Bridging Live and Virtual Radios Without Specialized Cross-Domain Solutions

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ABSTRACT

Since defense budgets continue to decrease there has been a strong need to maintain or increase the effectiveness of training, while reducing costs. One way to accomplish this is to combine the strengths of live training with the advantages of distributed virtual and constructive simulation based training. The foundation for this requires good tactical radio communications between live and virtual operators. Current technologies on the market make it possible for live and virtual radios to interoperate. These products need additional cross domain solutions (CDS) and security accreditations which are often difficult to obtain. The Pacific Air Force (PACAF) and the Joint Pacific Alaska Range Complex (JPARC) use a Live Virtual and Constructive (LVC) tactical radio communications solution which only requires a single CDS solution over a distributed network such as the Combat Air Force Distributed Mission Operations (CAF DMO) Distributed Mission Operations Network (DMON).

This paper describes solutions developed for PACAF to provide radio communications interoperability between simulated radios of an AWACS simulator located at Elmendorf Air Force Base and live radios located at the JPARC in a manner which does not require additional single purpose CDS devices. To achieve this, live radio communications are required to pass through the JPARC CDS. Since live radios, the CDS, and virtual radios all have different protocol interfaces, interoperability between these three different protocols is necessary: DIS for simulated radios at the AWACS simulator, TENA for the JPARC CDS, and SIP for live JPARC radios. The need described enabled us to bridge telephony and simulation domains as well as establish a new virtual radio object model in TENA. This paper will describe interoperability considerations between SIP, TENA, and DIS protocols, differing assumptions in the telecommunications and simulation worlds which provide unique implementation challenges, and the security challenges in adding additional single purpose CDS devices to live range architectures.

ABOUT THE AUTHORS

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Cindy Walker is a Lead Cyber Engineer for Air Force and Range programs. She has 25 years of experience in Information Assurance within the Department of Defense and Special Access Program arenas . Cindy is one of the original team members that developed the Distributed Mission Operations Network to include working with the Multi-Level Security Cross Domain Solution utilized for CAF DMO warfighter training. She currently provides guidance and direction with certification and accreditation requirements for connectivity of varies U.S. and coalition military/contractor systems and networks.

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INTRODUCTION

Tight defense budgets have accelerated the need to maintain or increase the effectiveness of training, while reducing costs. A new developed capability combining the strengths of live training with the advantages of distributed virtual and constructive simulation based training seems to be a solution to do just that. The foundation for this is having good tactical radio communications between live and virtual operators. Current technologies on the market make it possible for live and virtual radios to interoperate. These products require additional cross domain solutions (CDS) with security certifications and accreditations which are often difficult to obtain and maintain. Cross Domain Solutions require annual review and sometimes recertification due to new developments in technology and environmental threats. Modifications in system configuration management require thorough review for security relevant and non-relevant changes. The Pacific Air Force (PACAF) and the Joint Pacific Alaska Range Complex (JPARC) require a Live Virtual and Constructive (LVC) tactical radio communications solution. This solution would enable live ranges such as JPARC the ability for connections to distributed networks such as the Combat Air Force Distributed Mission Operations (CAF DMO) Distributed Mission Operations Network (DMON) and Joint Training and Experimentation Network (JTEN).

Marsden [1] et al. describe the unique solution implemented at the JPARC to integrate the CAF DMO Airborne Warning and Control System (AWACS) Mission Training Center (MTC) into live training events such as Red Flag Alaska (RF-A) and Northern Edge. Though there are three primary actions performed by the warfighter, i.e. move, shoot, and communicate, Marsden [1] primarily focused on the challenges of the movement or position of live aircraft in a virtual/constructive environment. The primary focus of this paper is on the radio communications between the same live and virtual participants and the associated security certification and accreditation challenges.

