NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

LIGHT RECONNAISSANCE VEHICLE (LRV): ENHANCING COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS AND INFORMATION SYSTEMS (C4I) TO TACTICALLY EMPLOYED FORCES VIA A MOBILE PLATFORM

by

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September 2006

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** September 2006	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Light Reconnaissance Vehicle (LRV): Enhancing Command, Control, Communications, and Computers and Information Systems (C4I) to Tactically Employed Forces via a Mobile Platform			**5. FUNDING NUMBERS**
6. AUTHOR(S) Thomas J. Haines and Michael P. McFerron			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

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1. A robustly networked force improves information sharing.
2. Information sharing and collaboration enhance the quality of information and shared situational awareness.
3. Shared situational awareness enables self-synchronization.
4. These, in turn, dramatically increase mission effectiveness.

The faculty and students at NPS are dedicated to researching methods to leverage science and technology in order to maximize the combat effectiveness of U.S. and allied forces. In teaming with our primary sponsor, U.S. Special Operations Command (SOCOM), NPS has developed the Tactical Network Topology (TNT) series of experiments aimed at providing the warfighter information solutions for the battle space. The NPS LRV was derived from an operational requirement to have a mobile C4I/ISR platform that provides enhanced real-time information sharing to tactically employed units. Total force combat effectiveness is growing more reliant on agile means of information sharing. Wireless communications and collaborative technologies are essential to ensuring dynamic, forward-deployed forces have the ability to transmit and receive critical information when and where it is needed. Through past TNT experimentation, the LRV has not demonstrated itself as a stable platform providing a high-bandwidth information sharing capability. This research advanced the LRV concept by bridging the multiple wireless technologies and providing a reliable high-bandwidth communications link.

14. SUBJECT TERMS Light Reconnaissance Vehicle, Tactical Network Topology, 802.16(2001), 802.11a/b/g, Command, Control, Communication, Computers and Information/ Intelligence, Surveillance, and Reconnaissance, Nomadic Wireless Broadband Access, Wireless Communications			**15. NUMBER OF PAGES** 93
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

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ACKNOWLEDGMENTS

Tom Haines – For introducing a new student here at NPS to the fantastic opportunities within the Tactical Network Topology research group, I am indebted to my childhood friend and fellow Auburn Alum, LT Joe Herzig. My effort here would not have been possible were it not for my loving wife, Deana. Thank you for your support while enduring the late hours and numerous travel periods associated with my research. Deana, you dreamed of sunshine and warm weather, which I now give to you with the completion of this study. For my daughter, Taylor, thanks for your patience with "Dear Old Dad" and I hope you enjoyed your day as a student here at NPS. To my son, Chandler, thanks buddy for asking me all of those entertaining questions about my experiments, but really just wondering about the tarantulas and other wildlife at Camp Roberts.

Mike McFerron – I would like to thank my wife, Mariah, for her understanding and encouragement during my research in support of this thesis. Her unwavering commitment to me and our family has proven to be the cornerstone of my every accomplishment.

The authors would also like to thank Doctor Alex Bordetsky and Doctor Dave Netzer for providing the creative insight and forward thinking that resulted in the LRV project. In addition, we would like to take this opportunity to thank Eugene Bourakov, Michael Clement, and Karl Gutekunst for their superior technical knowledge, logistical support, and most importantly, their friendship.

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I. INTRODUCTION

A. PURPOSE

The purpose of this research is to further refine the capabilities and deployment considerations of a Light Reconnaissance Vehicle (LRV). The LRV concept was developed through cooperative research during experiments conducted by the Naval Postgraduate School (NPS). NPS has been conducting experiments with agile and mobile platforms capable of supporting high-throughout wireless technologies. The LRV is the culmination of NPS efforts in developing a ground-based mobile command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) platform.

B. NETWORK CENTRIC WARFARE

The theory of Network Centric Warfare (NCW) prompted the United States (U.S.) military to deploy a more agile and mobile force. NCW is a developing concept in warfare, which places emphasis on information systems and technologies to push decision- making ability down to the lowest levels. Specifically, the tenants of NCW are:

1. A robustly networked force improves information sharing.
2. Information sharing enhances the quality of information and shared situational awareness.
3. Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command.
4. These, in turn, dramatically increase mission effectiveness {Alberts, David S. 2000}.

The LRV Project was born from the theory of NCW. NCW thrives on mobile platforms having the infrastructure to support information systems that in turn provide tactically deployed troops with agility.

C. INTO THE INFORMATION AGE

As information systems and technologies progressed during the 21st century and the world moved from the Industrial Age and into the Information Age, the US military wanted to capitalize on the inherent advantage information dominance may have on the battlefield. Communication has always been crucial for military commanders to exercise command and control. However, as the world moves into the Information Age, not only is the ability to communicate crucial, but moreover, the ability to communicate vast amounts of information quickly can create a distinct military advantage.

Some key characteristics that a system must possess in today's NCW environment are interoperability, adaptability, and agility. Interoperability needs to occur at a number of different levels or layers to enable entities to communicate, share information, and collaborate with each other {Alberts, David S. 2003}. The combat effectiveness of forces can be held directly proportional to the level of interoperability at which they operate. Entities having the ability to push or pull information in an efficient manner provide increased value to total force capability. Some challenges in high levels of interoperability include:

- the existence of stove-pipe legacy systems.
- rapidly changing advancements in technology.
- a program-centric approach to systems acquisition.
- doctrinal changes that do not reflect advancements in technology.
- the need to establish data standards among department and joint systems.

In general, today's warfare planning is predicated on more hostile and less permissive environments. These environments force NCW planners to focus on rapid, adaptive responses to unplanned and sometimes hostile actions. In the same context, communications and networks supporting NCW must adhere to this same sense of adaptability. Agility is the ability to move quickly while maintaining stability. Agility of force and the command and control (C2) structure are key concepts for the success of NCW.

D. DATA REQUIREMENTS

The requirement to send or receive large amounts of information in a relatively short period is becoming more important as technologies evolve. For example, personal identification through biometric data has developed into an intriguing capability for joint forces. Specifically, for joint forces, having the ability to correctly identify both hostile and friendly people within an area of operations (AOR) by referencing biometric data with a database will enhance war fighting efforts. However, biometric data tends to be very large, and the current communications equipment has proven ineffective in sending or receiving such large data in a timely manner.

Streaming video is another example of current communications equipment's capability not meeting the needs of the war fighter in tactical situations. Recent operations in the Middle East have demonstrated increased use of Unmanned Aerial Vehicles (UAV) in order to conduct reconnaissance and surveillance. In practice, these UAVs have captured streaming video as the pilots controlled them throughout an AOR. Commanders would like the ability to view the streaming video captured by the UAVs or broadcast the video to operation centers for analysis. However, the size of the data prevents successful and stable transmission of such video.

These examples illustrate that although recent technologies are advancing the information gathering across the battlefield, the information sharing still has yet to be solved. Getting large amounts of data from the point of collection to any point designated by the commander for analysis and pushing the information to key decision makers in the AOR remains an obstacle.

E. RESEARCH GOALS OF THE LIGHT RECONNAISSANCE VEHICLE

The LRV Project was designed to solve some of the major obstacles presented by the advanced information collection technologies versus the information sharing capabilities. In theory, a mobile platform capable of establishing a high-throughput communication link to an operations' center would allow large amounts of information to be transmitted from previously unknown locations in an AOR in a timely manner. In addition, this mobile platform could act as a Tactical Operations Center (TOC) in itself, offering an agile C2 node to a local detachment or convoy leader through different high-throughput wireless technologies. The main purpose of the LRV is to explore solutions for the information sharing portion of NCW and create a more mobile, adaptive, and agile joint force capability. Figure 1 shows the LRV aboard NPS preparing for a series of TNT experiments.

Figure 1. Light Reconnaissance Vehicle (LRV), February 2006

The research surrounding the LRV project can be broken down into three specific tasks. The first task is to test this mobile platform in order to bring together both mature and immature wireless technologies in an environment that allows for realistic scenarios while adapting to the situations incurred by the war fighter. By utilizing multiple wireless technologies the LRV explores the ability of diverse communication assets to interoperate with one another. However, the wireless transmission of data is only a piece of the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) puzzle. The next task is to demonstrate the ability of the LRV to improve the effectiveness of the combat units. Moreover, gaining the ability to operate in a collaborative environment, where all nodes within the network have access to current information and the ability to update and exchange that information remains a significant milestone. Improving the effectiveness of combat units through collaborative operations offers employed forces the ability to move quickly through the battle space while maintaining stable C2. In other words, this successfully demonstrating this second task would prove enhance agility of employed forces. Lastly, the LRV project attempts to incorporate the necessary hardware and software to provide network users at the tactical or command levels to perform either a push or pull of information as required by the operational situation. Addressing this final task will show increased adaptability by reacting to operational situations and the subsequent information sharing requirements these reactions will introduce. Moreover, the LRV hopes to present information collection and information sharing solutions in conjunction with operational situations.

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II. TACTICAL NETWORK TOPOLOGY

A. BACKGROUND OF TNT EXPERIMENTS

The Tactical Network Topology (TNT) experiments are the product of an extensive partnership between the U.S. Special Operations Command (SOCOM) and the Naval Postgraduate School (NPS).

Figure 2. Emblems of the Naval Postgraduate School and the United States Special Operations Command

The roots of the TNT experiments can be traced to field experiments that began during the fiscal year of 2002 using UAVs to assist in downed pilot rescue missions. In January 2003, these experiments with UAVs merged with another effort, the Surveillance, Targeting, and Acquisition Network (STAN,) and in July of the same year quarterly experiments began. The STAN experiments evolved into what is now TNT; through progressive quarterly experiments, TNT tests both mature and immature information and other technologies and their application to SOCOM missions. In addition, TNT is the basis for the formation of the Center for Network Innovation and Experimentation (CENETIX). CENETIX is a research center, formed in 2005, that partners NPS, the Lawrence Livermore National Laboratory (LLNL), SOCOM, and other agencies.

B. THE TNT TEST BED

CENETIX is based aboard NPS in Monterey, California, and maintains the Global Information Grid Applications and Operations Code Lab (GIGA Lab). Through the efforts of NPS faculty, staff, and students, CENETIX implements an 802.16 Orthogonal Frequency Division Multiplexing (OFDM) wireless network connecting

CENETIX facilities within the Monterey Area to experimentation facilities located about one hundred miles to the south at the Camp Roberts California Army National Guard Base.

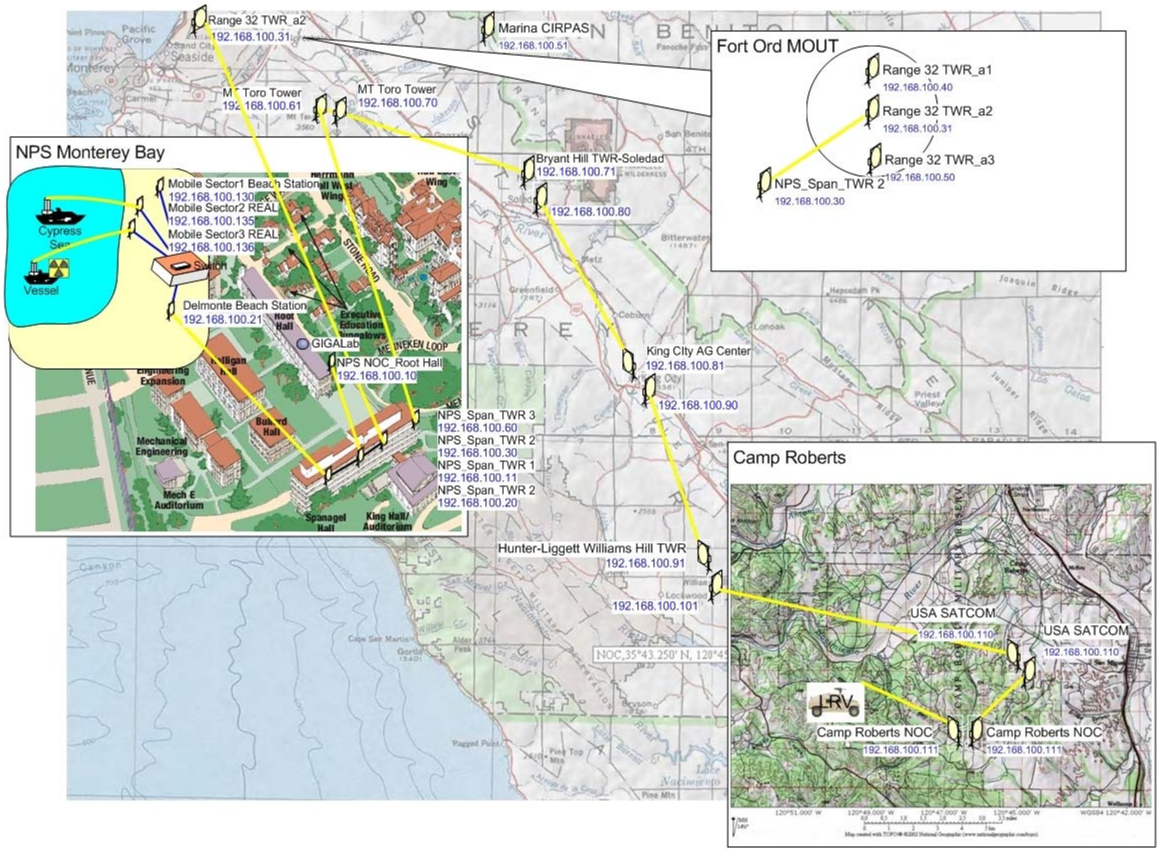

Figure 3. Network Diagram of CENETIX

These backbone connections of the network, along with connections to facilities at the beach laboratory in Monterey, the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) in Marina, California, Fort Hunter Liggett, the Military Operations in Urban Terrain (MOUT) facility at Fort Ord, U.S. Coast Guard facilities in San Francisco Bay, and Avon Park, Florida, along with additional ground, air, and maritime locations, allows for a collaborative test bed that provides a multi-theater C2 structure supporting missions and objectives of the CENETIX research team. Figure 3 depicts the CENETIX network backbone. The overall mission is to support advanced studies of wireless networking with unmanned aerial, underwater, and ground vehicles in order to provide flexible deployable network integration with an operating infrastructure for interdisciplinary studies of multiplatform tactical networks, Global Information Grid connectivity, collaborative technologies, situational awareness systems, multi-agent architectures, and management of sensor-unmanned vehicle-decision maker self-organizing environments. Specifically, CENETIX supports the following areas of research:

- Adaptive wireless sensor-unmanned vehicle-decision maker networks.
- Ad hoc wireless mesh networks.
- Global Information Grid applications
- Network operations and Command Centers.
- Collaborative technology.
- Shared-situational and network awareness technology.
- Self-organizing network-centric environments.
- Multiple-agent intelligent systems.
- Satellite, ultra-wideband, and RFID communications.

C. LRV INCORPORATION INTO TNT NETWORK

Since its inception, TNT experiments have focused on UAVs and the application of wireless technologies to enhance their information sharing capabilities. The LRV utilized the TNT experiments as a platform to test and evaluate existing wireless technologies similar to the technologies being tested aboard the UAVs. As a ground vehicle, the LRV has enabled the research team to push high-throughput information to tactical ground units. Incorporating high-throughput wireless technologies on UAVs and ground vehicles throughout a tactical area of operations offers employed troops various intelligence as well as C2 capabilities.

