Interfacing a Communications Effect Model to Provide Accurate Modeling of Communications in Computer Generated Forces

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ABSTRACT

Network-Centric Warfare (NCW) is characterized by geographically dispersed forces maintaining a high level of situational awareness, thus allowing increasing tempo of operations, increased responsiveness, lower risk, and increased combat effectiveness. One of the most important aspects of situational awareness is the ability to effectively communicate between entities and military organizations on the battlefield - real or simulated.

In a synthetic environment this communication capability is often simulated at a very low fidelity - if at all. Communications are often modeled as always being perfect, and even those simulations that do introduce imperfections rarely model factors such as time delays or network constraints. As a result, communications effects are not well considered, often causing the timing of actions resulting from near perfect communications to be unrepresentative of reality, contributing to negative analysis and training.

This paper examines and analyzes the impact of using a high fidelity communication model versus the limitations of simplified communication models in existing synthetic environments. The authors have created an interface control document (ICD) to allow integration of commercial communications effects servers into an HLA / DIS virtual environment. Utilizing this framework with commercially available communications and entity simulation software, the authors examine the impact of improved communications modeling fidelity on successful analysis and training results.

ABOUT THE AUTHORS

Mr. Alan Dickens joined MÄK Technologies in October 2005, where he is the Director of Program Management, managing the performance and financial aspects for all engineering services contracts. His duties include management of MÄK engineers working on contract development, technical coordination between programs, technical direction for each project, and providing engineering support for proposal efforts.

Mr. Dickens has over 20 years of experience in the Modeling, Simulation, and Computer Industry. His previous training and simulation experience includes working at BBN Systems and Technologies, where he developed vehicle kinematics and dynamics models for the original SIMNET M1 Abrams MBT simulation. While at Loral Advanced Distributed Simulation, he worked as a project leader developing manned simulators for the A-10 Warthog and AH-64D Apache. He also served as the principal investigator on a research project to develop a system of distributed representation.

Mr. Dickens holds a Bachelor’s degree in Computer Science from Brown University, awarded in May 1985.

Mr. Bob Holcomb joined MÄK in January 2006, where he is currently a Senior Simulation Consultant. He consults on the DIS and HLA standards and teaches user and developer level courses for MÄK's products. He also provides on-site support and customization of MÄK products. Mr. Holcomb assists with product development for VR-Forces, VR-Link and VR-Vantage between consulting jobs.

Before joining MÄK, Bob was a Captain in the United States Army's Aviation branch. He was a rated aviator in the OH-58D reconnaissance aircraft and responsible for 400 soldiers in his last unit. He served in leadership and staff roles from the Platoon to the Army level.

Mr. Holcomb holds a Bachelor of Science in Software Engineering from the United States Military Academy at West Point.

Mr. Lloyd Wihl joined Scalable Network Technologies (SNT) in January 2006, where he is Senior Application Engineer, providing worldwide pre-sales support for potential clients, developing system prototypes and technology interfaces, guiding future product development, providing guidance for customer model development, training customers, and managing customer engineering service contracts.

Mr. Wihl has over 28 years of experience in the Modeling, Simulation and Training industry. His experience prior to SNT includes 24 years at CAE, where he developed system architectures for military simulation and training, and led multi-million dollar projects in the areas of synthetic military environments, network-centric systems, distributed mission training, air traffic management, space systems, visual systems, and flight simulation.

Mr. Wihl holds a Bachelor of Engineering (Mechanical) with distinction, from McGill University.

Mr. Richard Aplin joined Boeing Defence Australia in October 2007, where he is the Operations Analysis Lead in the Systems Analysis Laboratory (SAL). He is responsible for managing the cross-domain operations analysts within the SAL working on a variety of tasks ranging from collaborative defense virtual warfighting experimentation to discrete event simulation and analytical model development.

Mr. Aplin holds a Bachelor's degree in Information Technology and Economics from the Australian Defence Force Academy and is currently studying for a Masters in Systems Engineering degree. Prior to joining Boeing Mr. Aplin served in the Australian Regular Army as a Special Operations Communications Officer where he was responsible for the establishment and maintenance of tactical, operational and strategic communications networks for training and operational deployments.

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INTRODUCTION

Most modeling and simulation systems assume the availability of perfect communications between entities in the virtual world. Unfortunately, communications are rarely perfect, and exercises have made clear the negative effects that result from such modeling. This effect is particularly relevant for the computer generated forces (CGF) based entities that populate virtual training environments.

Working together, the authors modified commercial off-the-shelf (COTS) software to enable the integration of a communications effects server with a CGF system. The resulting system much more accurately models the effects of imperfect communications on the virtual battlefield.

