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Bandwidth Optimizations for Integrated Tactical and Training Networks

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Abstract

This paper addresses the bandwidth and latency optimization of Embedded Simulation (ES) communications within tactical Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) networks while supporting an Enroute Mission Planning and Rehearsal (EMPR) for ground combat vehicles and other use cases. Simulation data obtained from One Semi Automated Forces (OneSAF) Testbed Baseline simulations is consistent with Future Combat Systems (FCS) Operations and Organizations scenarios of multiple-platoon, company, and battalion-scale force-on-force EMPR vignettes. The resultant simulation traffic is modeled and assessed within a hierarchical communication architecture consisting of Manned Platforms, Distributed Common Ground Systems (DCGS_A) and Multiband Integrated Satellite Terminal (MIST)s interconnected to Joint Tactical Training System (JTRS) and Warfighter Information Network-Tactical (WIN_T) networks, as foreseen by Future Combat Systems (FCS). The mentioned battle support vehicles operate as routers and hubs that interconnect Unmanned Air Vehicles (UAV), Unmanned Ground Vehicles (UGV), Apache Helicopters (Ah64) and Land Warriors (LW) with Continental United States (CONUS) based on a wireless C4ISR network infrastructure. The entire operation is directed and controlled via a CONUS based ground station and its corresponding satellite network.

Within this environment, three areas of ES bandwidth and latency research are addressed: *Simulation Traffic Analysis*, *Data Transmission Optimizations*, and *Traffic Modeling Tools / Demonstration sets*. Simulation Traffic Analysis tasks include the development of a tentative network for FCS and Simulator Training systems that can be used to analyze Packet Data Unit (PDU) transmissions of the most critical entity actions and assessment of the *operational-distribution of PDUs*. Future Data Transmission Optimization tasks include the development of *burst-free transmission scheduling*, *PDU replication*, *data compression*, and *OPFOR control hand-off* techniques. Traffic Modeling Tool activities

include the creation of *libraries for network capacity planning* and a self-contained *traffic modeling demonstration package* using Omnet++. Within this environment, we present results for *capacity estimates* for ES bandwidth in FCS battle applications.

FCS Bandwidth Optimization Problem.

Over the past decade, the U.S. Army's principal modernization initiative has been its digitization effort, designed to significantly improve the fighting capabilities of soldiers on the battlefield. But implementing that initiative presents significant challenges. Digitization requires the rapid transmission of large amounts of information over significant distances. Experiments conducted to date as well as recent operations in Iraq, where troops employed some of the results of the service's digitization efforts, have shown that that requirement is difficult to fulfill in any terrain conditions.

Consequently, the focus of the Army's modernization program has shifted in 1999 to what it terms transformation—making its forces deployable more quickly while maintaining or improving their lethality and survivability. Although digitization is no longer the Army's primary modernization initiative, it remains a key element of transformation. In the past several years, questions about the size of the information flow associated with digitization and the communications bandwidth to support it, have spurred the Army to adopt several large radio and network communications programs to study the total network capacity of Training Simulations and Real-Time battle communications to predict future FCS design considerations.

Future bandwidth demand shall increase as suggested by Rehmus[1] on his report to the Congressional Budget Office (CBO). He predicts that the peak network demands for the year 2003 are greater at the Brigade and Battalion levels by a factor of 10 to 20 when compared to standard network demands for networks that serve the Operations Officers (ops nets). That is, one message arrives on time for every 10 to 20 sent. Future advances in communications equipment that the Army plans to support include Joint Tactical Radio System (JTRS), Warfighter Information Network-Tactical (WIN-T) and Multiband Integrated Satellite Terminal (MIST) to further support communications at the brigade division and corps command levels increasing further the bandwidth needs. FCS shall exceed the current demands by 10 fold at the Corps and Division Command areas, due to the increase in video and imaging information[5]. In addition, lower communication noticed at other command levels will also increase in the future due to the added support systems and unmanned vehicles planned for FCS use.

Foreseeing the immense bandwidth needs, the Army is trying to reduce its current bandwidth demands by slashing functionality. Broadcasting UAV images, teleconferencing and other bandwidth intensive applications is no longer possible. Useful information has been replaced or eliminated to accommodate the existing network technology such as JTRS and WIN-T. Ironically, decreasing bandwidth needs reduces the success of the Army's digitization Initiative.