A major hurdle in the implementation of NCW is extending the network to what some have titled the last tactical mile. By using the TNT experiments, the LRV has shown a preliminary capability to extend a high-throughput network to tactically employed units. Specifically, the LRV has demonstrated the capability to connect to an operations center via a high-throughput 802.16 OFDM link within minutes of reaching a destination at a particular range. In addition, the LRV has demonstrated the ability to connect tactically employed troops and UAV ground control stations within a limited range of the vehicle via numerous wireless technologies that form a stable local area network (LAN). By forming a LAN around the vehicle and maintaining a high-throughput 802.16 OFDM link to an operations center, the LRV shows some promise of extending the network to the last tactical mile. Throughout the course of this research a significant limitation diminishing the promise of the LRV was the lack of true mobility. Specifically, as the conclusions of this research will portray, the LRV, with its current technologies, offers a nomadic network node vice a mobile one. At the same time, this shortfall was offset because of the network performance advantages realized through the deployment of the LRV and subsequent high-throughput connectivity to the last tactical mile.

III. LRV BASELINE FABRICATION AND FINDINGS

A. INITIAL PROCUREMENT, DESIGN, AND FINDINGS

Numerous initial experiments provided a baseline for this research. Specifically, the LRV concept refinement revised the theory of employment and suggested iterative modifications as the LRV evolved in supporting tactically relevant missions with numerous communication technologies. Evidence collected to support the preliminary thesis that the LRV provided enhanced Command, Control, and Communication (C3) to the last tactical mile were proven inconclusive and, therefore, experimentation and research continued. The next few paragraphs will offer the key milestones reached by students and faculty prior to the start of this research.

The original concept of deployment for the LRV was to offer a tactical satellite link, broadband long-haul terrestrial links, broadband local terrestrial links, and tactical air support communication capabilities. Figure 4 graphically depicts the original concept of the LRV. This original concept was soon adjusted to concentrate more on researching immature technologies such as the 802.16 OFDM long-haul terrestrial communication links and shorter distance terrestrial communication technologies utilizing mesh enabled architectures, 802.11a/b/g, and even 802.16.

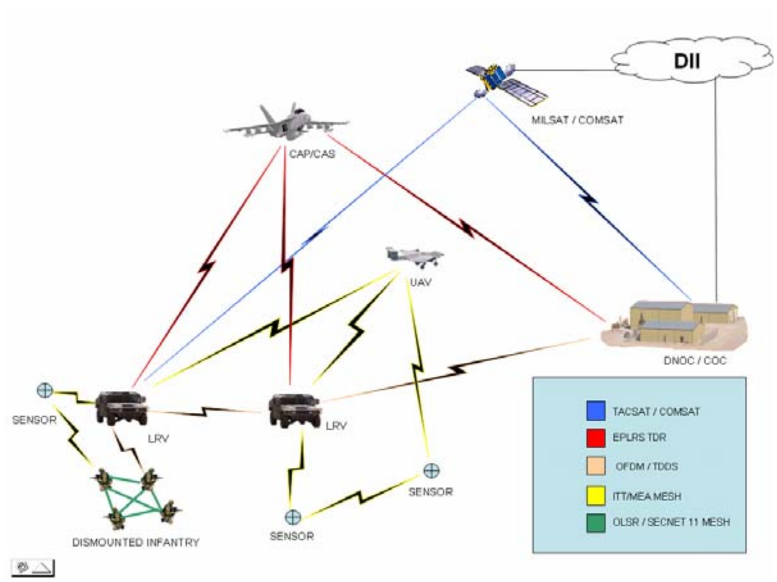

Figure 4. Original Concept of Development for LRV

Both students and faculty participated in defining what capabilities should be included or more specifically, what capabilities would tactically deployed forces require on such a vehicle. At the conclusion of the concept refinement phase the decisions were that the LRV would provide forward deployed UAV control, tactical intelligence collections, tactical echelon Mobile Network Operations Center (MNOC) abilities, tactical data distribution systems, and sensor deployment and recovery abilities. Once these capabilities were agreed upon, the LRV entered into the initial design phase. A notional systems lay-down was established to include the electrical system, data distribution system, and transmission system. After the capabilities and system lay-down were complete, the LRV was put into the acquisition process. With efforts from SOCOM and NPS research, the acquisition process brought aboard the vehicle to host the LRV capabilities and a plethora of hardware to include the 802.16 OFDM radios, laptops, antennae, etc. The LRV began participating in TNT Experiments shortly after the acquisition process began.

With requirements levied from SOCOM and an experimentation platform offered through NPS, the LRV was purchased, fabricated, and tested by the combined efforts of SOCOM personnel, NPS faculty, and NPS students. The initial platform purchased was a 2005 Toyota Tacoma 4x4 with the Toyota Racing Development (TRD) package.

During the TNT Experiment, TNT 05-04, which took place in August 2005, the LRV displayed some exciting capabilities, but also demonstrated the immaturity of some of the technologies. Specifically, the LRV team succeeded in installing numerous technologies such as multiple 802.16 OFDM radios, antennae, mesh enabled wireless technologies aboard a single vehicle while maintaining the power requirements for each and de-conflicting the frequencies utilized by the technologies. Although there were many successes during the initial experiment, there were also some shortfalls discovered. Deploying an 802.16 OFDM capability is a simple venture for short distances and good optical line-of-sight (LOS). When the distance grows further and LOS is lost, the deployment of an 802.16 OFDM link using RedLine AN-50e radios is much more challenging. Another technology that displayed its immaturity during the initial experiment was the mesh enabled wireless technologies that were expected to deliver local area connectivity to tactically deployed forces within LOS of the LRV. The mesh enabled technologies used never displayed a stable and reliable connection to the LRV. Some other issues discovered during the first experiments were specific to the hardware installed on the vehicle. The vehicle's suspension system was deemed too weak to properly handle the weight of all the systems installed on the truck. Additionally, the research team felt the air compressor used to lift the antenna mast was insufficient and a higher-capacity compressor should be installed. In order to supply power throughout an operation, an additional battery should be installed and paralleled in order to properly power the technologies aboard the LRV. These successes and shortfalls provided a baseline for this research.

B. LRV EXPERIMENTATION AND RESEARCH

At the onset of this research, the LRV mission was refined and it was envisioned to support three functional missions of a Network Operations Center (NOC), Tactical Operations Center (TOC), and Intelligence, Surveillance, and Reconnaissance (ISR) Platform. The primary communication capabilities offered through the LRV are multiple 802.16 Orthogonal Frequency-Division Multiplexing (OFDM) transmission links that support broadband data communications. Additionally, there continued to be experimentation with local area wireless technologies using mesh enabled architectures and 802.11a/b/g in order to provide localized command and control to units or individuals around the vehicle. The following paragraphs offer information on the LRV configuration that this research team started with and the specifications of the various hardware and software onboard.

1. Vehicle Configuration

a. 2005 Toyota Tacoma 4x4 TRD

With recommendations from SOCOM, a truck was purchased to serve as the host for the numerous hardware devices to be tested while exploring the capabilities of the different technologies presented in TNT. The truck is a 2005 Toyota Tacoma 4x4 Double-Cab with the TRD package. All manufacturer specifications can be found in Appendix A. This truck was chosen because it is currently being deployed by Special

Operations Forces (SOF). In addition, the Toyota Tacoma provides a narrow wheel-base that will accommodate its transportation via numerous aircrafts within the Department of Defense (DoD) inventory.

b. Will-Burt Company 30 Feet Telescoping Antenna Mast

To host the 30 feet Telescoping Antenna Mast, the fiber-glass truck-bed was reinforced with a 1/4 inch steel plate. The antenna mast was installed in order to raise an antenna payload to an operational level. It consists of several concentric nesting mast sections, fabricated from aluminum tubing, that extend and retract pneumatically. The LRV was fitted with a non-locking mast that must remain pressurized to support a payload at an extended height. While retracted the antenna mast measures 79.88 inches in height and can extend to 29 feet and one inch. The antenna mast weighs approximately 125 pounds and can support a payload of 150 pounds. In addition, a steel roll-bar was welded to the steel base providing added stability and a metallic shelf was welded to the roll-bar providing space for additional equipment.

c. QuickSet QPT-90 Pedestal and Controller

The QuickSet QPT-90 Pedestal is designed for heavy-duty mobile and fixed operation. It has the capability to pan 435 degrees and tilt 90 degrees. The pedestal has a load capacity of 90 pounds. The QuickSet Pedestal Controller is designed to control the pan and tilt of pedestals such as the QPT-90. It has the ability to operate both the pan and tilt functions at variable speeds. The controller includes the required power supplies for driving the motors at full speed as well as a connection for using an external joystick. The controller is housed in a three and one half inch high chassis and accepts 115 VDC power. The specifications of the controller unit can be seen in Table 1. Figure 5 shows the QuickSet pedestal installed above the Will-Burt Telescoping Antenna Mast.

Size:	9” W x 3.5” H x 7” D
Weight:	8 lbs.
Prime Power:	90 to 132 VAC, 50/60 Hz, 6 A max.
Front Panel Controls:	Power On, Local/Remote Joystick Selector, Pan/Tilt Joystick, Pan/Tilt Speed Pots
Front Panel Connectors:	Remote Joystick
Armature Output:	90 to 130 VDC max., @ .5 A max.
Field Output:	100 VDC @ 1 A

Table 1. QuickSet Pedestal Controller Specifications

Figure 5. Will-Burt Company Telescoping Mast with QuickSet Pedestal

d. PowerPlus Leveling System

Power Plus leveling systems are designed to meet the varying requirements of Vans and Mini-Motorhomes from 4500 lbs. through 20,000 lbs. The LRV's leveling system is a twelve volt DC configuration with controls for each of the four levelers located within the center console of the cab's interior. The PowerPlus leveling system has proven invaluable during the TNT experiments conducted in the rugged terrain of Camp Roberts providing a safe and stable platform for conducting network operations while in a stationary position. Figure 6 shows multiple views of the PowerPlus Leveling System installed on the LRV.

Figure 6. Power Plus Levelers

2. Communications and Electronics Configuration

The following section describes the networking hardware implanted into the LRV concept that has formed the backbone of the communications architecture. Figure 7 depicts the networking assets that are organic to the LRV.

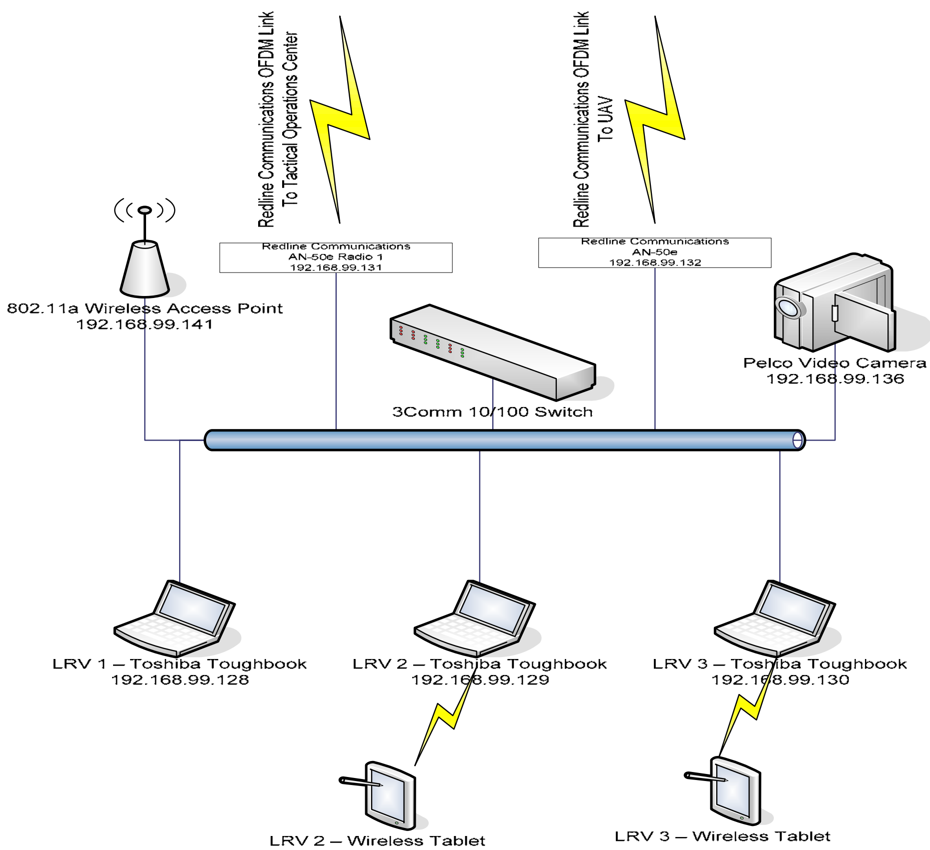

Figure 7. Network Diagram of LRV Standard Hardware Configuration

a. Panasonic CF-18 Toughbooks

The CF-18 Toughbook laptop computer was chosen for the LRV project due to its current use by deployed SOF Teams. There are three laptops that are located with the LRV. The first laptop is located in rear of the passenger compartment and is secured onto a sliding assembly that when not in use is stored within the network equipment rack. The primary purpose of this laptop is network and communications management. Figure 7 shows a Panasonic Toughbook secured on the network equipment rack. The second laptop is located at the front passenger seat of the cab and is secured in a storage compartment of the passenger door when not in use. The primary purpose of this laptop is battlespace information management, to include biometrics data and UAV video feeds. The third laptop has a primary purpose of allowing SOF Teams to access or enter tactical information while in the vicinity of the LRV. The separation from the vehicle is made possible by utilizing either 802.11x or mesh enabled technologies. The third laptop may also be used as a battle spare should either of the other laptops fail. All three laptops are configured in a similar fashion to allow for interoperability within the units. Specifications for the Panasonic CF-18 Toughbooks are contained in Table 2.

CPU	Intel® Pentium® M Processor ULV 753
Storage	60GB HDD
Memory	512MB SDRAM standard, expandable to 1536MB
Display	• Touchscreen PC version: 10.4” • 1024x768 (XGA). Active Matrix Color LCD • Intel® 915GM graphic controller, UMA up to 128MB
Expansion Slot	• PC Card Type II x 2 or Type III x 1 • Secure Digital Card
Keyboard and Input	• 82-key with dedicated Windows key • Pressure sensitive touchpad • Digitizer/Touchscreen LCD
Wireless LAN	• Intel PRO/Wireless 2915ABG network connection 802.11a/b/g • Security – Authentication: LEAP,802.1x,EAP-TLS,EAP-FAST,PEAP • Encryption: CKIP,TKIP,128-bit and 64-bit WEP,

	Hardware AES
Power Supply	• Lithium ION battery pack(7.4V,7650mAh) • AC Adapter: AC 100V-200V 50/60Hz, Auto Sensing/Switching worldwide power supply
Software	Microsoft XP, Hard Disk Erase Utility, Groove, MESH Viewer, Redline RF Monitor
Included Optional Equipment	Remote Tablet, GPS Receiver, External CD/DVD ROM

Table 2. LRV Panasonic CF-18 Toughbook Specifications

Figure 8. Panasonic CF-18 Toughbook Installed in LRV

b. 3COM 24-port Switch

The 3Com Switch offers 24 10/100 Ethernet ports. The switch has the ability to improve network performance by routing segmented traffic locally without the need to send the traffic to the network core routers. Through its support of dynamic routing, deployment and management is greatly simplified over working with static routes, with automatic reconfiguration when there are topology changes. By utilizing a switch instead of a router, the LRV team can offer network connectivity through numerous Ethernet ports aboard the vehicle without the confusion of re-programming a router with each new connection. Figure 9 shows an example of the 3Com 24-port switch.