Network-Centric Warfare

Network-Centric Warfare (NCW), also referred to as Network-Centric Operations, is a military doctrine that seeks to translate an information advantage, enabled in part by information technology, into a competitive warfighting advantage through the robust networking of well informed geographically dispersed forces. This networking, combined with changes in technology, organization, processes, and people allows new forms of organizational behavior. The doctrine contains the following four tenets in its formulation:

- A robustly networked force improves information sharing;
- Information sharing enhances the quality of information and shared situational awareness;
- Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command; and
- These, in turn, dramatically increase mission effectiveness.

As is obvious, NCW requires a robust communications backbone. Training soldiers in the use of NCW requires the use of accurate modeling of communications, in order to avoid negative training.

Modeling and Simulation

Computer-based simulations have long been used by the military to train troops and develop new warfighting techniques in the land, sea and air domains. Networked modeling and simulation systems realistically represent combat, from the physical behavior of weapons systems to the tactical behavior of individual entities and military units. They also incorporate detailed models of the natural environment (e.g., terrain and atmosphere) and the effect of these environmental factors on simulated activities and behaviors.

Computer Generated Forces (CGF) are used to populate the virtual combat space with entities – friendly (supporting), enemy (opposing) and neutral (e.g. civilians). These systems model many factors at play in combat, such as entity movement, effectiveness of weapons systems, terrain, and overarching combat strategy.

Communications Modeling

Historically, most simulations have assumed that communications are perfect – that any entity (whether virtual or constructive) can instantly and reliably communicate with any other entity, and that networks have infinite bandwidth and no latency. In reality, perfect communication is rarely if ever achieved in battle, especially in mountainous or urban terrain. A simulation is much more realistic when it is linked to a communications effects server, which uses a discrete event simulation engine to quickly and accurately determine whether a message is delivered.

LOW FIDELITY COMMUNICATIONS MODELING

Modeling of communications, especially in the land environment, is now a vital component of battlefield analysis, modeling, simulation and experimentation facilities. With defense personnel eager to understand the impact of NCW operations there is a growing requirement to model the effect of communications on the conduct of operations.

In recent years, international Boeing analysis facilities have found it difficult to adequately model the communication networks of Land Forces in realistic operational settings using a single commercial-off-the-shelf application.

One such experiment that was negatively impacted because of low fidelity communications modeling was a study looking at the implications of terrain on a Combined Arms Team's network connectivity. The difficulty that this study faced was being able to adequately model the communication networks for both traditional hierarchical and mobile ad-hoc networks (MANET) while at the same time representing realistic Combined Arms Team maneuvers in both urban and open terrain.

While a traditional CGF can be an ideal tool to represent a Combined Arms Team's maneuver in urban and open terrain both opposed and unopposed, CGFs provide only basic line-of-sight communications effects. On the other hand, communications effects applications provide an extremely good representation of the two communication networks, including routing protocols, waveforms, infrastructure, network performance and the introduction of interference, signal attenuation and other effects. Unfortunately these communications effects applications lack the detailed behavior, dynamics, and mobility present in CGFs.

As the main priority for the study was to investigate the implications of terrain on two different network types, a standalone communications effects tool was selected for use over a CGF. The subsequent results of the study, although valid for very basic maneuvers in open terrain, were not representative of realistic Combined Arms Team platforms or maneuvers, for the reasons cited.

HIGH FIDELITY COMMUNICATIONS MODELING

In a battlefield network, data is subject to delay, and the delays are not equal throughout the network. They depend on the routing protocols, the terrain, environmental effects and interference, the number of hops packets make, connectivity, priority, available bandwidth, and network traffic. As a result, the Perceived Truth can significantly lag Ground Truth. The inability of mission critical applications to receive timely data can affect decision making and significantly alter the battlefield outcome.

Because of these real-world constraints inherent to mobile networks, they need high fidelity end-to-end performance prediction. This places three conflicting requirements on the communications effects tool: Accuracy, Scalability, and Speed.

Accuracy

The communications effects tool must use high fidelity simulation models, starting at the physical layer, since the physical environment plays such a critical role in the performance of wireless networks. Attributes required at the physical layer include propagation models that calculate path loss and propagation delay in urban, suburban, and rural environments. The models must also include fading and shadowing effects, encoding, modulation, noise and interference, and directional antenna characteristics. The requirements at the physical layer extend to the environment including the effects of weather and terrain.

