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The Future of C2

Broadband Time Division Multiple Access (TDMA) Solution
(Tech Insertion - C4 Enhancement for the U.S. Army in Transformation)

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Abstract

The Battle Command Battle Lab located at Fort Gordon, Georgia (BCBL-G) leads the U.S. Army's efforts to bridge C4 (Command, Control, Communications, and Computers) capability gaps by leveraging leading edge technologies for rapid insertion into the operational force. The U.S. Army is presently undergoing a major transformation while conducting Operations Iraqi Freedom (OIF) which complicates this challenge immensely. The BCBL-G has focused its most recent support of the transformation effort by working to solve specific C4 shortfalls that were highlighted by the sub-marginal performance of the Army's tactical internal communications (Division and below communications systems) as experienced first hand during OIF.

Introduction

This paper will address the successful implementation of a Broadband Time Division Multiple Access (TDMA) satellite communications (SATCOM) based on the BCBL-G's C4 prototype solution. Furthermore, this paper will describe the methods this laboratory employed to meet the C4 requirements of the 1st Stryker Brigade Combat Team (SBCT), as well as subsequent follow-on deployments of this successful technology solution. As testimony to the worthiness of this technical solution, the TDMA SATCOM solution has been accepted by the U.S. Army acquisition community as the C4 solution to support the new modular force as the Army transforms from Divisions into modular organizations.

The paper will also highlight the technical advantages of broadband TDMA SATCOM over legacy systems currently in the Army inventory. Important tradeoffs such as the simplicity of the network management and manpower requirements to operate and maintain the systems will also be discussed in the paper. The paper will also highlight several other considerations such as the management requirements that have reduced the overall manpower, as well as the impact of additional training and skills required to provide the capability.

The Army Tactical Environment

The BCBL-G is an Army laboratory located at Fort Gordon, Georgia which is the home of the United States Army Signal Regiment. Its charter includes examining commercially available communications and information technologies for possible insertion into the military force[1]. Once a functional shortfall in the communications or information arena has been identified by a warfighting unit, an Operational Needs Statement (ONS) is crafted by the unit[2]. It is subsequently sent through official channels to the Department of the Army for approval. After approval, an executing agency is identified and tasked to provide recommendations for possible material solutions. To this end, the BCBL-G has, once again, marked a successful milestone into its robust experimentation history.

The fundamental concept of Time Division Multiple Access (TDMA) has been used for wireless commercial applications for several years[3]. The Telecommunications Industry Association (TIA) has adopted Time Division Multiple Access (TDMA) schematics since early 1991 for cellular communications[4]. TDMA was the primary access technology for cellular telephones until the efficient applications of Code Division Multiple Access (CMDA) was discovered. In 1994, the Federal Communications Commission (FCC) allocated a portion of the spectrum specifically for Personal Communications Service (PCS) technologies, which is known as *Sprint PCS*[5]. A third generation of cellular technology Global System for Mobile Communications (GSM) is based on an improved version of TDMA technology[6]. The fundamental concept of TDMA is the background of today's cellular structure, and it now has a new beginning in the Army communications community.

In 2003, BCBL-G demonstrated the military applicability of a Ku-band Broadband TDMA satellite communications (SATCOM) technology to operational military forces engaged in combat. BCBL-G developed an experiment (proof-of-concept) in which multiple configurations of leading–edge commercial communications technologies were tested to determine the optimal solution package. After acceptance of the results of the proof-of-concept by Army Acquisition authorities, the BCBL-G was tasked to deliver a working capability within 90 days. This effort culminated with the technical insertion of Ku-band TDMA SATCOM into the 1st Stryker Brigade Combat Team as it prepared for deployment to Iraq in November 2003.

In the tactical environment, broadband service has become indispensable joining networks via satellite accentuates the inherent flexibility of an organization's ability to provide global services over a tactical network. User demands continue to increase the bandwidth requirement in a limited bandwidth tactical environment, and are expected to continue to increase in the near-term.

Enhanced situational awareness and Information Superiority are capabilities that are now displayed on a Common Operational Picture (COP). This enables coordination, collaboration, and synchronization between commanders and subordinates. Situational awareness tools such as Force XXI Battle Command, Brigade-and-Below (FBCB2) operate over the L-Band utilizing Enhanced Position Location Reporting System (EPLRS) with maximum requirements of 57 kbps in order to receive real-time traffic[7]. Another situational awareness tool, Blue Force Tracking (BFT) provides interoperability with a satellite based system.