Figure 9. 3Com 24-port Switch

c. *Linksys WRT54 Wireless Router, 802.11 b/g*

The LinkSys wireless broadband router is capable of acting as an Access Point, three port switch, and a router. First, as an Access Point the LinkSys WRT54 allows devices to connect with both 802.11g at 54MBps and 802.11b at 11MBps. In addition, as a switch, the LinkSys WRT54 is capable of maintaining three full-duplex 10/100 Ethernet connections. These ports can allow computers, hubs, or other switches to be connected creating a larger LAN. Finally, the LinkSys WRT54 acts as a router capable of routing traffic through the LAN and onto a bigger network if available. Through experimentation the LRV project incorporated the LinkSys WRT54 in hopes of exploring the capabilities of this Access Point, router, and switch to provide forces within a local area around the LRV access to the larger TNT network. Figure 10 shows the LinkSys WRT54 Wireless Router.

Figure 10. Linksys WRT54G Wireless Router

d. Redline AN-50e Radio

RedLine Communications' AN-50e was the primary radio utilized throughout this research. This radio operates in the 5.8 GHz frequency range and offers throughput up to 54 MBps. Specifically, the Redline AN-50e is capable of frequencies ranging from 5.735 GHz through 5.815 GHz, which are separated into 9 recommended channels of 20 MHz. The AN-50e is a high-performance, high-speed wireless Ethernet bridge terminal providing a scalable multi-service platform from a common equipment infrastructure and management system. The system also features adaptive modulation in both directions to maximize data rate, and hence spectral efficiency. The AN-50e can be equipped with a narrow beam antenna to provide high directivity for long-range operations up to 30 miles (50 km) in line-of-sight (LOS) conditions, and up to six point two miles (10 km) in non-LOS conditions. The AN-50e system is a Class A digital device for use in a commercial, industrial, or business environment. A more descriptive list of specifications is contained in Appendix B.

Although these radios are not Worldwide Interoperability for Microwave Access (WiMax) certified and therefore do not meet the 802.16(2004) standard, they were designed to meet the original 802.16 standard. In general, 802.16 is a group of broadband wireless communications standards for metropolitan area networks (MANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). The original 802.16 standard was published in December 2001 and titled 802.16 Task Group 4 (TG4). Refer to Appendix C for an excerpt of the original 802.16 standard. Redline Communications designed their AN-50e to meet the 802.16 TG4 standard. Subsequently, IEEE continued to develop the 802.16 standard and it soon evolved into the 802.16a standard. Redline Communications designed their AN-100 radios to meet the 802.16a standard. Later, IEEE developed the 802.16(2004) standard and this standard was certified by WiMax, an advocacy group that actively promotes and certifies compatibility and interoperability based on the 802.16 specification. Redline Communications designed their AN-100u radios to meet the latest standard and these radios were WiMax certified. Although WiMax has certified an 802.16 standard there continue to be developments by IEEE workgroups to evolve the standard to meet the need for mobile wireless networks. Moreover, the 802.16e standard is on the horizon and it claims to answer the question of mobility {9 Institute of Electrical and Electronics Engineers 2006}. Because this research dealt solely with the AN-50e radio, and to avoid confusion, the links established with these radios will be termed 802.16 links throughout this paper.

e. Radio-Wave Parabolic and Sector Antennae

The Radio-Wave Parabolic Antenna is capable of operating in the frequency range from 5.250 through 5.850 GHz. This antenna measures a one foot diameter and offers a gain of 23 dB. The Radio-Wave Sector Antenna is capable of operating in the frequency range from 5.725 through 5.850 GHz. This antenna offers coverage of a 120 degree sector and 16 dB of gain.

f. Garmin Global Position System

GPS unit was enhanced functionally by inputting the GPS positioning data into a laptop running a GPS posting script software. This software transmitted the LRV position information to the TOC via the Iridium satellite phone system. This allows for position monitoring of the LRV by the TOC commander using the SA Agent collaborative software suite. Figure 11 shows the GPS suite of hardware that was utilized during experiments in order to pass position data to the TOC.

Figure 11. Garmin GPS with Iridium Data Uplink

3. Software Applications and Configuration

Numerous software applications have been incorporated into the LRV to both maintain and monitor the network and to provide for mission essential needs. This section gives a brief explanation of the LRV software suite. Table 3 lists the individual software applications currently in use within the LRV.

Hardware	Software	Remarks
Panasonic CF-18 Toughbook	Microsoft Windows XP (Operating System)	Common operating system (OS) utilized throughout DoD. This OS works well with the numerous software applications being run throughout the TNT network.
Panasonic CF-18 Toughbook	Ixia IxChariot Console	Application that allows users to run throughput tests by emulating actual data packets. This application can run throughput tests throughout the network via IP addresses as long as the tested endpoints have Ixia Endpoint loaded.
Panasonic CF-18 Toughbook	Microsoft Groove	Application that delivers worldwide collaborative capabilities within a shared workspace.
Panasonic CF-18 Toughbook	Situational Awareness (SA) Agent	Application that provides real-time SA by sending GPS data to a central server and then visually depicting all connected network nodes throughout the TNT network on top of map data.
RedLine Communications AN-50e	RF Monitor	Link monitoring application that provides a visual representation of the link performance. This application graphically displays current RSSI and SNR for the AN-50e.
ITT MESH	MESHview	Network administration tool used to manage, monitor,

		and troubleshoot the mesh enabled architecture environment. This tool also provides a visual representation of the mesh network.
ITT MESH	MESHtray	Provides status, configuration, and routing information for all nodes in the mesh enabled architecture.
Canon-Pelco Camera or other video stream devices	VStream Application	Application allows end-users to connect from one to four separate video streams originating from the LRV, UASs, TOC, or other connected nodes on the network.

Table 3. Software Applications with Associated Technology

a. Windows XP

Windows XP is an operating system developed by Microsoft Corporation and released in October of 2001. Windows XP was designed to deliver users a fresh user-interface while merging two of their premier operating systems, Windows NT and Windows ME. The laptops aboard the LRV were all configured with Windows XP Tablet PC Edition. This edition was released in November of 2002 and includes digital pen technology offering the capability to recognize handwriting while maintaining keyboard and mouse functionality. This operating system was chosen for the LRV because a majority of the students and faculty testing the LRV are comfortable using the operating system and it provides additional flexibility of using stylus pens to input data.

b. IxChariot

IxChariot is a software application that can test and measure performance between pairs of networked computers. Utilizing flows of real data, IxChariot emulates different kinds of distributed applications, and captures and analyzes the resulting data. This application was particularly useful in testing different nodes and their connection with the LRV. Being a nomadic network node, the LRV was consistently moving from area to area and re-establishing network connectivity with numerous nodes. IxChariot allowed the users to test, analyze, and record network statistics in order to evaluate the

LRV and its network performance. In addition, IxChariot can be installed on a number of operating systems to include Windows XP. Figure 12 shows a screen capture of IxChariot displaying data collected during an experiment.

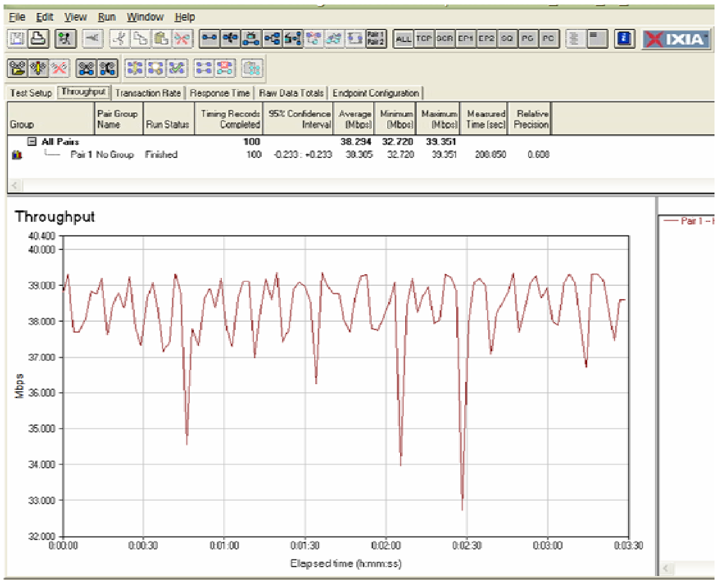

Figure 12. IxChariot Results, TNT 06-01

c. RF Monitor (Redline Communications)

RF Monitor is a software application designed by Redline Communications that can be used with the AN-50e Radio. This application allows the user to monitor the Received Signal Strength Indication (RSSI) and the Signal to Noise Ratio (SNR) between two nodes: RSSI and SNR are values given in dbm and dB respectively. Figure 13 shows a screen capture of data collected via RF Monitor during an experiment.

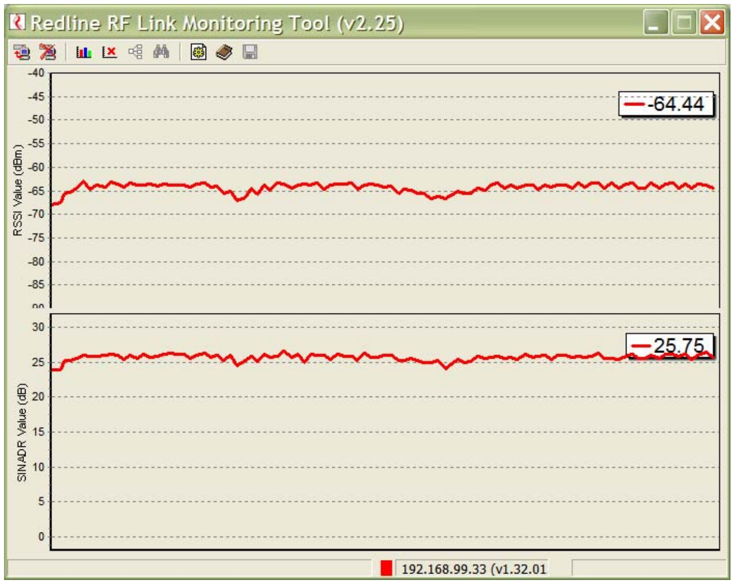

Figure 13. Redline RF Monitor Results, TNT 06-01

d. Groove

The Microsoft Groove collaborative software suite is an application that enables worldwide collaboration of effort in a shared workspace. Its near real time capability meets the DoD needs for tactical employment. Groove features give the field operators and both the strategic and tactical commanders the ability to segment individual workspaces accordingly and to control access to these sites. Within the TNT test bed, Groove workspaces are utilized for chat, file sharing, file storage and archiving, whiteboard notes, and scenario building. Figure 14 is a representation of the Biometrics Groove workspace utilized for TNT 06-04. Within the Biometrics scenario, forward-deployed Biometrics Fusion Center(BFC) personnel had the capability to load ten-print biometric data files into the Groove application where personnel located at NPS, participating in the Groove workspace, were able to download the file onto the Virtual Private Network established between NPS and the BFC in West Virginia. The data file could then be compared against files located on the BFC's SIPRNET server files containing biometric archives. A positive or negative can then be transmitted via Groove to the team in the field. At the TNT experiments, this biometric interrogation process took place in approximately four minutes.

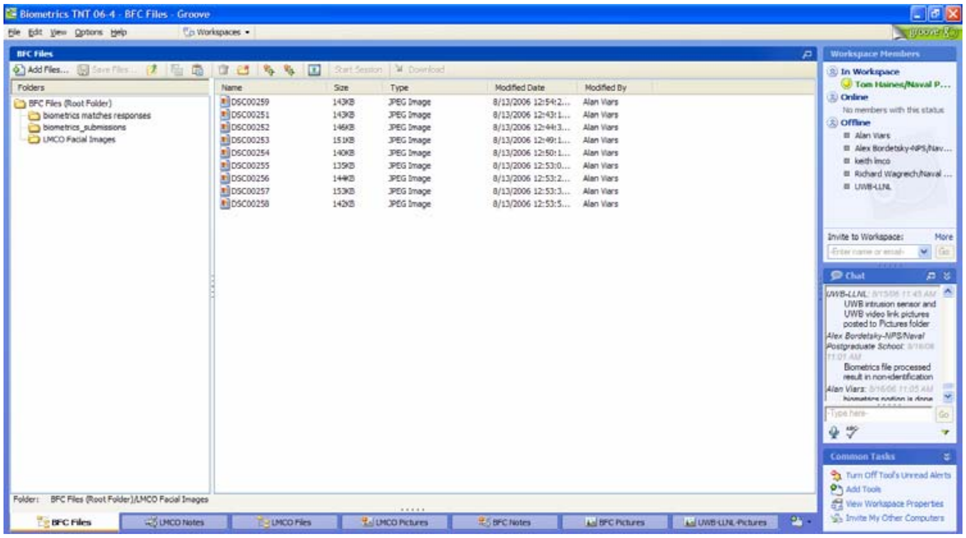

Figure 14. Microsoft Groove TNT 06-04 Biometrics Workspace

e. MESHView/MESHTray

The MESHView and MESHTray software applications allow for the management and monitoring of those network nodes that are employing mesh enabled networking protocols. Participating network nodes are tracked via media access control (MAC) addresses and their connectivity levels among other nodes on the mesh enabled architecture. MESHView allows the operator to have a graphical representation of the self-awareness and self-healing properties that are inherent to mesh enabled networks. The MESHView graphic below shows the multiple paths available for packet transfer within a mesh enabled network. This graphic, Figure 14, shows a screen capture of data collected using MESHView during an experiment.

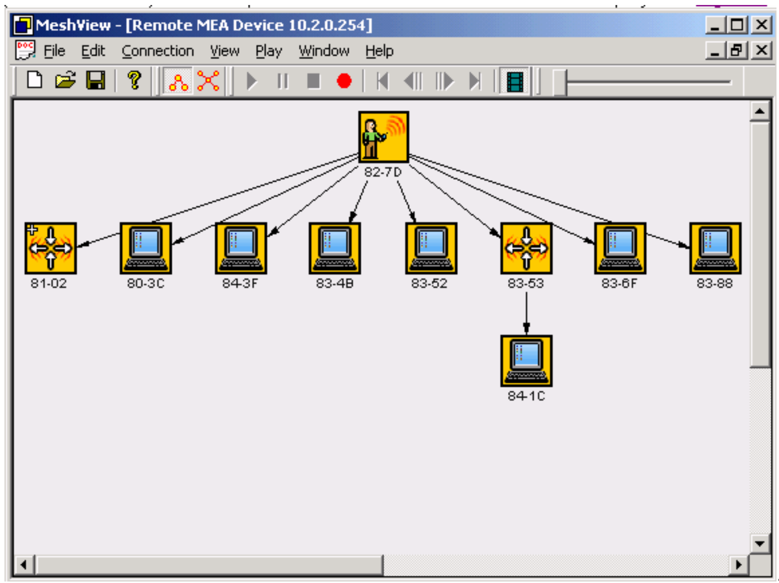

Figure 15. MESH View Network Monitoring Software

f. Vstream

The VStream software application allows multiple clients connected to a network to receive streaming video via a client-server based architecture. Multiple feeds can be monitored giving the tactical commander the ability to simultaneously monitor several UAV video feeds encompassing an entire area of operations. The software is IP-enabled and individual streams can be accessed by entering the specific node's IP address while interfacing with the server-based application. Figure 16 shows a screen capture of multiple video feeds being streamed during an experiment.

