Evaluation of a Wireless Network to Support Live, Virtual, and Constructive (LVC) Training

Leonid Veytser, Stephen McGarry
MIT Lincoln Laboratory
Lexington, MA
veytser@ll.mit.edu, smcgarry@ll.mit.edu

Mark Torpey, Matthew LeVan
Lockheed Martin Corporation
Burlington, MA
mark.torpey@lmco.com, matthew.d.levan@lmco.com

ABSTRACT

The Fifth Generation Advanced Training Waveform (5G-ATW) was developed to efficiently integrate airborne wireless participants into real-time distributed training events. The 5G-ATW provides low latency User Datagram Protocol (UDP) multicast delivery over the wireless segment that was optimized for the purpose of connecting tactical aircraft to distributed interactive training events. In this paper we evaluate the impact of the 5G-ATW performance on the distributed training architecture by assessing event outcomes as the performance of the waveform is altered. In this set of experiments, the performance of Distributed Interactive Simulation (DIS) models is compared between an ideal network and a wireless network of varying capacity and reliability to ascertain what level of performance is required from the wireless network in order to support distributed simulation with little or no impact. This outcome-based approach combines the use of real-time network emulation with real-time distributed simulation to examine the sensitivity of the Live, Virtual, and Constructive (LVC) training architecture to changes in wireless service and inform the network developers and the acquisition professionals who will establish the next generation system. This paper provides details about the experiment configuration, an overview of the 5G-ATW waveform, the scenarios that were run, and the results with recommendations.

ABOUT THE AUTHORS

Leonid Veytser is a member of the Tactical Networks Group at MIT Lincoln Laboratory (MIT LL). His research interests include design, modeling, prototyping, and evaluation of next generation tactical networks. His recent work focused on leading the development of media access and networking layers of a wireless network to support LVC training, as well as evaluating its performance under various DIS scenarios. He received his B.A. and M.A. degrees in Computer Science at Boston University.

Stephen McGarry developed manned simulators to evaluate weapon control algorithms at General Electric and transitioned to DIS during the Simulator Network (SIMNET) era at Bolt, Beranek, and Newman. He then contributed to the evolution of DIS and participated on the team that developed run-time infrastructure-simulation (RTI-S) for the High Level Architecture (HLA) at MIT LL. As Assistant Leader of the Tactical Networks Group at MIT LL, he is leading a team to develop a prototype wireless network to support LVC training. He holds a BSEE from Brown University and an MSEE from Syracuse University.

Mark Torpey is a member of the Group Technical Staff at the Advanced Simulation Centers within Lockheed Martin, where he leads the Virtual World Laboratory (VWL) and the Constructive Simulation & Interoperability Laboratory (CSIL). Mark's primary areas of research include (1) the use and development of web- and game-based technologies and processes for training and education, (2) the development of software infrastructure for distributed simulation and collaboration, with a focus on scalability and interoperability, and (3) the development of distributed simulation and infrastructure software that supports large-scale, human-in-the loop exercises. He received his B.S. and M.S. degrees in Computer Science at the University of Massachusetts.

Matthew LeVan is a Senior Software Engineer that has been a part of the technical staff at the Lockheed Martin Advanced Simulator Center (ASC) for over 15 years. Matthew is currently part of the Navy Warfare Development Command (NWDC) engineering team responsible for maintaining and improving the NWDC branch of the Joint Semi-Automated Forces (JSAF) simulator.

Evaluation of a Wireless Network to Support Live, Virtual, and Constructive (LVC) Training

Leonid Veytser, Stephen McGarry
MIT Lincoln Laboratory
Lexington, MA
veytser@ll.mit.edu, smcgarry@ll.mit.edu

Mark Torpey, Matthew LeVan
Lockheed Martin Corporation
Burlington, MA
mark.torpey@lmco.com, matthew.d.levan@lmco.com

INTRODUCTION

In this paper we treat the wireless network as a component of a larger system used to support integrated LVC training, and in particular the use of the wireless network to integrate the tactical air combat aircraft into the virtual and constructive environment (Keeler, Testa, Opella, 2002). In our study, a detailed model of the 5G-ATW is used as the wireless network segment. The model provides a pulse-by-pulse real-time emulation of the waveform, accounting for antenna characteristics, propagation delay and attenuation, interference, radio frequency (RF) channel characteristics, physical layer, and network layer waveform behavior. DIS data is exchanged in real-time through the wireless network model between simulations that are not modified to account for wireless network transport. The entity behaviors are provided by the JSAF application that is categorized as a constructive simulation in the LVC domain.