The Army faces a number of problems in implementing its IT strategy on the battlefield. The service needs much more bandwidth than it has available today to support both its current systems and those planned for the future. Being Bandwidth the central issue for the communications system, we propose to study the future network requirements. Unfortunately, real time bandwidth measurements are rather complex, particularly when the network topologies are not well defined. To analyze the communication needs we propose to obtain Semi-Automated Forces (SAF) data from the OneSAF Testbed Baseline Simulator (OTB), used by the Army to plan, execute and review battles in remote locations. OneSAF can provide useful data to further study the future network requirements of FCS. Then, using a network constructive discrete simulator such as OmNet++[2], it is possible to further study the future bandwidth needs and suggest possible optimizations.

Bandwidth considerations for FCS Simulation model.

FCS networks, vehicles and system functionality depend on existing and emergent technologies. Thus, effective bandwidth measurements for future combat systems are difficult due to the inventiveness of the designs. However, certain Bandwidth expectations for certain vehicles are estimated based in information provided by Army Subject Matter Experts (SME) [10]. Data rates have been assigned for certain vehicles for voice, data and imagery. Table 1 lists the effective data rates for FCS vehicles.

FCS Vehicles and Effective Bandwidth.

FCS Vehicles and Support Systems	V:VOICE D:DATA I:IMAGE V:VIDEO	VOICE DATA RATE (Kbps)	VOICE DATA PACKET SIZE (KB)	DATA DATA RATE (Kbps)	DATA PACKET SIZE (KB)	IMAGERY DATA RATE (Kbps)	IMAGERY PACKET SIZE (KB)	VIDEO DATA RATE (Kbps)	VIDEO DURATION (sec)
Aerial Common Sensor	D,I			60	60	60	6144	1000	10
AQF/Prophet	D			30	60			1000	10
AWACS	V	100	20						
Comanche	I			5		5	6144	1000	10
Global Hawk/Predator UAV	D,I			300	60	300	6144	1000	10
J-STARS	NA			NA	NA	NA	NA	NA	NA
Rivet Joint	D			300	60				
Satellite	D,I			600	60	600	6144		
U-2 ASARS II	D,I,V			300	60	300	6144	1000	10
Unmanned Aerial Vehicle (UAV CL I)	D,I,V			0.017	5	10	410	1000	10
Unmanned Aerial Vehicle (UAV CL II)	D,I,V			0.017	5	10	410	1000	10
Unmanned Aerial Vehicle (UAV CL III)	D,I,V			0.017	5	10	820	1000	10
Unmanned Aerial Vehicle (UAV CL IVa)	D,I,V			0.017	5	10	820	1000	10
Unmanned Aerial Vehicle (UAV CL IVb)									
Unmanned ARV-A(L) (2.5 ton)	D,I,V			0.017	5	10	410	1000	10
Unmanned ARV-RSTA (6 ton)	D,I,V			0.017	5	10	820	1000	10
Unmanned Ground Vehicle (MULE)	D,V			0.017	5			192	86400
Unmanned Ground Vehicle (SUGV)	D,I,V			0.017	5	10	820	1000	10

Table 1: FCS Vehicles Effective Bandwidth.

Tanenbaum [7] defines Bandwidth as the range of frequencies transmitted without being strongly attenuated. It can be attenuated as transmission distances increase. Bandwidth units for digital media is known as Bit Rate, the number of bits per second transmitted; not to be confused with Baud Rate the number of signal changes per second. Bit Rate and Baud Rate are related by the following equation.

$$\text{Bit Rate} = \log_2 M * \text{Baud Rate } [8]$$

Therefore, Bandwidth decreases with distance and terrain interference and transmission medium used, an additional channel characteristic that needs to be modeled when building C4ISR network channels. Note that Throughput is analogous to Bandwidth.

Communications traffic can be thought of either approximately continuous or episodic. In the former case, called continuous-flow information (throughput), a bit per second (bps) is the relevant measure; in the later case, referred to as episodic, the size of the message file (in bits) is the appropriate gauge. Table 1 one depicts voice, data, video and imaging throughput for the most common vehicles. Notice that some vehicles transmit voice data only, as the Airborne Warning and Control System (AWACS), while others transmit voice, video and images using the same channel, e.g. UAV.