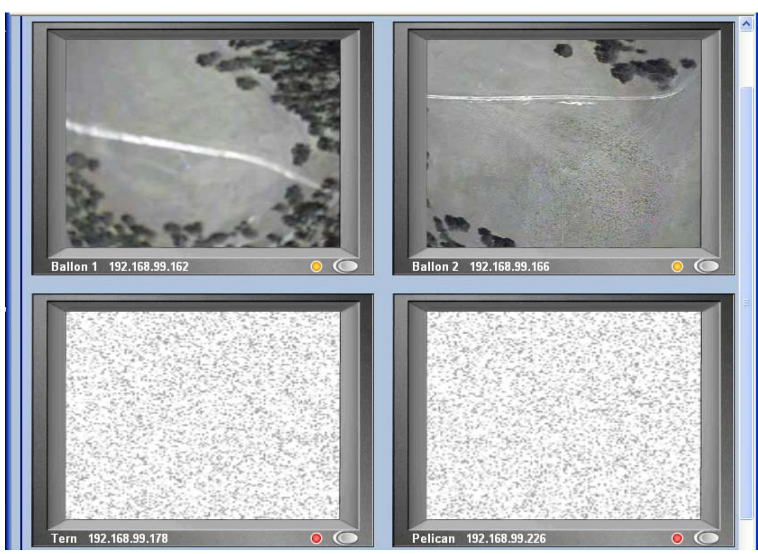

Figure 16. Video Stream Capture via VStream Application

g. SA Agent

Situational Awareness (SA) Agent is a software application that was developed and produced by Eugene Bourakov, a Research Associate at NPS. This application offers real-time tracking capability for network nodes throughout the Area of Operation (AOR). The SA Agent application runs on top of Macromedia's Flash MX software. During TNT Experiments, an SA Server application runs at the Network Operations Center (NOC) aboard NPS. Network nodes that are to be included in the situational awareness picture are required to run the client program, SA Agent. These nodes running SA Agent, once connected to the network, will push positioning information to the server and the server will superimpose icons over digital mapping to show where the nodes are located in the AOR. The LRV has included SA Agent with its list of required software in order to share its position with those at the NOC or Tactical Operations Center (TOC). Figure 17 shows a screen capture of SA Agent being used during an experiment.

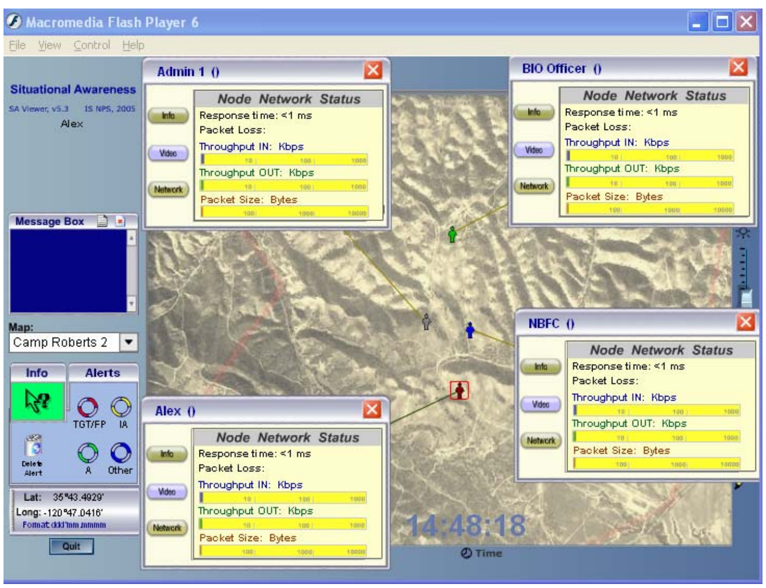

Figure 17. SA Agent Screen Capture

C. SUMMARY

The original concept of the LRV was modified and refined in order to concentrate on adapting wireless data terrestrial technologies such as the 802.16 standard for use aboard a mobile platform. In addition, the LRV was defined as offering a NOC, TOC, and ISR capability to tactically deployed forces. The Toyota Tacoma, selected upon recommendation from SOCOM, proved a capable platform for the LRV project. It allowed for custom installation of support infrastructure such as electrical distribution and suspension modifications to ensure the vehicle was able to provide communications and networking capabilities in remote and adverse environments. By establishing a baseline networking topology, additional hardware selection for the vehicle could be expanded or compressed as dictated by changes in mission requirements. The functional modularity of the employed wireless technologies such as 802.11a/b/g, 802.16 and mesh enabled technologies allowed the LRV research team to evaluate the vehicle's potential in several C4I mission areas. Mission areas and support roles the LRV hardware and software were to be evaluated on include:

- Reconnaissance video provided by LRV
- UAV launch, recovery, and control capability
- Multiple UAV video for local and remote analysis
- Biometric data queries for target immediate identification or data archiving
- Near real-time collaborative decision making
- Peer-to-peer tactical networking and information exchange
- Tactical data transmission including voice, data, and streaming video

This thesis will provide an evaluation of the mobility, robust communications, and networking capabilities of the LRV, which may lead to the improvement in the combat effectiveness of SOF personnel.

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IV. TNT EXPERIMENTATION TEST BED

The methodology employed while evaluating the LRV during the TNT experiments varied dependent on the scenario that the vehicle was supporting. Network throughput and link reliability were the two common metrics applied to all of the scenarios and continue to be the primary focus. The means for evaluating throughput was accomplished using the IxChariot software application. Typically, a 'High Performance Throughput' script was run via the IxChariot application that collects data by sending a 10 megabyte stream from one endpoint on the network to another endpoint. This data stream is sent one-hundred times over a ten minute period and the data collected include metrics involving throughput, transaction rate, response time, and raw data totals.

The reliability of the communications link was based on the total time that link was required to pass data versus the actual time the network was communicating in a manner to support the tactical scenario. Other metrics that were used in the evaluation of the network, specific to the 802.16 OFDM nodes, were the observed RSSI and SNR measured between 802.16 OFDM transmitters and receivers. In general, the RSSI and SNR are indicators of how well the link is functioning and allow for generic predictions on network throughput and modulation schemes. In addition to the performance metrics, notations will be made on observed operational capabilities of the LRV in specific tactical scenarios.

A. TNT 06-01 EXPERIMENT

1. Pre-Experiment Details and Plans

SOCOM and NPS conducted the first quarter fiscal year (FY) 2006 TNT Experiments in Camp Roberts, California from 14-18 November 2005. These experiments focused on applications of advanced technology and networks in support of SOF missions. Specific areas of research for these experiments included:

- Test and evaluate the ability to launch, fly, and control multiple UAVs in a limited combat airspace.
- Evaluate the ability of networked UAVs, ground and remote assets to pass and receive data to and from SOF operators during realistic operations.
- High Value Target (HVT) identification through biometrics
- Route reconnaissance
- Target tracking
- Area security
- Human Systems Integration / Human Factors Considerations

Prior to the experiment, an operationally relevant scenario was developed to provide a framework for all events. Multiple UAVs, the LRV, a simulated SOF Team with Biometric Collection equipment, network intelligent interface devices, and multiple wireless links provided the experiment framework. The scenario was designed to stress time-sensitive collection and transmission of data requiring high rate network throughput. The LRV's primary role was to connect the ground control stations of multiple Raven Unmanned Aerial Systems (UAS) to the TOC via a LOS 802.16 OFDM link. Specifically, the LRV was to deploy with a convoy of Raven UAS ground control stations to a designated location approximately three kilometers from the TOC. From this position the LRV could accomplish LOS with the TOC by positioning the vehicle on high-ground and utilizing the 30 feet antenna mast. Once the 802.16 OFDM link was established from the LRV to the TOC, the LRV would then attempt to connect three Raven UAS ground stations via wireless ITT Mesh technology. In theory, the ground stations could connect via ITT Mesh to the LRV and the network would be extended via the 802.16 OFDM link back to the TOC.

2. Experiment Execution

The following figure depicts the assets geographical positions at commencement of the scenario.

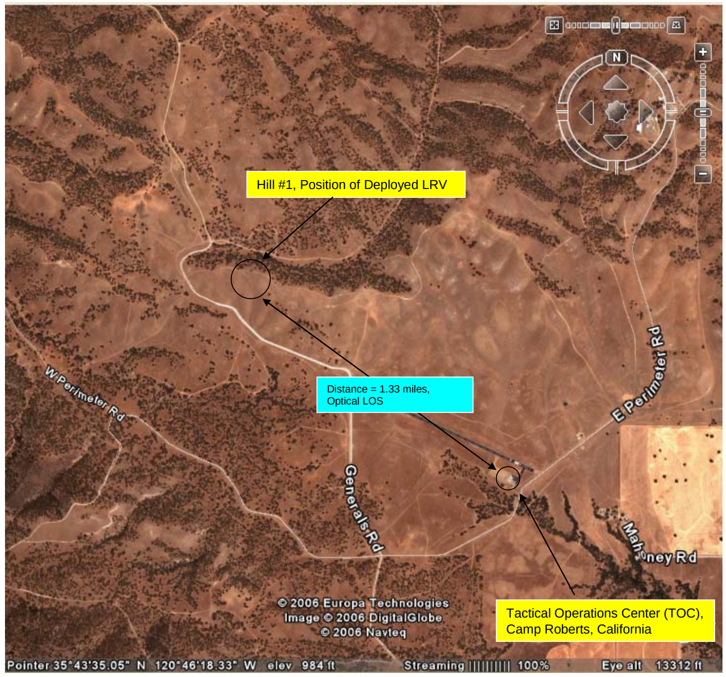


Figure 18. Aerial View of LRV LOS Position

The initial scenario took place with the LRV in a LOS position approximately one and one half miles from the TOC. The LRV was able to establish a high-throughput link within five minutes of arriving on station. The link was maximized by raising the antenna mast to its thirty feet maximum height and stabilizing the LRV on uneven terrain by deploying the vehicle's leveling system. While operating within LOS of the TOC, the LRV realized a throughput of approximately 14 Mbps with continuous connectivity. This allowed for the transmission of biometrics data to be transmitted from the LRV to the TOC utilizing the Groove collaborative software application running on the laptop within the LRV. While that portion of the scenario was successful, the wireless mesh enabled network links, utilizing ITT Industries P2P 2.4 GHz MESH (ITT MESH) communications, created to provide communication between the Raven ground control stations and the LRV proved unreliable at ranges over 100 meters limiting the tactical positioning of the ground control stations.

Figure 19 shows the second iteration of the scenario that was designed to push the network further into the operational area while maintaining communications between deployed units and the TOC. The LRV attempted to establish an effective communication link from two different non-LOS positions. At both locations the 802.16

OFDM link had measured RSSI values between -79 dBm and -89 dBm, which is not sufficient in supporting high-throughput communications. Figure 20 illustrates the results collected from RF Monitor and PING commands issued to a distant end computer while the LRV was in position three.

Figure 19. Aerial View of LRV Non-LOS Positions

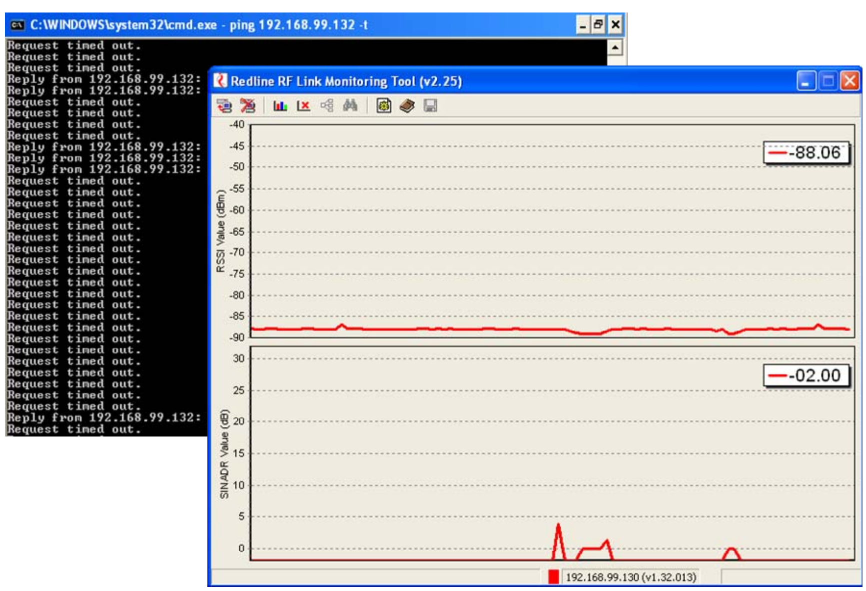


Figure 20. RF Monitor and PING Command Results, TNT 06-01

3. Observations and Key Issues

Key observations, specific to the LRV operation, were as follows:

- Identified network performance variations as a function of geography, geometry, and range
- Identified planning tools necessary to maximize performance as function of geography
- Identified mesh characteristics to optimize network performance
- Successfully demonstrated advanced HVT identification from the field by transmitting a ten fingerprint file to the Biometrics Fusion Center (BFC) and receiving a proper identification match in six minutes. The LRV played a key role in this demonstration in that the biometric data was uploaded from the LRV and sent via the OFDM link to the TOC.
- While in LOS conditions, the LRV was able to establish a 14 Mbps link to the TOC while maintaining 100 percent network reliability.
- In non-LOS conditions, the LRV was unable to establish a reliable link to the TOC. Network reliability was characterized by extremely low RSSI and SNR values.

Initial antenna alignment has continued to be a major hurdle in the employment of the LRV. The three issues involved in antenna alignment include:

- Antenna azimuth – once in place, the LRV operators must 'aim' the LRV antenna at the TOC. This objective is accomplished by using handheld GPS. The operators must ensure the TOC's location is programmed into the GPS prior to departing the TOC. After arriving at the employment location the GPS has the capability to find the TOC and provide the operator an azimuth to the TOC. Once the azimuth to the TOC is obtained, the operator does his best to point the antenna in the appropriate direction. However, there is no precise mechanism in place to ensure the LRV's antenna is accurately positioned to the optimal azimuth. To compound the precision issue, there is no mechanism in place at the TOC to ensure its antenna is also positioned accurately toward the LRV.