In our study we vary the network performance across a wide range of parameters that model a light, medium, and heavily loaded wireless segment. We can measure the specific impairments to the network in terms of packet and message loss and delay, and other network performance metrics. Our study shows that the networked training applications are tolerant to widely varying wireless network performance and indicate that LVC training does not require a tightly synchronized, low-loss wireless network in order to provide sufficient training outcomes. Further, we suggest the outcome-based approach used gives greater insight into the overall suitability of the network as opposed to comparison of network parameters alone.

FIFTH GENERATION ADVANCED TRAINING WAVEFORM (5G-ATW)

DIS has long been an early adopter of evolutions in network technology. As computers became more powerful and networks became faster, albeit at a slower rate, the driving need to manage the communication versus computation trade-off started to fall away. The need to integrate live participants – those participants using their military equipment, vehicles, and other kit – has migrated the community to incorporating wireless networks to facilitate the integration. Notwithstanding the cell phone evolution, wireless networks have not enjoyed the tremendous capability improvements of the terrestrial infrastructure. So to successfully integrate the live participants with the virtual and constructive, we can again look at trades associated with constrained communications environments and propose approaches that will satisfy the needs of DIS.

The 5G-ATW is proposed as an approach to integrating the tactical aircraft into the LVC training architecture. This waveform has been developed with features that favor the distribution of distributed simulation network traffic which is:

- UDP rather than Transmission Control Protocol (TCP)
- Broadcast/multicast rather than unicast or point-to-point
- Bursty rather than uniform

To date, no other wireless network has been proposed that optimizes these trades with DIS traffic as the primary user.

5G-ATW combines a spread spectrum physical layer with a random access, medium access control layer, and a multicast networking layer that has been optimized to provide best service to multicast UDP over Internet Protocol (IP) messaging such as DIS. Some aspects of this waveform were initially proposed as the P5 Advanced Data Link (ADL); however, it has been substantially modified from its initial form to better suit the DIS LVC network environment. The following section provides details of the 5G-ATW.

The 5G-ATW waveform divides its band of operation into channels of 833.33 kHz each. Fixed and known channels are used for synchronization. The rest of the channels are used to carry data. The basic concept of operation is the receiver listens on a sync channel until it receives a sync pulse with a known sync pattern. The sync pulse data is processed to extract the known pattern for the hopping frequencies (channels) that carry the data pulses.

The 5G-ATW is designed to support up to 64 channels of 833.33 kHz each. The channels can be contiguous and non-contiguous, as shown in Figures 1 and 2.

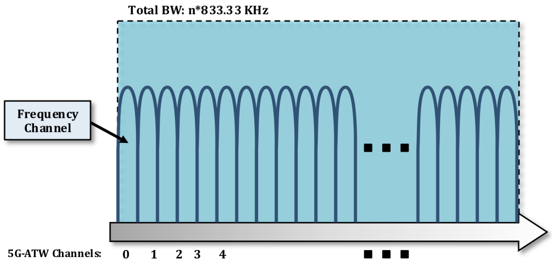

Figure 1. 5G-ATW Contiguous Channels

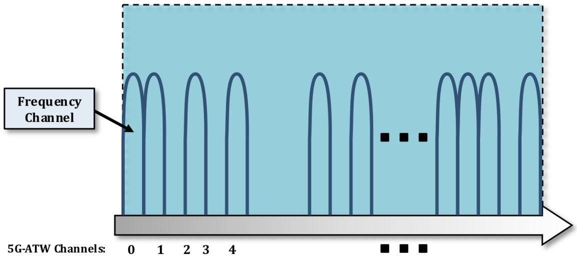

Figure 2. 5G-ATW Non-contiguous Channels

Each channel is modulated using absolute Gaussian minimum shift keying (GMSK) with a bandwidth symbol duration product of BT = 0.3. A 5G-ATW frame is composed of four synchronization pulses followed by 16 data pulses for a 2 kbit encoded frame or 32 data pulses for a 4 kbit encoded frame. The pulses are spread over 20 milliseconds for the 2 kbit frame and 40 milliseconds for the 4 kbit frame. Synchronization pulses are sent on well-known channels and are used to indicate the start of a 5G-ATW frame. Each synchronization pulse is 162 microseconds in length and includes three 32bit known symbol sections that are used for correlation and identification of the synchronization pulse and a Reed-Mueller encoded synchronization data field of 64 bits. Each data pulse is 192 microseconds long and includes the 128 bits of turbo-coded and interleaved data and two 32 bit known symbols. Figure 3 shows the time and frequency layout for a typical 5G-ATW frame.

