

Airborne Wireless Real-Time Distributed Simulation Network Architecture

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ABSTRACT

The network architecture for real-time distributed simulation was established during the Simulator Network (SIMNET) program in the 1980s and 1990s and evolved into the Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) network protocols. Research was conducted to scale these networks up to large numbers of participants on local and wide area networks and this eventually became accepted practice in the training domain. As we extend the training network protocols to include tactical aircraft over a wireless network segment, the network architecture for this segment needs to be examined and compared with commercial best practices and emerging network research. We need to determine whether all of the network components are available, or alternatively need to be developed, to provide the scalability and service from the wireless network that we have leveraged from the proliferation of the terrestrial Internet Protocol (IP) networks. This paper examines alternative approaches to the wireless network routing and forwarding architecture for both tethered (using range support) and untethered (without range support) configurations, presents network modeling and simulation comparisons, examines security architecture implications, and makes recommendations for a viable wireless network architecture for Live, Virtual, and Constructive (LVC) training in the tactical airborne environment.

ABOUT THE AUTHORS

Steven Finn received B.S., M.S., E.E., and ScD. electrical engineering degrees from the Massachusetts Institute of Technology (MIT) in 1969, 1969, 1970, and 1975, respectively. From 1975 to 1980 he worked for Codex/Motorola Corporation where he held various R&D positions, including Director of Network Product Development and Director of Network Research. While at Codex he was also a member of ANSI and CCITT (ITU-T) committees involved in networking standards development. In 1980 he founded Bytex Corporation, a data communications equipment manufacturer. Dr. Finn held the position of CEO and Chairman of the Board through 1987 and 1990, respectively. In 1991 Dr. Finn returned to MIT as a Vinton Hayes Fellow and Principal Scientist in the Laboratory of Information and Decision Sciences. Currently he is a Senior Member of the Technical Staff at MIT Lincoln Laboratory (MIT LL).

Stephen McGarry developed manned simulators to evaluate weapon control algorithms at General Electric and transitioned to DIS during the 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 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.

Leonid Veytser is a member of the Tactical Networks Group at 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 B.A. and M.A. degrees in Computer Science at Boston University.

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INTRODUCTION

In this paper we examine network routing and forwarding architecture alternatives for utilizing the Fifth Generation Advanced Training Waveform (5G-ATW) wireless radio component of a larger system used to support LVC training in the tactical airborne environment. In particular, this paper examines alternative approaches for both tethered (using range support) and untethered (without range support) configurations. We use simulation to evaluate network performance, examine security architecture implications, and make recommendations for a viable 5G-ATW wireless network architecture to support LVC training in the tactical airborne environment (Keeler, Testa, Opella, 2002).

In our study, a detailed simulation model of the 5G-ATW is used to model the wireless network segment. The 5G-ATW uses fixed length broadcast frames to carry DIS IP data packets to support the tactical airborne LVC training application. The simulation model provides a frame-by-frame event-based simulation of the waveform and supports simplified aircraft missions, flight dynamics, network routing/congestion/queueing models, propagation delay, signal attenuation, and transmit-receive multi-access interference. We evaluate network performance for both engineering data and DIS data exchanged in simulated real-time through the 5G-ATW wireless network. For tethered configurations, we assume the training range has a high capacity ground network for connecting virtual and constructive entities to the 5G-ATW wireless network through a Range Control Node (RCN).

In our study we explore network performance across a range of network loading scenarios that model light, medium, and heavily loaded wireless segments. We measure a number of system performance metrics based upon the network architecture choices for the 5G-ATW network design.

FIFTH GENERATION ADVANCED TRAINING WAVEFORM

The 5G-ATW combines a spread spectrum physical layer with a random access medium access control (MAC) layer and a multicast networking layer that has been optimized to provide best service to multicast User Datagram Protocol (UDP) over 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. The channels can be continuous and non-contiguous, as shown in Figures 1 and 2. Fixed and known channels are used for synchronization. The rest of the channels are used to carry data.

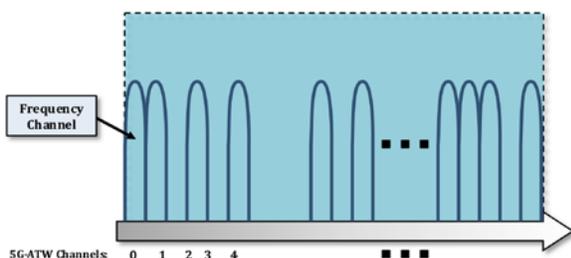


Figure 1. 5G-ATW Non-Contiguous Channels

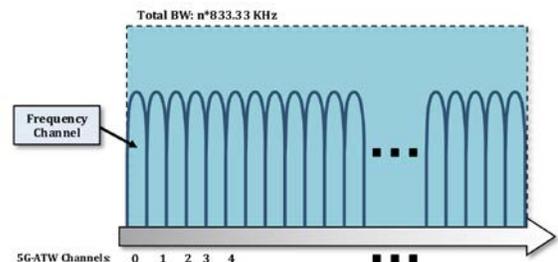


Figure 2. 5G-ATW Contiguous Channels

The basic concept of operation is that the receiver listens on the sync channels 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.