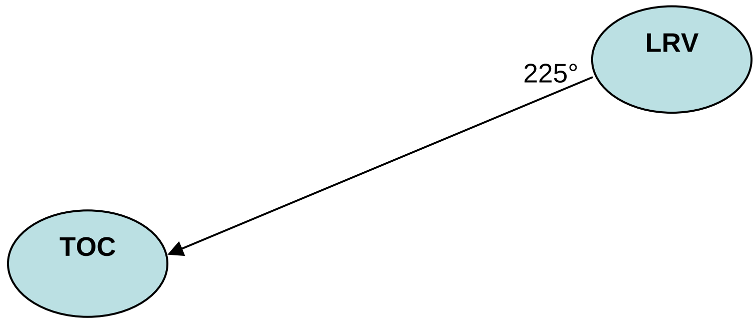


Figure 21. Depiction of Azimuth Alignment from LRV to TOC

- Antenna height – after the antenna has been pointed in the proper direction the mast can be raised to obtain a higher elevation for the antenna. With a capability to raise 30 feet above the vehicle, the possibility to obtain a signal by raising the antenna should improve. However, the operators must work using Redline's RF Monitor software to place the antenna at an appropriate elevation and have no precise mechanism to ensure the optimal antenna height is reached to achieve the best signal.

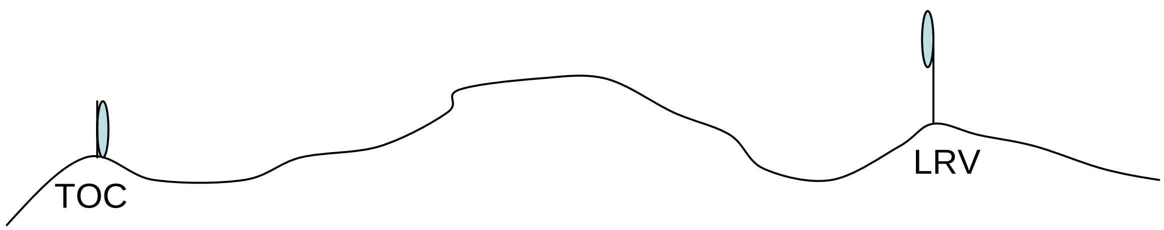
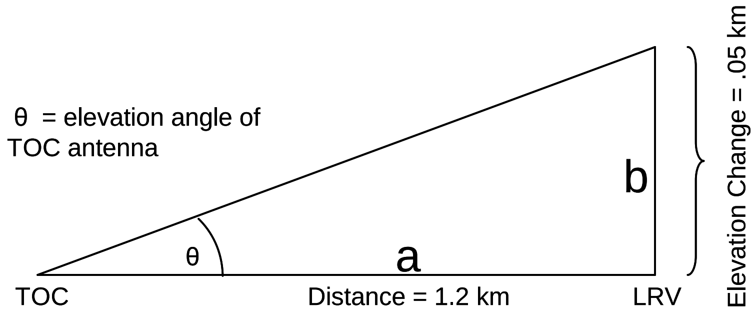


Figure 22. Depiction of Antenna Alignment with Non-LOS Conditions

- Antenna elevation angle – the final variable for the LRV to receive the best signal possible is the antenna elevation angle. After the antenna has been positioned with the correct azimuth and the antenna height has been determined to provide the best signal, the operators can attempt to improve the signal by increasing or decreasing the antenna elevation angle. Because of the great distances between the TOC and LRV, but proportionately little difference in elevation, the antenna elevation angle should be very small (sometimes less than one degree). Using the trigonometric functions, one can derive the required elevation angle with known distances and elevation changes. Figure 23 depicts a representation of the trigonometry used in deriving the elevation angles for the antennae. Although the operators can derive the proper elevation angle for each antenna at a given range and height, the actual placement of the antenna remains difficult for there is no antenna angle indicator on the system. Specifically, with such small calculated angles, the operators would require a tool that would provide a precise measurement of the actual antenna elevation angle.



$$\tan \theta = b / a$$

$$\theta = \tan^{-1} (.05/1.2)$$

$$\theta = 2.3°$$

Figure 23. Example Use of Trigonometric Functions

4. Experiment Conclusions

The LRV can provide a nomadic link between the deployed SOF Team and the larger tactical network. The LRV displayed the ability to set-up the 802.16 OFDM communications link from remote sites to the TOC utilizing a parabolic antenna in optical LOS conditions. The LRV to TOC communications link proved capable of maintaining data feeds from multiple UAS ground stations within close range and while supporting active Groove collaboration utilization for the biometric data processing of potential hostile targets. The challenges for the LRV, as discovered during this experiment series, are the establishment of a forward network presence with ranges exceeding two miles and the ability to effectively position the UAS ground control stations at a much farther range in order to maximize combat effectiveness while maintaining a reliable communications link with the LRV.

In order to move forward and iteratively improve the capabilities of the LRV while stabilizing the TNT network, the research team came upon several recommendations to put in place prior to the next series of experiments. The first of these recommendations would be to place a tracking antenna on the LRV that would track the position of the TOC via programmed GPS coordinates. This tracking would ensure the LRV’s antenna was precisely positioned along the proper azimuth. To ensure proper alignment a tracking antenna would also have to be placed at the TOC to mirror the actions of the LRV antenna. This second antenna would require dynamic GPS coordinate collection because the LRV would be moving into position and no pre-programmed GPS coordinates would be available. Therefore, another network capability would have to be in place to pass the GPS coordinates of the LRV to the TOC prior to establishing the 802.16 OFDM link. Two ideas for establishing a network link capable of passing GPS data would be either a lower frequency radio or UAV support. A lower frequency, such as 900 MHz, may provide farther reach and improved non-LOS connectivity. Although the throughput of such a technology would be limited it may be enough to pass GPS data. On the other hand, a UAV could establish LOS conditions with both the TOC and the LRV. While in LOS of both nodes, the UAV may be able to pass the GPS coordinates of the LRV once in place to the TOC.

Another iterative improvement to the experiment network that may provide more freedom of movement to the LRV would be establishing a relay station on high-ground aboard Camp Roberts, California. Such position was identified aboard Camp Roberts. This position, Nacimiento Hill, can be seen throughout much of the training base. Specifically, positions as far as ten kilometers away from the TOC were still capable of maintaining optical LOS to Nacimiento Hill. Coupled with the optical LOS Nacimiento Hill has to the TOC, this high-ground should provide more freedom of movement to the LRV in establishing an 802.16 OFDM link through Nacimiento Hill and to the TOC.

The final recommendation to provide a more reliable and stable LRV capability would be to acquire hardware and software tools that would give precise measurements of the antenna azimuth and antenna elevation angle. In addition, measurement tools that would provide the optimal antenna height according to the geographic position of the LRV would be required. These tools would allow the research team definitive knowledge of the precision positioning of the LRV’s antenna. Moreover, if the 802.16 OFDM link was unable to establish connectivity with the TOC, then the research would know that the environment was to blame and not the aforementioned variables of antenna positioning.

B. TNT EXPERIMENT 06-02

1. Pre-Experiment Details and Plans

The second quarter fiscal year 2006 TNT Experiments took place at Camp Roberts, California from 27 February to 03 March 2006. The continuing goal of the Cooperative Field Experimentation Program is identifying the challenges of advanced technology employment in the field, specifically in the areas of network communications, unmanned systems, and net-centric applications. The specific technologies that were scheduled to be evaluated at Camp Roberts during TNT 06-02 are as follows:

- Advanced network backbones
- Mobile Tactical Operations Center (TOC) / Light Reconnaissance Vehicle (LRV)
- High Value Target (HVT) identification with biometrics
- Non-LOS Communications
- Precision Targeting from UAS video
- Network Controlled UAS
- Transmit Raven B UAS video to tactical aircraft (FA-18) for Close Air Support (CAS) mission

The primary mission of the LRV for this series of tactical scenarios would be to establish a forward-deployed network capable of transmitting multiple UAS video feeds to the TOC. A major change in the communications infrastructure was the addition of a communications relay station located on Nacimiento Hill at Camp Roberts. Geographically, Nacimiento Hill is one of the highest elevation points aboard Camp Roberts and allows for projection of the 802.16 OFDM network while maintaining LOS conditions. While the LRV to TOC LOS was approximately one and a half miles during TNT 06-01, by relaying LRV to TOC communications through Nacimiento Hill the network could be extended to approximately six miles during TNT 06-02. Communications between the LRV and the Raven UAS ground control stations would then be accomplished via amplified ITT MESH technologies. Amplification was added due to the challenges discovered during the TNT 06-01 experiments. Biometric data interrogation would also be transmitted over the LRV 802.16 OFDM link via the Groove software application. A new tactical concept being evaluated during this experiment series would be the use of organic asset (Raven B) video being transmitted to a tactical fighter in support of a Close Air Support mission.

2. Experiment Execution

The initial positioning of the LRV during the Convoy/HVT scenario is depicted in Figure 22. Utilizing the high-point relay, the LRV was placed in a non-LOS position from the TOC. The LRV received video from four Raven UAS aircraft; three would be connected using amplified ITT MESH technology while one ground station was hard-wired into the 3Com switch with Category 5 (CAT5) cable. The hard-wired Raven ground station was placed within thirty meters of the LRV and the other three Ravens ground stations, ranging from 500 meters to 1500 meters away, were connected via amplified ITT MESH. It was from the LRV position that biometric data would be transmitted via Groove software running on a CF-18 Toughbook computer inside the LRV. During the execution of the experiment it was noted UAS video from the hard-wired aircraft was constant, while video from the amplified ITT MESH-connected aircraft was unreliable. These amplified ITT MESH links were determined as unreliable because the TOC could not view all four videos simultaneously. Instead, personnel in the TOC could view the video from the hard-wired Raven ground station and two other video feeds for approximately three minutes. After approximately three minutes the two video streams connected to the LRV via amplified ITT MESH would stop. The research team assumed at issue was the amplified ITT MESH connection, because the hard-wired ground station's video, connected to the TOC via the 802.16 OFDM link through Nacimiento Hill, was available throughout the scenario. The research team confirmed the problem with ITT MESH connectivity by issuing PING commands through the command line interface to three computers at the Raven ground stations. These PING commands were issued to run constantly and the PING replies from each computer would gradually get slower and slower until receiving no reply from the Raven ground station computer.

Decreasing the frames per second of these video feeds provided moderate improvements, but continuous video from remote locations proved a challenge while using amplified ITT MESH. Biometric data transmitted from the LRV to the TOC proved effective with interrogation responses averaging four minutes.

Figure 24. Aerial View LRV Position in Support of Raven Ground Stations

During the Close Air Support mission scenario, the LRV acted as communications relay between SOF personnel calling the CAS mission and TOC personnel. The positioning of the LRV evaluated an 802.16 OFDM link of approximately six miles. While serving in this capacity the LRV observed a 14 Mbps throughout with continuous connectivity with the TOC throughout the scenario.

3. Observations and Key Issues

While solutions for the LRV 802.16 OFDM connection are proving successful, practical solutions for the LRV to UAS ground control stations have proven difficult. The key observations concerning the LRV participation in TNT 06-02 are provided below:

- Communication relay on Nacimiento Hill allowed for extremely reliable link with stable high throughput rates while LRV is in non-LOS condition with TOC
- OFDM throughput at ranges of four and six miles averaged 14 Mbps with 100 percent reliability once the link was established. Figure 25 displays the test results from the IxChariot High-Performance Throughput script.

- UAS video from ground control stations transmitted over amplified wireless ITT MESH had difficulty providing reliable connectivity and data rates in which tactical decisions could be made.

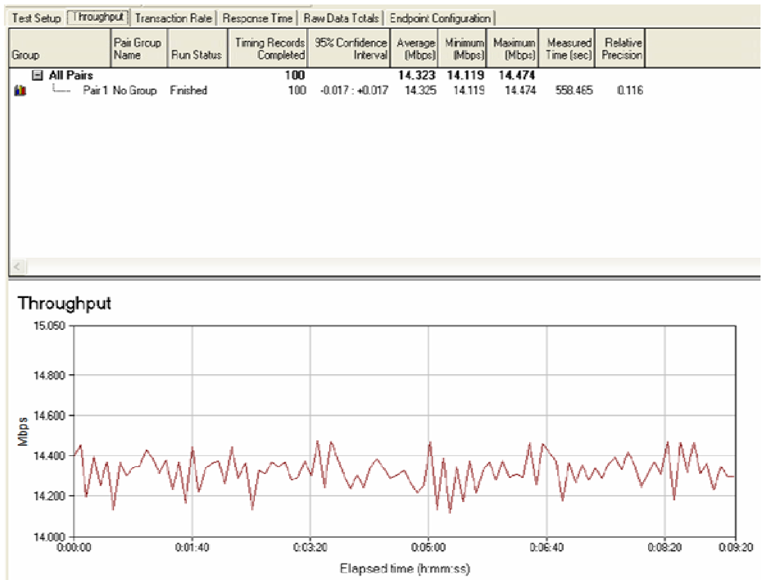


Figure 25. IxChariot High-performance Throughput Results, TNT 06-02

Through two field experiments, the research team has experienced limited ability to reliably connect nodes within the local area of the tactically deployed LRV. The primary technology used in attempting to connect these nodes was mesh enabled technologies. These technologies included the 2.4 GHz ITT MESH and the 2.1 GHz amplified ITT MESH. ITT MESH technologies have demonstrated dynamic capabilities while connecting nodes on-the-move by maintaining network connectivity. However, during these experiments when the Raven ground station nodes remained in place and attempted to push large data packets, streaming video, over the network the ITT MESH technologies could not maintain consistent network connectivity. The mesh enabled technologies had much lower throughput ability than 802.16 OFDM links and the technology limited the ground stations by forcing each to maintain optical LOS at extremely short distances. The UAS operators wanted to push each ground station much farther in order to fly their UASs in search patterns conducive to the tactical scenario.

4. Experiment Conclusions

Following TNT 06-02, the research team concluded that another technology was required to link forward deployed UAS ground stations to the LRV in order to pass video over the network and into the TOC. Because the team experienced successful and stable connectivity using the 802.16 OFDM links through Nacimiento Hill and onto the TOC, using this same technology to connect forward deployed UAS ground stations to the LRV was considered. Specifically, this change would require each ground station have a RedLine AN-50e radio as well as an antenna. Also, three additional RedLine AN-50e radios would be required aboard the LRV with the supporting antennae. Although the move to 802.16 OFDM links may be cumbersome because of the extra equipment and may require some operator training (i.e. antenna alignment, radio configuration), the research team maintained that moving to 802.16 OFDM links would enhance the network by establishing reliable links able to pass video. Another benefit may be the additional distance that each Raven ground station can move away from the LRV in order to maximize their flights to meet certain search pattern criteria.

The research team also completed the TNT 06-02 series of experiments with a better understanding of variables involved when establishing wireless communication networks. Specifically, the team began calculating link budgets prior to deploying the LRV in order to get expected values for the RSSI and SNR. The expected values offered the team insight into each links' viability. In addition, variable such as Fresnel zones, fade margin, and free space path loss began to be considered during the LRV deployment and this insight gave the team more confidence in establishing reliable network connectivity.

5. Calculating Link Budgets

The link budget refers to the calculation of the amount of excess signal strength that exists between the transmitter and receiver {Joshua Bardwell 2005}. Specifically for the LRV research, the link budget would be the signal strength from the transmitting radio aboard the LRV to a receiving radio on top of Nacimiento Hill, at a Raven Ground Station, or at the TOC. The calculation would include all of the gains and losses in the path from transmitting radio to receiving radio. For example, to calculate the link budget, you would start with the transmission power from the radio, subtract any cables or connector losses from radio to antenna, add the antenna gain, subtract the Free Space Path Loss, add the receiving antenna gain, and finally subtract any cable or connector loss from the receive antenna to the receive radio. The following figure provides an overview of the link budget calculation.