Building a network simulation using OmNet++ modules to represent FCS network communications is possible. The resultant Bandwidth capacity of the C4ISR based FCS network can be simulated by encoding the corresponding wireless channels and their bandwidth capacity. Satellites, Vehicles and Land Warriors can be modeled as network components with specific data generation characteristics and effective bandwidth. Since all modules in the system transmit in broadcast mode (DIS specification), the overall network throughput and the channel collisions can be analyzed to optimize the available bandwidth. Moreover, channel bottlenecks and slack time can be studied to further optimize the overall throughput. However, simulation and modeling and the software that makes then function is designed according to certain assumptions about the communications network in which they operate and the rates of information available as parameters. Therefore, the results of this experimental simulation are an attempt to provide measurable results and determine the possible network tribulations that future combat systems may present as they intercommunicate through different networks and satellite links in benign environments.

Omnet++ Modeling

OMNeT++ is a discrete event simulation environment. Its primary application area is the simulation of communication networks, but because of its generic and flexible architecture, is successfully used in other areas like the simulation of complex IT systems, queuing networks or hardware architectures as well. The simulator provides component architecture for models. Components *(modules)* are programmed in C++, then assembled into larger components and models using a high-level language *(NED)*. Models are provided free of charge[3].

For this particular simulation we choose to model a communications topology based on a battle scenario suggested by the Army SME. The *used case* involves land-unmanned vehicles, air and land support and UAVs, all communicating at a Brigade level. --A brigade is the smallest Army force structure that utilizes a satellite link [1]. A brigade is typically commands the tactical operations of two to five organic or attached combat battalions. Normally commanded by a colonel with a command sergeant major as senior NCO, brigades are employed on independent or semi-independent operations. Armored, cavalry, ranger and Special Forces units are categorized as regiments or groups [2] –.

Four communication channels are necessary and modeled according to the characteristics suggested in C4ISR document for wireless communication [4] and the bandwidth predictions for JTRS (200 Kbps) and WIN_T (2.5 Mbps) networks obtained from [1] .

The following figure 1 is generated by the OMNet++ simulator and depicts the current network layout. The first channel is the *wireless ground to satellite (wirelessGS.)* This channel connects CONUS networks with the satellite network that transmits battle command information to remote locations all over the world. The second channel, *wireless to ground network (wirelesWSGN)* supports apache helicopters (AH-64) and Distributed Common Ground Systems (DCGS) vehicles that serve as a router to *WIN_T* networks. The third channel, *WIN_T* connects DCGS vehicles with Manned Platform Vehicles as they also serve as a router for JTRS networks. The last and fourth channel connects wirelessly all Unmanned Ground Vehicles (UGV), Unmanned Air Vehicles (UAV) and Land Warriors (LW) together.

