit causing the interference many more valuable hours of test time would have been lost as the test director and others tried to trouble shoot the problem.

Finally, the 5.7 GHZ frequency range will be examined as potential interference detected in taking our measurements (Figure 52). Figures 67 to 69 had the following systems identified:

- 802.16 link from TOC to Nacimiento Hill. 5765 MHZ.
- 802.16 OFDM backbone relay node Nacimiento Hill to LRV. 5795 MHZ.
- 802.16 OFDM backbone relay node Nacimiento Hill to CR TOC. 5765 MHZ.

From the readings that were taken and documented in Figure 52 a direct source of the signal was unable to be determined. However, from the examination of the signal and the operations being conducted it is a confident assumption that the signal detected was from the 802.16 network.

C. WEB SITE PROTOTYPE LESSONS LEARNED

From examining and using this website from the last TNT Exercise until the writing of this thesis there are several points of conjecture that have been learned. First of all, the TNT-MIO Frequency Manager Website is a great tool for the Operational Frequency Manager and with some minor modifications could be an effective DSI. The excellent characteristics of the website are not going to discussed in detail because those functions work well and do not need to be changed. However, any helpful additions to the website that have been postulated will be a discussed.

The following is a quick overview of the website. The TNT-MIO website allows users to register and for the Frequency Manager to be the site manager. The website allows those registered to enter specific details that can be listed on the site as well mapped in both the Frequency Utilization Explorer and Google Earth. The Frequency Manager also has a notepad page to enter notes, which has been used to enter the specifics of the measurements that have taken.

It would be useful if on the Frequency Utilization Request page that lists the status of all the systems, Figure 53, would organize all the frequencies in frequency numerical order. If Figure 53 is examined it can quickly be observed that the first three frequency entries are out of order. They are listed 402-404. 2450-2510, then 900 MHZ. By having them organized in order it will allow the Frequency Manager the ability to identify systems that may cause mutual interference more intuitively.

The Frequency Utilization Explorer is a great tool; however, it is a little slow and cumbersome to use. For example, if a large green area is identified (Note Figures 70 and 71) the user must resize the area down until all the individual systems can be identified. Then each one must be examined separately until the right one is found. Although for an overall planning tool it is useful. However, when the user is in a situation where the test director or mission commander is waiting for an answer to a question and time is limited then this becomes very cumbersome to use. When Frequency Manger has to answer operational questions one must resort to looking at the list of frequencies then shifting the display to their note pages to get information then possible shifting to the geographic map. If there was a way to have measured frequencies, geographic mapping, frequency mapping, and notes displayed simultaneously that would be a complementary benefit. As discussed previously planning the mission or testing prior to the event the website supports those functions well. However, as a real world DSI having the ability to look at all the areas mentioned would be essential.

When looking at the Google Earth mapping capability, Figures 72 to 78, which is very useful there are a couple of recommend additions. First, the request numbers are not readily cross-referenced to the Figure 53. The shade of coloring is good but it would also be useful if range rings were displayed and for a directional antenna if the direction of the radiation could be documented.

D. CONCLUSION

The experience obtain during the different TNT experiments it has become apparent that anytime there is multiple wireless technology equipment being operated and brought together it is essential to have an operational frequency manager as part of the team. The addition of this person will potentially save the test director or personnel in charge of the operation many hours of de-conflicting interference issues. The Frequency Manager must be a part of the planning as well as operational portions of the events. For the Frequency Manager to be a successful member of the team they must adhere to the steps discovered and outlined by this thesis.

First, the Frequency Manager must have a clear understanding of the area of the test or operation. The earlier the better, for this will give the individual time to do the research needed to be successful. Research of the area must be conducted to identify what antennas, towers and frequencies are currently being used in the area. By doing this the individual will potentially be able to associate frequencies received when taking measurements with the mapped out frequencies in use.

Next, the Frequency Manager must take a spectrum analyzer and other needed equipment, GPS receiver for example, to the anticipated area of operation or testing. Having a few days in the area to take measurements is useful. It will allow trends to be identified and documented. From this information the Frequency Manager will have the data necessary to develop the geographic map as well as the spectrum map. It has been discovered that the mapping of frequencies in both arenas is very useful for the de-confliction of wireless systems.

Upon completing the mapping of documented and measured frequencies in the environment the Frequency Manager must examine all the wireless systems being brought to the test or area of operations and by whom. Once the list of wireless systems to be used is developed, something similar to the TNT frequency utilization website can be used. Now the Frequency Manager must de-conflict the wireless systems that are operating on the same or similar frequencies. Understanding what systems have priority to operate and deciding that only one system can be used at a time can do this. The individual must help coordinate the interference problems that may be caused by their own systems. This can be accomplished by time of use, space the system is operating arena, adjusting power out of the systems, adjusting the operating frequency or the polarization of antennas if possible. There are many things to consider when de-conflicting individual systems.

After, individual systems are de-conflicted then the Frequency Manager must identify what systems are in danger of being interfered with based on the measurements that were taken earlier. Once this is accomplished then the test director or mission commander must be briefed on the potential of interference of the systems scheduled to be used. An overall risk assessment can be accomplished along with contingency plans in case interference gets to the point of making some of the systems unusable.

By the Frequency Manager following these steps for either test or operational events the team will be able to avoid the many hours of frustration associated with trying to de-conflict interference issues with wireless systems. In fact, this can be the difference between success and failure of the test or mission.

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VI. TEST PLAN TWO AND RESULTS

A. BACKGROUND

This is the second test plan formulated for the thesis and is for the purpose of frequency mapping in support of future (Tactical Network Topology) TNT experiments in the San Francisco Bay area. The results will be used to modify our frequency mapping diagrams and tools. Test Plan Two will be incorporated into the thesis and will be amplified and/or modified by thesis advisors as needed. The purpose of this test is for the thesis researchers (Scott Walker and Lauro Luna) to take frequency measurements in and around the antenna sites used to relay data during the MIO TNT (Maritime Interdiction Operations) events.

This test will be conducted over a 2-3 day period using the TNT test bed established in the San Francisco Bay area. Equipment to be used for the test will be as follows:

- The TNT network test bed in the San Francisco Bay area.
- Portable spectrum analyzer to be provided by Dr. Bordetsky.
- Lap top computer for research and notes to be provided by research students.
- Administrative supplies (paper, pencils and pens, folders) to be provided by research students.

B. SITES TO BE MEASURED

Test Plan two will be conducted in the San Francisco Bay area and will complete the second phase of tests and experiments for thesis documentation. The TNT sites to be visited are the following:

- Antennas located at the Lawrence Berkeley National Lab.
- Antennas located at San Francisco Police Golden Gate Bridge Building.
- Antennas located on Yerba Buena Island.
- Antennas located at Lawrence Livermore National Lab.

C. TEST PLAN TWO SPECIFIC STEPS

1. Ensue equipment is available to run test.
2. Determine dates for the test.
    a. De-conflict other local events
    b. De-conflict classes
    c. Obtain Dr. Bordetsky's approval on test dates
3. Once dates are approved
    a. Submit request for thesis travel
    b. Through student services arrange lodging
    c. Acquire orders and approval for POV or car rental.
4. Prior to departure
    a. Familiarization with equipment set-up and operation to include software and hardware of specific systems to be used during the experiment.
    b. Map out area and plan out travel to and from test sites.
    c. Ensure all equipment is in hand to include this test plan.
5. Day One
    a. Visit and conduct tests at:
        i. Antennas located at the Lawrence Berkeley National Lab.
        ii. Antennas located at San Francisco Police Golden Gate Bridge Building.
        iii. Antennas located on Yerba Buena Island.
    b. Document readings.
6. Day Two
    a. Visit and conduct tests at:
        i. Antennas located at Lawrence Livermore National Lab.
    b. Document readings.
7. Day Three
    a. Will be used as a back-up day for events unable to be accomplished from day's one and two.
    b. Used to test ideas and theories gained from the previous two days of testing.
8. Return from San Francisco Bay area.
    a. File travel claim
    b. Conduct briefing with Dr. Bordetsky of results and lessons learned from experiment.
    c. Write the test results up as part of the thesis.

D. INTRODUCTION

Test Plan Two was conducted 25 January 2008 to 26 January 2008 in the San Francisco Bay area. The purpose of this testing is to give the test directors of the MIO

TNT an understanding of the electromagnetic environment that will be encountered and provide the information as to potential interference issues. An Anritsu MS2721B spectrum analyzer was used with the following antennas:

806 – 869 MHZ
896 – 941 MHZ
1.71 – 1.88 GHZ
1.85 – 1.99 GHZ
2.4 – 2.5 GHZ
5.725 – 5.825 GHZ

The object of this test is to take frequency readings for the purpose of mapping these frequencies for thesis studies. The objectives are to become familiar with the procedures to detect and document the frequency environment and to provide a basis for frequency management. The information gathered will be documented in this thesis.

E. WEATHER CONDITIONS: 25 – 26 JANUARY 2008

During both days of taking readings heavy rain and wind was experienced. Due to these weather conditions and wanting to protect the test equipment being used precautions were taken by taking readings in sheltered areas near the antenna structures. The exact source of detected signals received was undetermined, however all signals detected were perceived a potential cause for interference.

F. SCANNING RESULTS LAWRENCE BERKELEY NATIONAL LAB

The routers supporting TNT were labeled as follows:

- LBNL to GGB 5735 MHZ (192.168.72.200)
- LBNL to CGI 5815 MHZ (192.168.72.206)
- LBNL to Alameda 5790 MHZ (192.168.72.202)

Frequency Measurements:

- 500 – 750 MHZ had a lot of noise and the below frequencies raised out of the noise.
- 640 MHZ to about 59 DBM.