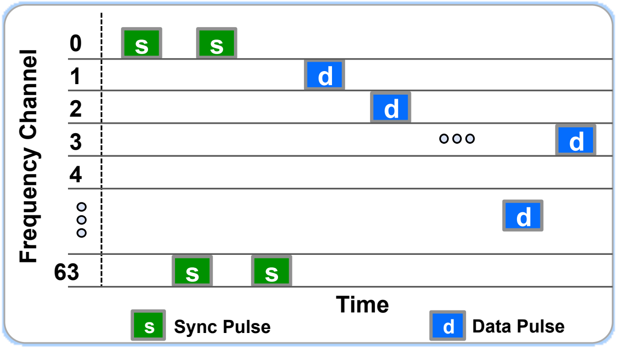

Figure 3. 5G-ATW Frame

There are 512 transmit patterns that are used to randomize the time interval between pulses and the channel used for each data pulse. These patterns are chosen to reduce the probability of pulse collisions among multiple transmitters.

5G-ATW Network and Media Access Control (MAC)

The 5G-ATW network and MAC layers provide network forwarding and routing, as well as fair channel access for the delivery of IP packets over the random access physical layer described above. In addition, these layers provide IP header compression and segmentation and reassembly to efficiently package a datagram into one or more 5G-ATW frames. Three data frame sizes are available: 680, 872, and 1752 bits, which are coded into 2k, 2k, and 4k bit total data frames. Therefore, the 5G-ATW will operate most efficiently with small IP datagrams that will fit into the smallest data frame size. It has been shown that if Compressed DIS (C-DIS) is used to compress the DIS protocol, more than 95% of the DIS Protocol Data Units (PDUs) will not need to be fragmented and the waveform will be allowed to run most efficiently. C-DIS is a newly proposed standard that compresses the DIS PDU contents to reduce the size of the frames sent over a wireless medium. C-DIS can be implemented as a gateway that performs translations to/from DIS/C-DIS, allowing LVC applications to continue exchanging data using the DIS standard while the smaller C-DIS PDUs are exchanged over the air (OTA).

The 5G-ATW MAC layer exchanges periodic information peer-to-peer to identify one hop neighbors and assess demand on the network from each participating node. The MAC incorporates a back-off algorithm at each node to temper demand and allow for fair access to the media. This mechanism smooths out peak demand and allows for greater overall network throughput.

The network layer provides forwarding using Simple Multicast Forwarding (SMF) (IETF 2012) with Neighborhood Discovery Protocol (IETF 2011) to flood datagrams throughout the wireless segment of the network. SMF is most suitable for small, mobile ad-hoc networks where flooding is a viable alternative; it defines mechanisms to provide efficient duplicate packet detection and reduced relay sets for multicast data, which can reduce the redundant traffic in the network.

5G-ATW EMULATION MODEL

For our study, an emulation of the 5G-ATW was built using the Extensible Mobile Ad-hoc Network Emulation (EMANE) framework and the Common Open Research Emulator (CORE) toolset. These tools provide a framework for developing waveform models and setting up virtual networks for evaluating these models. By using this environment, we can rapidly evaluate the performance of wireless networks carrying actual application traffic across hundreds of nodes in a laboratory environment well in advance of implementing the waveform in a modem or radio hardware. This provided insight into implementation choices while developing the waveform, and predicted behavior of the network running at scale with actual application traffic.

Figure 4 depicts the distribution of the 5G-ATW model across EMANE components.

A CORE Container is used to manage applications and network-layer traffic in each participating node in the environment. In our case, a node is an instance of a radio running the 5G-ATW in the wireless network and the associated applications that are generating or receiving traffic associated with that node. The EMANE OTA and event channels are used to distribute data and control across all of the instances of EMANE in the environment.

The physical layer (Framework PHY) contains models of the environment and applies them to each transmission in the system to determine if the message can be received. In this layer propagation loss, antenna gain, and line of sight modeling is performed. If the signals are deemed to be received by the physical layer they are passed to the higher layer of emulation, in this case the 5G-ATW MAC.