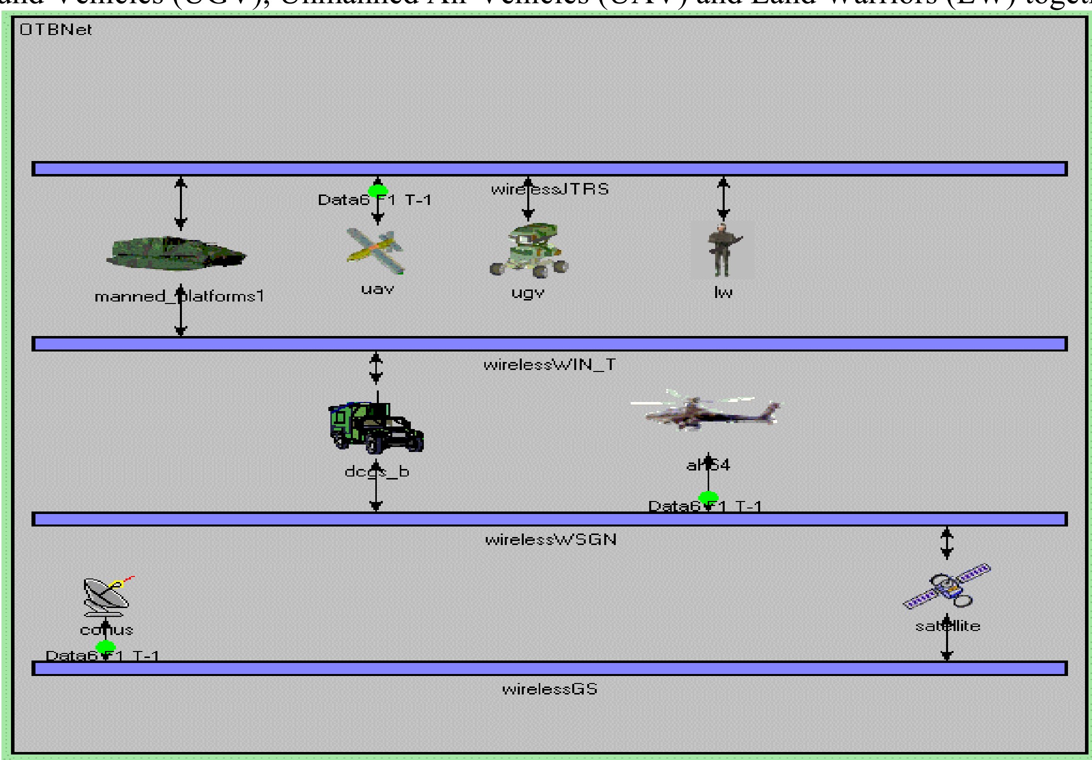


Figure1: OMNet++ C4ISR network channel connections for WIN-T and JTRS networks.

Each channel depicted in blue (elongated rectangles), serve as a bus that transports data from one network channel to the other. Channels are modeled according to the channel characteristics of the protocol. e.g., Wireless LANs use IEEE 802.11 protocol.

Models connect to each channel using *nodes* a sub-module provided by the channel. There is a one to one correspondence between modules and channel nodes. Figure 1 depicts several

green colored circles, these are the packets sent by each host generator. Each module is defined according to the desired module specification and characteristics.
A simple module contains a *Generator* and a *Sink*. *Generators* are sub-modules programmed to generate packets at their discrete time only limited by the throughput of the channel it connects to. Generators will broadcast a packet when the packet's time is due. If the packet is to be sent at time t, but the bus due to its limited bandwidth cannot service it, a negative time slack is created and recorded. If the packet leaves on time, a positive slack is recorded. If the packet is serviced, but on his way out to the channel collides with an incoming packet, a *collision* is detected and recorded. The *Sink* on the other hand, will retrieve packets from the channel with a destination address of –1 (Broadcast Destination) or its own destination (network dependent number). Figure 2, depicts the internal configuration a UAV as shown by OMNett++.

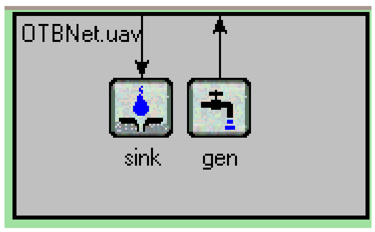


Figure 2: UAV internal sub-modules.

The *Generator* can be programmed to create data packets at a specific data rate and size or it can read data from data text files a rate determined by each in packet's timestamp. When data from an Army simulator is provided such as OneSAF, data can be parsed and reorganized to be read later by the *Generators*. Figure 3 depicts the current data format for packet generation using a text file, therefore for this method, data from OneSAF needs to be parsed accordingly to meet the following requirements.

Column 1 contains packet time information in Hexadecimal 1/100 of a second. The next column contains the packet size information. Original data is converted to generate columns three and four. The *Generator* module reads the data text file and generates Column 3 which contains the converted time in Min:Seconds.Hundreths of a second. Column 4 contains the line number.

0x4f690c7a	32	:18:36.707	1
0x4f7ab058	32	:18:37.676	2
0x4f8ca818	32	:18:38.663	3
0x4ffc8a88	92	:18:44.809	4
0x513da63a	100	:19:02.448	5
0x51752798	92	:19:05.497	6
0x531629f4	92	:19:28.404	7
0x53617074	100	:19:32.539	8
0x548db8ba	92	:19:49.034	9

Figure 3: Data format for packet generation using a text file.

In cases where a single module will generate three different types of data, three *Generators* will be contained in each module, one for each data type and rate.