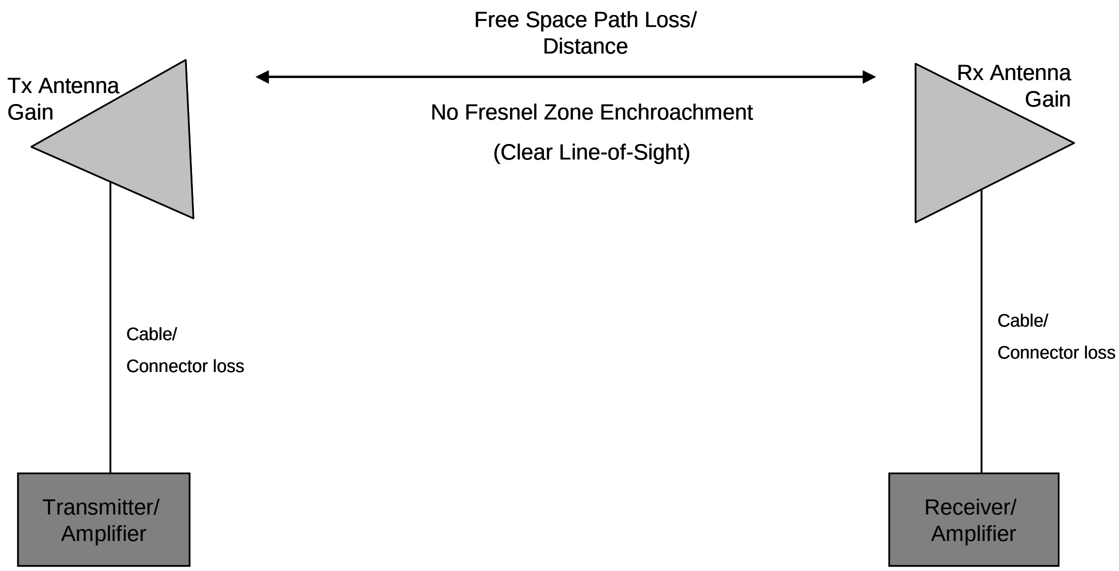


Figure 26.   Overview of Link Budget Calculation

Once the link budget is calculated the user should know or be able to find the receive sensitivity of the receiving radio. The experiments have shown that in order to establish a reliable link able to pass video using the RedLine AN-50e one would require a receive sensitivity of -78 dBm or better. By using RedLine Communications' RF Monitor software the user can monitor the receive sensitivity, which in this application is titled the Receive Sensitivity Signal Indicator (RSSI). Figure 27 offers an example of the RSSI data gained using RF Monitor.

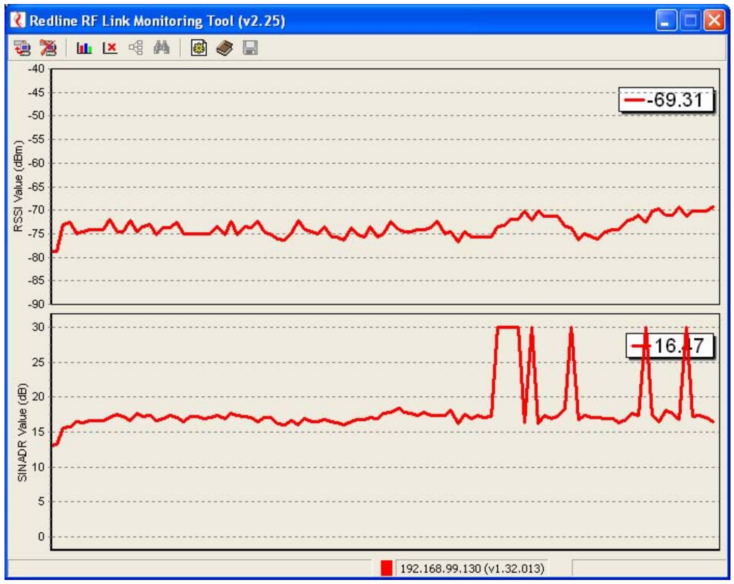


Figure 27. Screen Capture of RedLine Communications' RF Monitor

When calculating a link budget it becomes apparent that the most prominent loss incurred is due to free space path loss, sometimes referred to as power loss in space or path loss attenuation. Free space path loss refers to the loss incurred by an RF signal due to 'signal dispersion' or a natural broadening of the wave front {Bardwell, Joshua 2005}. The equation to calculate free space path loss is:

$L_s\,(dB) = 37\,dB + 20 \log f_{mHz} + 20 \log d_{miles}$ {Young, P.H. 2004}

Whereas, L_s is the free space path loss, f is the frequency used, and d is the distance between transmitting antenna and receiving antenna. Typically, the free space path loss incurred between antennae will range from -90 to -130 depending on the distance. With this amount of loss it is apparent that somewhere gains will have to balance out the heavy losses in order to reach a -78 or better RSSI. The two gains that will balance out the heavy losses are the power output of each radio and the gains of the antennae used. The RedLine AN-50e's are limited to 20 dBm power output. During these experiments the typical antenna used provided gains of 17 to 23 dBi.

An alternative to calculating a link budget with the equation above is to use automated tools. RedLine Communications provides a link budget tool, which is a software application that will automatically calculate the link budget as well as the free space path loss, Fresnel zones, and fade margin. Figure 28 offers an example of RedLine Communications' Link Budget tool.

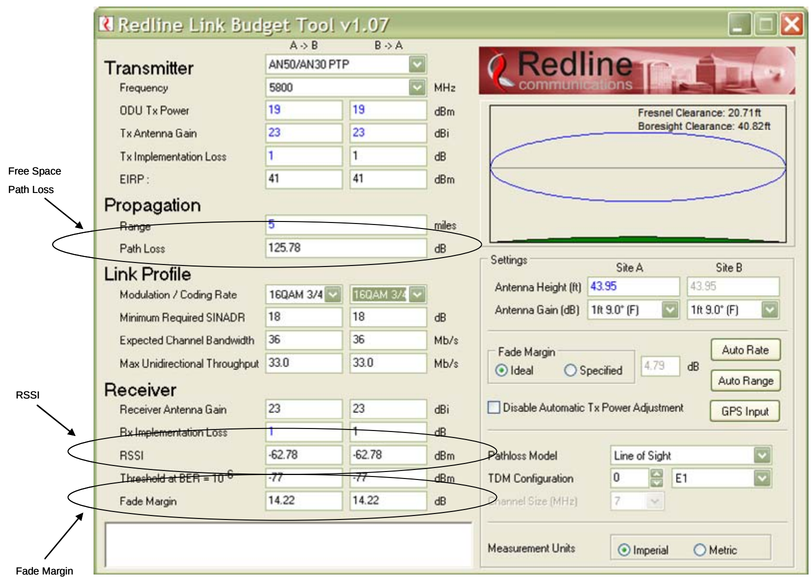


Figure 28. Screen Capture of RedLine Communications' Link Budget Tool

This tool provides a reasonable method for users to input variables into the application to get expected values before deploying the LRV. There are some limitations to RedLine Communications' automated tool. One limitation is the expected values calculated have been determined to be generous. Specifically, once the variables are input into the application the expected values calculated are better than those calculated using the free space path loss equation. Another limitation using the automated tool is the difficulty in calculating reliable expected values in specific terrain. Specifically, this tool allows only LOS, optical LOS, NLOS, and NLOS in urban area. This application uses assumptions and standardizes the assumptions into the aforementioned four types of terrain. Better expected values would be available if specific terrain, distances, and obstacles were input into the tool. Overall, RedLine Communications' Link Budget Tool is a good application to use in order to get information about the expected feasibility of a link, however, it should not be relied upon as a guarantee for the expected performance of the link.

There are a couple variables worth noting in calculating a Link Budget and predicting expected values of specific links. The first of these variables seen in the RedLine Communications' Link Budget Tool is EIRP or the Equivalent Isotropically Radiated Power. This variable is important because it is regulated by the Federal Communications Commission (FCC) and places limits on the amount of EIRP within the frequency band being utilized by the LRV. The EIRP can be defined as the power that is actually being radiated by the antenna elements and therefore takes into account the power output of the radio, any losses due to cables and connectors, and the antenna gain {Bardwell, Joshua 2005; }.

Another variable that can be calculated either automatically via the Link Budget Tool or through mathematical equations is the fade margin. Fade margin calculations are useful when implementing long-distance outdoor links. In general, the common practice of including a few extra dBm of signal strength into the link budget in order to deem the link viable is the definition of fade margin. This variable is important because of the generous expected values offered from automated tools and equations. In practice, the expected RSSI has been lower than the actual RSSI. Therefore, by calculating a fade margin prior to deployment the operators can see how much 'cushion' they have in the expected versus required RSSI. Such things as antenna misalignment, weather, interference, and obstacles make a fade margin calculation necessary. Through research a fade margin of ten dBm or greater from the required to actual is the minimum recommended fade margin {Bardwell, Joshua 2005} .

One final variable that the research team became familiar with while employing the LRV is the Fresnel zone. The Fresnel zone is an area centered on the optical LOS between the transmitting and receiving antennae. Although the zone is transparent, it can be envisioned as an elliptical area; narrow close to the antenna and at its widest midway between the two antennae {Bardwell, Joshua 2005}. When an RF waveform leaves a radiating antenna, it does not remain concentrated. Instead the RF waveform disperses and widens. As the waveform disperses and widens, the likelihood of obstacles obstructing some of the waveform increases dramatically. Therefore, even though optical LOS conditions may exist, the research team typically experienced improved RSSI and SNR when the telescoping mast was raised. The assumption was made that as the telescoping mast raised the radiating antenna, the 802.16 OFDM waveform’s Fresnel zone became unobstructed by trees and hills.

C. TNT EXPERIMENT 06-03

1. Pre-Experiment Details and Plans

The Camp Roberts TNT experiments for third quarter fiscal year 2006 took place from 3–9 June 2006. The key technologies and operational concepts, relating to the LRV, being evaluated include:

- Command and Control of UAS assets
- Forward-deployed wireless network performance
- Target identification utilizing biometric technologies

Based on after action reports generated following TNT 06-02, the primary focus for the LRV team was to provide a solution to enable critical decision making based on multiple UAS video streams being transmitted over a wireless network. It was determined during TNT 06-02 that the 802.16 OFDM link enabling information flow from the LRV to the TOC was sufficient, communication via wireless mesh enabled technologies between the LRV and the Raven ground control stations were inadequate to base critical tactical decisions on. Given the field-proven performance metrics of the 802.16 OFDM link from the LRV to TOC, it was decided to employ 802.16 OFDM technology throughout the entire wireless network. In utilizing 802.16 OFDM technology to the very edge of the wireless network particular attention would have to be given to frequency management and deconfliction. Table 4 provides the center frequencies of the five primary channels and sub-channels recommended by RedLine Communications when using their AN-50e radios.

Channel	Frequency
1	5735 MHz
1A	5745 MHz
2	5755 MHz
2A	5765 MHz
3	5775 MHz
3A	5785 MHz
4	5795 MHz
4A	5805 MHz
5	5815 MHz

Table 4. AN-50e Center Frequencies of Each Permitted Channel

Four separate 802.16 OFDM links were in the immediate vicinity of the LRV, in addition to the three other 802.16 OFDM links operating within the local area TNT network.

Figure 29. TNT 06-03 802.16 Frequency Deconfliction Diagram

Depicted above in Figure 29 is the final outline of the 802.16 OFDM links in addition to the center frequencies selected for each link. Based on the recommendations within the RedLine AN-50e manual, radios located in the same immediate vicinity had center frequencies separated by a minimum of 20 Mhz to minimize noise being induced from unintentional emitters. Statistics on network throughput and reliability would be monitored to track the deltas in the communication links from the LRV to Raven GCS locations. Biometric technology and wireless network performance, as well as the Raven to LRV communication link would be evaluated during the same HVT/Checkpoint scenario performed during TNT 06-02.

2. Experiment Execution

The geographical set up of the HVT/Checkpoint scenario, which evaluates both UAS and biometric technologies, would be similar to the scenario executed during the previous TNT. The LRV would be located approximately four miles from the TOC and establish an 802.16 OFDM link to the TOC via the Nacimiento Hill relay. Four Raven UASs would be deployed within LOS of the LRV: the farthest Raven ground station would be placed at a range of two miles, two more ground stations were be placed at slightly shorter ranges, and one was hard-wired to the LRV. The hardware for the LRV to Raven ground stations links required a Redline AN-50e radio and an antenna/transceiver at each ground station. In addition, three additional RedLine AN-50e radios with antenna/transceivers were installed on the LRV. Figure 30 depicts the LRV utilizing the telescoping antenna mast establishing the 802.16 network backbone to the TOC via the Nacimiento relay station, in addition to the three antennas receiving video and targeting information from tactically positioned Raven ground control stations.

Figure 30. LRV to Multiple UAS and TOC Antenna Configuration

Figure 31 shows the interaction of the LRV-established communications and the overall communication links of the operational units involved in the HVT/Checkpoint scenario.

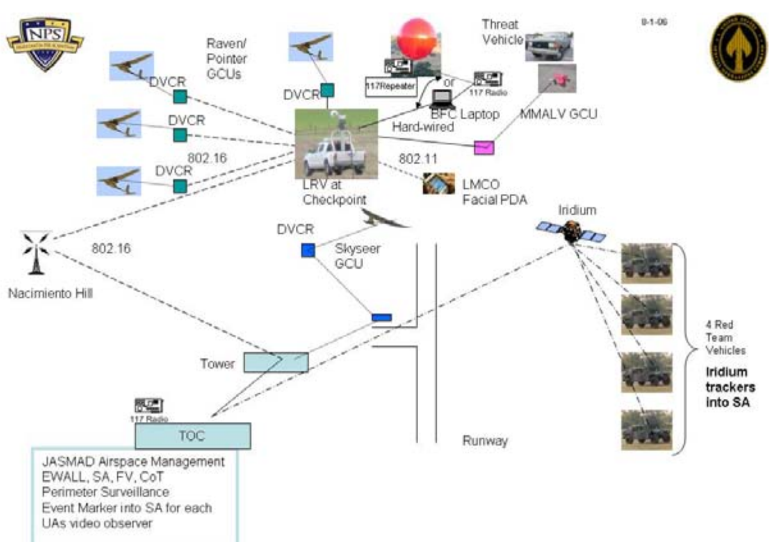


Figure 31. TNT 06-03 HVT/Checkpoint Scenario

3. Observations and Key Issues

When initially deploying the LRV and Raven ground stations the 802.16 OFDM links were quickly established with each node, although, using RF Monitor, the RSSI and SNR for Raven ground station #3 was much lower than the expected values when calculating a Link Budget. Specifically, the RSSI for this link was recorded at -77 and the SNR bounced between 10 and 15. In searching for the cause of such low RSSI and SNR, the research team reviewed the frequencies of all 802.16 OFDM links within the AOR of the LRV. The team identified the frequency of the 802.16 OFDM link between Nacimiento Hill and the LRV was too close to the frequency assigned to the link between Raven ground station #3 and the LRV. Using the remote configuration capability, opening the graphical user interface of each radio via a web browser, the team was able to change the frequencies of the links in order to provide the recommended frequency separation.