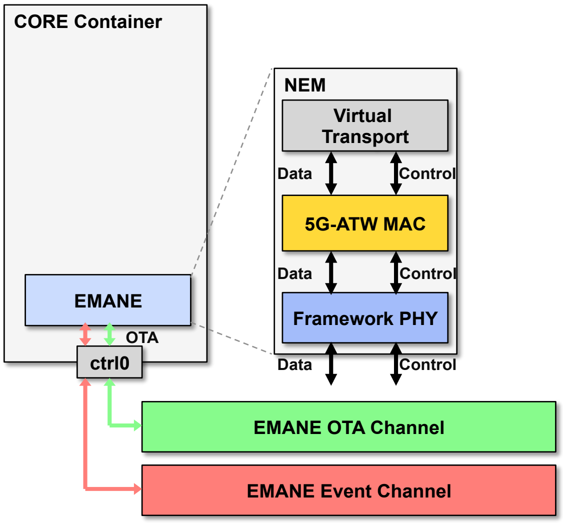

Figure 4. 5G-ATW Components in the EMANE Architecture

When a 5G-ATW frame is received from the physical layer, the 5G-ATW MAC performs signal interference calculation by using a pulse-by-pulse signal-in-space model. Based on the interference level provided by the signal-in-space model, the coding and modulation models are used to determine if the synchronization and the data portions of the frames were received. If the frame is successfully received, the 5G-ATW MAC provides IP header expansion and re-assembly if the frame is part of a fragmented message, and then passes the fully formed IP packet up to the network layer that is running SMF as a CORE Container application.

JOINT SEMI-AUTOMATED FORCES (JSAF)

JSAF is a U.S. government owned and developed constructive simulation system. It is widely used in training and experimentation. The JSAF application is an entity-level warfare simulation that can transmit and receive both HLA and DIS packets. It includes models of air, land, and sea forces of various nations and alliances. Entities can be created at the individual or aggregate level and placed in a simulated battle space. Objects can be created and commanded autonomously, or as part of a larger group (squadron, company, brigade, etc.). These entities replicate the outward behavior of their component vehicle and weapon systems and are used for testing and combat development. When an object is created, it is given extensive capabilities, such as avoiding obstacles, shooting guns, and launching missiles, and can be tasked to execute a mission. Units can take advantage of situational awareness and opportunities for cover and concealment when they perform tactical movement and combat. The user can interact with the simulation to create, load, and run scenarios to simulate a battle space situation. For the purposes of our study, JSAF is used to provide the location and mobility of nodes in the wireless network and the DIS traffic that would be produced by the entities in the network, whether or not they are on the wireless segment. Also, JSAF provides the behaviors of the participants in a way that is operationally relevant, reasonably repeatable, and responsive to the information carried over the network.

JSAF is a stochastic, real-time distributed simulation that is designed to be a participant in a larger environment and to be tolerant of both packet loss and latency. It is composed of physics-based models that are parameterized to represent the characteristics of a particular system. Behaviors are used to coordinate these models into a set of actions, such as fly information, target an adversary, or perform an evasive maneuver. Probabilities are used in both the models and the behaviors to better represent the performance of the system being modeled and to inject the variability expected in human performance. So a sensor will have a probability of detection (Pd), a weapon will have a probability of kill (Pk), and a behavior will have a probability of not choosing the correct response. As such, JSAF does not attempt to be a causal or repeatable simulation tool, but instead aims to provide simulation outcomes that adequately support training objectives in these distributed and user-driven contexts. For our study, therefore, we have attempted to normalize these variabilities through the experiment design and execution. We use the same random seed for each run and we characterize the variability using ideal network connectivity as the control case.

EXPERIMENT DESIGN AND CONFIGURATION

The objective of our experiment is to measure the level of wireless network reliability needed to allow for LVC training using DIS compliant systems. To accomplish this, we have chosen to measure network reliability in terms of packet loss rate. We then record the results of iteratively running a DIS exercise across a wireless network and compare the results across runs where the network connectivity is varied from ideal, to increasingly degraded. The results are recorded as a time series of events in the simulation environment. If the results of a run correlate closely to the ideal network case results, given chosen scenario outcome metrics, we say that the network did not impact execution of the run. Because the behavior of the JSAF entities are probabilistic, several runs are made at each level of network performance and average observed outcomes are compared.

Experiment Set Up

The primary tools used in the study are the JSAF constructive simulation and the wireless network model running in EMANE. To emulate the ideal network, we used EMANE's bypass model; to emulate the 5G-ATW network, we used the 5G-ATW model. Several other tools are required to complete the integration. Figure 5 provides an overview of the complete experiment set up.