- 748 MHZ to about 60-62 DBM.
- 755 MHZ to about 62 DBM.
- 935 MHZ to 65 DBM and there was a lot of background noise around this signal.
- 1.5 GHZ 75-80 DBM
- 2.43 GHZ to 72-80 DBM (Note: This may have been a microwave signal that is operating on the roof at 2.4 GHZ)
- 5.73 GHZ to 68-70 DBM (Note: This may be the LBNL to GGB link.)
- 5.79 GHZ to 68-70 DBM (Note: This may be the LBNL to Alameda link.)

G. SCANNING RESULTS SAN FRANCISCO POLICE GOLDEN GATE BRIDGE BUILDING

- Note: 0-1 GHZ is very noisy.
- 100 MHZ to 55 DBM
- 195 MHZ to 62-69 DBM
- 500 MHZ to 60 DBM
- 725 MHZ to 65 DBM
- 880 MHZ to 55 DBM is a very strong signal.
- 2.4 GHZ is a weak signal but had occasional bursts.

H. SCANNING RESULTS YERBA BUENA ISLAND

455 MHZ – 1 GHZ had a lot of background noise and various signals. The following signals stand out:

- 730 MHZ to 69-73 DBM
- 765 and 768 MHZ to 68-70 DBM had to distinct spikes.
- 850-900 MHZ to 62-78 DBM
- 915 MHZ to 52 DBM an intermittent signal.
- 927 MHZ to 51-84 DBM
- 941 MHZ to 51-84 DBM
- 1.85-1.98 GHZ to 68-84 DBM.
- 2.43 GHZ to 50-89 DBM.

I. SCANNING RESULTS LAWRENCE LIVERMORE NATIONAL LAB

- Note: 100 MHZ - 1 GHZ is very noisy.
- 120 MHZ to 70 DBM
- 400 MHZ to 65 DBM
- 475 MHZ to 78 DBM intermittent signals.
- 628 MHZ to 65 -68 DBM
- 755 MHZ to 68 - 75 DBM
- 875 MHZ to 70 - 80 DBM
- 950 MHZ to 68 DBM
- 1.88 GHZ is a very weak signal.

J. CONCLUSIONS

In discussions with Dr. David Netzer and Dr. Alex Bordetsky prior to this TNT event it is apparent that frequency management is a key component to the success of the TNT-MIO experiments in the San Francisco Bay area. Historically, at these events there have been delays and complications in conducting these test events because of frequency conflicts that prevented events from successfully executing on time. Frequently this problem is the effect of running different events where equipment operated on similar or the same frequency resulting in events being delayed until the conflict had been resolved.

The purpose of conducting a frequency spectrum analysis is to test and determine the frequency environment that the TNT MIO test events will be operating in while in the San Francisco Bay area. The frequency manager to manage potential interference and conflicts would draw on these measurements along with the identified and documented frequencies used to support the events. It is apparent that the frequency manager must have knowledge of the frequency environment and have a detailed understanding of the event timelines, frequencies used by various equipment and test scenarios. To help in the prevention of mutual interference avoiding events from executing in accordance with the schedule each test group must not activate their equipment prior to receiving permission from the frequency manager.

As noted from the previous test it is important for the frequency manager be knowledgeable about the frequency environment. For example, below is a list of information that the frequency manager needs to know prior to the start of events:

- Are the antennas being used omni-directional or directional?
- What power out is being used?
- Is the equipment fixed frequency or frequency hopping?
- Can the equipment frequency be adjusted?
- What location will the antennas be operating in?
- What are the test objectives?
- What systems have priority during what events?
- Knowledge of the existing frequency environment prior to lighting off any test equipment to understand where there may be problems that are not caused by test equipment conflicting with each other.

Having a designated frequency manager that is involved from the beginning of exercise planning through completion of the test events is critical to the success of any test or operational event. Without a designated frequency manager there is a very serious potential for many wasted hours of frustration as test coordinators spend hours trying to de-conflict interference problems as they arise. The frequency manager removes this burden from the exercise coordinators and takes responsibility for the de-confliction of frequencies in the environment and operational event frequencies being used.

These measurements were taken to validate the frequency environment for the frequency manager prior to the TNT- MIO events. The environment was measured and the readings were documented. All experimental equipment operational frequencies will be documented in the TNT Frequency Manager DSI prior to the event. The measurement information along with the equipment frequency information correlation with the schedule of test events will assist the frequency manager to properly advise the test director of potential interference problems.

VII. MAPPING RESEARCH APPLIED BASED ON SAN FRANCISCO EXPERIMENTS

A. BACKGROUND

Based on the research conducted at San Francisco and the review of existing websites that offer a form of frequency mapping, documented in Chapter III, a prototype frequency management tool has been developed that is linked to the TNT webpage. This prototype will take into account the lessons learned from the test events and from the collected measurements. This site will be the basis for a Frequency Manager Decision Support Interface.

In support of the upcoming TNT-MIO event that will be taking place in March 2008 and to research interference problems encountered during the last TNT-MIO event in 2007 measurements have been taken at the four designated areas where TNT has antennas that support the backbone of the TNT network. The areas visited were Berkeley National Labs, Lawrence Livermore National Labs, Yerba Buena Island and the San Francisco Police Golden Gate Bridge Building.

From the frequency measurements that were recorded the rest of this chapter will walk through the frequency manager planning process. The specific results that will be entered into the notes portion of the Frequency Manager DSI linked to the TNT website are as follows:

Scanning Results Berkeley Lab:

The routers identified supporting the TNT backbone were labeled as follows:

- LBNL to GGB 5735 MHZ (192.168.72.200)
- LBNL to CGI 5815 MHZ (192.168.72.206)
- LBNL to Alameda 5790 MHZ (192.168.72.202)

500 – 750 MHZ had a lot of noise and the below frequencies raised out of the noise.

- 640 MHZ to about 59 DBM.
- 748 MHZ to about 60-62 DBM.
- 755 MHZ to about 62 DBM.

896-941 MHZ has a lot of interference.

935 MHZ to 65 DBM and there was a lot of background noise around this signal.

1.5 GHZ 75-80 DBM

2.43 GHZ to 72-80 DBM (Note: This may have been a microwave signal that is operating on the roof at 2.4 GHZ)

5.73 GHZ to 68-70 DBM (Note: This may be the LBNL to GGB link.)

5.79 GHZ to 68-70 DBM (Note: This may be the LBNL to Alameda link.)

Scanning Results Golden Gate Bridge:

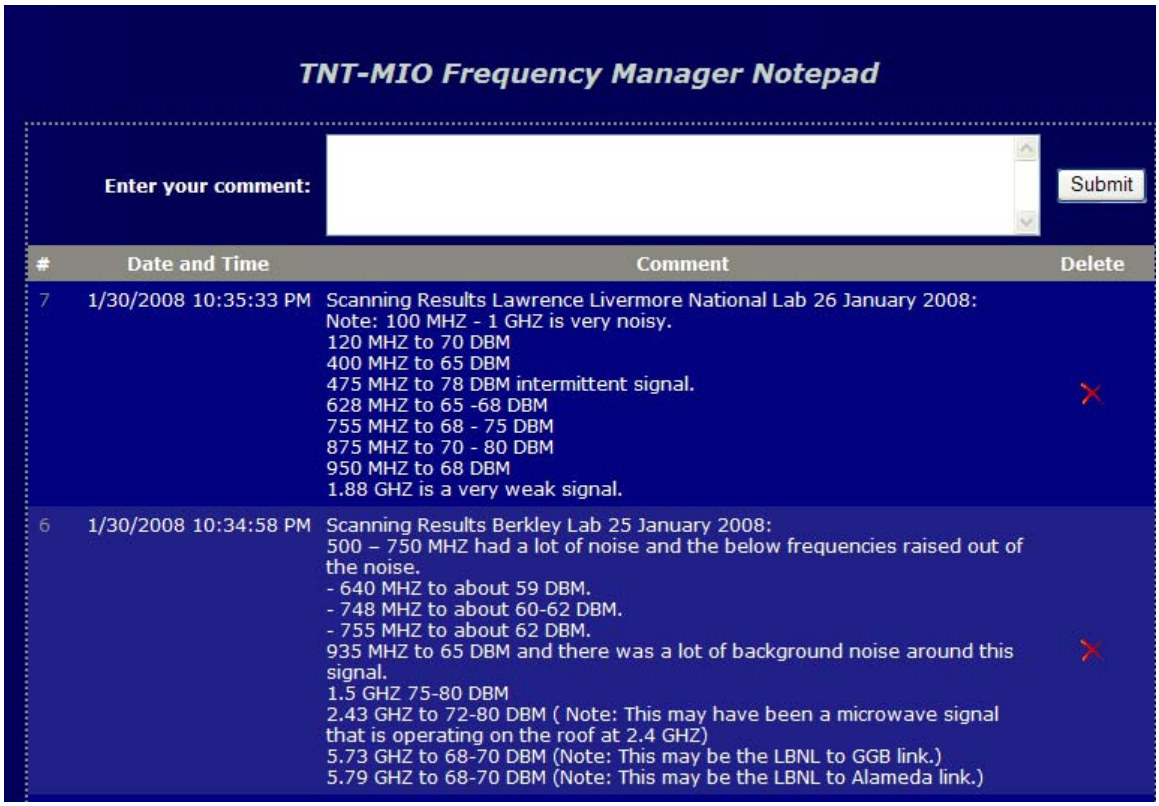
- Note: 0-1 GHZ is very noisy.
- 100 MHZ to 55 DBM
- 195 MHZ to 62-69 DBM
- 500 MHZ to 60 DBM
- 725 MHZ to 65 DBM
- 880 MHZ to 55 DBM is a very strong signal.
- 846-941 MHZ has a lot of noise.
- 2.4 GHZ is a weak signal but had occasional bursts.