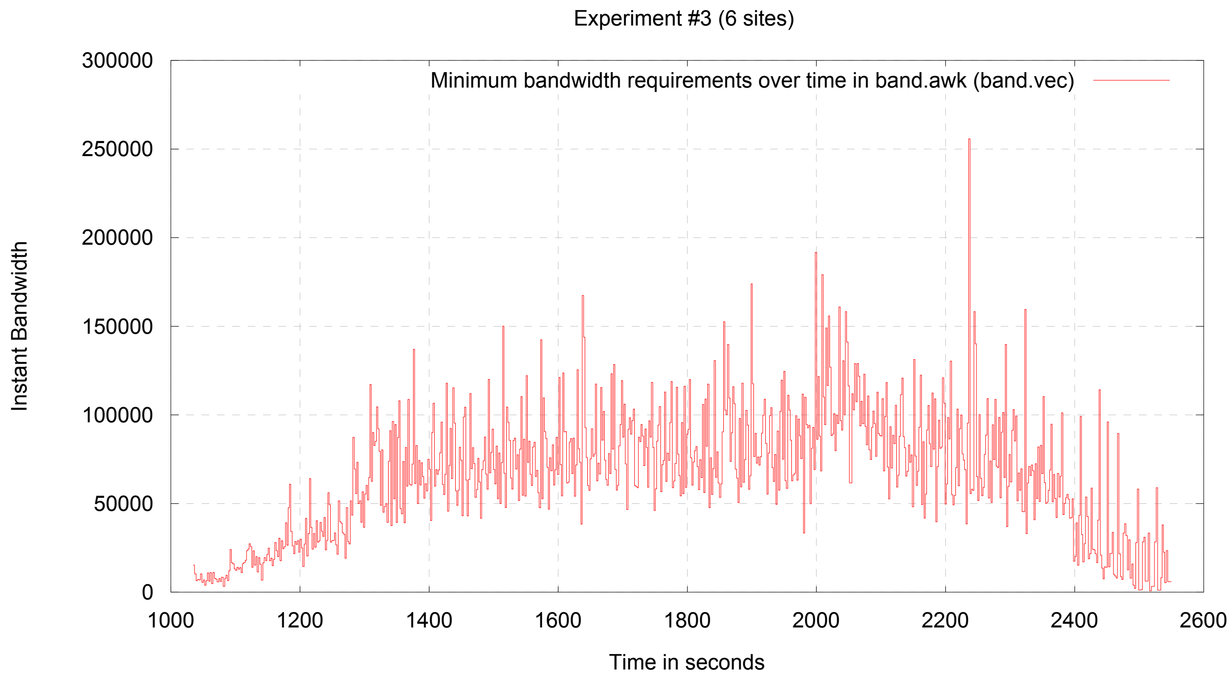
Once all network components are in place, different network configurations can be explored by rearranging the connections to the channels. Statistical results based on different simulations can be used to aid future designs. The goal is to determine if the current bandwidth utilization is wide enough to accommodate FCS.

Simulation Results

Peak effective bandwidth demand for future combat systems can exceed the current expectations. The Army has studied the peak demands for continuous flow-information on division, brigade and battalion levels for the digitized division. The study has found that peak effective bandwidth can be between 2.5 Mbps and 4 Mbps. Our intent is to find the possible bottlenecks in the system and further optimize transition to obtain better bandwidth optimization.

Vehicles such as the Manned Platforms, Army Battle Command System (ABCS) and the DGCS act as centers of communication in the battlefield. Such vehicles act as routers for the JTRS and WIN_T networks and Satellites used in battle at the Brigade, Division and Corps levels. These vehicles are suspects of intense collisions due to the intense routing they perform. The present simulation shall provide collision information on these vehicles as results are obtained from OTB sample data. Unfortunately, the used cases utilized for FCS using OTB have not yet been released as unclassified. Such data and the results of the proposed OMNet++ simulation shall be available prior to the oral presentation.

However, the following graph presented on figure 4, depicts the bandwidth utilization results of an earlier simulation at the satellite module using similar OMNet++ models that supported Joint Tactical Training System (JTRS). The OTB vignette supported six C-130 Hercules air carriers on flight and the communication between them as a battle training simulation was executed inside the three vehicles that each plane transports. Data used on this Omnet++ simulation was also obtained from OTB. It is easy to observe that a 200 Kbps channel is necessary at the satellite link to provide optimal service.



Simulation results and an updated paper shall be presented the day of the oral presentation. The suggested data rates depicted on table 1 for the unmanned vehicles are ready to be used and incorporated into the respective modules and provide additional data to the JTRS and WIN_T networks. As we receive the Army OTB unclassified data that represents the bandwidth utilization of our C4ISR proposed network, our simulation shall produce similar results as proved useful in earlier simulations.

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