A high level of accuracy can be achieved with an architecture which follows the OSI reference model. This ensures that every individual packet is modeled and moves from layer to layer just as in a physical network. By using the gaps between layers, an Application Programming Interface (API) can be used by real protocols to access the different simulated layers. Taking this concept one step further, real world applications and existing or proposed network protocols or waveforms can be integrated with the simulator simply by adding the appropriate API calls. This ensures the highest possible fidelity. By modeling every packet with no abstractions, it also enables real network equipment to interoperate with the simulation, streaming real-time traffic such as live voice or sensor or video feeds through it, and allowing direct observation of the degradation due to network effects.

Figure 1 illustrates the results of experiments streaming identical video through a simulated mobile network, but varying the routing protocol. As can be seen, the resulting video degradation perceived at the Command and Control station varies greatly. Effects such as this can only be seen with high fidelity communications modeling.

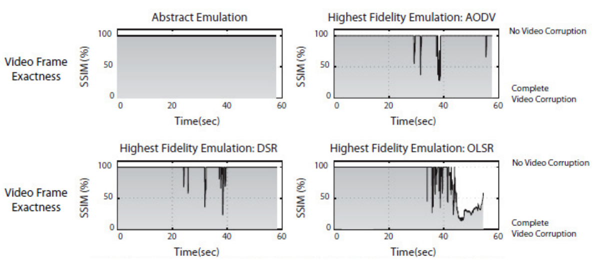

Figure 1. Video emulation fidelity

Scalability

Real world exercises may include hundreds or even thousands of communicating devices. An accurate analysis of network performance should model the entire deployed network. Analyses based on smaller subsets of the network may yield overly optimistic performance results, as protocols may break down as the network becomes more complex.

Speed

Operating a communications effects simulation in real time is critical in order to integrate with a CGF, live system, or human-in-the-loop simulator. Real time is achieved when the time required to simulate delivery of a packet never exceeds the time for actual delivery of the packet in the real network.

For large networks, the processing power needed to meet the real time constraint increases rapidly. The communications effects tool must be able to partition the network and make use of parallel processing to keep execution time manageable. This task becomes increasingly problematic in the federated environment when both message and behaviors are provided by an entity external to the communications effects tool and the ability to look-ahead is compromised.

SOLUTION: INTERFACE CONTROL DEFINITION

Working together as a team, VT MÄK (MÄK), Scalable Network Technologies (SNT), and Boeing have addressed this problem using COTS software, notably MÄK's VR-Forces CGF, working together with SNT's QualNet communications effects server. Both were modified to take advantage of an Interface Control Document (ICD) that works via the High Level Architecture (HLA) signal and data interactions to facilitate communications modeling between HLA federates. See Figure 2 for an overview of the architecture, and how it relates to the OSI stack.

ICD Overview

The communications modeling between QualNet and VR-Forces is conducted via HLA signal and data interactions. SNT designed and released an extension to the standard Real-time Platform Reference (RPR) Federated Object Model (FOM) 1.0 called the Interface Control Document that transports communications effects messages.

The ICD does not define any new HLA objects or interactions, but instead uses the existing ApplicationSpecificRadioSignal and Data interactions defined in the RPR FOM and populates the data fields with QualNet-specific enumerations and signal data.

While the ICD is not a standard sponsored by an international standards body, one possible future for the ICD would be consideration by a body such as SISO or IEEE.

CGF Implementation

As off-the-shelf software, the baseline VR-Forces communications system is composed of two major systems:

- A radio that is attached to the entity; and
- The communications model.

When one VR-Forces entity needs to send a radio message to another, the radio model passes the message to the communications model, which then processes the message based on the radio's parameters and the parameters of the communications model. The communications model then delivers the message to any entities that are capable of receiving the message. The receiving entities then process the message they received, possibly taking new action as a result of contents of the message.

The default communications model within VR-Forces is designed for efficiency and does not take into account environment impacts on electromagnetic signals that exist in the real world. This simple approach does support some desired training goals, particularly in small exercises conducted over small geographic distances. However, signal loss is a reality when replicating command and control in a virtual environment, especially when communicating in mountainous regions or over long distances.

Rather than re-implement, embed or directly connect to an environmental effects server within VR-Forces' communications model, VR-Forces was modified to allow integration with an external communication model, using QualNet as the communications effects server.

When an external communications effects server is in use, the VR-Forces radio model works the same as in the baseline system. However, when a radio message is ready to be sent, the new VR-Forces communications model sends a request to the QualNet server and holds the signal message until the server adjudicates the signal, and responds. When the VR-Forces communications model receives the response from QualNet it delivers the message to the entities that are able to receive the signal – or not, as appropriate.