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 4 synchronization pulses followed by 16 data pulses for a 2kbit encoded frame or 32 data pulses for a 4kbit encoded frame. The pulses are spread over 20 milliseconds for the 2kbit frame and 40 milliseconds for the 4kbit 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 32 bit 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. A feature of the 5G-ATW that makes it uniquely suited to distributing LVC traffic is the capability to map IP multicast addresses to sync pulse known symbols. We define this mapping as the creation of “interest groups” and use this feature to reduce load on the receiver in heavily congested LVC networks. 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.

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.

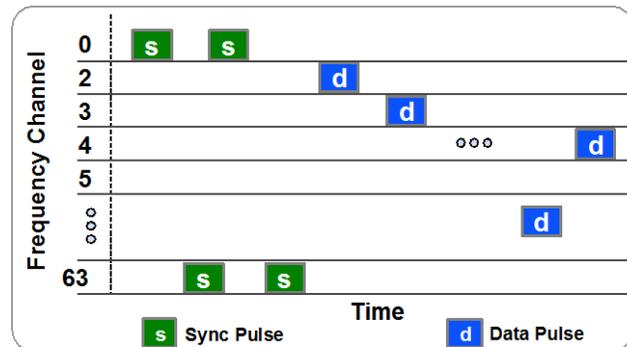


Figure 3. 5G-ATW Frame

5G-ATW Network and Media Access Control

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-bit, 2k-bit, 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 (CDIS) is used to compress the DIS protocol, more than 95% of the DIS PDUs will not need to be fragmented and the waveform will be allowed to run most efficiently.

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.

5G-ATW Network Layer Routing and Forwarding

In general, all platforms/nodes in the training range cannot hear all transmissions due to 5G-ATW wireless segment limitations such as radio transmission range, terrain obstructions, platform body blockage, and antenna gain patterns. To achieve a fully connected network, some transmissions will need to be forwarded to platforms that cannot hear a transmitter directly. The 5G-ATW network layer defines the frame forwarding (routing) and queuing disciplines necessary to provide reliable communications in the wireless domain.

In order to design an appropriate networking layer, the traffic load must be considered. For this paper we used the small, medium, and large LVC Use Cases in Table 1 to bound network size and traffic loading requirements for some simulated LVC combat training scenarios.

Table 1. LVC Use Cases – Number of Entities Sending Data

Case	Live Aircraft	Total Aircraft	Ground Movers	Ground Stationary	Radars	Identification Friend or Foe	Simultaneous Weapons	Simultaneous Chaff/Flare
Small	20	53	30	81	65	53	20	30
Medium	60	102	30	81	129	102	30	48
Large	100	199	80	141	170	199	50	75

We evaluated four primary frame forwarding models as network architecture alternatives:

- 1HOP:** This is an “ideal” wireless network transmission model where each transmitted frame reaches all receivers and no forwarding is necessary. Each frame is transmitted only once, optimizing bandwidth utilization and providing an upper bound on network performance.
- SMF:** Simplified Multicast Forwarding (SMF) (2012) is an Internet Engineering Task Force (IETF) standard routing algorithm (IETF RFC-6621) which floods data packets throughout the wireless segment of the network to assure packets reach all destinations. SMF is simple to implement, however flooding traffic grows geometrically as the network size increases. It is most suitable for small mobile ad-hoc networks where flooding is a viable alternative. SMF defines mechanisms to provide efficient duplicate packet detection to reduce the redundant traffic in the network.
- MNR:** Maximal Neighbor Routing (MNR) is an optimized version of SMF used with the Neighborhood Discovery Protocol (NHDP) (IETF 2011). NHDP is also an Internet standard protocol (IETF RFC-7466). In MNR, similar to NHDP, platforms/nodes exchange connectivity information; however MNR dynamically computes rooted relay trees which maximize the number of nodes added at each relay branch point. Subject to network discovery delays and overhead traffic, this routing strategy tries to minimize the number of airborne relays required for a transmitted frame to reach all other platforms.
- 2HOP:** This is a 5G-ATW unique routing discipline optimized for tethered LVC training scenarios. 2HOP takes advantage of attributes of the 5G-ATW radio to significantly improve performance over SMF and MNR routing/forwarding approaches. In this discipline, live airborne platforms only transmit data on unique downlink interest group channels to ground node(s). Other live airborne platforms do not listen on these interest group channels. The ground node(s) repeat the downlink data, as well as other LVC data, on special uplink data interest group channels that airborne platforms monitor. This architecture eliminates airborne relay.

While it is assumed that most of the airspace in a ground tethered training test range will be covered by the ground range radios and antennas, a Disadvantaged Platform Relay System (DPRS) augments the 2HOP strategy for platforms that cannot communicate to the ground radios directly due to terrain or transmission range issues. A feature of the DPRS algorithm is that it creates low capacity, minimum delay “Range Safety Network” routing that interconnects all platforms in the training range. This Range Safety Network can be used to reach all platforms with emergency traffic.

Note that for all 5G-ATW network/frame forwarding models, multi-access interference, platform transmitter and receiver resource limitations, and platform queueing limitations will impact network performance.

5G-ATW RADIO MODEL AND PERFORMANCE CHARACTERISTICS

A wireless network will have performance limitations due to the waveform’s design, radio implementation limitations, and the network architecture design. The waveform is highly capable, but is subject to physical layer multi-access interference and radio hardware processing limitations. Three important hardware limitations are assumed in our simulated implementation of the 5G-ATW radio. They are 1) the receiver cannot “hear” when the transmitter is transmitting data and sync pulses, 2) the receiver has a limited number of SYNC interest group patterns that it can simultaneously scan for, and 3) the receiver has a limited number of receiver frame decode processors (we call “Rx Chains”) that it can use simultaneously to receive and decode incoming data frames.