Live range architectures often place radios at a lower classification level than most other range data while distributed virtual radios most often operate at the same classification level as the Mission Training Center (MTC). This fact requires a CDS solution to be placed between live and virtual radios. Live range architectures utilize CDS solutions to separate different live range classification levels of data. These solutions are specific to the needs of the range. In the case of JPARC, with its native TENA interface, utilizes SimShield as their CDS device. In order to avoid the addition of another CDS solution for tactical radio communications and their associated costs and time, a solution that allows bridging of live and virtual radios in a native TENA format needed to be developed. This solution required the bridging of three separate protocols: DIS for simulated radios at the AWACS simulator, TENA for the JPARC CDS, and SIP/RTP for live JPARC radios. In order to develop this solution, it was necessary to bridge telephony and simulation domains as well as established a new virtual radio object model in TENA. This paper will describe our experience and solutions for interoperability considerations between SIP, TENA, and DIS protocols as well as the differing assumptions in the telecommunications and simulation worlds which provide unique implementation challenges.

BACKGROUND

JPARC/PACAF

The JPARC with its 67000 square miles of airspace and instrumentation is the USAFs premier live training range. JPARC instrumentation consist of range radars, aircraft training pods, manned and unmanned Electronic Warfare (EW) threats, Surface to Air Missiles (SAMs), Anti-Aircraft Artillery (AAA), “smokey SAM launches”, high-fidelity target arrays, and radio/DataLink communications.

Red Flag Alaska

RED FLAG-Alaska (RF-A) is a Pacific Air Forces-sponsored, Joint National Training Capability accredited exercise. Red Flag Alaska was initiated in 1976 as COPE THUNDER in order to give aircrews their first taste of warfare and increase their chances of survival in combat environments. RF-A executes the world's premier tactical joint and coalition air combat exercise designed to provide or replicate the stress a warfighter might face during their first ten combat missions.

RF-A participants are organized into coalition "blue" , aggressor "red", neutral "white" forces. The blue force includes the full variety of U.S. and coalition tactical and support units. The force includes air-to-air fighters, surface air defense forces simulating threats from potentially hostile nations. These red forces employ defensive counter-air tactics directed by ground-control intercept sites. Range threat emitters simulate SAM and Anti-Aircraft Artillery (AAA) providing valuable surface-to-air training.

JPARC LVC

PACAF and JPARC's approach to achieve an LVC training capability is to integrate JPARC's TENA-based architecture with CAF DMO's standards-based architecture. The choice to fuse the JPARC's architecture with a standards-based architecture provides an environment that is conducive for developing a repeatable LVC training environment.

The first CAF DMO system to be integrated into the JPARC was Command and Control (C2) platforms such as AWACS. Marsden [1] et al. describes the integration challenges that have been faced with the integration of virtual AWACS trainers and live JPARC aircraft with respect to Time Space Position Information (TSPI), radar, and Joint Tactical Distribution System (JTIDS) Link-16. The integration of virtual C2 platforms also introduces the challenge to provide bi-directional radio communications between pilots in live and virtual aircraft. This requirement is critical for C2 platforms to perform their role during training.

CAF DMO

CAF DMO is a program which has revolutionized training for the United States Air Force (USAF). Its purpose is to provide training to USAF warfighters in a variety of team combat skills. This training is accomplished through daily use of MTCs and their high-fidelity, man-in-the-loop, virtual pilot trainers. These training centers utilize training aides such as Computer Generated Forces, threat and instructor stations, and brief/de-brief systems to achieve the required training environment.

These geographically separated CAF DMO MTCs provide both intra-team and inter-team composite force training for warfighters. This provides the warfighter the ability to train as team and enhance individual skill proficiencies. The main objective is to train them on mission essential competencies required for combat readiness. This paper describes recent development toward the integration of the JPARC TENA architecture, Live Simulations Communications Interface (LSCI), DMO Portal, and live and virtual radios.

Marsden [1] et al. describes the interoperability challenges between CAF DMO MTCs and live ranges such as JPARC which utilize a native TENA architecture. He describes the CAF DMO standards based architecture approach as a JPARC and DMON interoperability solution. This paper builds on that principle and extends the CAF DMO standards approach to solve live and virtual radio interoperability while also eliminating the need for Cross Domain Solutions (CDS) just for radios.