In detail, the ApplicationSpecificRadioSignal interaction message is sent from VR-Forces to QualNet. The message parameters follow the format described in the RPR FOM. The UserProtocolID is set to 10000 to denote a QualNet message and the signal data consists of attribute-value pairs encoded as ASCII text. The attribute-value pairs describe the request that VR-Forces wants QualNet to adjudicate. QualNet uses the Data interaction to define three response messages. The Process Message interaction is sent when one or more entities are able to receive the message. There may be more than one Process Message interaction sent for each request. When VR-Forces receives this message from QualNet it passes the signal message to the listed receiving entities. The Timeout message is sent when QualNet is done processing a request and all Process Message interactions are sent. The optional Ready To Send Signal (RTSS) interaction is sent from QualNet to VR-Forces to indicated that it is ready to receive requests.

All of these interactions can be done using forced reliable, sent reliable, or sent unreliable communications, depending on the degree of fidelity required of the simulation.

Communications Effects Server Implementation

Using components from the ICD definition, QualNet monitors the HLA federation, listening for VR-Forces to send HLA interactions to QualNet requesting processing of communications effects. QualNet responds by sending HLA interactions to VR-Forces to report on results of communications. While monitoring the state of the virtual world as represented in HLA, QualNet tracks the following information:

- Entity objects, including location, orientation, speed, and damage state
- Radio objects, on/off state
- ApplicationSpecificRadioSignal (ASRS) interactions

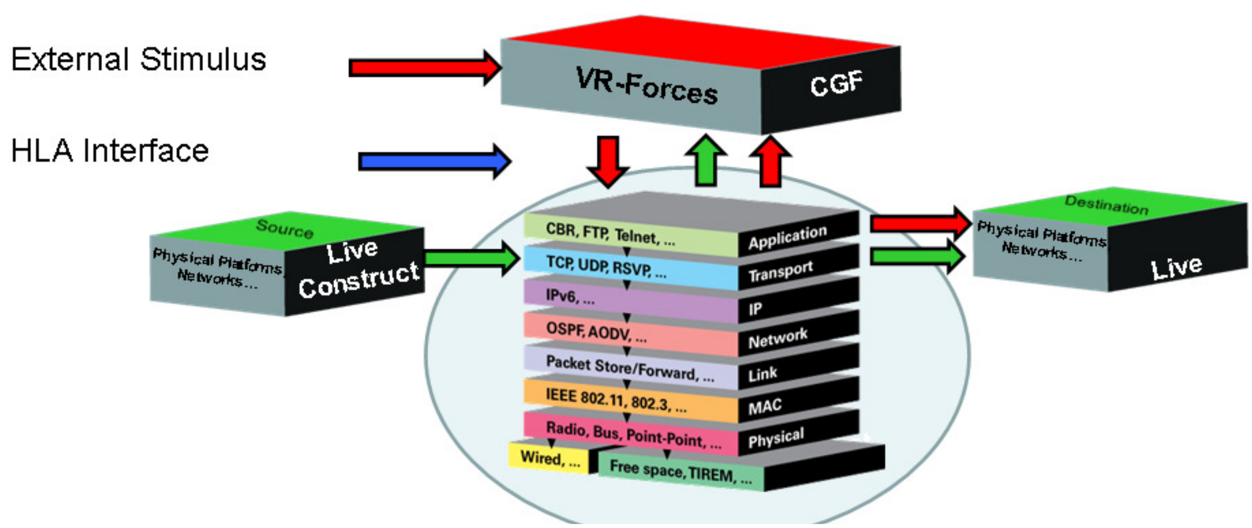

Figure 2. VR-Forces / QualNet interactions: a complete communication stack

- QualNet-specific messages indicated via UserProtocolID parameter

Using this information, QualNet determines:

- Changes in the mobility patterns of QualNet nodes (each node corresponds to one radio)
- Changes to maximum transmit power due to entity damage
- Disabling of QualNet nodes due to entity damage and on/off toggling
- Modeling of network communications following receipt of ASRS interaction using contents of SignalData parameter (message size, timeout, optional unicast destination)

The ASRS definition includes the data rate, data signal length and signal data as part of the message transaction. These fields supply QualNet with sufficient information to determine factors such as fragmentation, routing and delay based on environmental and network constraints at the time of the transaction.

If conditions are such that a message can be successfully delivered to the receiving entity, QualNet responds with a Process Message interaction to the intended receiver. If the message can not be delivered, then the intended message recipient acts against the Timeout interaction message it received directly from QualNet independently from the actual Data Message.