Scanning Results Yerba Buena Island: 455 MHZ – 1 GHZ had a lot of background noise and various signals. The following signals stand out:

- 730 MHZ to 69-73 DBM
- 765 and 768 MHZ to 68-70 DBM had to distinct spikes.
- 850-900 MHZ to 62-78 DBM
- 915 MHZ to 52 DBM an intermittent signal.
- 927 MHZ to 51-84 DBM
- 941 MHZ to 51-84 DBM 1.85-1.98 GHZ to 68-84 DBM.
- 2.43 GHZ to 50-89 DBM.

Scanning Results Lawrence Livermore National Lab:

- Note: 100 MHZ - 1 GHZ is very noisy.
- 120 MHZ to 70 DBM
- 400 MHZ to 65 DBM
- 475 MHZ to 78 DBM intermittent signal.
- 628 MHZ to 65 -68 DBM
- 755 MHZ to 68 - 75 DBM
- 875 MHZ to 70 - 80 DBM
- 950 MHZ to 68 DBM
- 1.88 GHZ is a very weak signal.



5	1/30/2008 10:33:55 PM	Scanning Results Yerba Buena Island 25 January 2008: 455 MHZ – 1 GHZ had a lot of background noise and various signals. The following signals stand out: - 730 MHZ to 69-73 DBM - 765 and 768 MHZ to 68-70 DBM had to distinct spikes. - 850-900 MHZ to 62-78 DBM - 915 MHZ to 52 DBM an intermittent signal. - 927 MHZ to 51-84 DBM - 941 MHZ to 51-84 DBM 1.85-1.98 GHZ to 68-84 DBM. 2.43 GHZ to 50-89 DBM.
4	1/30/2008 10:33:02 PM	Scanning Results Golden Gate Bridge 25 January 2008: Note: 0-1 GHZ is very noisy. 100 MHZ to 55 DBM 195 MHZ to 62-69 DBM 500 MHZ to 60 DBM 725 MHZ to 65 DBM 880 MHZ to 55 DBM is a very strong signal. 2.4 GHZ is a weak signal but had occasional bursts.

Figure 79. Measurement information entered into the TNT Frequency Manager Website (From: [4]).

Figure 80. Google Earth display of the antenna locations where measurements were taken (From: [4]).

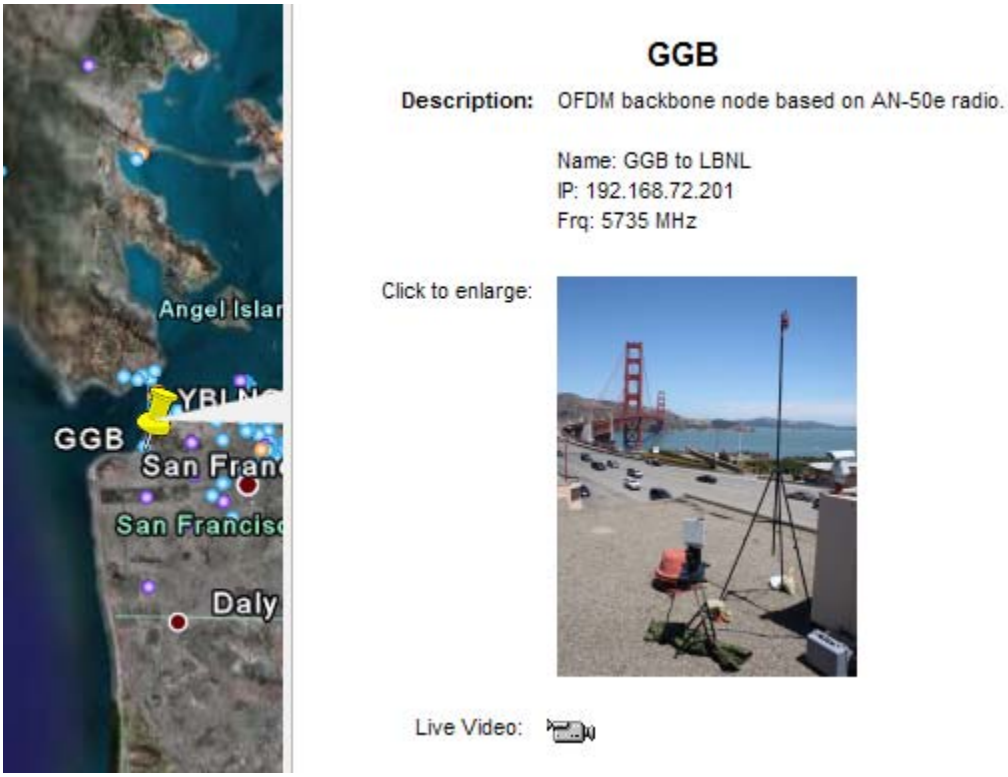


Figure 81. Details of the San Francisco Golden Gate Bridge Building location (From: [4]).

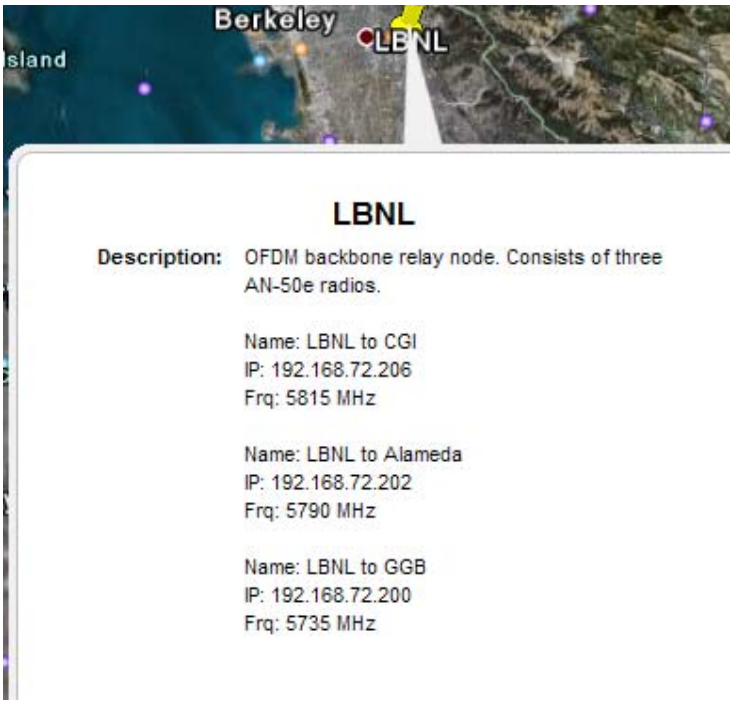


Figure 82. Details of the Lawrence Berkeley National Lab location (From: [4]).

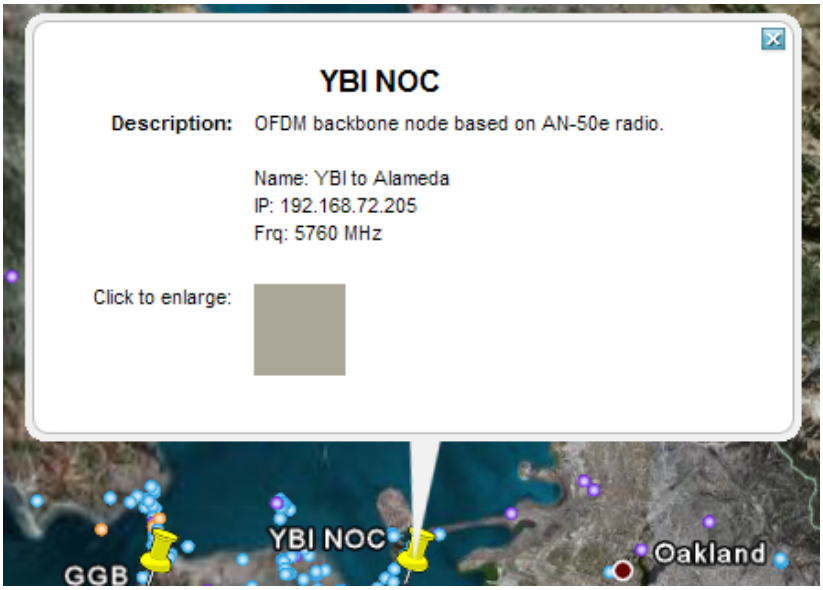


Figure 83. Details of the Yerba Buena Island NOC (From: [4]).