LVC Radios

There are many products on the market that convert live analog radio to DIS. The gateway chosen for early AWACS integration was the Government Furnished Equipment (GFE) Virtual Tactical Bridge (VTB). The VTB is a Marine Digital Voice (MDV) based application which has been experimentally used at JPARC in exercises such as Northern Edge 2008. In this exercise two live radio frequencies were translated to the virtual domain allowing virtual C2 platforms to communicate with live fighter surface strike aircraft. The JPARC is a native TENA interface with a native TENA CDS device. The VTB is considered a CDS and as such is subject to certifications and accreditation challenges. The VTB CDS and its DIS interface introduced an additional CDS device into the JPARC Architecture. During Northern Edge 2008 and 2011 approvals to operate were obtained, though only during

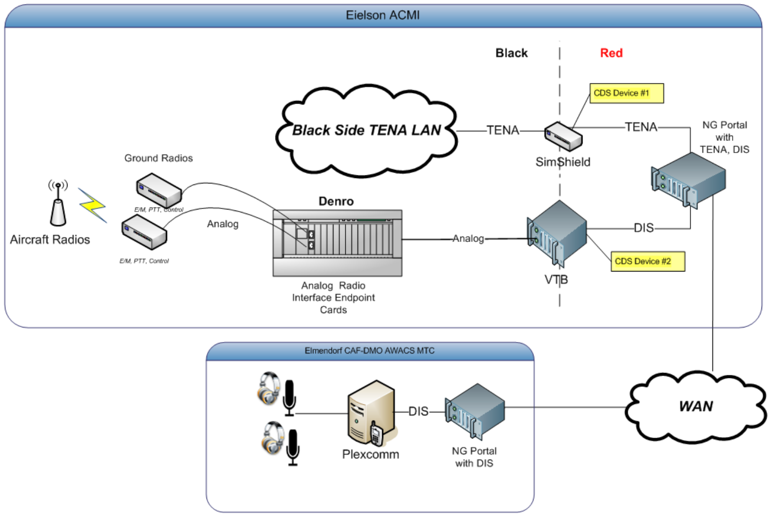

Figure 1. Two CDS Solution

the exercise. Due to the success of the VTB at Northern Edge 2008 the VTB was permanently installed at the JPARC for future LVC exercises.

Though the VTB was permanently installed at the JPARC, security accreditation challenges were encountered and thus a TENA based solution needed to be explored. The resulting TENA based solution is the Northrop Grumman LSCI system. This paper discusses in detail this new solution and its range security certification and accreditation advantages.

Virtual Radios

CAF DMO MTCs and similar distributed simulation sites do not utilize live radios. Instead they employ simulated radios. These radios allow distributed users to communicate just as if they were using live radios. This is accomplished by transmitting the radios characteristics and audio data over IP networks using simulation protocols such as DIS and HLA. Virtual radio operation is done in a standards driven approach. The DIS standard defines the process by which a virtual radio shall send its radio characteristics and audio data over the simulation network. The DIS standard requires that a virtual radio shall send a Transmitter PDU describing characteristics of the radio, such as center frequency and average power, prior to sending audio voice data. This initial Transmitter PDU shall also indicate the state of the transmission. This state is set to “transmitting” prior to the initial transmission. Once the initial Transmitter PDU has been sent, the audio voice data should be sent by way of a Signal PDU. The Signal PDU shall contain the audio voice data and its characteristics, such as encoding type and sample rate. Once the radio is finished sending voice data, the virtual radio shall send a terminating Transmitter PDU with a transmit state set to “not transmitting”.

Like live radios, virtual radios will only make audible voice stream from a source that matches the current settings of the radio. These settings range from frequency, modulation, crypto, etc. If a virtual radio receives Transmitter values that match its current settings the virtual radio will process the Transmitters associated incoming Signal PDUs and make the incoming audio voice audible for the user. If a virtual radio is modeling line of sight then the transmitting and receiving radios location will also aid in determining if the incoming Signal PDUs should be processed. If the settings do not match the Transmitters associated received Signal PDUs will be ignored and the audio will not be audible.