TETHERED SCENARIOS – NETWORK TESTING CONFIGURATION

Tethered Scenario Test Range Environment

To evaluate the tethered system performance of the 5G-ATW radio with various network routing and forwarding alternatives, we created a model test range 250 nm by 250 nm. Within the test range, airborne platforms fly in preconfigured orbital paths with specified length, width, turning radius, and cruising speeds. Speeds are randomized so that the aircraft do not fly in synchronized orbits. For this work, we fly large body platforms at speeds of 250–350 nm/hour with turning radius of 8–16 nm and we fly fighter aircraft at 400–500 nm/hour with turning radius of 2–4 nm. Platforms are modeled to have two types of packet traffic – DIS packet traffic and random broadcast background packet traffic. All packets are modeled as being coded into a single 5G-ATW frame.

Engineering Test Cases

Our engineering test cases explore 5G-ATW performance with random background traffic only. DIS applications are disabled. We evaluated network performance for 10–100 live aircraft with average background traffic rates of 1–5 frames/second/platform. Inter-arrival time between background transmission frames is a uniform random variable.

A sample map of one simulated tethered scenario for 40 live aircraft platforms is illustrated in Figure 4. Platform orbits are randomly located in the 250 nm \times 250 nm training range with a RCN in the lower left corner of the range. LVC traffic enters the 5G-ATW network at the RCN. Sample flight orbits include 30 nm \times 30 nm “square” routes, 30 nm \times 20 nm elliptical orbits, and 10 nm circular orbits. We modeled both the RCN and airborne 5G-ATW radios to have a transmission range of 85 nm. This means that a 5G-ATW radio will at most cover about 35% of the test range. Packet/frame routing and forwarding is necessary for full radio coverage of the test range.

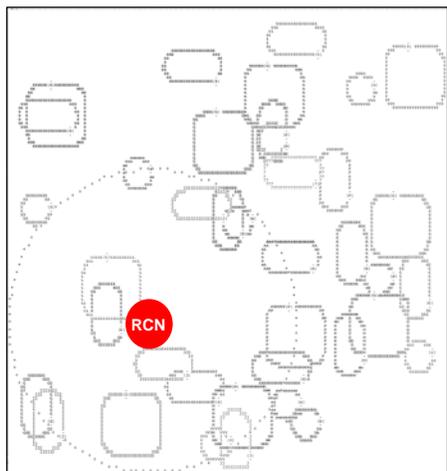


Figure 4. Sample 40 Platform Scenario

In evaluating the 5G-ATW performance, we focus on a metric we call the “Delivery Ratio.” The delivery ratio is the fraction of transmitted packets from platform “A” destined to platform “B” that are received and decoded successfully. Given that the training mission will involve multiple security domains, transmitted packets arrive at other platforms subject to “cross domain solution” (CDS) security filtering. We do not explicitly simulate the CDS in this work.

1HOP Results

The network performance results for a 1HOP 5G-ATW simulation study of 10 to 100 airborne platforms with traffic loads of 1–5 fps/platform are presented in Figures 5 through 7. The CDS must be implemented at each platform. Our simulation model for the 5G-ATW Forward Error Correction (FEC) code is that correct reception of 12 out of 16 transmitted data pulses are needed for correct reception of a frame. Emulation work at MIT LL has found this to be a good estimate for the 872 bit 5G-ATW frame.

In Figure 5 we plot a comparison of an analytical model of receiver performance (solid lines) versus the results of our simulation (dashed lines) for a platform that is receiving only. What we observe is multi-access interference. The agreement between simulation and analysis is quite good. Multi-access interference is small and at network loads of up to 500 fps over 99.7% of the frames can be received

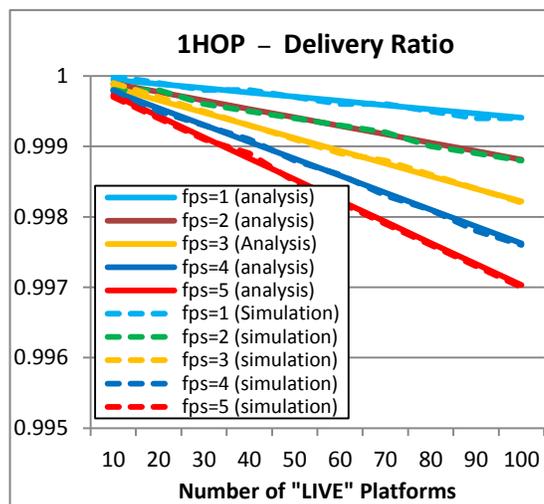


Figure 5. Delivery Ratio of Successful 1HOP Frames while Receiving Only

In Figure 6 we plot the same comparison when a platform is transmitting while trying to receive. The probability of successful reception is primarily impacted by the platform’s own transmitter load and not multi-access interference. This is due to the current limitation that the 5G-ATW radio cannot “hear” during the time it is transmitting.