Today, commanders require large bandwidth consumers like BVTC to complete coordination and operational planning. BVTC requires approximately 128kbps[8]. Currently, Ku-band will be the part of the spectrum to provide this functionality. Additionally, situational awareness bandwidth will consume high resolution graphic files of critical site locations, maps of particular areas, and live video and information feeds from Unmanned Aerial Vehicles (UAV) will consume large amounts of bandwidth[9]. Again, Ku-band will provide the transport layer to this end. Finally, there is an impending expectation for increased requirements for Voice over IP (VoIP) that will continue to significantly grow. All of these requirements have made satellite resources an indispensable asset and the combat-environment transmission-medium-of-choice.

NTDR Failure; TDMA Success

In 2003 the 1st Stryker Brigade went through an organizational test and evaluation in preparation for its deployment into Iraq. This certification exercise, known as a Joint Readiness Training Center (JRTC) Rotation, was conducted at Fort Polk, LA. As part of their communications package, 1ST SBCT had Near Term Digital Radio. This technology operated on 225 to 450 MHz with maximum throughput of 288kbps[10]. The NTDR was expected to support Battlefield Collaboration, Situational Awareness, and Data Imagery between the battalion and brigade Tactical Operational Centers (TOC)[11]. The NTDR used a digital cellular-like semi autonomous network environment where there were no designated base stations. It used Direct Sequence Spread Spectrum (DSSS) modulation requiring three separate channels to communicate.

After-action reports (AARs) described a major communications capability deficiency determined to be critical to the command and control of the organization[12]. This deficiency described the inability of the Stryker Brigade to communicate to its subordinate organizations when it was outside the range of their Line-of-Sight communications assets. The certification event determined that once the NTDRs were more than 5 kilometers apart, each radio had to communicate through a relay point. This eventually created choke points which greatly diminished the available throughput. The NTDR was incapable of transmitting the volume of digital traffic at an acceptable speed and with reliability to the battalions.

1ST SBCT now had a requirement to resolve the communication network gap between the battalion and brigade. BCBL-G was directed to determine a technical solution. BCBL-G began its research and subsequently conducted experiments that used a commercial satellite system that had to be interoperable with the other communication systems that are part of the 1st SBCT communications package.

Ultimately, BCBL-G identified a digital IP-based TDMA solution for 1ST SBCT. The *Linkway 2100* is the defining component for the configuration of this technical insertion effort. It supports Ku band (approx. 12.5-18GHz. The *Linkway 2100* offers multi-rate, multi-carrier (MF-TDMA-Demand Assigned Multiple Access), and protocols that support ATM, IP, Frame relays, and ISDN[13]. In addition, the modem platform supports mesh, star and virtual star topologies.

The TDMA network is controlled by the Network Control Center (NCC) that runs the Network Management System (NMS) server and performs the bandwidth management functions. The NMS is a java web-based technology that supports remote and local access. The NCC provides centralized management, monitoring, control, configuration and accounting functions. The primary NCC is designated as the Master Reference Terminal with local or remote redundancy to sustain the network in case of any outages[14].

Time Division Multiple Access (TDMA)

The fundamental concept of TDMA is very important in understanding the principal functions of the process. TDMA signals are assigned to time slots. These time slots are transmitted in what are known as bursts. TDMA is defined as a digital transmission technology that allows a number of users to access a single radio frequency carrier at a specified time slot by allocating unique time slots to each user on each carrier[15]. The disadvantage of this technology is known as static allocation where channel time is wasted if a station has nothing to transmit during its allocated time.

The alternative to static TDMA allocation is dynamic allocation where the assigned time slices varies with the need of each transmission. DAMA technology allows multiple Very Small Aperture Terminal (VSAT) users to use the same carrier frequency. MF-TDMA-DAMA allows a network manager to add an entire bandwidth of frequencies. Now all of the users share the bandwidth pool from one or more separate carriers as long as they are on the same polarization of a satellite[16].

Figure 1 & 2 illustrates the spectrum analysis of FDMA and TDMA SATCOM technologies. Figure 1 demonstrates two FDMA links. This figure clearly shows the carrier committed to a customer regardless of whether or not there is traffic traversing the medium. Though this link is very reliable, it scales poorly since another carrier would have to be dedicated to add another terminal. Figure 2a shows a TDMA setup which depicts no utilization when there is not any traffic to transmit. Figure 2a & 2b both represent a 5 Mega symbol per second carrier for transmit and receive. Figure 2a displays a carrier without any traffic being passed at that instance in time. Figure 2b shows a fully utilized carrier. MF-TDMA-DAMA can accommodate adding one or more carriers to support an expanding network.