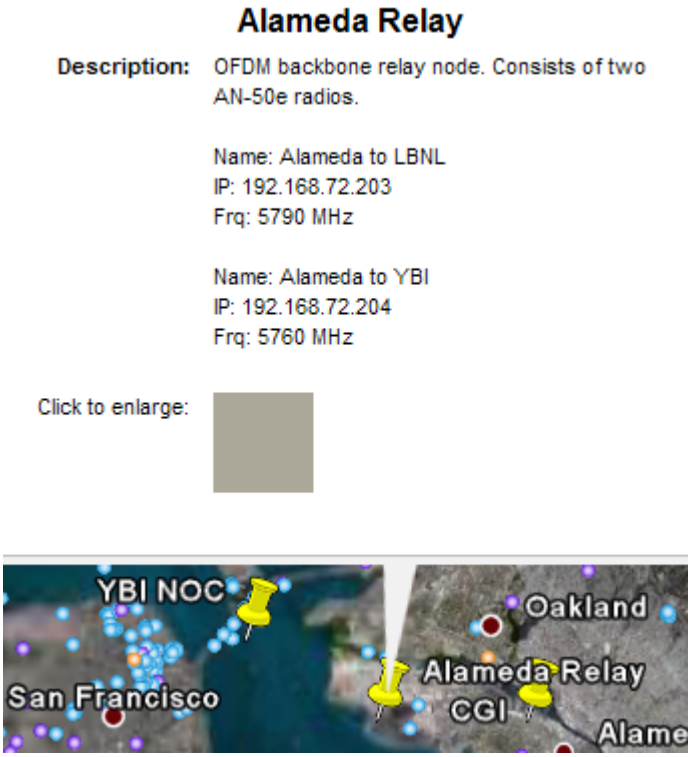


Figure 84. Site where measurements were NOT taken (From: [4]).

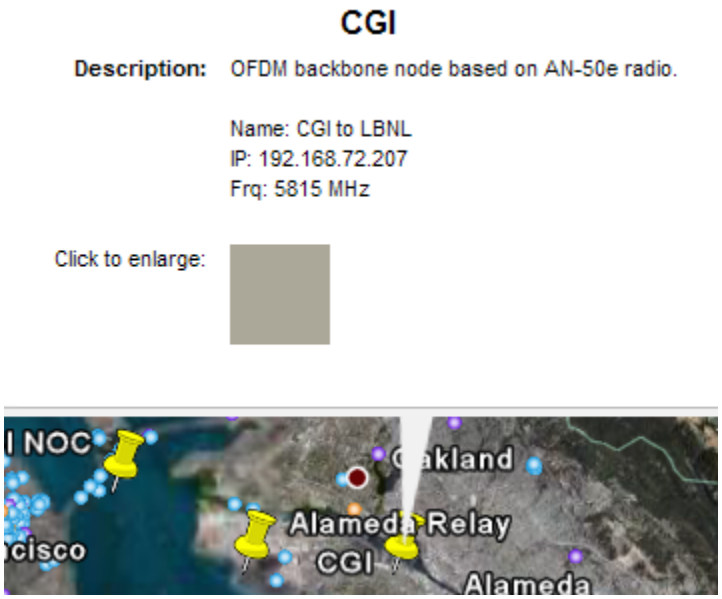


Figure 85. Site where measurements were NOT taken (From: [4]).

The next step the frequency manager needs to do is research any other possible sources of radiating sites in the area. Examining the information provided by the FCC website did not prove very useful. This is because there was no clearly defined frequency data that could be correlated with the frequencies that were collected by the measurements taken. Examining the amateur radio repeater mapping website there is not only location data but also frequency information that may possibly correlate with the measurements that were collected. According to this site there are 82 sites in the San Francisco Bay area that could be of interest. These sites operate in two distinct frequency areas: 145.11 to 147.975 MHZ and 440.075 to 446.7 MHZ. This explains a good portion of the noise that was observed below the 500 MHZ frequency range. This is important information for the frequency manager.

Now the frequency manager will examine all the possible conflicts that could occur by both mutual interference and interference from outside sources given the frequencies that were measured.

Frequency Utilization Requests

Frequency Utilization Request	Requestor	Date/Time Received	Status
402 - 404 MHz, Weather Balloon (Rad...	NPS, peter guest	5/8/2007 10:16:39 AM	Approved
2450 - 2510 MHz, Data link for ZigB...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:48:34 AM	Approved
900 MHz, Data link for Zagi aircra...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:46:42 AM	Approved
2390 MHz, Audio/Video relay link fo...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:45:18 AM	Approved
2370 MHz, Audio Video link for MMAL...	BIS Lab NPS, Robert Bledsoe	5/3/2007 12:44:03 AM	Approved
4400 - 4775 MHz, BUSTER UAS - FSK /...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:26:16 AM	Approved
220 - 380 MHz, BUSTER UAS Control F...	Mission Technologies, Inc., Scott Mansito	5/2/2007 10:19:09 AM	Approved
920 - 928 MHz, Back up antenna for ...	NPS, Ben Wring	5/2/2007 9:06:28 AM	Approved
920 - 928 MHz, Command and control ...	NPS, Ben Wring	5/2/2007 9:04:51 AM	Approved
2400MHz, Mesh link to Scan Eagle UA...	NPS, Ben Wring	5/2/2007 8:52:34 AM	Approved
2400 - 2406 MHz, This is the analog...	jhu-apl, chad hawthorne	5/2/2007 7:54:54 AM	Approved
900 - 933 MHz, Our three UAVs will ...	jhu-apl, chad hawthorne	5/2/2007 7:46:34 AM	Approved
900 - 933 MHz, CBRN UGS #2	jhu-apl, chad hawthorne	5/2/2007 7:43:51 AM	Approved
900 - 933 MHz, CBRN UGS 1	jhu-apl, chad hawthorne	5/2/2007 7:42:45 AM	Approved
5765MHz, Link Name: CR TOC to Nacim...	NPS, Eugene Bourakov	4/20/2007 11:56:58 PM	Approved
2430MHz, Mesh Access Point. Instal...	NPS, Eugene Bourakov	4/19/2007 11:09:12 PM	Approved
910MHz, SAOFDM control link	NPS, Eugene Bourakov	4/19/2007 10:53:11 PM	Approved
5795MHz, OFDM backbone relay node. ...	NPS, Eugene Bourakov	4/19/2007 10:24:14 PM	Approved
5765MHz, OFDM backbone relay node. ...	NPS, Eugene Bourakov	4/19/2007 10:20:56 PM	Approved

Click on Frequency Request text to obtain detailed information

View Frequency Map **Frequency Utilization Explorer**

Figure 86. The Frequency Utilization Request test systems and their operating frequencies (From: [4]).

The Frequency Manager can now start the de-confliction process; the above data is the Camp Roberts systems but does provides an example of the San Francisco Bay MIO-TNT systems that may be submitted. This information will be used as if it was the data for the San Francisco Bay test. The first thing to consider is mutual interference:

- The 900 MHZ data link for the Zagi aircraft, 900-933 UAV's from John Hopkins and the two ground stations, and the 910 MHZ for SAOFDM may be in conflict. The 900-933 UAV's and two ground stations are all operated by John Hopkins University therefore these will be easy to de-conflict amongst themselves. Also, the 920-928 MHZ control link and backup control link for Scan Eagle are operated by the same organization

and both can be easily de-conflicted. However, if the Zagi aircraft and/or Scan Eagle are scheduled to fly at the same time and in the same vicinity of the John Hopkins operation then there may be interference. Finally, the 910 SAOFDM control link may experience interference with the control link if it being operated in the same vicinity and in the line of sight of the UAV's. However, the SAOFDM control link is directional and for interference to occur there needs to be substantial noise in the same frequency range or in the line of sight of these antennas.

- The 2390 MHZ audio/video relay for Zagi, the 2400 MHZ mesh link for Scan Eagle and the 2400-2406 MHZ analog video link for the John Hopkins UAV's are in close proximity enough to cause conflict. Because all are identified as UAV's the assumption is that all are operating at some area in the vicinity of the airfield and this needs to be considered.
- The two 5765 MHZ signals may need to be de-conflicted. One is for the link from the CR NOC to Naciemento Hill and the other is part of the OFDM backbone. Since both of these systems are operated by NPS this will be easy to de-conflict if it is an issue.

Given the information above the Frequency Manager can now interact with the TNT Test Director to see if the schedule time line and/or area of operation de-conflicts any of these systems. Any of the test systems that are not de-conflicted will need to be addressed with the TNT Test Director and the system's sponsor agency for more information. This will permit for pre-determined Test Equipment priorities in case of interference and pre-planned decisions on what systems will be shut down in what order based on the established precedence.

Next, the systems need to be looked at in regards to the background noise from the frequency measurements collected in the area.

Berkeley Labs:

- The 935 MHZ signal with the background noise running from 896-941 MHZ signals may interfere with the systems operating in the 900 MHZ range. The majority of the 900 MHZ signals for the test systems support UAV's. Because of the altitude that UAV's operate there will most likely be little interference to these systems. The SAOFDM control link is a different issue. This system, because of the way it is designed and employed may experience significant problems because of this interference.

- The 2.43 GHZ signal that was measured is a weak signal, however, agencies operating test systems in this range must be made aware of potential intermittent interference from this signal.

Golden Gate Bridge:

- There was a lot of noise from 846-941 MHZ that may cause interference with the SAOFDM links. The intermittent signal at 2.4 GHZ may cause interference problems for agencies operating test systems in this range and they must be made aware of potential intermittent interference from this signal.

Yerba Buena Island:

- The 850-900 MHZ , 915 MHZ, 927 MHZ, 941 MHZ may cause interference problems with some of the UAV's. However, due to the altitude that UAV's operate at this interference may be mitigated. Once again the SAOFDM control link may have difficulty operating in this area as well.
- The 1.85-1.98 GHZ and the 2.43 GHZ signals may be a source of some interference with the test systems operating near these frequencies.

Livermore National Lab:

- There was a lot of noise measured from 0 – 1 GHZ with significant signals at 875 MHZ and 950 MHZ. This may cause slight interference with the SAOFDM link but will most likely not impact the UAV operation.
- The weak signal detected at 1.88 GHZ will most likely have no impact at all.