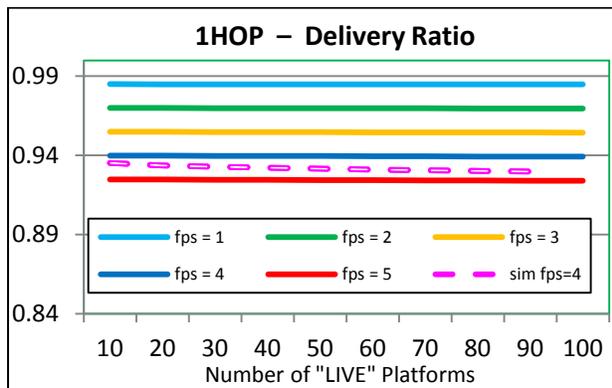


Figure 6. Delivery Ratio of Successful 1HOP Frames while Transmitting

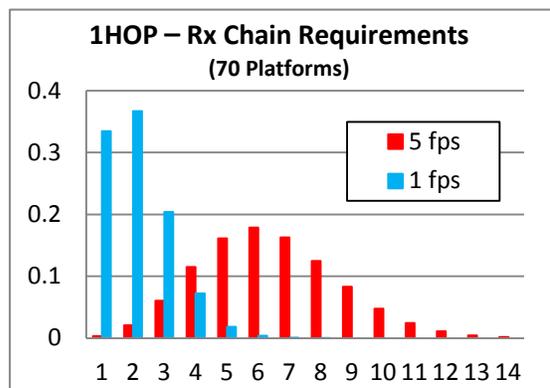


Figure 7. PDF of Number of Simultaneous 1HOP

The number of decode processing resources available to receive simultaneous incoming frames is an important 5G-ATW radio design parameter. Figure 7 shows the number of receiver decoding resources (“Rx chains”) needed to receive the incoming frames in a 70-platform 1HOP network with platform transmission rates of both 1 and 5 fps.

At 5 fps, nine Rx Chains are required to process 90% of the incoming frames, while 12 Rx Chains would be required to process 99% of the incoming frames; note that even with 14 Rx chains, not all frames will be received successfully. Multi-access interference and data and sync pulse collisions with the local transmitter pulses (called “TxRx self-interference”) will cause some frames not to be successfully decoded.

Simplified Multicast Forwarding (SMF) Results

In Figures 8 and 9 we present the network performance results for the 5G-ATW network using the SMF forwarding algorithm. With SMF, every unique received frame is retransmitted at every node. At 5 fps and 100 nodes, the total traffic in the network could exceed 49,000 fps with each platform having to forward as much as 495 fps. This implies that a transmitter would need to be able to send at least 10 simultaneous frames in a 20 msec period.

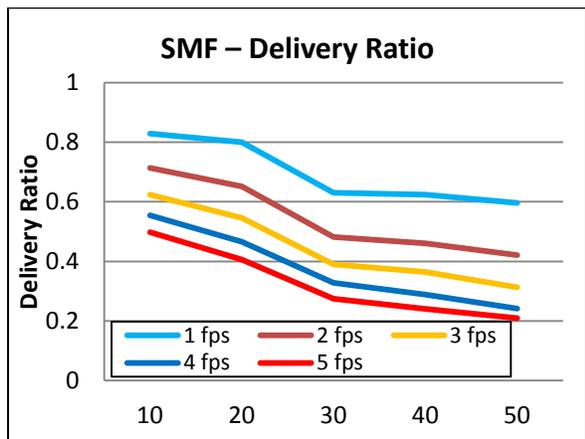


Figure 8. Delivery Ratio of Successful Rx Frames

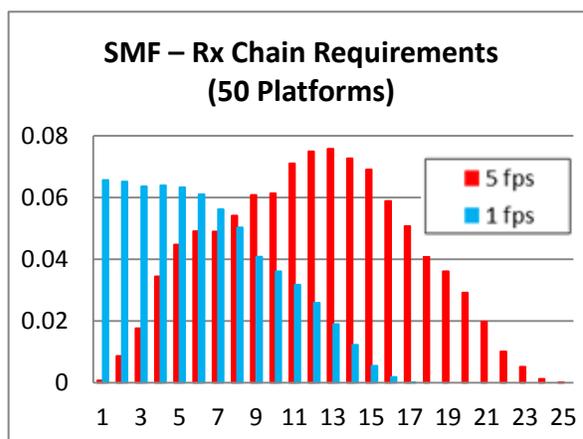


Figure 9. Delivery Ratio of Successful Rx Frames

One result we see is that the high SMF transmitter load interferes with much of the incoming traffic due to TxRx self-interference. Most packets are not received successfully. Therefore, the platform's transmitter does not need to forward many frames. An equilibrium seems to occur where fewer successful incoming packets leads to lower transmitter loads, which leads to more successful incoming packets. While many packets are blocked, the high packet redundancy in the SMF flooding approach yields higher network delivery ratios than expected. However, packets with multiple hops are significantly disadvantaged. In Figure 9 we see that at least 19 Rx Chains are needed in a 50 platform scenario for a 90% delivery ratio. The required number of Rx Chains grows as the square of the number of platforms in the network. It may be difficult to build such a radio if the SMF strategy is used.