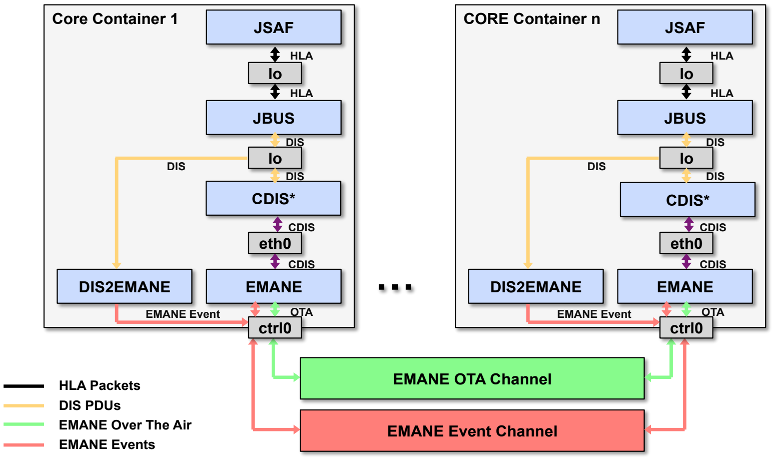

Figure 5. Experiment Overview

The location and mobility of the nodes in the wireless network are modeled in the JSAF instances, and the resulting DIS traffic is carried over the wireless network emulation. The JSAF network traffic is produced as HLA so the Joint Simulation Bus (JBUS) converter is used to map between HLA and DIS protocols. Since the performance of the wireless network varies with the size of the IP packets flowing through it, the C-DIS module is used to compress and expand the DIS PDUs so that small packets are sent over the wireless segment. Since the performance of the wireless network also varies with the distance between the wireless network nodes, we must provide the locations of the wireless participants to EMANE and maintain them over time so that the position and orientation of each antenna can be used in the signal strength calculations. A software module DIS2EMANE was developed to drive the 5G-ATW model with DIS PDUs.

Since multiple JSAF instances were distributed among multiple CORE Containers, the JSAF scenario simulation start times had to be synchronized. JSAF was modified to specify the scenario start time, synchronizing scenario timing among every JSAF instance. Additionally, JSAF's random seed setting was fixed across all the runs to reduce the variability in scenario outcomes run-to-run.

For the scenario in our study, one CORE Container was used to model each of the nodes in the wireless network. In addition, a Noise Generator node, modeled in one CORE Container, was used to consume wireless network resources and cause the level of degradation in network performance needed. Also, a time series database was used to record significant events for each run. The number, time, and order of these events is compared run-to-run to determine the correlation between runs.

Experiment Scenario

The scenario used to for this study is depicted in Figure 6.

In this scenario, a blue force entity and a red force entity are flying towards each other to trigger combat engagement as they reach appropriate distance. This simple two-entity scenario allows for easily understandable scenario outcomes and lets us study the differences of these outcomes as the underlying network conditions change.

Each aircraft entity has an associated CORE Container, with all of the applications described in the previous section dedicated to it. Additionally, each aircraft entity has its own model of the wireless network running (either 5G-ATW or Ideal) and all the DIS interactions are performed over the modeled network.

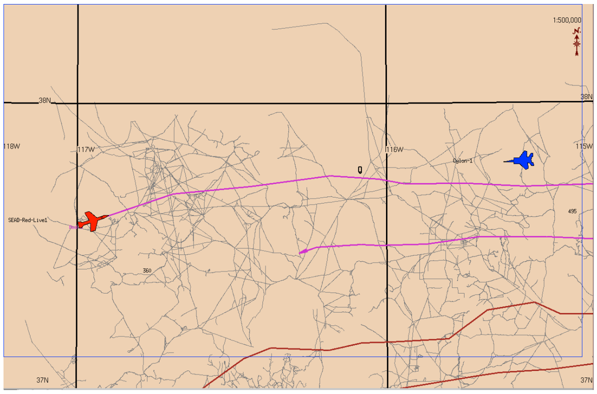

Figure 6. Experiment Scenario

Controlling Network Performance

The experiment runs were conducted over multiple levels of wireless network performance, based on the level of packet loss in the network. To effect this performance degradation it is useful to allocate resource bounds on each of the emulated radio nodes and to create cases where we are operating within and outside of those resource bounds. For our case with the 5G-ATW waveform, we can define a receiver resource as the ability to receive a single 5G-ATW frame over a 20 millisecond window or 50 frames per second. If we allow two receiver resources we can receive 100 frames per second, and so on. In our experiment we set ten receiver resources, which allows 500 frames per second of receiver capability. Frames in excess of 500 at any given time are counted as dropped by the receiver.