FDMA Spectrum Plots

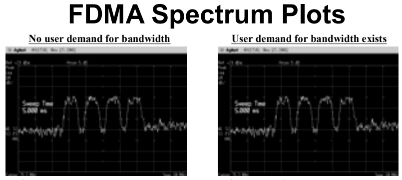

Figure 1a Figure 1b

TDMA-DAMA Spectrum Plots

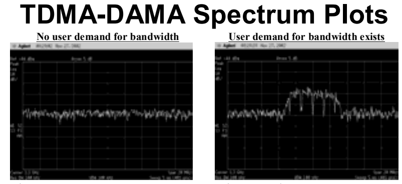

Figure 2a Figure 2b

As shown in figure 2b, TDMA traffic is transmitted in bursts. To manage that burst activity, it is important to understand the burst distribution for the Linkway modem. First, a burst is a bit string of adjoining time slots. Information is transmitted in a discrete burst rate regardless of the amount of bits that are transmitted. In all of the network architecture implemented by BCBL-G, 64k traffic bursts on a 27 ms frame was the optimal setting. The traffic burst sizes for this modem can be adjusted to 8, 16, 32, 64 and 128 k burst rates. The total available throughput depends on the modulation. Since the links were not power limited, the optimal usage was QPSK ¾ FEC Reed Solomon. These settings required 6.5 MHz carrier on a satellite transponder and resulted in a maximum aggregate of 4.7Mbps. In addition, there is a 3 µs guard band between traffic burst on a 27 ms frame to avoid bleed over.

Network Management

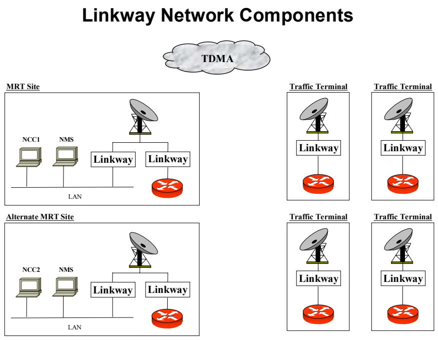

FIGURE 3

In a TDMA network using the Linkway Modem, the control stations must be configured appropriately. Figure 3 simply illustrates the primary elements that are necessary in each network. There is a Linkway at each VSAT location, but they don't all have the same function. The Linkway at the MRT site is configured and identified to assists with any traffic that is transmitted and received to control the network. Only one MRT can assume control of the network at a time. If there is more than one MRT simultaneously functioning as controller of the network, the network will immediately crash. To preclude this occurrence, the network manager contacts the location of the alternate site on an engineering order wire to ensure that this does not happen.

The MRT and the AMRT can be collocated or geographically separated. If the MRT and the AMRT are collocated, the AMRT immediately assumes control of the network upon the failure of the MRT. However, if they are geographically separated the fail over response will require 5-10 seconds. Prior to the AMRT assuming control from the automatic failover, the network manager is prompted to allow the MRT to assume control over the network. This is especially important to ensure that the primary MRT does not make an attempt to reacquire all of the traffic terminals when it comes back on station at the same time as the AMRT.

Despite the complexity inherent in these technologies, the *Linkway 2100* modem has no user interface. Configuration of each modem requires uploading a text file that gives the initial frequency, power, location and timing required to establish connectivity. This is easily done using a program such as Hyper-terminal at the MRT or any remote site that has identified access. After this initial setup, all additional configurations are done remotely over the air. To enable network management each network requires in addition to a Master Reference Terminal (MRT), a Network Control Center (NCC). Between the MRT and NCC, they provide the control of all the modem nodes in the network.

The NCC is the central control for the entire network. Its primary functions are configuration management, acquisition, synchronization control, and bandwidth management. Through the user interface for configuration and monitoring of the NCC is done via Http using a laptop with a web browser as the graphical interface. The NCC controls the designated MRT which is a standard Linkway 2100 modem. The node with the MRT and NCC is equally capable of passing traffic as any normal node in the network. A secondary NCC can exist in the network that can be configured to either manually or automatically take over should the primary NCC fail. Figure 5 illustrates the MRT used for 1st SBCT.