Maximal Neighbor Routing (MNR) Results

One way to address SMF traffic flooding overload is to use a "structured" routing approach where the topology of the network is factored into the routing. IETF NHDP (RFC-6130) is an example of a structured routing approach. We developed a variant of NHDP, which we call MNR, where the topology of the airborne network is used to build dynamic forwarding trees that try to minimize frame-forwarding transmissions. In Figures 10 and 11 we show the performance results for our test scenario using MNR. The delivery ratio has some of the characteristics of the 1HOP strategy in that it seems independent of fps load; however, while the throughput is lower than 1HOP, it is better than SMF for high loads. The 5 fps MNR Rx Chain requirements are significantly lower than those required for SMF, with only 10 Rx Chains needed to receive 90+% of the incoming frames for a 50 platform scenario.

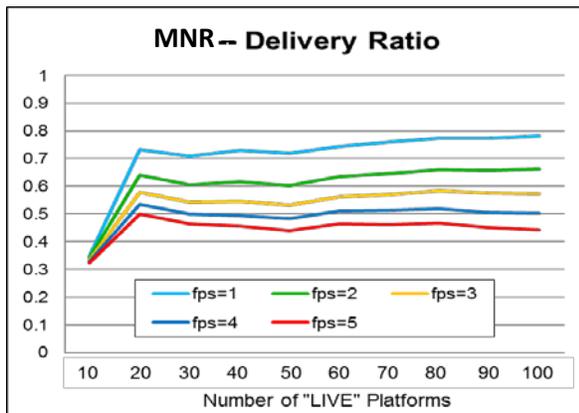


Figure 10. Delivery Ratio of Successful Rx Frames

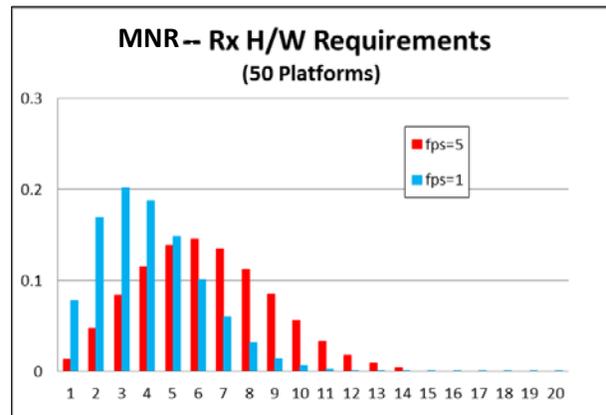


Figure 11. PDF of Number of Simultaneous Rx Frames

We believe the primary difference in performance between the MNR algorithms and the 1HOP routing is that the 5G-ATW airborne relay transmitters get congested as traffic loads increase. We developed the 2HOP architecture to mitigate this problem.

2HOP Results

The 2HOP architecture is intended to exploit the resources, broad coverage, and traffic asymmetry of the ground network and is specifically proposed for the tethered scenario. In the 2HOP architecture the goal is to minimize or eliminate airborne relay traffic. This is achieved by sending all traffic from air platforms on a "downlink" interest group to the RCN. At the RCN the CDS is applied to the downlink traffic and downlink traffic is then merged with local LVC traffic. The combined traffic is then sent on an "uplink" interest group to the airborne platforms, as well as delivered to the other LVC platforms. Airborne platforms only listen to the uplink interest group.

In our test scenarios, the test range is intentionally large compared to the 5G-ATW radio's transmission range. For 2HOP to be efficient, the RCN will need to have multiple antennas in the test range so that most airborne platforms will have an uplink and downlink connection to the RCN. The training range is modeled as having a local area ground network to be able to interconnect multiple test range antennas to the RCN. When a platform flies into an area not covered by the multiple antennas, we say that the platform is "disadvantaged," and it executes a special DPRS algorithm to remain connected to the 2HOP network. We discuss the DPRS in a later section.

A notional test range radio coverage map is illustrated in Figure 12 and the performance of the 2HOP architecture is presented in Figure 13.

Because the RCN is forwarding the combined LVC traffic on the uplink, it needs to have more capacity than transmitting a single frame every 20 msec. We model the RCN as having multiple transmit capability. To minimize airborne Rx Chain requirements, we schedule the RCN transmitters to space out the uplink frames evenly. A “gear shifting” algorithm is used to dynamically activate as many uplink transmitters as necessary to keep the average uplink queue size below a configured parameter, currently set at 70 milliseconds.

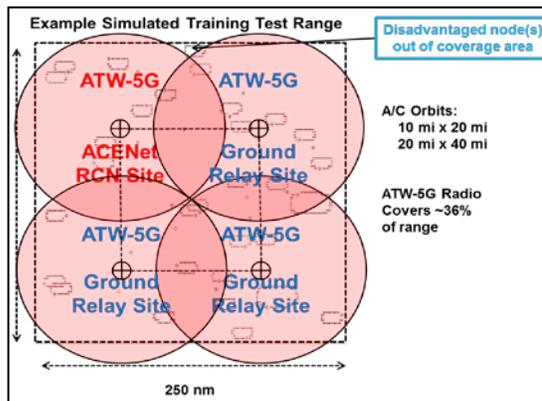


Figure 12. Sample Multi-Antenna Training Test Range

In Figure 13 we see that 2HOP performance is almost the same as the ideal 1HOP performance, even though every downlink frame is sent twice because it is relayed on the uplink interest group “channel” by the RCN. By implementing a coordinated “gear shifting” uplink transmitter, we also see in Figure 13 that reduced numbers of Rx Chains are needed on the airborne platform’s 5G-ATW radio.