All the data and information obtained from analyzing the potential mutual interference of test systems and problems that may be encountered from the measured background noise needs to be briefed to the TNT Test Director prior to the test events. This will allow time, if needed, for more site readings to be taken and if the source of any specific signals can be identified. Once all this is done, the Frequency Manager must be present for test events from the first day. All systems must be measured when operated to validate the frequency range they are operating on. Any discrepancies must be noted and briefed to all effected. Also, the Frequency Manager, on the first day of testing at the in brief must brief to all any specific issues and potential interference problems. This brief must include the procedures followed if any priority test event is experiencing interference and the ability to execute.

VIII. ADDITIONAL MAPPING CONSIDERATIONS FOCUSED ON LIVERMORE CALIFORNIA EMERGENCY SERVICE EXERCISE

A. BACKGROUND

On 30 October 2007 at the Livermore Valley Joint Unified School District Office (LVJUSD) a meeting was held to discuss an upcoming emergency service exercise for the City of Livermore California. The emergency service exercise was scheduled on 29 November 2007 in the City of Livermore using a portion of the District Office building as a command control center. The scenario was to support the response initiated by a 6.9 earthquake.

The objective of the scenario was to exercise those individuals that will take positions within the command center and for them to familiarize themselves with their appropriate emergency action binder. The other objective was to introduce various technologies that could possibly be incorporated in the future. The focus was on introducing broadband technologies available but not in use by first responders.

The Naval Postgraduate School (NPS) was asked to demonstrate technologies that were used to support TNT test events. NPS established a backbone network, using 802.16 technology, OFDM antennas and cameras. The establishment of this network demonstrated how the Command Control Center could monitor various activities at various locations as deemed necessary by the use of remote cameras connected to the network. NPS linked Granada High School, Sunset High School and the Temporary District Office.

B. OBSERVATIONS

During the scenario event it became obvious early on that this was a walk-thru to familiarize the first responders responsible for the initial action duties in an emergency catastrophic event. There were representatives from several organizations with displays and demonstrations of various technologies that could be incorporated to automate procedures and technologies and if adopted could potentially provide more information to

the Command and Control Center. From our observation very little technology was in use. For status boards, there were large sheets of paper hung along the walls for individuals to write on. It appeared the majority of the emergency action personnel were opening three inch binders that were filled with outlined procedures, points of contacts and required reports. From our observations it appeared that many of these procedures could be automated and to take advantage of existing technologies.

C. THESIS APPLICATION

During a catastrophic event such as a natural disaster, terrorist attack or an industrial tragedy multiple agencies will respond that must communicate. This was evident from the responses to the attacks of 9/11, Hurricane Katrina, and even more recently the wild fires in Southern California. Each one of these agencies brings with them their own sensors, communications, networks and other technologies. Anytime there are multiple agencies that come together with their own wireless technologies mutual interference is always a concern as observed during the various TNT test events.

During TNT events when there is mutual interference between test participants or interference from unknown sources many hours of de-confliction takes place. This may result in many wasted hours of key personnel trouble shooting the problems and at worst the loss of a scheduled test event. However, similar problems encountered by first responders could result in the inefficient use of resources that could easily result in the loss of life or property. Therefore, it becomes essential that there is proactive management of the wireless frequency spectrum. This management needs to be conducted by an Operational Frequency Manager with associated support and measurement equipment.

As demonstrated during the TNT events at Camp Roberts and in the San Francisco Bay area operational frequency management has been successful and many of the technologies and procedures used could be applied to support first responders, emergency services and command control centers. The technologies and procedures will be discussed below.

First, all the agencies from city to federal need to devise an interagency database that lists all the various wireless communications and technologies that each agency operates. The Decision Support Interface, located at the TNT frequency manager's website, used for the TNT test events is a good example that provides web interface as discussed in earlier chapters of this thesis. This would allow the Operational Frequency Manager to examine the communications equipment that each agency is operating as a first responder. This would allow for the de-confliction of first responder wireless technologies by either frequency and or location. This would allow those in charge at the command control center to be briefed of potential conflicts and allow the knowledgeable dispatching of emergency services to appropriate areas knowing the potential risk of mutual interference.

It is unreasonable to think that there would be background measurement available for everywhere a first responder may be needed. However, it would be useful to have measurements at the primary and secondary locations of fixed command and control centers. As well as any other fixed repeater or antenna that may be used in conjunction with the command and control of emergency services. Below are the measurements taken in the vicinity of the Livermore Valley Joint Unified School District Office (LVJUSD), the primary fixed command and control center for the City of Livermore California:

- 100 – 500 MHZ there was so much frequency saturation that our spectrum analyzer annotated 'mixer saturation".
- 475 MHZ
- 620 MHZ
- 630 MHZ
- 725 MHZ
- 755 MHZ
- 875 MHZ
- 935 MHZ
- 2.4 GHZ a weak signal.

In the examination of the amateur radio repeaters in the area there were about 68 registered sites. They operate at approximately 145 – 150 MHZ and 440-450 MHZ. This probably explains why 100-500 MHZ was saturated. Therefore, if there is any wireless device that operates in the 100-500 MHZ range around the command center it has a high probability of experiencing interference. Furthermore, it may be said that any wireless device operating in the 100-500 MHZ frequency range will experience interference in most Livermore locations.

As conducted to support the TNT test events the Operational Frequency Manager uses a DSI listing the wireless devices used by the various agencies as well as the measurements taken to support frequency mapping. Provided the information in the DSI the Frequency Manger will be able to brief command and control personnel of the potential conflicts. This will allow placement of assets and/or the adjustment of frequencies in such a way as to minimize interference.

The next thing that should be done is a database of wireless devices and equipment at each of the potential command and control nodes. For example, the picture that was produced using Google earth shows the primary command and control site linking to potential alternate sites that could be used in case the primary site was unusable. This type of picture is to be used not only to show command and control sites but critical crisis communication links as well. This type of Google Earth display will also be used to do frequency mapping like that used to support TNT.

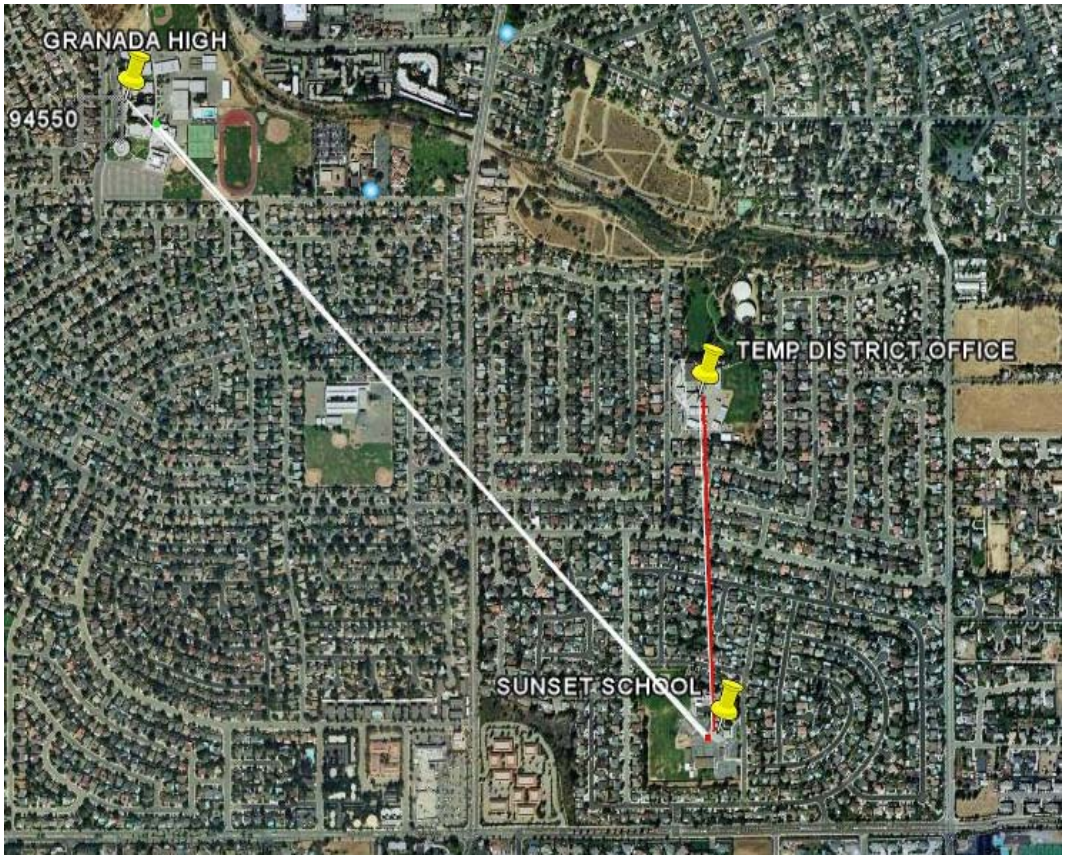


Figure 87. This picture was used in the brief given by Pat Lathier to brief the earthquake scenario.

To support the command and control decision makers it is important to recognize the capabilities of each site. Consequently the example map above will need to have a drill down capability. This drill down capability will allow the Frequency Manager to select any of the marked spots for amplifying information. When a site is selected it would bring up figures similar to the ones below that were provided by Kevin Peterson, ISS Specialist, LVJUSD.