In turn, as a result of the message transaction the results returned to VR-Forces are:

- A Data interaction indicating whether a communication attempt was a success or failure
- Real-time statistics for selected metrics sent using Comment interaction.

During the course of the federation, QualNet models the network traffic at all layers of the OSI model and will send a Data interaction indicating message was delivered to destination (a Process Message interaction). This occurs in real-time (if the message is modeled to arrive at time 10, the Data interaction is sent at time 10). Additionally, QualNet will send a Data interaction summarizing delivery status to all potential recipients after a timeout value indicated in the original ApplicationSpecificRadioSignal interaction.

RESULTING APPLICATIONS

With the creation of the ICD, Boeing's international analysis facilities have now been able to develop applications to better represent a Network-Centric Battlespace in both virtual and constructive experimentation. The first application developed was the Network Effects Server (NES). Through the implementation of the ICD, NES is able to apply communications effects, such as delivery delays and dropped packets, to Signal and Data interactions generated in a distributed interactive simulation (DIS) or HLA RPR FOM federation. Boeing has used NES in recent virtual warfighting experimentation to provide communications effects on data communications such as the impact of voice-data contention, terrain occlusion, and bandwidth constraints on command and control applications. One such application development which makes use of the communications effects capabilities of NES is Boeing's Reconfigurable Operator Console for Experimentation (ROCX).

Support to the UK Future Rapid Effects System program highlighted the importance of "networking" in the land battlespace. The traditional analog voice communications and paper maps used in military operations and associated experimentation now required digitization to successfully represent operations in the network-enabled Land environment. ROCX was developed as a warfighter operator console emulation toolkit for virtual experimentation to provide the land warfighter with the shared situational awareness benefits experienced by those operating in the air and maritime domains (Arnott, 2008). In recent Boeing experiments both in the UK and Australia, ROCX has been used to emulate a Land Battle Management System (BMS) and has used the ICD to enable the transmission of reports, sensor tracks, messages and tactical white-boarding data between BMS stations via simulated radios which are linked to communications effects applications.

Two of these recent experiments included a Joint Fires Experiment in the United Kingdom and a Tactical Unmanned Aerial Systems (TUAS) Experiment in Australia. See Figure 3. ROCX was used as both a BMS emulator and a TUAS Ground Control Station while NES provided communications effects on the network (McMahon et al., 2009).

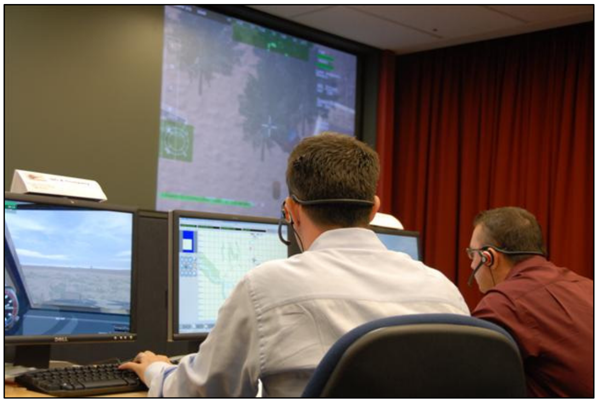

Figure 3. Australian TUAS Experiment Commander Station (Feb 2009)

In both activities, the impact of communications effects on the updating of the Common Operating Picture had significant implications for participant situational awareness. These impacts were most evident when low-bandwidth channels formed the network back-bone, operations were conducted in urban terrain and during periods of high-voice traffic where voice-data contention placed considerable delay on BMS updates. The Australian TUAS experiment also highlighted the requirement to apply communications effects to streaming video feeds and development is underway to implement this capability in ROCX through the use of a higher-fidelity communications effects server.

As the examples clearly indicate, without the use of the ICD to couple the ROCX BMS with communications effects applications such as NES and QualNet, Boeing would have been unable to provide a representative battle management picture impacted by radio and network constraints. It has also enabled high-fidelity communications modeling of the net-enabled Land warfighting environment, providing the capability to trial different radio and network configurations and to analyze the impact of these configurations on the conduct of operations.

CONCLUSION

To date, most modeling and simulation systems assume perfect communications between simulated entities. Since real world constraints frequently limit the communications capability, however, the use of a perfect model creates negative training effects and provides substantially imperfect analysis.

By using commercial off-the-shelf software, the authors integrated a commercial grade computer generated force projector with a leading communications effects server. The result is a robust system which dramatically increases the fidelity level of modeling in the virtual world, and which as a result has been proven to provide better training and improved analysis capabilities.

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