Radio Communications in TENA

Unlike DIS and HLA, TENA did not have a Stateful Data Object or message to transport radio communications. The TENA community is made up of live range users who can communicate with live radios. This fact needed to be addressed and required the guidance of the TENA SDA and collaboration with the TENA community.

JPARC Live Radios

The integration of simulated radios into the JPARCs live architecture occurred in two phases. The first phase made use of the analog Denro radio and the MDV based VTB. These Denro radios required a 4 wire analog connection made at the Denro punch down blocks to allow the VTB to communicate to the JPARC range radios.

The second phase of integration of simulated radios made use of the upgraded Voice over Internet Protocol (VoIP) Denro radios called the Denro Nodal Switch. Our integration with the Denro Nodal Switch no longer relied on the VTB or analog connections. The Denro Nodal Switch, can utilize standard SIP and RTP protocols to communicate the audio voice data over the JPARCs IP network. This second integration phase led to the development of a new device called the LSCI which takes advantage of the standard SIP and RTP interface and communicates directly to the JPARC range radios.

This second integration would place the LSCI on the unclassified side of the JPARC network and does not touch the classified side. The device obtains approval to operate as equipment under the overarching approval of the JPARC unclassified network. It does not require a separate approval to operate as a cross domain device would. This simplifies the Certification and Accreditation (C&A) process. Now, instead of requiring separate approval for two devices, the requirement shifts to only one.

The following paragraph describes the C&A process, its purpose, approving authorities, and challenges.

CERTIFICATION & ACCREDITATION(C&A) PROCESS FOR CROSS DOMAIN SOLUTION

C&A is performed on every information system utilized to process classified information. Threats and vulnerabilities can cause harm to systems and users, which ultimately creates risk. Unfortunately, some risk is always present. Since risk can't be eliminated entirely, it must be cost effectively mitigated to protect lives and missions. Certification and accreditation is the process of evaluating technical and non-technical features of an information system and its environment. The Designated Approving Authority (DAA) then reviews that evaluation and supporting factors to make a determination if the risk has been mitigated as much as possible. The mitigation must also be acceptable and not cause further risk for accomplishing the mission in the identified environment.

Roles, Activities and Documents

C&A involves multiple players with defined roles that are responsible to produce and implement the best result. The DAA is just one of those roles. The DAA grants approval to use systems prior to operation and accepts all residual risk upon granting approval to operate.

C&A requires multiple documents that are geared toward the audience that will be involved with maintaining and accepting the system operation and risk throughout its life-cycle. These documents will provide a current snapshot and are modified, as necessary, when the system or its environment changes.

Activities involved in C&A include Certification, Accreditation, Re-certification and Re-accreditation.

Process and Approach

The DOD, IC and Civilian government have each developed an approach for their community.

For this paper, we will be discussing the DOD – SABI/CDS. The Secret and Below Interoperability (SABI) CDS process involves three organizations: The National Security Agency (NSA), the Cross Domain Technical Advisory Board (CDTAB), and the Defense IA/Security Accreditation Working Group (DSAWG). NSA personnel perform lab-based Certification, Testing and Evaluation (CT&E) of CDS products. The CDTAB is a board that provides a recommendation to the DSAWG and the DSAWG makes the final decision to approve/disapprove operation of the CDS at a site location.

CROSS DOMAIN SOLUTIONS AND CHALLENGES

When requesting from the DAA an approval to connect systems or networks and Cross Domain Solutions the requestor is most often confronted with multiple DAAs. Hence, more than likely a Memorandum of Agreement (MOA) between DAAs may be required. This is an agreement for accepting residual risk when all the systems/networks/devices are connected and operational. The coordination behind obtaining all the signatures required on this documentation can be a long process. Most DAAs are extremely busy, travel frequently and are ultimately responsible for many systems/networks/devices in multiple locations.