During this experiment, the research team clearly identified the need to de-conflict the frequencies utilized when operating multiple radios within range of one another. While connecting three Raven ground stations to the LRV via 802.16 OFDM links provided increased range for each ground station it also highlighted the importance of planning out the frequency assignments of each radio. Specifically, at the LRV site there were 4 links that required frequency de-confliction in order to maximize the RSSI and SNR experienced at each node. RedLine Communications outlines recommended channels to utilize when deploying multiple radios in close range (see Table 3). The research team identified the necessity to refer to the recommended channels and separate the four links; Nacimiento Hill to the LRV, Raven ground station #1 to LRV, Raven ground station #3 to LRV, and Raven ground station #4 to LRV. Once the team assigned frequencies to each node according to the channels on the table, there was significant improvement in the RSSI and SNR in each node. In de-conflicting the frequencies the research team attempted to separate the links as much as possible assigning Raven ground station #1 to LRV Channel #1 (5735 MHz), Raven ground station #2 to LRV Channel #3 (5775 MHz), and Raven ground station #4 to LRV Channel #5 (5815 MHz). In addition, the link from the LRV to Nacimiento Hill was within the same area as the ground stations, so it was assigned Channel #4 (5795 MHz).

To avoid further interference, frequencies outside the aforementioned area were also altered to recommended frequencies that were not assigned to any node. The link from Nacimiento Hill to the TOC was assigned Channel #1a (5745 MHz) and the link from the TOC to the Camp Roberts Satellite Station was assigned Channel #3a (5785 MHz). The frequency de-confliction allowed for a much better understanding of why certain frequencies were used, but also offered the most efficient separation of frequencies.

4. Experiment Conclusions

After completing the TNT 06-03 series of experiments, the research team demonstrated a more stable and reliable network via 802.16 OFDM links. By replacing mesh enabled technologies with 802.16 OFDM links, each Raven ground station maintained network connectivity with the LRV and to the TOC while sending video packets for review at the TOC. Although there were a number of concerns with deploying three additional 802.16 OFDM links, the execution of the experiment demonstrated a stable and reliable network. The remaining issue with deploying a number of 802.16 OFDM links within the same AOR is de-conflicting the frequencies to allow for adequate RSSI and SNR.

RedLine Communications offers specific guidance when deploying numerous AN-50e's within the same AOR. They give information on recommended frequency separation and channels associated with such separation. TNT 06-03 demonstrated the importance of separating the frequencies accordingly.

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V. RESEARCH CONCLUSIONS AND RECOMMENDATIONS

A. RESEARCH CONCLUSIONS

Throughout the LRV Project, the goal has been to demonstrate a more agile and reliable communication asset. Although the LRV has developed into a reliable communication asset by demonstrating decreased set-up time and stable network connectivity, the agility of such an asset remains in question. Specifically, at the onset of the project, the LRV was to deliver a Mobile Network Operations Center (MNOC) capability. This function was later altered, however, to a ground-based mobile C4ISR platform and the research team continued to strive towards this goal. Although there were many milestones in providing a more agile capability, at no time was the LRV deemed a mobile asset. A more precise term to describe the LRV's faculty is nomadic.

1. Nomadic Wireless Networks

As wireless data networks mature they are typically divided into three categories. These categories are Fixed Networks, Nomadic Networks, and Mobile Networks. From the first instance of connecting two computers together, Fixed Networks have been the most common and simplest category of network available. Specifically, Fixed Networks were characterized by their point-to-point nature and the fixed position of each node. As wireless technologies matured and became more popular, people wanted to stray from fixed positions and move toward a more flexible type of network. Many broadband technologies used in the past few years have remained with the fixed position theory because it is the easiest to implement and support. For example, the 802.16 standard was specifically designed to support metropolitan area networks (MANs) and the original 802.16 standard specified fixed point-to-multipoint broadband wireless networking {www.ieee.org}. 802.16 standards are expected to offer Wireless Internet Service Providers (WISPs) alternatives to the expensive cabling otherwise required to network fixed positions to one another and the Internet.

On the other spectrum of network categories is the Mobile Network. This type of network is by far the most complex to implement. A true broadband mobile technology would have to provide ubiquitous coverage, while supporting high-velocity mobile nodes. Although there are no standards currently available that provide a true mobile broadband capability, there are two standards that show some promise in meeting these needs. A further amendment to the 802.16 standard, 802.16e, and another standard titled 802.20 are expected to offer network connectivity to mobile nodes.

Somewhere in between the aforementioned categories of wireless networks lie Nomadic Networks. While there are plenty of Fixed Network capabilities and no mature Mobile Network capabilities, many organizations are testing, evaluating, and implementing Nomadic Networks. Nomadic Networks are characterized by connecting an individual node to the network and not necessarily another specific node. The Nomadic Network would provide some flexibility to an individual node by allowing on-demand connectivity. For instance, an individual node would get into place, connect to the network, and be permitted to move within a local area while maintaining network connectivity {Olexa, Ron 2005}.

Defining the LRV as nomadic can be viewed as a major milestone in that the technologies utilized to provide the primary link, the RedLine AN-50e, were designed to supply users with a broadband point-to-point or point-to-multipoint over fixed positions. The RedLine AN-50e's, which deploy a waveform meeting the 802.16 TG4 standard, were designed to give fixed positions such as WISPs a wireless broadband alternative. The adaptation of this technology into a nomadic, deployable communication asset remains the crowning achievement of this research project.

2. Maximizing Throughput

Another interesting result of our research resulted from the numerous modulation schemes and subsequent throughput capabilities of the RedLine AN-50e radios. While the research team collected throughput rates ranging from 10 – 14 Mbps on many of the 802.16 OFDM links, some of the radios were capable of much higher throughput. Specifically, the AN-50e is capable of modulating the waveforms at Biphase Key Shifting (BPSK), Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM) and 64 QAM. These different modulation schemes offer varying average throughput ranging from 5 to 48 Mbps. The 64 QAM capability is an added feature of the AN-50e and most of the radios purchased from RedLine Communications were only capable of modulating at QPSK.

After searching through the AN-50e's available, the ones that were capable of 64 QAM were re-configured and placed in positions that would take advantage of their increased throughput capability. Specifically, one of the radios used by a Raven Ground Station and another radio that was off-line were found to have the 64 QAM modulation capability. These radios were re-configured and replaced the radios atop Nacimiento Hill providing the experiment backbone. Once the radios were in place the entire backbone of the TNT network had radios with the 64 QAM capability. The other radios without the 64 QAM capability were deployed from the LRV to the Raven Ground Stations.

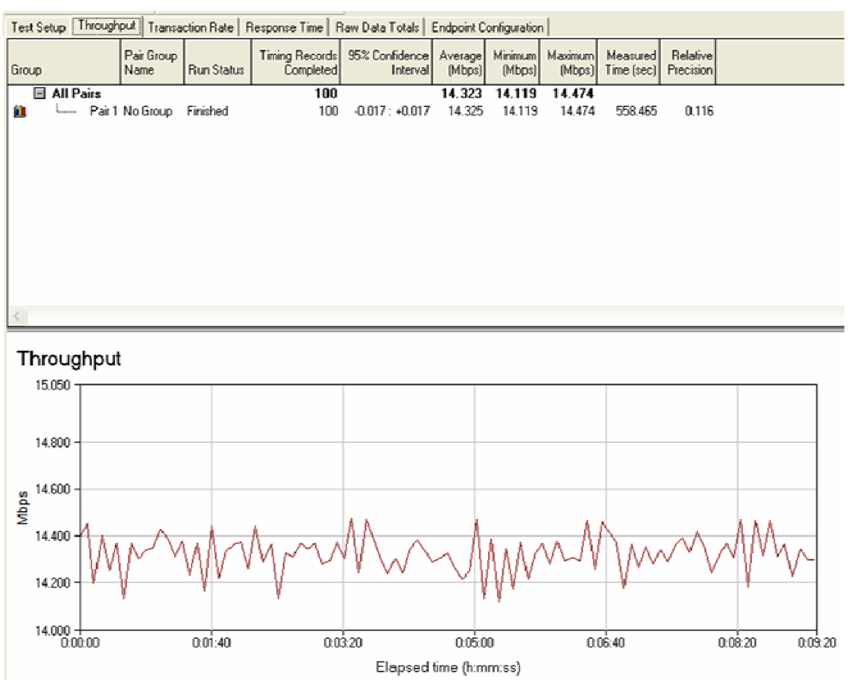

Figure 32. IxChariot High-performance Throughput Results at QPSK

Figure 33. IxChariot High-performance Throughput Results at 64 QAM

By re-arranging the higher throughput capable radios to support the experiment's network backbone, we experienced much higher average throughput and no bottleneck of throughput at the LRV. Figure 32 depicts the results of an IxChariot High-Performance Throughput Test, which was run with radios only capable of modulating at QPSK. Figure 33 depicts the results of an IxChariot High-Performance Throughput Test, which was run after switching to radios capable of modulating at 64 QAM.

This throughput bottleneck initially occurred because three Raven ground stations were pushing 14 Mbps to the LRV and the LRV could only push 14 Mbps to Nacimiento Hill. After the re-configuration, the Raven ground stations continued to see their 14 Mbps throughput to the LRV, but the average throughput from the LRV to Nacimiento Hill increased to 26 Mbps. The major lesson learned through this experience was to push lower throughput systems to the edges and maintain higher throughput systems within the network backbone. Because only some of the radios were capable of the 64 QAM modulation, these radios should be placed in support of the network backbone and other less capable radios should be given to the edge nodes, such as the Raven ground stations.

All of RedLine Communications' AN-50e radios are capable of modulating at 64 QAM. However, this modulation scheme is considered an upgrade and therefore requires a software key to release this capability. If adaptive modulation is selected on the radios via the graphical user interface the radios will negotiate with one another to choose the highest possible modulation of both radios with consideration to the RSSI and SNR of the link itself. If one of the radios can only modulate at QPSK, then the throughput will be maximized around 14 Mbps. Likewise, if both radios have been upgraded via the software key to modulate at 64 QAM, then the throughput will drastically increase without changing antennae, power output, or even the radio as the research has demonstrated.

3. Three-tiered ISR Approach

The implementation of the LRV platform into the special operations concept of operations has the potential to become a force enabler on the tactical mission front. The LRV is allowing the SOF team to deploy into an area of operations with the organic assets to provide time-critical data and information exchange to both the field operators and the tactical/theatre commanders. The capabilities being provided by the technologies employed on the UAS combined with existing technologies create a three-tiered approach that increases the situational awareness of forward deploy forces.

The first tier in this methodology is the high altitude UAS. While SOF personnel often benefit from the tactical information provided by high altitude UASs such as the Predator, these aircraft are national assets and are assigned priority missions that may supersede the mission requirements of an individual SOF team. The result of the mission prioritizing of national assets can be that tactical decisions are being made on time-late data that can increase the risk to personnel and mission failure. While high-altitude UAS targeting and surveillance is critical, the capability for individual SOF teams to employ multiple low-altitude UASs in support of a particular operation is vital. This critical need has produced the need for a second ISR tier, which the LRV has enabled. SOF personnel embarked in the LRV can launch and control multiple low-altitude UASs to receive accurate data on specific targets in near-real time. The organic nature of these aircrafts will ensure availability of tactical data on demand. The availability of this information to be shared with command post personnel in a collaborative environment further allows for accurate decision making. In additional, small organic UASs are relatively inexpensive and therefore can be employed in situations where costly national asset aircraft may not be employed. The third and final tier of this ISR methodology enabled by the LRV is the ground asset component. SOF personnel can receive relevant tactical data via wireless networks established in the vicinity of the LRV. This also provides peer-to-peer communication and information exchange between SOF team members to include the command element providing analysis of real-time data. The cumulative effect of this three-tiered approach to ISR serves as a force multiplier to the combat effectiveness of deployed SOF teams in the tactical environment.

B. FUTURE RESEARCH RECOMMENDATIONS

1. Mobile Wireless Networks

There are multiple opportunities, specific to mobility, available for future research. The first of these research opportunities could be the use of tracking antennae aboard the LRV to track the TOC while in motion. Past experiments have demonstrated success in using a tracking antenna aboard the LRV to track a UAS flying overhead in order to maintain network connectivity. The application and use of a tracking antenna to track the TOC while the LRV is in motion could result in maintaining network connectivity aboard a mobile platform, although there will remain limitations specific to LOS.

2. Antenna Array Technology

Another research opportunity available for future research is the employment of antenna arrays. Over the past year, individuals at NPS have developed a Smart Antenna Array and Smart Antenna Processor. The theory behind antenna arrays is that using multiple antennae to receive a signal could result in one of the many antennae receiving the signal better than the others. After the antennae receive the signal, the processor would determine which antenna is receiving the best signal. Then the processor would ensure the signal being received is in phase and correctly polarized. Antenna array technology is attempting to answer the mobility question in urban terrain. The RF signal may be reflected and defracted off buildings or other man-made objects putting a signal out of phase and possibly changing the polarity. Initial steps have already been taken to begin testing antenna arrays, however, the Smart Antenna Processor, has not yet been fielded.

3. Immature Wireless Communication Standards

A third research opportunity exists in the testing and evaluation of new wireless standards such as 802.16e and 802.20. Instead of continuing to adapt technologies meeting 802.16 TG4, 802.16a, and 802.16(2004) standards which were designed for fixed networks and adapted for nomadic use, further research could include new standards that specifically address mobility. Mobility is the final hurdle in proving the LRV as a mobile platform that meets the tenets of NCW.

4. Refining the Concept of Operations

In addition to answering the mobility question, further research could be conducted in the tactical employment of an LRV. For example, most scenarios practiced during recent TNT experiments utilize the LRV as a bridge for UAS ground control units dispersed within a one and one half mile radius of the LRV. These ground control units carry their own RedLine AN-50e’s, antenna, UAS, and UAS control equipment. Additionally, these ground control units consist of two to four personnel. Instead of continuing to act as a bridge for the video feed from the UAS to the TOC, the LRV team could incorporate a UAV, or multiple aircraft, into its mission package. SOF personnel currently receive training on operation and employment of UASs so the challenge is creating storage and transportation mechanisms within the bed of the LRV that maintain the integrity of the aircraft while allowing for rapid deployment. With that challenge met, the LRV team could deploy into the field with the capability to establish a high-throughput data link to the command post and launch multiple organic UASs for data collection. With the additional UAS resource, the LRV would better meet the definition of an ISR platform. This concept of operations shift would further the emphasis of the three-tiered ISR approach enabled with the employment of the LRV.

5. Tactically Employing a Local Area Network

Consideration should also be given to continuing the research on the LRV's local area network functionality. Specifically, the LRV normally deploys with an 802.11a/b/g router aboard, however due to the potential risk to data assurance and integrity within the 802.11 a/b/g standard, the wireless router has seen little action. There has also been some initial testing with mesh enabled architectures in order to provide a wireless local area network around the LRV. These experiments using mesh-enabled architectures have been unstable and unreliable. Experimentation should continue in order to facilitate a wireless local area network, so that the LRV can demonstrate its ability to offer a communication link to tactically employed forces within an area around the LRV.