As well as controlling burst allocation, the NCC is able to add, remove or change frequencies of all carriers in the network with little effort. In total, the NCC can allocate up to 255 carrier frequencies with each carrier capable of up to 5Mega symbol per second with 2/3 FEC. That equates to a throughput of approximately 4.3Mbps. In addition, there is a maximum total network throughput of approximately 4.5Gbs theoretically possible. For 1st SBCT a bandwidth pool of 9 Mbps between the 12 nodes was allocated with a maximum throughput of 4Mbps per terminal dynamically assigned according to need. As of October 2005, the network has increased to a total of 18 nodes.

Figure 4 depicts the graphical interface of the burst utilization of a two carrier multi-frequency network. This interface allows the network manager to visualize the networks current burst allocation and overall networking loading. The reference carrier, which is normally carrier 0, is the only carrier that illustrates the distribution of the management bursts. The initial part of the 27ms frame is allocated for these bursts and include: reference bursts, signaling bursts, acquisition bursts, and control bursts. Each burst has a separate task. Although their links are full mesh and provide a hub less architecture, the management features of the network rely on a star topology, which means the MRT has a small dedicated timeslot to each terminal. For instance, the MRT establishes synchronization, timing and frequency to all of the traffic terminals through the reference burst. The MRT also periodically synchronizes all of the traffic terminals that it manages through control bursts. Prior to each Traffic Terminal (TT) transmitting user data, it transmits and receives a traffic request from the MRT through the signaling bursts. Finally, the Mesh connectivity is illustrated with the connection of the traffic burst. These connections indicate point to point connectivity for any identified Linkway link in the network. The traffic bursts in Figure 4 illustrate traffic loading on every carrier.

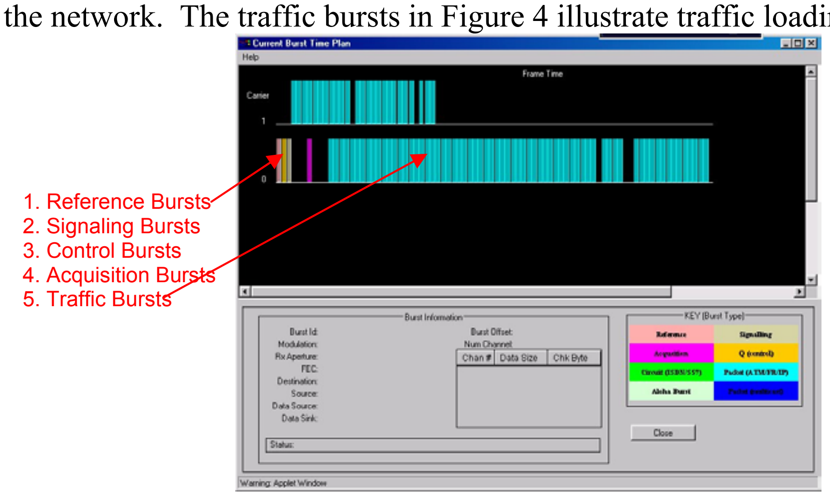

Figure 4. The rectangles represent the burst, and the first four are a part of the network management that requires direct links with the MRT and each TT. The light blue rectangles represent the traffic bursts.

1st SBCT

There are some distinct differences between the MF-TDMA-DAMA package that was delivered to 1st SBCT, and the suite that was delivered to all TDMA SATCOM efforts following delivery to 1st SBCT. The network architecture for 1st SBCT provided a classified backbone where the unclassified portion was tunneled through the classified network (secret). Figure 6 & 7a depicts a picture of a traffic terminal. The Taclane router (KG-175), an IP encryptor, provides separation of the enclaves from an unclassified to a secret network. Above that, this secret router provides access to the tactical network which interfaces to the Brigade Switch Node (BSN). The second Taclane provides transmission security over the radio frequency path. The next router's sole purpose is to encrypt the Taclane IP address over the air, and it does that using Triple Data Encryption Standard Algorithm (3DES)[17]. Last, the Linkway modem provides access to the SATCOM Network. A schematic of the deployed configuration at a traffic terminal is at Figure 5 and 6.