Cross domain ATO's are usually granted for a period of one year. At the end of this year, they need to be submitted to the same appropriate approval authorities for re-accreditation. DAA's often change and although the system may have been approved previously under one DAA, the incoming DAA may not feel comfortable with accepting the previous DAA's approval. A CDS that may have been approved for operation is suddenly facing long delays and networks are non-operational awaiting recertification. This may occur even if no security relevant changes have happened since the last DAA approval. This can cause extreme frustration to the organization requesting approval and all of the network users. Since this re-certification occurs every year, it may take a year to complete that re-certificaton process, limiting network connectivity to every other year at best.

Security Relevant and Non-Relevant Changes

Since all information systems are continually evolving, there are changes that are required to be made to hardware, software and configuration for the system to maintain its mission. Technology is moving at a rapid pace and it is necessary to be better, faster, and cheaper in order to be successful in business. When these changes are made to an information system they could possibly affect the security integrity of the system and produce more risk than what could be determined by the DAA as acceptable. Therefore, the system owners are responsible to report and assist with the determination if there are security relevant or security non-relevant changes. These determinations are usually done through a Configuration Control Board (CCB) or Configuration Review Board (CRB). Members of these boards are Information Assurance Professionals (IAO/IAM), CA, PM, SME's, Software Developers, Engineers etc. If there is any doubt whether the change is security relevant and/or the risk is acceptable, the highest DAA authority will make the decision. It may become necessary as determined by the DAA to conduct recertification of the system with the new changes. It may also be necessary to re-accredit the system based on changes. Coordination, concurrence, recertification and reaccreditation for maintaining a system C&A, require time. During these periods of uncertainty when changes may need to take place, the system is no longer approved to operate until all parties are in agreement and the DAA has concurred with the system's ability to operate within acceptable risk limitations. This means the system is non-operational during this process.

Multiple Cross Domain Solution Challenges Magnified

When dealing with multiple cross domain solutions, each of these devices may experience any of the challenges previously discussed.. . For example, some of our challenges in the past have been that CDS "A" may be in the process of recertification for a version change which could mean possible security relevant changes. During this time, that device is non-operational until all parties have determined a resolution. Once the approval is received then CDS "B" may be expired and require it's annual recertification. This means this device is non-operational and so on and so forth.. Before long, your ability to keep multiple cross domain solutions operational is shortened tremendously and you become non-operational more than you are operational.

SOLUTION

Live Simulation Communications Interface

The Live Simulations Communications Interface solution not only required the translation of live SIP and RTP radio data into a format that is compatible with simulated DIS and HLA radios, it also required to turn simulated radio communications into a format that is suitable for live radios. Compared to a DIS to HLA gateway, this was not a simple translation. This requires bridging the gap between the requirements of communicating to live radios, telephony SIP/RTP protocols and TENA, DIS, and HLA.

As you can see in Figure 2, the LSCI is on the low side of the network. It translates SIP to and from TENA. The TENA data will flow through the CDS where it will then go over the WAN to the AWACS MTC. Because there are no TENA virtual radios, the existing in place DMON Portals are used to translate the TENA radio data to and from DIS for consumption by the AWACS MTC. While it may seem inefficient to translate the radio data from SIP to TENA to only have it translated again to DIS. Keeping the radio data in TENA is the only way to utilizing the existing TENA CDS. In the existing two CDS solution, the MDV based VTB translated the voice communications directly into DIS. The end result was that this solution introduced great complexity. The complexity was especially evident in the security domain, and kept the solution mostly inoperative. The one CDS solution removes this complexity.