APPENDIX A. 2005 TOYOTA TACOMA MANUFACTURER SPECIFICATIONS

Specifications	Tacoma Double Cab,4x4 Short Bed
Mechanical / Performance	
2.7-liter DOHC EFI 4-cylinder with VVT-i 159 hp @ 5200 rpm 180 lb.-ft. @ 3800 rpm	NA
4.0-liter DOHC EFI V6 with VVT-i 236 hp @ 5200 rpm 266 lb.-ft. @ 4000 rpm	S
4WDemand: part-time 4-wheel drive system with 2-speed electronically controlled transfer case	S (4x4)
Transmission	
5-speed manual transmission with overdrive	NA
6-speed manual transmission	NA/S
Clutch start-cancel switch	S (4x4)
4-speed electronically controlled automatic overdrive transmission with intelligence (ECT-i)	NA
5-speed electronically controlled automatic overdrive transmission with intelligence (ECT-i)	S/A
Final axle ratio -- MT	3.73
-- AT	3.73
Body / Suspension / Chassis	
Body construction	One-piece frame rails with seven cross members and fully boxed front sub-frame
Front suspension	Coil-spring double wishbone suspension
Rear suspension	Leaf spring suspension with staggered outboard-mounted gas shock absorbers
Front stabilizer bar (dia., in.)	1.18
Steering	Variable-assist power rack-and-pinion steering
Steering wheel turns, lock-to-lock	3.64

Power-assisted ventilated front disc brakes (dia., in.)	12.56
Rear brakes	Rear 10-in. drum brakes with tandem booster
4-wheel Anti-lock Brake System (ABS) with Electronic Brake-force Distribution (EBD) and Brake Assist	S
Dimensions	
Exterior Measurements	
Overall length (in.)	208.1
Overall height (in.)	70.1
Overall width (in.)	74.6
Bed length (in.)	60.3
Bed height (in.)	18.0
Bed width (in., total/between wheelwells)	56.7/41.5
Wheelbase (in.)	127.8
Track (in., front/rear)	63.0/63.4
Turning circle diameter, curb-to-curb (ft.)	40.7
Interior Measurements	
Head room (in., front/rear)	40.1/38.5
Leg room (in., front/rear)	41.7/32.6
Shoulder room (in., front/rear)	57.7/59.3
Hip room (in., front/rear)	53.6/55.2
Interior passenger volume (cu. ft., front/rear)	55.8/43.1
Maximum seating capacity	5
Off-Highway	
Approach/departure angle (degrees)	35/26
Ramp breakover angle (degrees)	21
Minimum running ground clearance	9.5/9.4
4x4 transfer case ratio (high/low, 4x4 models)	1.00/2.57

Weights and Payload / Towing Capacities

Curb weight, manual transmission models (lb.)	NA/4055
Curb weight, automatic transmission models (lb.)	3845/4080
Gross Vehicle Weight Rating (GVWR) (lb.)	5350/5450
Payload , manual transmission models (lb.)	NA/1395
Payload, automatic transmission models (lb.)	1505/1370
Tongue load (lb., standard / maximum)	350/650
Standard towing capacity (lb.)	3500
Maximum towing capacity (lb.)	6500
Gross Combined Weight Rating (GCWR) (lb.) -- 4 cyl.	NA
-- V6 (with Towing Package)	8100
	(11,100)
Vehicle Stability Control (VSC) + Traction Control Packages	
VSC + Traction Control only (V6 MT models)	-/O
VSC + Traction Control with Hill Start Assist Control (HAC) (V6 AT models)	O/-
VSC + Traction Control with automatic limited-slip rear differential (MT models)	-/O
VSC + Traction Control with automatic limited-slip rear differential and Hill Start Assist Control (HAC) (AT models)	O
VSC + Traction Control with Downhill Assist Control (DAC) and Hill Start Assist Control (HAC) (4x4 V6 AT models)	O
EPA Mileage Estimates / Capacities	
4.0-liter V6 engine with 6-speed manual (city/hwy)	NA (4x4:16/20)
4.0-liter V6 engine with 5-speed automatic (city/hwy)	18/22 (4x4:17/21)
Fuel tank (gal.)	21.0
Standard tire size	P245/75R16
Tire type	Mud-and-Snow

S	**=**	Standard
A	**=**	Available
-	**=**	Not Available

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APPENDIX B. AN-50 SYSTEM SPECIFICATIONS

<table>
<tr><th colspan="2">AN-50 SYSTEM SPECIFICATIONS</th></tr>
<tr><td>System Capability</td><td>Non-line-of-sight operations, PTP mode</td></tr>
<tr><td>RF Band</td><td>5.725 – 5.825 GHz (unlicensed band)</td></tr>
<tr><td>Channel Center Frequencies</td><td><table>
<tr><td>Channel</td><td>1</td><td>1a</td><td>2</td><td>2a</td><td>3</td><td>3a</td><td>4</td><td>4a</td><td>5</td></tr>
<tr><td>Frequency</td><td>5.735 GHz</td><td>5.745 GHz</td><td>5.755 GHz</td><td>5.765 GHz</td><td>5.775 GHz</td><td>5.785 GHz</td><td>5.795 GHz</td><td>5.805 GHz</td><td>5.815 GHz</td></tr>
</table></td></tr>
<tr><td>Channel Size</td><td>20 MHz</td></tr>
<tr><td>RF Dynamic Range</td><td>> 50 dB</td></tr>
<tr><td>Modulation/ Throughput</td><td><table>
<tr><td>Modulation</td><td>Coding Rate</td><td>Over the Air Rate (Mbps)</td><td>Uncoded Burst Rate (Mbps)</td><td>Average Ethernet Rate (Mbps)</td></tr>
<tr><td>BPSK</td><td>½</td><td>12</td><td>6</td><td>5.82</td></tr>
<tr><td>BPSK</td><td>¾</td><td>12</td><td>9</td><td>8.63</td></tr>
<tr><td>QPSK</td><td>½</td><td>24</td><td>12</td><td>11.38</td></tr>
<tr><td>QPSK</td><td>¾</td><td>24</td><td>18</td><td>16.7</td></tr>
<tr><td>16 QAM</td><td>½</td><td>48</td><td>24</td><td>21.77</td></tr>
<tr><td>16 QAM</td><td>¾</td><td>48</td><td>36</td><td>33.01</td></tr>
<tr><td>64 QAM</td><td>½</td><td>72</td><td>48</td><td>44.1</td></tr>
<tr><td>64 QAM</td><td>¾</td><td>72</td><td>54</td><td>48.8</td></tr>
</table></td></tr>
<tr><td>Maximum Tx Power</td><td>-20 to +20 dBm (region specific)</td></tr>
<tr><td>Rx Sensitivity</td><td>-86 dBm at 6 Mbps</td></tr>
<tr><td>IF Cable</td><td>o Maximum length up to 250 ft (76m) using RG6U / 500 ft (152m) using high-grade RG11U
o Maximum allowable losses at 2.5 GHz:
RG6: 10 dB/ 30m (100 feet) at 25 degrees Celsius
RG11: 5 dB / 30m (100 feet) at 25 degrees Celsius
o Multiplexed IF, DC power, control (Tx/Rx, AGC, APC)</td></tr>
<tr><td>Network Attributes</td><td>o Transparent bridge
o DHCP passthrough
o VLAN passthrough</td></tr>
</table>

	o 802.3x Ethernet flow control o 802.1p Network Traffic Prioritization
Modulation	Dynamic Adaptive Modulation (bi-directional) auto selects: o BPSK o QPSK o 16 QAM o 64 QAM
Over the Air Encryption	Proprietary 64-bit encryption
Coding Rates	1/2, 3/4, and 2/3
MAC	o Point to Point o Automatic Repeat Request (ARQ) error correction o Concatenation/ Fragmentation
Range	o Over 10 km / 6 miles non-line-of-sight o Over 80 km / 50 miles line-of-sight
Network Services	Transparent to 802.3 services and applications
Duplex Techniques	Dynamic TDD (time division duplex)
Wireless Transmissions	OFDM (orthogonal frequency division multiplexing)
Backhaul Connection	10/100 Ethernet (RJ45)
System Configuration	o Web interface and SNMP o CLI via Telnet and Local Console Port
Power Requirements	Single or dual 110/220/240 VAC (auto-sensing) 50/60 Hz, 39W maximum
Operating Temperature Range	AN-50 Terminal Operating Conditions: 41F to 104F / 5C to 40C AN-50 Terminal Short-Term Conditions: 23F to 41F and 104F to 131F/ -5C to 5C and 40C to 55C for up to 16 hours T-58 Operating Conditions: -40F to +140F / -40C to +60C
Wind Loading	An-50 Radio: 137 mph / 220km/hr
Physical Configuration	AN-50 terminal, AN-50 Radio
AN-50	17” x 12” x 1.75” / 431.8 mm x 304.8 mm x 44.45 mm

Dimensions	
Component Weights	o AN-50 Terminal ………………………………………………. 2.0 kg o T-58 Transceiver ………………………………………………. 1.0 kg o Vertical Mast Bracket Kit …………………………………….... 3.0 kg o Vertical Mast Bracket Hardware Kit ……………………...…… 0.5 kg o Cable, F Male/ F Male, RG6, 100 ft …………………………… 1.3 kg o Antenna ………………………………………………………… 1.0 to 27.0 kg

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APPENDIX C. EXCERPT OF IEEE 802.16-2001 STANDARD (OVERVIEW)

IEEE Standard for

Local and Metropolitan area networks

Part 16: Air Interface for Fixed Broadband Wireless Access Systems

1. Overview

1.1 Scope

This standard the air interface, including the medium access control layer (MAC) and physical layer (PHY), of fixed point-to-multipoint broadband wireless access (BWA) systems providing multiple services. The MAC is structured to support multiple PHY specifications, each suited to a particular operational environment.

For the purposes of this document, a "system" consists of an IEEE Std 802.16-2001 MAC and PHY implementation with at least one subscriber station communicating with a base station via a point-to-multipoint air interface, along with the interfaces to external networks and services transported by the MAC and PHY.

1.2 Purpose

This standard is intended to enable rapid worldwide deployment of innovative, cost-effective, and interoperable multivendor broadband wireless access products, to facilitate competition in broadband access by providing alternatives to wireline broadband access, to facilitate coexistence studies, to encourage consistent worldwide allocation, and to accelerate the commercialization of broadband wireless access spectrum.

The applications depend on the spectrum to be used. The primary bands of interest are as follows:

1.2.1 10-66 GHz licensed bands

The 10-66 GHz bands provide a physical environment where, due to the short wavelength, line of sight is required and multipath is negligible. The channels used in this physical environment are typically large. For example, channels 25 or 28 MHz wide are typical. With raw data rates in excess of 120 Mbit/s, this environment is well suited for point-to-multipoint access serving applications from small office/home office (SOHO) through medium to large office applications.

1.2.2 2-11 GHz

This work is in development under IEEE Standards Association Project P802..16a.

1.3 Reference Model

Figure 1 illustrates the reference model and scope of this standard.

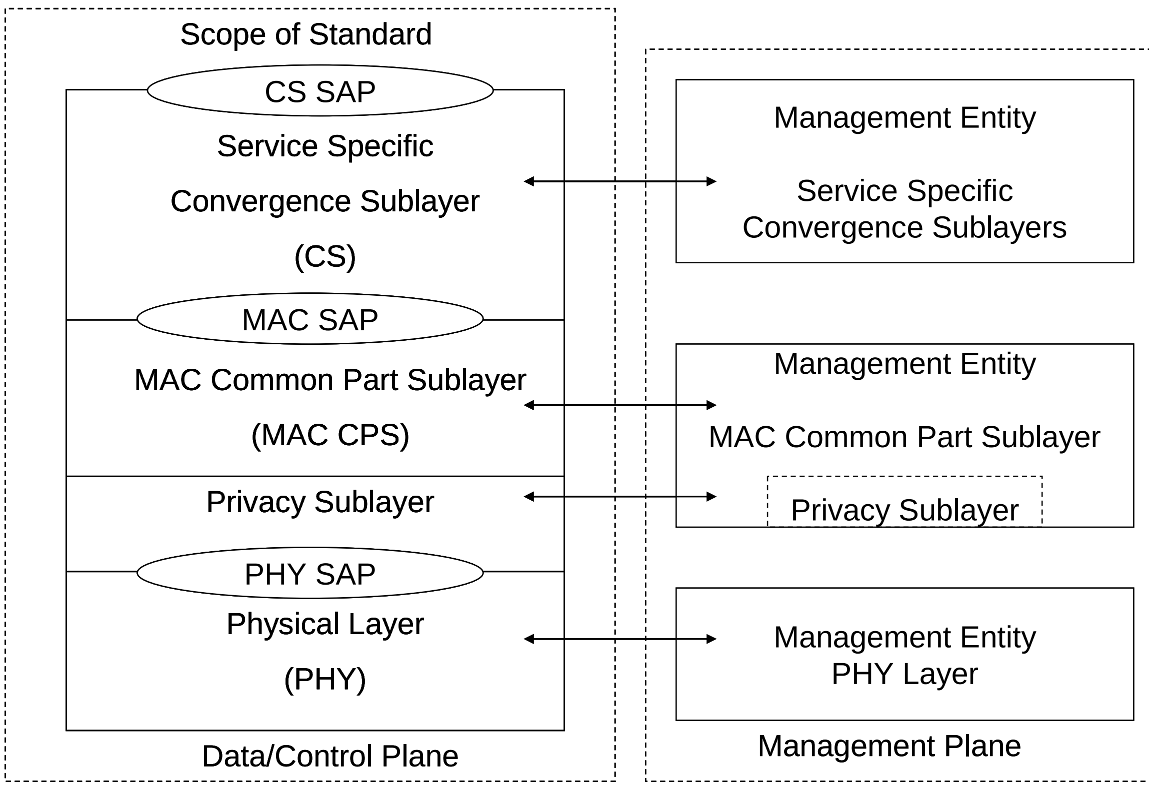

Figure 1 – IEEE Std 802.16-2001 protocol layering, showing service access points (SAPs)

The MAC comprises three sublayers. The Service Specific Convergence Sublayer (CS) provides any transformation or mapping of external network data, received through the CS service access point (SAP), into MAC SDUs received by the MAC Common Part Sublayer (MAC CPS) through the MAC SAP. This includes classifying external network Service Data Units (SDUs) and associating them to the proper MAC service flow and

Connection Identifier (CID). It may also include such functions as payload header suppression. Multiple CS specifications are provided for interfacing with various protocols. The internal format of the CS payload is unique to the CS, and the MAC CPS is not required to understand the format of or parse any information from the CS payload.

The MAC CPS provides the core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance. It receives data from the various CSs, through the MAC SAP, classified to particular MAC connections. Quality of Service (QoS) is applied to the transmission and scheduling of data over the PHY.

The MAC also contains a separate Privacy Sublayer providing authentication, secure key exchange, and encryption.

Data, PHY control, and statistics are transferred between the MAC CPS and the PHY via the PHY SAP.

The PHY may include multiple specifications, each appropriate to a particular frequency range and application. The various physical layer specifications supported are discussed in Clause 8.

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