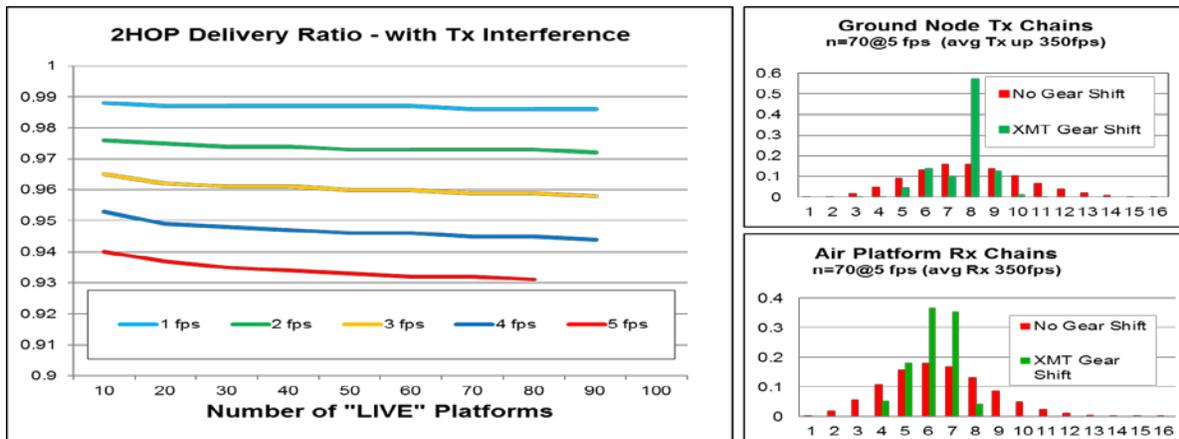


Figure 13. 2HOP Simulated Performance

Disadvantaged Platform Relay System (DPRS) Algorithm

A concern in the LVC training mission is the potential loss of connectivity to the RCN by live airborne platforms.

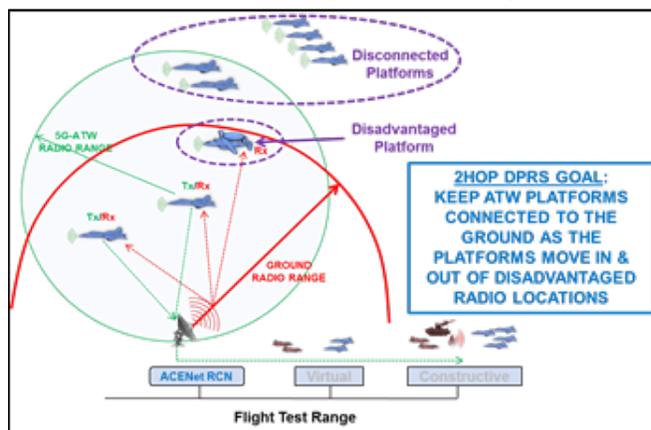


Figure 14. DPRS 2HOP Scenario

Such a loss might cause a virtual or constructive element in the training scenario to disappear from the live platform’s mission screens. Loss of connectivity might be due to terrain blockage, radio range limitations, or other impairments. The MNR and SMF algorithms may be able to maintain available connectivity, but at a cost to overall system performance due to airborne routing and forwarding overhead.

We propose augmenting the 2HOP architecture with a DPRS algorithm, which only operates when a platform’s uplink or downlink loses connectivity to the RCN. Figure 14 shows a DPRS scenario.

A crucial design parameter for this protocol is the need to address the highly asymmetric traffic flow in the tethered environment where large traffic volume is transmitted by the RCN and a much smaller volume by the air nodes. Selecting a single relay platform is insufficient because a single airborne cannot relay all of the virtual and constructive traffic transmitted by the RCN. When a platform discovers that its uplink is lost, it broadcasts a help request message. A platform that hears this help request and 1) is connected to the RCN uplink, and 2) has the resources to help, responds to the request. The disadvantaged platform then notifies all those responding to relay a fraction of the uplink traffic to the disadvantaged node. By splitting the uplink traffic among a number of helpers, each uplink helper’s traffic load is reduced, conserving transmit resources at the helper. Because the RCN uplink carries the most traffic in the system, uplink helper nodes may be unable to forward all the uplink traffic requested by the disadvantaged platform. In that case it discards low priority traffic it cannot handle. The downlink case is handled similarly but only a single relay platform is chosen because there is less downlink traffic to relay.

The DPRS algorithm needs to be dynamic and responsive because airborne platforms may fly in and out of coverage locations rapidly and may fly out of range of helper nodes unexpectedly. The algorithm uses timers to detect loss of RCN connectivity and to disconnect from the DPRS system. The timeouts in the currently implemented algorithm are set to 3–5 seconds for uplink and downlink DPRS algorithms. Simulations showed that uplink and downlink DPRS recovery generally occurred within 2–3 seconds of detecting loss of connectivity.