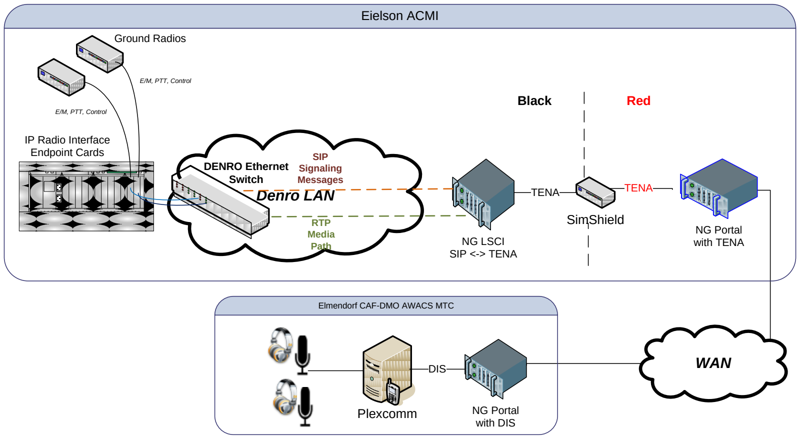

Figure 2. One CDS Solution

Radio Communications

PACAF requested a significant upgrade to their in place LVC voice solution. They required support for 16 simultaneous radios each of which can correspond to multiple live radios. They also required a daily training capability and support for the new VoIP based radio communications solution (Denro Nodal Switch). This is contrasted with the previous VTB based analog solution that supported 2 channels and, in effect, needed a cross domain solution approval to operate.

To provide this capability the LSCI integrates with the in place Denro Nodal Switch. The Denro Nodal switch is a mesh based system with each node talking directly to each other node. A node can be a physical radio or handset. This meant that the LSCI needed to interface directly with each radio. The standards based protocol the Denro Nodal switch communicates is SIP/RTP.

Radio Communications over TENA

The use of TENA to transport radio communications is a new requirement to the TENA community. This required the design of a new TENA object model to transport the live and virtual radio data. This new object design is modeled after DIS and High Level Architecture (HLA) Protocol Data Units (PDUs) and object classes. The reason for this influence is the end consumer of this data is most likely to be virtual radios found at simulation sites such as the AWACS MTC at Elmendorf Air Force base. Live ranges have live radios and do not rely on simulated radios for communications. This live data, when modeled, should be done in such a way that existing and future TENA-to-DIS and TENA-to-HLA gateways can convert the radio audio data to and from TENA in a manner similar with the SISO and IEEE standards.

Virtual radios, in the DIS case, require at least two different PDUs to communicate: Transmitter and Signal PDUs. This DIS and HLA behavior is mirrored in the TENA domain. A new TENA Stateful Data Object named RadioTransmitter has been created to resemble the Transmitter and RadioTransmitter versions found in DIS and HLA. It was designed to provide the descriptive radio characteristics such as relative location of the radio, frequency, power, modulation, and antenna radiation pattern required by simulated radios.

In addition to the TENA RadioTransmitter SDO, a new TENA RadioSignal message has been created. Just like DIS and HLA, this object is not considered Stateful. In TENA an object that is not Stateful is a message type. This object is responsible for carrying the live/virtual audio data as well as describing the encoding scheme, sample rate, etc. With the addition of the RadioTransmitter and RadioSignal to TENA, it is now possible to model live radio communications that is interoperable with virtual radios operating at distributed simulation sites.

SIP Telephony

Session Initiation Protocol (SIP) and Real-time Transport Protocol (RTP) is a standards based approach to doing telephony. These protocols are usually used for voice telephony applications commonly referred to as VoIP. With the use of SIP for communicating with the Denro Nodal Switch, the LSCI doesn't have to do Analog to Digital conversion, but it means that the LSCI needs to bridge the gap in assumptions between simulation protocols and telephony protocols. To the

Denro Nodal Switch, radio communications are equivalent to one continuous phone conversation on a specific phone line. In the virtual domain, to the AWACS, radio communications function closer to the radio they are modeling. For live communications, there is no connection setup like there is in SIP, a message is just broadcasted out on a specific frequency. It is up to the recipient to decide whether or not to play that message to the user.

To bridge the difference between live and virtual domains, the LSCI has to do two main tasks. The first is to implement a radio model. The second is to try to emulate the virtual aircraft based radio, with the ground based range radios. This is necessary because the virtual aircraft radio doesn't actually exist.

Because there was no requirement to provide training for radio interruptions or other difficulties, the decision was made to always choose the technical solution that provided the best radio connectivity. It is for this reason the radio model was made as simple as possible. In the virtual to live direction, this turned out to be very simple indeed. Its only task is to provide a mapping between the virtual frequency and the live radio group.