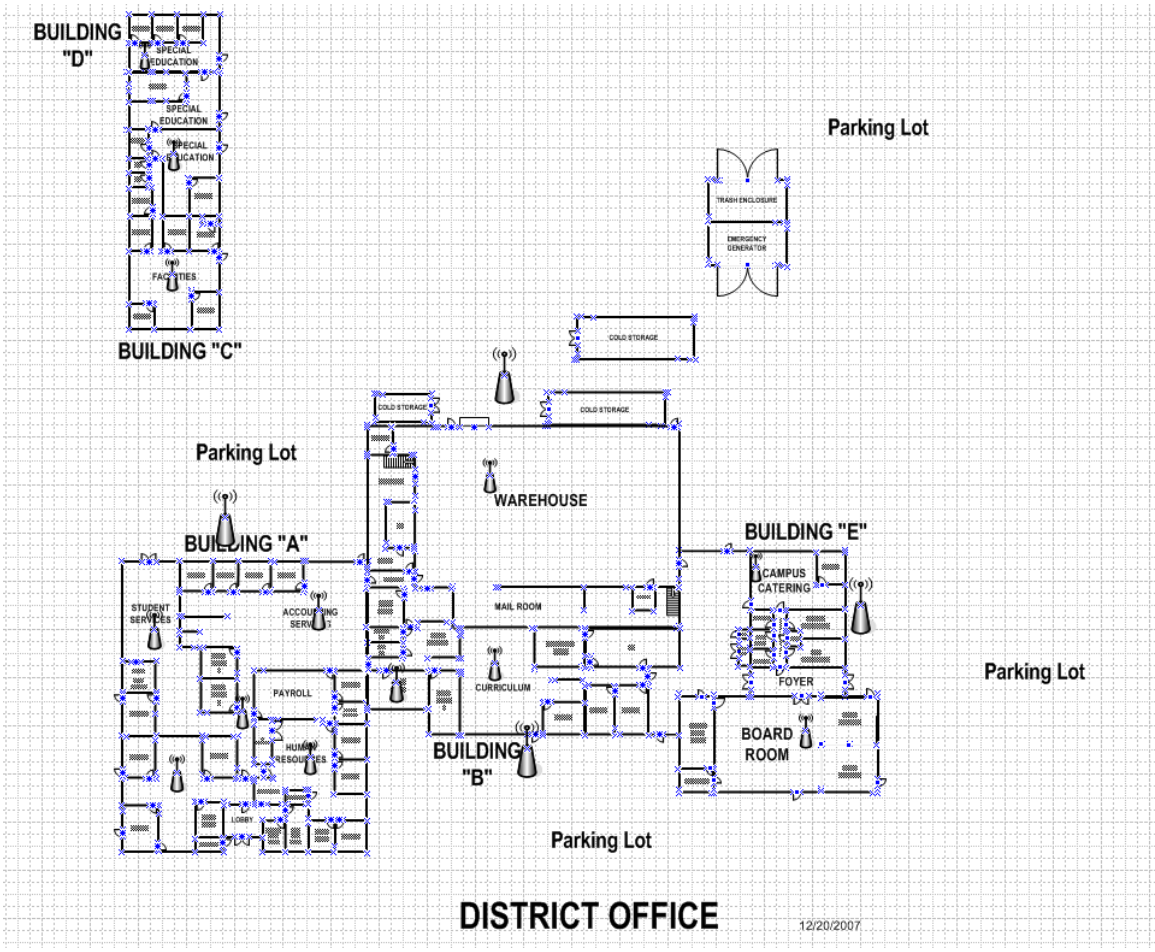


Figure 88. District Office.

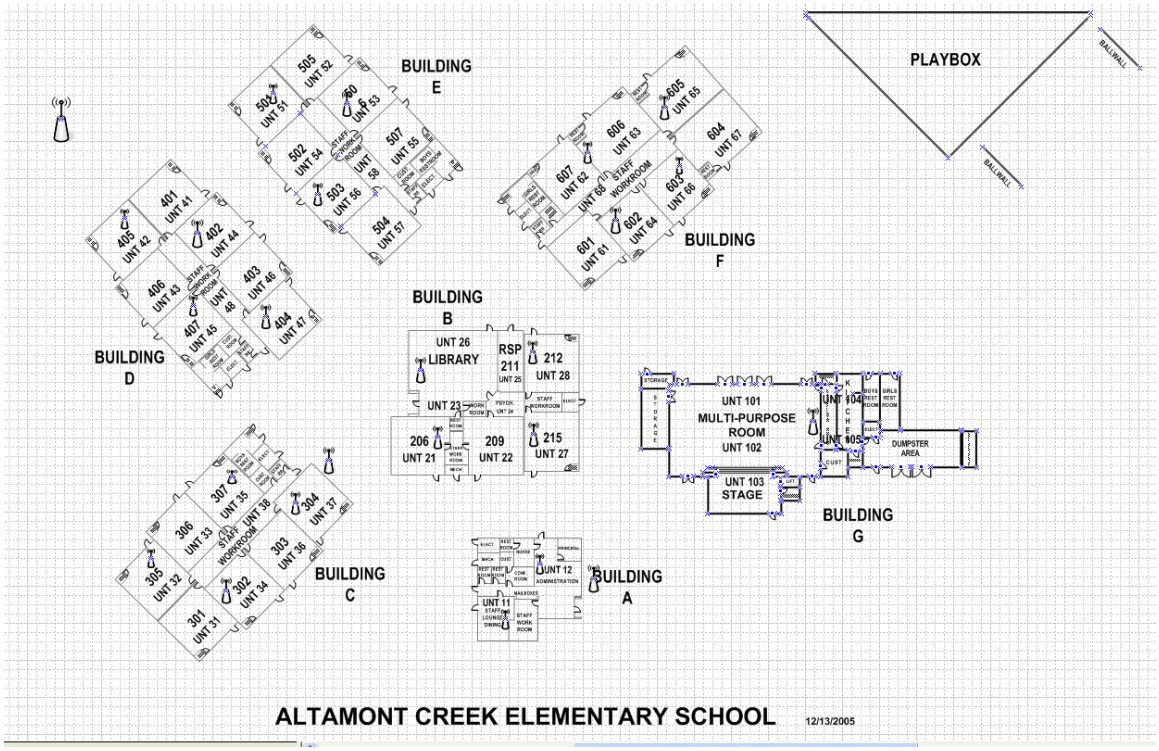


Figure 89. Altamont Creek Elementary School.

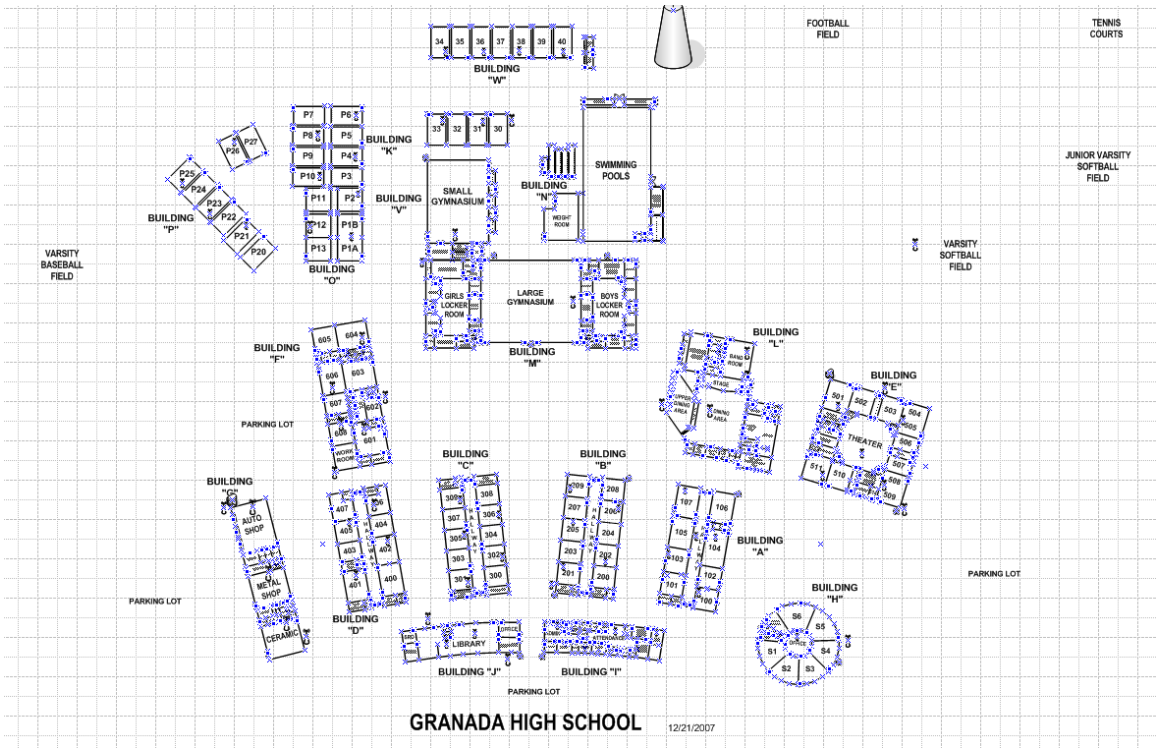


Figure 90. Granada High School.