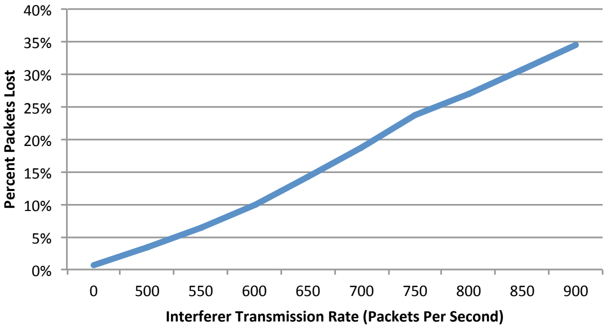

Figure 7. 5G-ATW Packet Loss Rate Given Various Levels of Interfering Traffic

Since the scenario is identical to run-to-run, the level of the DIS network traffic is about the same. In order to create load on the network, and therefore degrade performance, a traffic generator was added to the experiment. The traffic generator provided uniform randomly distributed network traffic to fill up the receive resources and cause the receivers to randomly drop frames that exceed the allocated receiver resources.

Interfering traffic levels were chosen between 500 and 900 packets per second. Average packet losses were measured as between 3.5% and 34.5%, corresponding to various levels of interfering traffic. The packet loss over 5G-ATW with no interferer was measured as 0.5%. This loss was due to the interference caused by only DIS traffic in the network. The packet loss in the ideal network was measured as 0%. Figure 7 depicts the measured packet loss rates over 5G-ATW, based on various interfering traffic levels. Calibration runs were made to establish that the measured packet losses at each of the interference levels was consistent.

Experiment Execution

We conducted our experiment by configuring the network interference to the levels shown in Figure 7 and then running the scenario 100 times for each interference level and for the ideal network case. For each scenario run, the events were recorded as a time-ordered list in the database. We then compared the key scenario outcomes and statistics observed under various 5G-ATW network conditions to those observed under the ideal network conditions. The three metrics we concentrated on were entity kill rate, entity kill event time, and number of fire events.

- Entity kill rate calculated the percentage of time an entity generated a damage assessment of “Catastrophic damage” and thus deemed to be killed. As the network degrades and more packets are lost, we expect the scenario outcomes to begin to diverge from the ideal case, changing the number of times certain entities get killed. We defined the entity kill rate to be similar to that of the ideal case if the measured rate was within 10% of the entity kill rate measured under the ideal network conditions.
- Entity kill event time measured the average time in the scenario when an entity got killed. As the network degrades and more packets are lost, we expect certain scenario events like entity kills to happen at increasingly different times from the ideal case. We defined an entity kill event time to be similar to that of the ideal case if it was measured to be within a standard deviation of the average entity kill event time under the ideal network conditions.
- Number of fire events calculated the number of fire PDUs generated by an entity. As the network degrades and more packets are lost, we expect the number of fire PDUs generated to begin to increase from the ideal case to complete the engagement with the enemy entity. We defined the number of fire events to be similar to that of the ideal case if they were measured to be within a standard deviation of the average number of fire events under the ideal network conditions.

If all three metrics were calculated to be similar to the ideal case, then we can say that the network performance did not impact the execution of the scenario; hence, is not likely to impact training in the LVC environment.

DIS Reliability Enhancement

To make DIS more resilient to degrading network conditions, a simple DIS reliability enhancement was implemented. This enhancement was not a modification to JSAF, JBUS, C-DIS Gateway, nor to the DIS specification, but rather a proxy application that operated between DIS applications and the radio. This proxy application intercepted certain DIS PDUs that were deemed to be critical and re-transmitted them two more times for a total of three transmissions. In our experiment, both Fire and Detonation PDUs were re-transmitted for higher reliability. Because both Fire and Detonation PDUs were an insignificant portion of the overall DIS traffic, this reliability enhancement did not add any tangible additional overhead to the network.

To understand the impact of the DIS reliability enhancement, we conducted experiments with both standard DIS and with the reliability enhancements. We then compared the scenario outcomes in both configurations to see if the DIS reliability enhancement allows the LVC training environment to tolerate more challenging network conditions.