Due to the size and mountainous terrain of the JPARC, multiple Denro radios and antenna are required to provide full coverage for the range complex. This created two different challenges to providing LVC interoperability. The first involves the radio transmission in the virtual to live direction. Since the virtual radio doesn't actually exist, it has to be emulated by the live radios. Accurate live simulation of virtual aircraft's radios is problematic using ground based radio transmitters, because ground based radio don't have the same reach or coverage footprint as radios flying high above ground on an airplane. Multiple radios operating on the same frequency are needed to provide coverage for the whole range. As a result users are allowed to configure the LSCI to group range radios by frequency. The challenge became how to properly utilize available radios to emulate the reach of virtual airborne radios. Our initial thought was to select the closest transmitter to the radio sending the transmission, but no single radio can reach the whole range as illustrated in Figure 3.

To solve this problem, the LCSI adopts the same solution the Denro Nodal switch uses. It sends simultaneously to a configured group of radios that are all on the same frequency. While this poses a risk of interference, this risk hasn't been realized during testing.

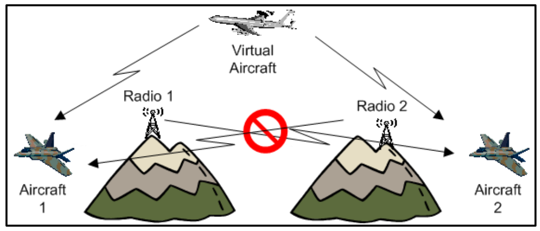

Figure 3. One ground based radio is unable to have the same reach as the airborne radio.

In the live to virtual direction a similar situation also occurs. There is no single range radio that can receive from the whole range. So again it is required to use a group of radios to cover the whole range. As Figure 4 illustrates, this runs into a problem when an aircraft is able to reach more than one radio. Using the radio data from both radios would results in bad communications for the virtual aircraft.

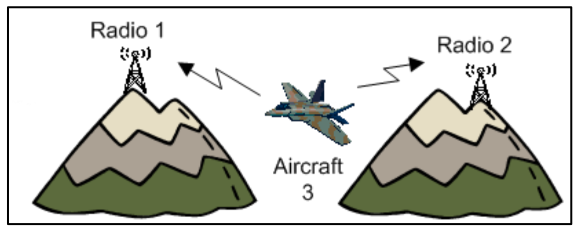

Figure 4. Aircraft is able to transmit to two radios.

The solution to this problem is simple and works in practice; only allow one radio transmission at a time to be modeled in the simulation. The first radio in a group, on the same frequency, that triggers its VOX threshold as receiving a radio transmission will be the radio selected for transmission to TENA. The "first to transmit wins" algorithm is contained in a modular component. If a more robust algorithm is found to be needed, it can be added as future work. Selecting the transmission with the best signal to noise ratio is a promising area of future exploration.

A similar problem occurs when going from virtual to live. In the virtual domain there can be multiple radio transmissions on the same frequency originating from different sources, but LSCI can only send one stream of audio data to the SIP radio. While multiple solutions were considered, the simplest solution was decided upon. The LSCI used the same "first to transmit wins" algorithm to only allow one range radio transmission at a time.

Standards Based Approach

The DIS and HLA influence of the design of TENA radio object model allows the transport of radio communications in a standardized process. TENA as a protocol does not formally describe how the process of modeling radio communications should occur. TENA as a protocol is not an international standard that defines how and when objects and messages should be used. The TENA protocol is community driven and often times individual ranges or sub communities can develop solutions in stove pipe fashion. In order to avoid the newly created radio object model from becoming another stove pipe solution, we are engaged in the process with the TENA SDA and community to make this radio object model part of the standard set of TENA objects. This does not guarantee that other stove pipe solutions will not be developed, but it does make that less likely. This is because the TENA standard set of objects are often the first to be searched when looking for solutions to TENA data modeling challenges. Until the TENA community adopts an accepted standard for how and when its objects should be used, interoperability challenges and stove pipe solutions will continue.