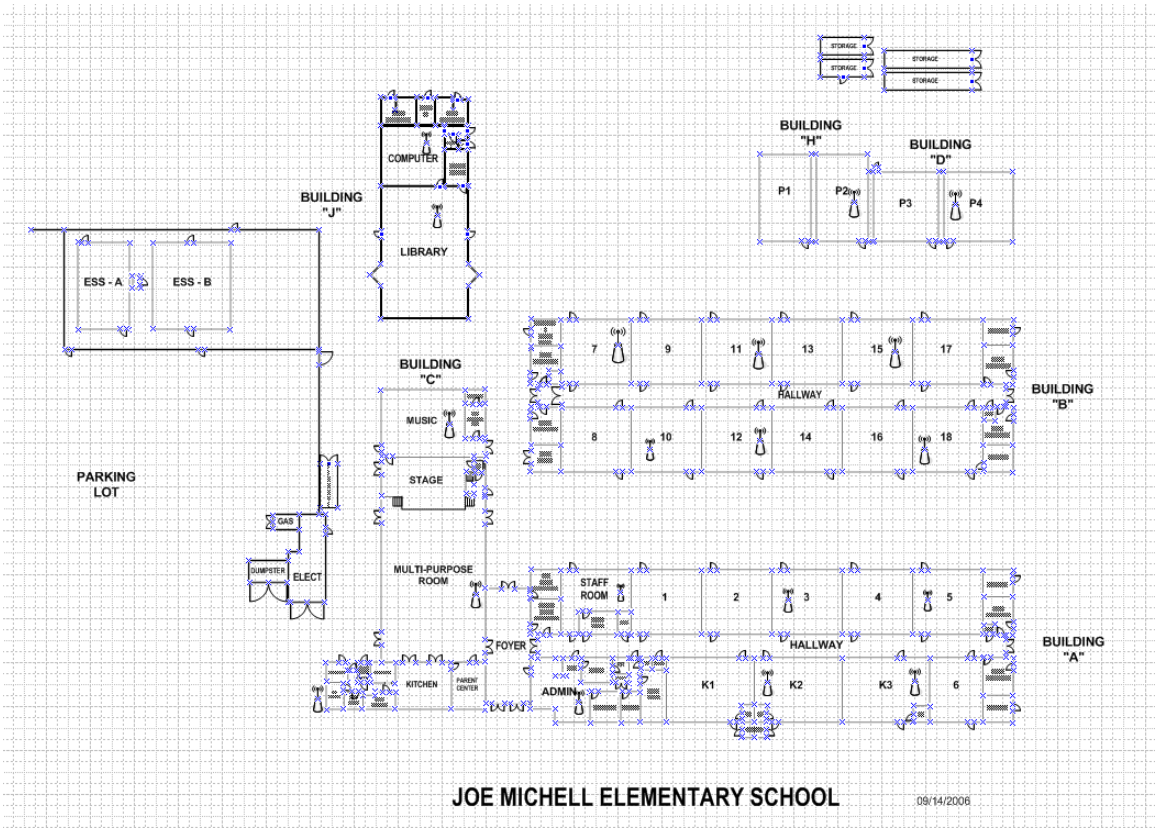


Figure 91. Joe Michell Elementary School.

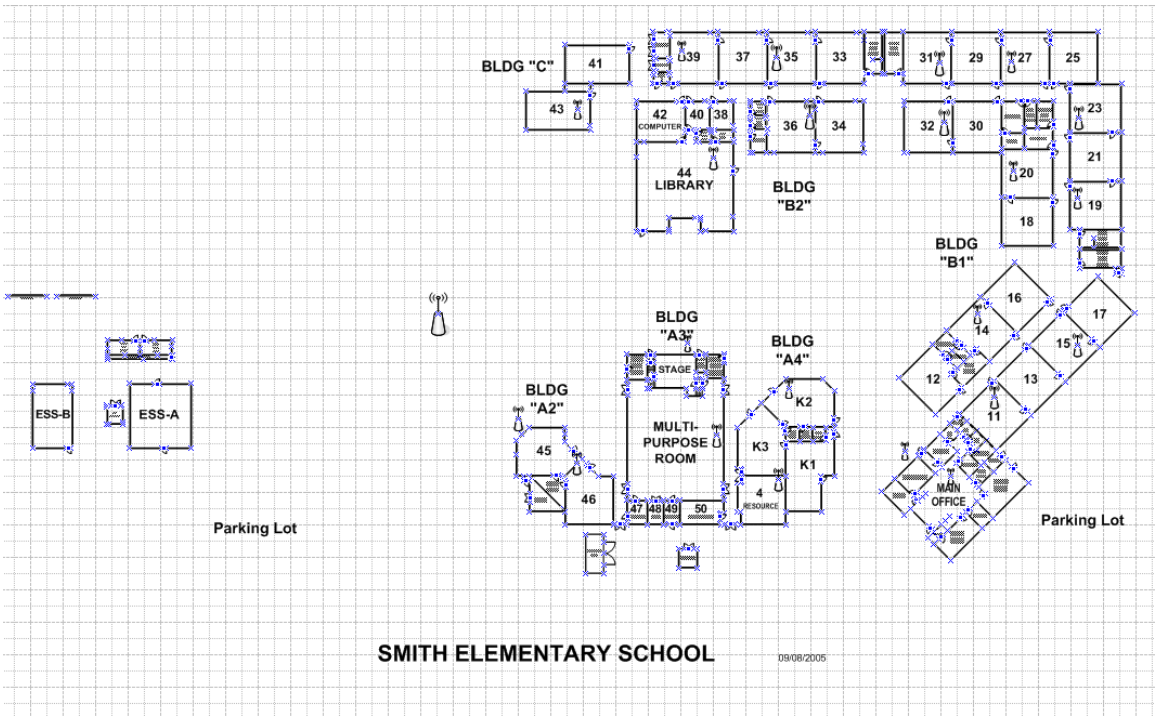


Figure 92. Smith Elementary School.

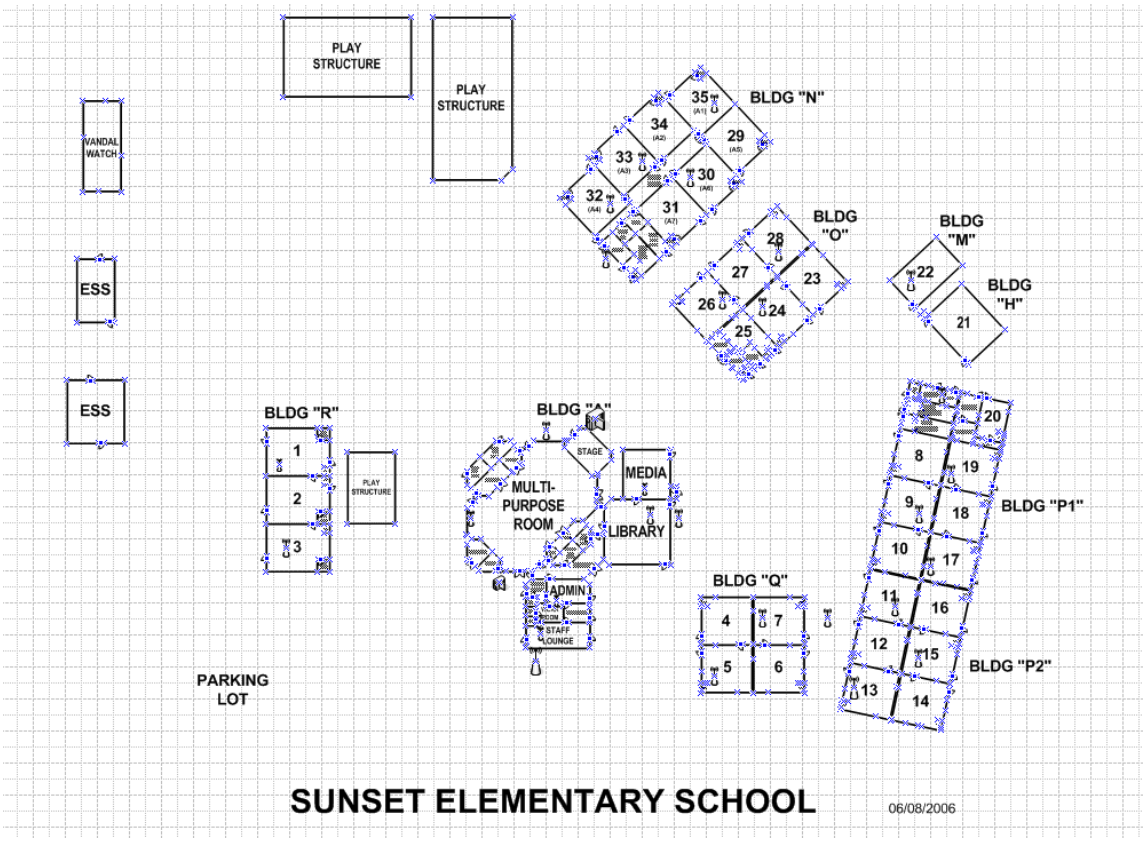


Figure 93. Sunset Elementary School.

The figures listed above are an example of the objects that would be provided to the Frequency Manager when drilling down on the selected maps. The figures would present a layout of the sites and the location of wireless access points, available servers and computers. This information would be essential in assisting the decision makers of the fixed command and control sites in deciding if there is a more appropriate location to set up the command and control organization or if the primary site was not available for whatever reason. Also, if the command and control site had to be re-located it would allow the logical selection to be made based on location, resources available and time to get the alternate site up and operating.

D. CONCLUSION

This section of the thesis elaborates on the previous chapters on the importance and growing role of an Operational Frequency Manager. The individual would have a DSI to assist them in making decisions and recommendations regarding the operation of wireless systems. The frequency manager would be able to de-conflict systems from mutual interference. A spectrum analyzer would be used to measure and map the existing frequency environment, thereby allowing for interference to be identified that might inhibit operations. The Frequency Manager would brief the risks to the operational decision makers so that interference may be mitigated and managed by adjusting system frequencies or by geographically separating the systems.