Figure 5

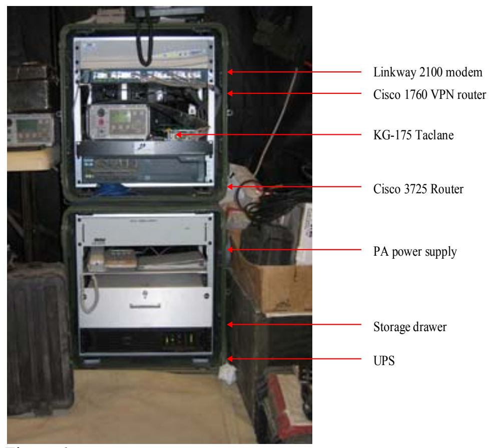

Figure 6a

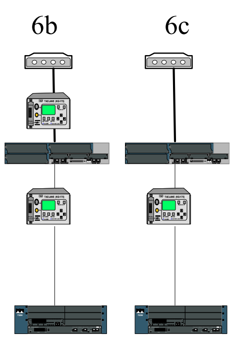

Figure 7. The first one is the original concept for 1st SBCT, and the second concept was used for all of the follow-on fielded untis.

In all, 1st SBCT's Broadband MF-TDMA-DAMA network provided the following:

- Red VoIP to all sites.
- Black VoIP to select sites for an in-band engineering order wire.
- Data pull from the Brigade Web server.
- A 10 node Battlefield VTC capability.
- Interconnection to Secured Internet Protocol Router Network (SIPRNet) for Brigade and Battalion.
- Collaboration tools using Microsoft Net Meeting.

Military ruggedization was achieved by the choice of SGT with a proven record. The TDMA SATCOM terminal equipment was mounted in 6g shock mounted transit case and deployed in a tent with Environmental Conditioning Units (ECU). The ground segment consists of Very Small Aperture Terminals (VSAT) operating in the Ku band (11-14 GHz). The MRT, located at the Brigade TOC, uses a 2.4m Vertex RSI Flyaway SGT. It requires 9 transit cases for the antenna and 3 transit cases for the electronics. The Traffic Terminals at the Battalion TOCs used a 1.5m Vertex RSI Flyaway ground terminal, and these require 3 transit cases for the antenna and 2 transit cases for the electronics. Neither of these SGT offer auto tracking and therefore, requires a small amount of accuracy in the initial setup to ensure minimal proper antennae peaking. Both of these SGT use 16W solid state power amplifiers and an LNB. The SGT are depicted in Figure 8.

Figure 8

The Linkway modems have a full mesh capability which enables the connection of the routers in a full mesh. However, this requires that each of the VPN tunnels in the mesh be allocated a holding burst for 'stay alive' communications[18]. Such a configuration would tie up 66 bursts each of 64kb in every frame. This reduces the advantage of dynamic bandwidth allocation as 4224kb would be tied for 'Stay Alive'[19]. For this reason, a logical dual hub spoke configuration was chosen with the Brigade TOC as the hub of the network. Through experimentation, burst size of the stay alive bursts was reduced to 32kbs on the secure hub and spoke data architecture. This was necessary to allow applications such as ABCS, SNMP, FBCB2 and BFT to function seamlessly

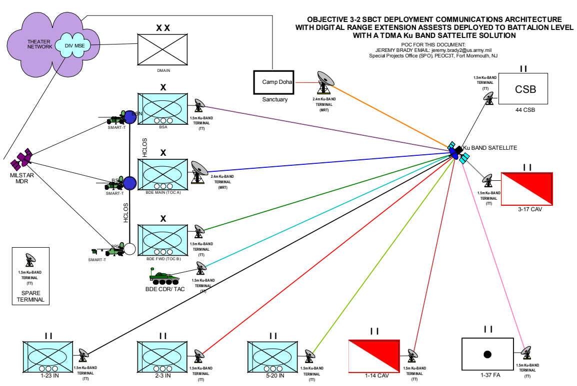

Figure 9

3RD Infantry Division (3ID) Redesign (Reception Staging Onward Movement Integration [RSOI])

3ID was the first to undergo the Modular Redesign of all of the U.S Army's divisions[20]. For communication systems, the focus of this transition was the replacement of the legacy communication node (Mobile Subscriber Equipment (MSE) Node Center) with the Joint Network Node (JNN), which is an alternative to the BSN that are located at the SBCTs. This redesign required a beyond line-of-sight capability, high data throughput, and a bandwidth efficient method with ad-hoc capability down to the battalion level[4]. The resolution for this problem practically mirrored the solution with minor adjustments of the previous efforts, although on a much larger scale. To support a highly mobile division-size element, the communications suites were installed on a transportable-mounted trailer which is depicted in Figure 10a & 10b. The scope of implementing broadband satellite services for an entire division prior to deployment to Iraq for OIF-III required implementation, verification, and validation of the 1ST SBCT network. BCBL-G preceding experience with the formerly mentioned efforts made them Subject Matter Experts (SME). Their expertise proved invaluable with the configuration, engineering, instructional and hands-on training of the broadband commercial (Ku band) SATCOM networks.