The use of a standards based solution allows the approach to potentially be used in a wide variety of ranges. While this solution was first demonstrated on the Eielson range, care was taken to make the solution applicable to any range that uses TENA as the range protocol and whose radios are interoperable with SIP. More generally our approach to using the existing TENA based CDS, is potentially applicable to all Air Force ranges.

LVC Integration Challenges

There were several translation challenges that are unique to integrating live and virtual domains. The differing needs between live and virtual cause different data needs between domains. One of these is that the TENA Transmitter object has a transmit state flag that doesn't exist in the SIP protocol. The states are "off", "on but not transmitting", and "on and transmitting". The transmit state flag is initially set to "off". The LSCI sets the transmit state flag to "on but not transmitting" when the SIP connection to the range radio is first completed. It is set to "on" when the LSCI first receives audio data from a range radio. It is set to "on but not transmitting" when a configurable amount of time has elapsed with no audio data from the range radio.

The way SIP and TENA establish packet breaks and ordering is different. TENA uses the current time as the packet ordering identifier and SIP uses a packet sequence number. To create the TENA timestamp, the LSCI multiplies the SIP sequence number by the audio packet length in milliseconds, to achieve time. To create the SIP sequence number the LSCI does the reverse. It couldn't just increment the sequence number each time we sent a packet to the SIP radio, because breaks in the sequence number signify breaks in the audio data, which we need to represent. So the LSCI divides the time by the audio packet length to get the sequence number. Care must be taken when doing these calculations because single precision floating point will introduce jitter in the calculations. Therefore double precision floating point is recommended.

The Denro Nodal Switch has a fixed one packet buffer and a fixed packet input size. This requires the implementation of a repacketizer to make sure every packet is the same size, and a jitter buffer with out of sequence packet reordering. The length of the audio data in a TENA RadioSignal message doesn't have a fixed size. Even if the virtual radio's packet size is set to the exact same size as the Denro Nodal Switch, the virtual radios last packet is almost always a different size. This means that the LSCI needs to take every audio packet it receives from TENA, extract the audio data and produce regularly sized packets of a different size. This process inherently creates bursty traffic. That means that a jitter buffer needs to be implemented to reduce the jitter back down to less than the length of one packet. While order is not guaranteed for a UDP network it was thought that reordering packet is unlikely given that the Ethernet network is single path. This should give a fixed latency with low jitter. But it turns out that a common virtual radio produces significant amounts of jitter directly from the radio and a robust reordering and jitter buffer implementation is needed.

LESSONS LEARNED

Our experience in the live domain has shown that volume levels often don't match between simulators. This causes the audio volume at one simulator to be painfully loud and the audio levels at another site to be very low. There was a concern that we would see similar problems with this effort. Preparations were made to do gain adjustment, but no audio levels problems have been encountered.

The biggest integration problem encountered was related to performing radio communications tests with pilots. It has been difficult finding a time when the pilots are not too busy to perform an audio check. Because it would be inefficient and prohibitively expensive to send up an aircraft and pilot to do a simple radio communications check, we have to piggyback radio communications checks on routine training missions. Obviously, we can't do a radio check when the pilot is engaged in a training mission, but often times after the mission is complete the pilot will quickly change to the air traffic controller frequency.

CONCLUSION

A capability to provide interoperability between live and simulated radios was demonstrated at Eielson Air Force Base. This capability was accomplished without the need for an additional single purpose CDS device. This accomplishment will greatly reduce the amount of time required for JPARC to receive approvals to connect to outside networks such as DMON. This will also mean less network down time and more training for the warfighters by not having to wait for additional approvals. This paper shows great progress toward achieving a distributed LVC communications capability that can be achieved without significant C&A delays. SIP and RTP was successfully translated into the TENA domain through the LSCI and new TENA radio objects. The LSCI mitigated the interoperability challenges between telephony and simulation domains. No issues were observed during the demonstration and integration efforts.

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