DIS Application Test Cases

The engineering test cases discussed previously were compared based upon the performance measures of Delivery Ratio and TxRx resource requirements. To evaluate the “effectiveness” of the alternative network architecture and frame forwarding strategies, we modeled a simplified small Advanced Technology Demonstration (ATD) training scenario. We simulated 20 airborne platforms and 33 constructive airborne platforms, along with an additional 279 other Virtual and Constructive entities according to Table 1 in a 250 nm × 250 nm training test range. In all, 332 ATD entities were simulated. The traffic loads for each of the entities were set according to an ATD DIS Bandwidth Analysis Report dated November 25, 2013. We simulated DIS traffic at both the average platform packet generation rate and at the worst case platform packet generation rate. For this simulation, the RCN was modeled to have 20 gear shifting transmitters and a 20 Rx Chain receiver. Each airborne platform was modeled to have a single transmitter and a 10 Rx Chain receiver.

The simulated DIS process generated position and velocity dead-reckoning updates at a minimum rate of once per 5 seconds for fast moving platforms and once per 55 seconds for other platforms. In addition, the platform maintained a local “predicted” position and velocity based upon its last DIS dead-reckoning update transmission. If the local “predicted” position and the actual position differed by more than 1 meter, the DIS algorithm would transmit a new dead-reckoning update. The simulator kept track of three effectiveness measures:

- 1) Avg situational awareness (SA) Error: This is the average error of the local dead-reckoning estimate for all other platform positions, based on received DIS update messages and the actual positions of those platforms.
- 2) RMS SA Error: This is the RMS error of the local dead-reckoning estimate for all other platform positions, based upon received DIS update messages and the actual position of those platforms.
- 3) Avg % Available: This is average percent of time that each platform is known to each other platform. This statistic is based upon a platform receiving a DIS message from other platforms within the last 12 seconds for fast movers and 200 seconds for others. If a platform becomes “unavailable” in the simulation due to distance or some other reason, SA position error measurements are suspended.

The results of the DIS runs are shown in Figure 15. The RCN LVC traffic from the 279 Virtual and Constructive entities varies from 157 fps to 480 fps. Both the 1HOP and 2HOP/DPRS strategies keep the platforms 100% connected and average SA errors below 1 meter. With the SMF and MNR strategies, platforms lose connectivity 4% and 13% of the time, respectively. However, this result is with only one RCN antenna. Further work is needed to clarify how these strategies would work in the multi-antenna case.

AVG DIS B/W* (ATD Gnd Tx (~157 fps) @ DR Threshold 1 M) MAX DIS B/W* (ATD Gnd Tx (~480 fps) @ DR Threshold 1 M)					
ATD	Link	Network	SA	SA	SA
	Delivery Ratio	Delivery Ratio	Avg. SA Error (M)	RMS SA Error (M)	Avg. % Available
1HOP	0.99 / 0.96	1.0 / 0.99	0.2 / 0.3	0.8 / 3	100% / 100%
SMF	0.41 / 0.40	0.76 / 0.74	0.8 / 9.0	4.2 / 83	96% / 97%
MNR	0.89 / 0.84	0.83 / 0.79	4.9 / 42	29 / 301	88% / 87%
2HOP	0.98 / 0.99	1.0 / 0.99	0.2 / 0.3	0.6 / 1.4	100% / 100%

Figure 15. ATD DIS Effectiveness Metrics

UNTETHERED SCENARIO – NETWORK TESTING CONFIGURATION

We conducted a brief engineering study of an untethered test training scenario illustrated in Figure 16. We simulated this scenario to compare untethered 1HOP, SMF, and MNR routing/forwarding strategies. This “4v4 Fly-By” scenario is representative of a typical small unit training event.

The 5G-ATW radio is assumed to have one transmitter with a 65 nm transmission range, 10 Rx hardware Chains, and unlimited sync correlators. These parameters are not representative of a particular radio, but rather were chosen to create the interesting and stressful network cases for our study.

In this engineering test scenario, four live Blue fighters and four live Red fighters are in 75 nm long elliptical orbits whose centers are 90 nm apart. With the positions, as shown in the Figure 16, which are at the midpoint of the orbits, the Red and Blue radios are out of radio range of each other. While the whole training network is disconnected because of radio range limitations, the Blue and Red fighters groups remain connected. As the Red and Blue fighters fly within 65 nm of each other, all the live platforms become reconnected. When the lead Red and Blue fighters are within 30 nm of each other they lose contact with their Red and Blue counterparts at the far parts of their orbits. This engineering test scenario has the 5G-ATW network changing connectivity and routing dynamically as the platforms fly their orbits at 425 nm/hr.

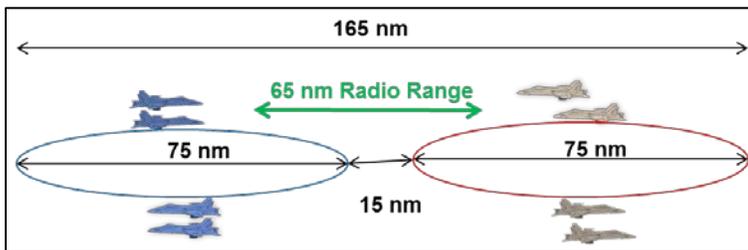


Figure 16. Untethered Scenario

We define 5G-ATW network connectivity as the average percent of the time a platform’s 5G-ATW radio can reach every other platform’s 5G-ATW radio. Based upon this scenario’s flight paths and the 5G-ATW radio’s transmission range, the network connectivity can be calculated to be 58%. This means that over time at most 58% the DIS packets could reach their intended destination. We define a “normalized delivery ratio” as the fraction of packets that reach their intended destination divided by the maximum number of packets that could reach their intended destination given network topology, radio range, and line-of-sight limitations. In the current scenario, if 58% of the packets reach their destination then the “normalized delivery ratio” would be one (1.0).