Although the focus of this network is similar to the 1ST SBCT's network the focal point of the commercial SATCOM network was more robust. The MRT was a part of a Surrogate Teleport, which consisted of three separate trucks with functions of the Baseband, FDMA hub, and TDMA hub. Each hub consisted of interface equipment that was mounted inside and outside of the truck shown on figure 10c. There are two Surrogate Teleports with the initial intent of one being an alternate located in a sanctuary, the other at the Division Commander's immediate access. The TDMA hub consisted of 12 Linkways. Two Linkwaysof them supported the management of the network for the MRT and AMRT. The other 10 Linkways supported the traffic in which each Linkway supported one Unit of Action (UA).

Prior to deployment to Iraq, 3ID conducted a Mission Readiness Exercise that evaluated the implementation of the Joint Network Node (JNN) into a tactical network where the network architecture was heavily reliant on commercial SATCOM. The network included TDMA (Ku), FDMA (Ku), High Capacity Line of Sight (HCLOS), legacy communication nodes, SMART-T, TSC-85, and TSC-93. As shown in Figure 9, the SATCOM network supported commercial satellite assets with one 5 Mega Symbol per second carrier (Linkway 2100) and 7 FDMA carriers with a total utilization of 27MHz. This exercise validated and increased the confidence of the Warfighters prior to deployment. 3ID has returned back to Iraq for OIF-III rotation equipped and trained with the Ku-band technology

Figure 10a

Figure 10b

Figure 10c

NETWORK DIAGRAM (JNN/SATCOM)

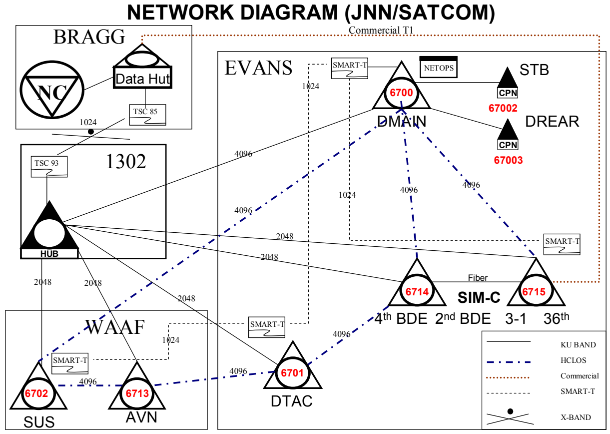

Figure 10

Conclusion

The broadband TDMA SATCOM solution is an outstanding example of how rapid technical insertion is the preferred method when compared to normal military acquisition process. This effort has demonstrated at all levels of Department of Defense the timely and efficient success of using Battle Lab methodology for prototyping and experimentation with leading edge and emerging technologies. By leveraging the body of complimentary SATCOM work done previously, BCBL-G and the Army acquisition community effectively managed the program to deploy capabilities to support urgent operational requirements.

Broadband TDMA SATCOM is clearly demonstrating in these current operational environments, that along with VoIP, they are mature technologies which are able to cope with the difficult demands of the harsh environment in the Arabian Gulf[5]. Equally, the advantage of a single bearer protocol with convergence of voice, video and data onto a TCP/IP backbone has shown marked efficiencies in cost as well as the potential for improved QoS to the user[21]. The simplicity of the network and its management has reduced manpower, training and skills required to provide the capability. In addition, BCBL-G has subsequently been given the Army lead in evaluating the most promising of current commercial-off-the-shelf technologies that could potentially be used to fill the current gap in mobile wide-band (256 Kbps or greater) communications to support Battle Command-On-The-Move. In response to this task, BCBL (G) has begun collaborating with a number of industry, academic, Army and Joint organizations to identify a solution. Though the objective solution for the Army future force is Ka-band technology[22], the success of the Ku-band solution hold great promise until both the technology and the satellite constellations are available to realize the Ka-band solution[23].

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