This chapter of the thesis extrapolated the responsibilities of the Operational Frequency Manager to include having the ability to geographically display not only the frequency mapping but also resources available to the individual. In any operation or event that involves multiple wireless systems that agencies operate it necessitates de-confliction. Also, the available command and control infrastructure must be identified and monitored. The DSI would provide information on the primary as well as potential secondary command and control sites. This information is critical for the decision maker in the event the primary command and control site is unavailable or needs to be relocated.

IX. CONCLUSION AND RECOMMENDATIONS

A. BACKGROUND

When this thesis was first contemplated the intention was to focus on the electromagnetic effects specifically on 802.16 wireless networks. However, over time as research was conducted in conjunction with the TNT test events at Camp Roberts and in the San Francisco Bay area the thesis has evolved based on discovered needs. In Chapter I a series of questions on 802.16 was outlined that would be answered. The initial intention was to follow those questions concisely but with the encouragement and direction given by the thesis advisor and second reader (Dr. Alex Bordetsky and Eugene Bourakov) an adjustment in the direction of the thesis changed the focus to the problem of frequency management.

During many test events and from the experience in real world military operations electromagnetic spectrum interference causes real world problems. Specifically, in TNT test events the lack of frequency management has caused the delay of scheduled events and the loss of precious time for all the individuals involved as measurements, de-confliction, and resolution take place. Often the problem is self imposed caused by poor planning on who, what, where, and when equipment will be in operation. Therefore, with the help of Eugene Bourakov a frequency manager website was developed as a DSI directly tied to the TNT website.

However, with the testing and observations conducted during TNT exercises acceptable answers to the questions asked in Chapter I have been produced. Below are the questions and the answers generated based on the observations during the various TNT test events.

B. SPECIFIC THESIS QUESTIONS ANSWERED

- What interferes with 802.16?
    - Primarily other systems operating on the same or similar frequency in the same location. Also, if a directional antenna is pointing

directly at the OFDM antenna for the 802.16 then it has the very likelihood of jamming and interrupting the 802.16 signal.

- What are the electromagnetic effects on 802.16 network connectivity?
    - Atmospheric interference was not observed with 802.16 network connectivity. However, interference and a loss of connectivity was observed when there was a system operating in close proximity to the same frequency using a directional antenna pointing in the direction of the test site.
- How does antenna placement compensate for electromagnetic effects on network connectivity?
    - With the OFDM antennas it was noted that there was a loss of connectivity caused by interference with the control frequency that operates in the 900 MHZ range. Therefore the antennas were unable to maintain alignment and thus lost network connectivity. Also, when working antenna placement in an area where there is systems operating on a similar or the same frequency by adjusting the polarization of the antenna from vertical to horizontal would be enough compensation for the system to operate and maintain connectivity.
- Can electromagnetic interference be compensated for based on adjusting antenna position and or adjusting power out?
    - Yes, by adjusting either the geographic location or increasing or decreasing the power out this may compensate for the interference. Also, as discussed above in the previous question the polarization can help compensate for interference as well. As far as adjusting the power out of a system by increasing the power one may be able to overpower the interference and thus maintain connectivity. However, if the system is the source of interference with another system then by decreasing the power out this may allow the other system to operate while still maintaining enough power of the adjusted system to maintain connectivity.
- Can a model be developed to take electromagnetic inputs and provide optimal antenna placement to support 802.16 wireless connectivity?
    - This portion of the thesis was not specifically tested. However, from the experience working with the spectrum analyzer and the frequency manager

mapping program that is in development (Decision Support Interface) DSI there is the probability that it can be done. This area of research alone can be developed into a thesis research topic and DSI development project.

- Will this provide a framework to support 802.16 wireless network rapid deployment?
    - Yes, the frequency manager DSI being developed and linked to the TNT website may be used in such a manner. If the area of the rapid deployment is known then map the known infrastructure, similar to the plans conducted on DSI for the TNT test events. Subsequently based on the mapping and knowledge of the power out of the antennas this equates to distance. By this point a frequency manager may have examined all the pieces, map where the command center will be located followed by laying out the antenna placement plan. Next capture the latitude and longitude points and using GPS for insertion of the 802.16 wireless network for rapid deployment can be completed.
- Can the electromagnetic effects be documented and planned for in 802.16 network development and placement to optimize performance?
    - This depends on a number of factors. If the proper frequency mapping process that has been addressed in this thesis is followed then the electromagnetic effects can be documented for best network performance. However, anytime someone operates at a similar or the same frequency or points a high powered antenna at the working 802.16 network antennas then there is a high probability of interference that was unplanned nor unavoidable.

- How can 802.16 point - to - point antennas be mapped?
    - 802.16 point-to-point antennas can be mapped using the right spectrum analyzer with the right training and knowledge of the frequency spectrum.
    - Can 802.16 network point - to - point antennas be detected, located and mapped?
        - Yes, any antenna that radiates can be detected but the difficulty is locating and identifying their position. Using the proper equipment and given enough time 802.16 networks can be detected, located and mapped.

- Can other wireless services in the area be mapped?
    - Yes, any service that operates in the spectrum that is being analyzed can be detected. Once the wireless service is detected then comes the dilemma of locating it but with direction finding equipment this would be easier. Although, identifying the specific service with the spectrum analyzer used in this thesis is not possible.
- How does multi path propagation affect the ability to locate and map network point - to - point antennas?
    - Multi-path propagation makes locating and mapping point- to point antennas difficult to impossible. One of the problems encountered when analyzing signals with the spectrum analyzer is trying to determine if the observations detected is a direct path signal or a multi-path signal. Without knowing this it makes locating and mapping difficult to impossible.

- How can 802.16 OFDM be exploited or interfered with?
    - There are many ways to interfere or exploit 802.16 OFDM networks. The easiest way to interfere with this system was observed during one of our TNT test events when a directional antenna was inadvertently pointed directly at one of our OFDM antennas and connectivity was lost. The exploitation of 802.16 in this thesis will not be discussed because most of what would be addressed is above the classification of this thesis.
        - Can the knowledge of location and the mapping of existing network point - to - point antennas allow for its exploitation in an urban environment?
            - Yes, however explaining the specifics of this is above the classification of this thesis and is subject alone for a thesis.
        - How easily can 802.16 be jammed or interfered with?
            - It can be easily jammed or interfered with as was noted above.
        - Can the side lobes and back lobes of 802.16 OFDM backbone be exploited?
            - Yes, in conducting testing and frequency measurements with the spectrum analyzer side and back lobes were detected. If the side lobes and back lobes can be detected then they can be exploited but once again when discussing exploitation of wireless devices it is beyond the classification of this thesis.

- This question was not in the original set of tasks outlined in Chapter I of this thesis, however, due to its importance we would like to give some thought to the effects of cellular communications on 802.16.
    - Although there were no direct observations noting the effects of cellular communications on 802.16 during the test exercises a brief discussion is required. 802.16a standard that operates between 2-11 GHz may mutually interfere with 3G cellular communications due to operating in the 2 GHz range. However, not just want to look at potential mutual interference but opportunities that may result from current 3G technologies and beyond. As Voice over IP becomes more prevalent and cellular communications operates in similar frequency ranges as 802.16 the potential to incorporate these technologies to take advantage of each other's strengths may be possible.

C. RECOMMENDATIONS

Based on the research conducted in the writing of this thesis and lessons learned from fieldwork the following recommendations are made. Further development of the Decision Support Interface (DSI) and the frequency mapping processes to include the following:

- A geographic interface that allows frequency mapping around terrain features.
- A user input tool to allow the use of environmental data that could affect the frequency spectrum and show ducting, spreading, blind zones etc.
- Continued refinements to the Decision Support Interface (DSI) based on the findings and recommendations in this thesis.
- To assist in frequency mapping a spectrum analyzer with direction finding capability.
- The development of an interface between the spectrum analyzer and the DSI that would allow tagging of specific frequencies from the spectrum analyzer that would automatically be mapped into the appropriated portions of the interface.

The goal of this research was to provide a systematic approach to detecting existing network and telecommunication frequencies and mapping their positions. The information collected, analyzed and synthesized could subsequently be used by a Frequency Manager for planning operational test exercises and for operational forces that

may operate in an area that is frequency saturated. In these situations and with the knowledge of existing frequencies these forces will be better able to manage, configure, and exploit existing network communications. The experimental study conducted included the collection, data processing, modeling and mapping of existing networks and their electromagnetic effects in both a rural and urban environment using the TNT 802.16 OFDM test bed in the San Francisco Bay area and Camp Roberts. The research conducted analyzing the electromagnetic spectrum frequency mapping and management provided a direct avenue for the development of a prototype frequency manager decision support interface. The DSI developed and used in support of TNT testing and experimentation provides an ideal foundation for amplified research. The research conducted opens the doors to continued efforts that could have significant contributions to both the Department of Defense and the civilian sector.

LIST OF REFERENCES

[1] V. Dubendorf, "A History of Wireless Technologies," *Wireless Data Technologies*, 2003, http://media.wiley.com/product_data/excerpt/95/04708494/0470849495.pdf (accessed February 2008).

[2] J. Layton, M. Brian, and J. Tyson, "How Cell Phones Work," 2000, *How Stuff Works*, http://electronics.howstuffworks.com/cell-phone7.htm (accessed February 2008).

[3] Federal Communications Commission Website, www.fcc.org (accessed October 2007).

[4] NPS TNT-MIIO Frequency Management Web Site: CENETIX, Naval Postgraduate School, Monterey, 2004-2008, http://cenetix.nps.edu/FrqManager/ (accessed January 2008).

[5] K5EHX X.net, K5EHX Amateur Radio Repeater Mapping, http://k5ehx.net/repeaters/qrepeater.php (accessed December 2007).

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