We simulated the above untethered scenario with each live platform transmitting from 1 to 10 fps, with and without TxRx self-interference. Figure 17 shows the normalized deliver ratios for 1HOP, SMF, and MNR relay strategies. Results are also shown for the case where platforms do not relay any frames. We note that the platform’s normalized delivery ratio is impacted by its own transmission rate.

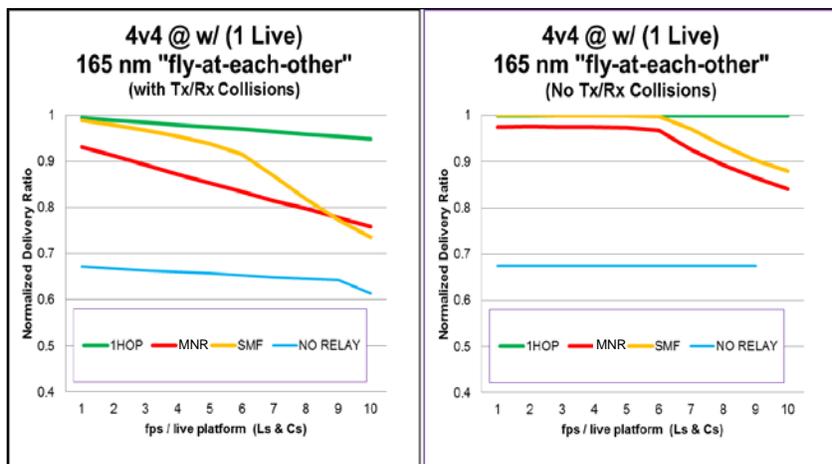


Figure 17. 4L v 4L Live Fly-By Normalized Delivery Ratios

In Figure 17 when there is no TxRx self-interference, we see that at 7 fps the delivery ratio takes a significant down turn. This is due to congestion at the relay platform(s). The 5G-ATW transmitter sends at 50 fps. With eight platforms there is a point in the simulation where one platform needs to relay all the traffic from the other seven platforms. At 7+ fps the relay node is overloaded and traffic begins to be lost. A single 5G-ATW transmitter cannot handle the simple 4L v 4L scenario.

We look at the same scenario in Figure 18 where each live platform is now also simulating four constructive entities.

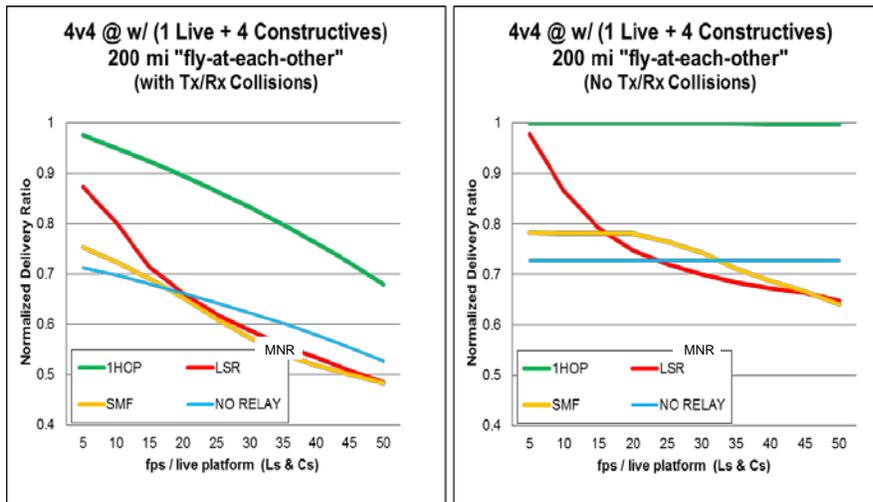


Figure 18. 4(L+4C) v 4(L+4C) Live Fly-By Normalized Delivery Ratios

We model each entity, live and constructive, as generating traffic at 1–10 fps. Therefore, each live platform will have a transmission rate of 5–50 fps.

We see the dramatic impact of adding constructive entities to live platforms. The relay strategies, SMF and MNR, as well as 1HOP, degrade dramatically due to transmitter overload and TxRx self-interference. Eliminating TxRx self-interference does not eliminate the impact of limited transmitter and Rx Chain resources.

Some strategy to mitigate these impacts will be required to support larger untethered training scenarios that require relay to keep the training scenario connected.

SUMMARY & CONCLUSIONS

We examine alternative approaches to the 5G-ATW network routing and forwarding for both tethered (using range support) and untethered (without range support) configurations for the wireless network architecture for LVC training in the tactical airborne environment.

We presented network modeling comparisons, considered security architecture implications, and made recommendations for 2HOP with a DPRS network architecture for a tethered LVC tactical airborne training system. We further explored simple untethered training scenarios and found that the current network routing and forwarding solutions do not appear to work well for the 5G-ATW radio we modeled and the simple scenario we explored.

To successfully support the untethered training environment for moderate traffic loads, two key technical issues need to be addressed in the 5G-ATW radio implementation. They are:

- 1) Mitigating TxRx self-interference, and
- 2) Implementing transmit capacity greater than one frame per 20 msec.

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