RESULTS

We found that the scenario with the default DIS configuration maintained a similar performance to the ideal network with packet loss rates close to 15%. We also found that adding the simple DIS reliability enhancement increases the packet loss tolerance to close to 24% loss. This implies that LVC training environment can be tolerant to fairly high packet loss and does not require a tightly synchronized, low-loss wireless network in order to provide sufficient training outcomes. A further discussion of the experiment results follows below.

Results For Default DIS Case

Entity Kill Rate

The first metric we evaluated was the entity kill rate for both entities. First, we first measured the entity kill rate under the ideal network and then compared the entity kill rates under the increasingly degraded 5G-ATW network. As described in the previous section, if the entity kill rate was within 10% of the ideal case then the scenario outcome was deemed similar to the ideal scenario outcome.

Figure 8 depicts the entity kill rates that were measured in our experiments. We looked at entity kill rates of both entities in our scenario. The green and purple horizontal lines show the entity kill rates for both entities measured under the ideal network. The error bars show the 10% threshold for measured kill rates to be within the ideal network's kill rate. The blue and red solid curves show the kill rates measured under the 5G-ATW network with increased packet loss, based on the increasing interferer transmission rates shown in Figure 7. Finally, the vertical solid line depicts the highest packet loss rate environment, where both entities' packet loss rates are within the 10% threshold of the ideal case.

As can be seen in Figure 8, Entity 2 was killed 100% of time in the ideal network. Entity 1, however, was killed about 5% of the time as the missile fired by Entity 2 was released in time before it got hit by Entity 1. The entity kill rates under various 5G-ATW packet loss rates are similar to the ideal network until the 14.21% packet loss rate. After that, the entity kill rate, for example of Entity 2, dramatically decreases, providing significantly different outcomes from the ideal case.

Entity Kill Event Time

The second metric we evaluated was the entity kill event time. If the average entity kill event time was within the standard deviation of the average entity kill event time observed under the ideal network, then the scenario outcome was deemed similar to the ideal scenario outcome. Since Entity 1 kill events were so rare, there were not enough data points in our 100 trials to produce statistically significant average kill event times for Entity 1. Therefore, we only analyze the kill event times for Entity 2.

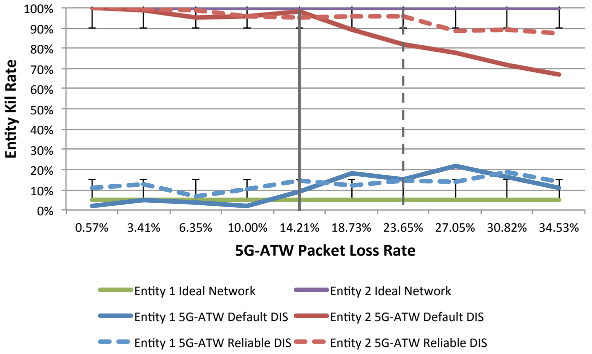

Figure 8. Entity Kill Rate

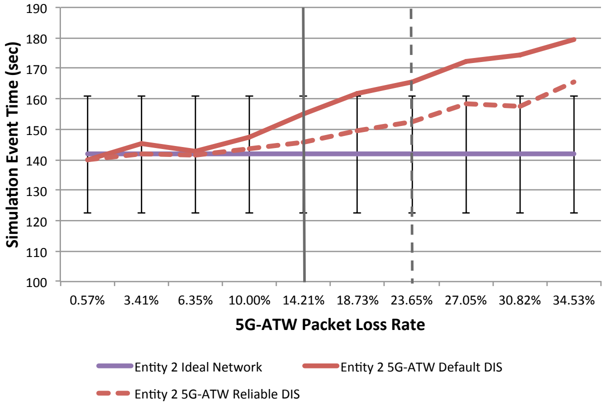

Figure 9. Entity Kill Event Time

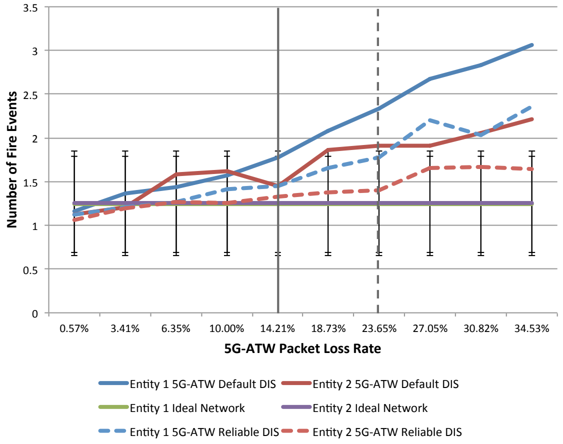

Figure 10. Number of Fire Events

Figure 9 depicts the entity kill event times that were measured in our experiments. The horizontal purple line depicts the measured average entity kill time under the ideal network and the error bars depict the measured standard deviation. The solid red curve depicts the measured average entity kill event times measured under the 5G-ATW network with increasing packet loss. Similar to the entity kill rates, the scenario outcomes stayed similar to the ideal case in network conditions with up to 14.21% packet loss rates.

Number of Fire Events

The final metric we evaluated was the number of fire events generated by each entity. Figure 10 depicts the measured results and it has a similar structure to Figures 8 and 9. The number of fire events metric correlates with the kill rate and kill event time metrics and shows that the number of fires remained similar to the ideal cases in network conditions with up to 14.21% packet loss rates.

Results for DIS Reliability Enhancement Case

DIS reliability enhancement re-transmitted both Fire and Detonation PDUs two more times using a proxy application that operated between DIS applications and the radio. As the network conditions degraded and packet loss rates increased, this simple reliability enhancement attempted to increase the chances that the Fire and Detonation PDUs made it to the destination, thus increasing the chances of the scenario outcome similar to the ideal case.

Figures 8, 9 and 10 also depict the measured scenario performance with the DIS reliability enhancement enabled. The dashed curves depict the performance with the DIS reliability, as opposed to solid curves with default DIS. As you can see, the scenario performance does indeed improve over the default DIS case and all three metrics remain similar to the ideal case under the network packet loss rates of up to 24%. The dashed vertical lines on each of the three figures also depict this performance. The improved performance highlights the DIS simulation's tolerance to packet loss if some key messages are delivered more reliably. Losing a high number of entity state, emitter, and IFF messages did not significantly affect the scenario and yielded similar outcomes to the ones measured under the ideal network conditions.

SUGGESTIONS FOR FUTURE WORK

- **Larger size scenarios**: The current study was performed on a small, two-entity scenario. While it allowed us to clearly understand the scenario outcomes, a study involving larger scale scenarios, can be done to further understand the impact of the 5G-ATW network on the scenario outcomes.
- **Cross correlation algorithm**: In the current study, we concentrated on three scenario-based metrics: entity kill rate, entity kill event time, and number of fire events. Further research is needed to develop a more extensive cross-correlation algorithm that can compare and correlate time-ordered scenario events among multiple runs and network conditions. Such an algorithm will be helpful in understanding the scenario outcomes of larger size scenarios.
- **Airframe blockage and terrain modeling**: In the current study, the modeled sources of packet loss in the 5G-ATW network were interference effects and receiver hardware resource limitations. Adding blockage effects, both due to airframe blockage and terrain blockage, will help study the effect of these types of losses on the LVC training outcomes.

SUMMARY

In this paper we evaluated the impact of the 5G-ATW performance in terms of packet loss on the distributed training architecture by assessing event outcomes as the performance of the waveform was altered. A detailed model of 5G-ATW was used as the wireless network segment and JSAF was used to simulate entity behaviors and drive DIS traffic. An interferer node was used to gradually increase the packet loss rate of the emulated 5G-ATW network by increasing the DIS traffic. Scenario event outcomes over a degraded 5G-ATW network were compared to the outcomes measured over an ideal network. Three metrics were chosen to gauge scenario event outcomes: entity kill rate, entity kill event time, and number of fire events.

We found that scenario event outcomes remained similar to the outcomes observed under the ideal network with 5G-ATW packet loss rates of up to 15%. Additionally, if our simple DIS reliability enhancement was used, the packet loss tolerance of the scenario event outcomes improved to 24%. This implies that the LVC training environment can be tolerant to fairly high packet loss and does not require a low-loss wireless network in order to provide sufficient training outcomes.

REFERENCES

IEEE (1995) Protocols for Distributed Interactive Simulation Application *IEEE 1278.1*

IETF (2011) Mobile Ad Hoc Network (MANET) Neighborhood Discovery Protocol (NHDP) *IETF RFC 6130*

IETF (2012) Simplified Multicast Forwarding (SMF) *IETF RFC 6621*

Keeler, J., (2002) Data Link Architectures for Combined ACTTS *Proceedings IITSEC 2002*

Keeler, J., Testa, J., Opella, D., (2002) NEXRI Interoperability Concepts for the Joint Strike Fighter *Proceedings IITSEC 2002*