Toward Interoperability between Test and Training Enabling Architecture (TENA) and Distributed Interactive Simulation (DIS) Training Architectures

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ABSTRACT

Numerous DIS-to-HLA gateways exist for literal translation of simulation data, but few perform real-time mitigation of the technical performance differences, e.g. data refresh rates, between these protocols. As the TENA protocol evolves in support of live training, similar challenges will need to be overcome when translating this protocol into DIS and HLA to realize the kind of technical performance required to avoid negative training between trainees in live aircraft and virtual platform simulators; and safety-critical issues for live participants. This paper presents a unique solution that is currently being implemented on the Pacific Alaska Range Complex (PARC) to integrate the Combat Air Force Distributed Mission Operations (CAF DMO) AWACS Mission Training Center into live training events such as Red Flag Alaska (RF-A).

Significant data transmission latencies exist between live and virtual training systems. These latencies ultimately result in differences of wall-clock time on the order of seconds. In combat situations, every second counts. The three primary actions performed by war fighters in a battlespace are move, shoot, and communicate. For TENA, location data of training platforms is communicated at reasonable rates and precision, but with low spatial accuracy. This deficiency results in significant visually-observable "jitter" of the reflection of live platforms in the virtual battlespace. This paper presents a solution for reducing this jitter.

The translation of data communication, e.g. Link-16 and IFF, between trainees is also addressed. This paper presents a solution to augment live track IFF data with the data necessary for interoperability with virtual and constructive assets. A technical solution is presented for Link-16 interoperability in light of the on-going development of the TENA Link-16 object model. Finally, an approach for an audio communications solution and an approach for the simulation of live-to-live, live-to-virtual, and live-to-constructive weapons engagements are proposed as future work.

ABOUT THE AUTHORS

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Mike Aldinger is the Manager for Advanced Programs and Technologies at Northrop Grumman Information Systems on the Combat Air Force (CAF) Distributed Mission Operations (DMO) program. He holds a B.S. in Industrial and Systems Engineering from the University of Florida and an M.S. in Simulation Modeling and Analysis from the University of Central Florida. He 18 years experience spans manufacturing, work design, prototyping, integration and test, and modeling and simulation. His current roles include DMO Standards Development Lead, DMO-Space Chief Architect, and PACAF L-V-C Program Manager/Tech Lead.

Benjamin Leppard graduated with a B.S. in Computer Engineering from the University of Central Florida. Benjamin has over 7 years experience developing mission-critical, advanced multi-threaded, low-latency, high-throughput software for the Air Force, Army, and Navy. He currently leads the team that develops the Northrop Grumman Portal for the CAF DMO program. This software allows for high-fidelity, real-time training systems to prosecute training missions together at multiple locations.

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INTRODUCTION

Numerous DIS-to-HLA gateways exist for literal translation of simulation data, but few perform real-time mitigation of the technical performance differences between these protocols, such as the need for persistent heart-beating and explicit removal of entities. As the TENA protocol evolves in support of live training, similar challenges will need to be overcome when translating this protocol into DIS and HLA to realize the kind of technical performance required to avoid negative training between trainees in live aircraft and virtual platform simulators; and safety-critical issues for live participants.

Hudgins et al [1] provide a contemporary review of the application of TENA gateways to various test and training ranges, including the Pacific Alaska Range Complex (PARC). They state that “many platforms have trained at PARC, including fighters, bombers, tankers, C2, ground, and C4ISR.” [1] However, none of these platforms have been CAF DMO virtual training assets. This paper presents a unique solution that is currently being implemented at the PARC to integrate the CAF DMO Airborne Warning and Control System (AWACS) Mission Training Center (MTC), a virtual/constructive simulation training platform, into live training events to such as Red Flag AK (RF-A).

Significant data transmission latencies exist between live and virtual training systems. These latencies ultimately result in differences of wall-clock time on the order of seconds. This leads to inconsistencies in the battlespace, which leads to problems with the three primary actions performed by war fighters in a battlespace, i.e. move, shoot, and communicate. This paper focuses on the movement of entities in the battlespace and the ability to transfer data communications between them.

CAF DMO OVERVIEW

CAF DMO Mission Training Centers

DMO is critical to Air Force readiness and is the cornerstone of Air Force training transformation in accordance with OSD-directed Joint National Training Capability (JNTC) Initiative. Testa et al provide an excellent review of the DMON, the DMO Portal, and the CAF DMO Standards, which enable “a truly routine, daily training capability.” [2]

Hudgins et al assert that the PARC is “the largest instrumented air, ground, and electronic combat training range in the world… [it] is conditionally Accredited and Certified (A&C) as a JNTC venue and is the first live training range within USAF to receive JNTC A&C.” [1] The PARC’s size and A&C make it an excellent candidate live test and training range for Live, Virtual, and Constructive (LVC) training systems integration with CAF DMO virtual and constructive training assets; and the CAF DMO Network (DMON).

CAF DMO is the foundation for revolutionizing training for the United States Air Force (USAF). The purpose of the CAF DMO program is to train USAF warfighters in the full-spectrum of team combat skills. This is accomplished by bringing warfighters together virtually on a daily basis from multiple MTCs. MTCs contain high-fidelity, man-in-the-loop, virtual pilot stations; and Command and Control, Intelligence, Surveillance, and Reconnaissance (C2ISR) crew stations. These training stations, or platforms, are complemented with training aids, such as manned threat stations, instructor-operator stations, Computer Generated Forces (CGF) systems, and brief/de-brief systems, to achieve the required full-spectrum training environment.

Collectively, CAF DMO MTCs support both inter-team and intra-team composite force training for warfighters located in geographically separate locations. This mirrors current doctrine, where the CAF DMO program provides warfighters the ability to train as a team, while supporting the enhancement of individual proficiency. The primary focus is comprehensive tactical training for all warfighters. These training objectives are, of course, common objectives for the training exercises held at the PARC. The main goal is always to train them on Mission Essential Competencies needed for combat readiness. In a small step forward, this paper describes some recent accomplishments toward the integration of the PARC TENA network, the DMON, the DMO Portal; and live and virtual training platforms.

Hudgins et al illustrate how the DMO Portal integrates with the PARC TENA architecture in Figure 2 of [1]. Effectively, the DMO Portal provides not only translation, but more importantly strives for standards-based interoperability, between the TENA protocol and the 2 predominant protocols within CAF DMO: Distributed Interactive Simulation (DIS) and High Level Architecture (HLA). Apart from TENA Object Models and the suggestions of Hudgins et al in [1] and Testa et al in [2], no interoperability standards exist for LVC training venues. Therefore, where the success of CAF DMO and the DMO Portal DIS and HLA can be leveraged, a DIS-to-TENA interoperability feature has been developed with existing CAF DMO interoperability standardization in mind.

CAF DMO has standardized the representation of modeled entities to achieve correlated representation of the state of all platforms in the battlespace. Additionally, standards have been adopted to maintain consistent and accurate data link communications, such as Link 16. Entity representation and data link communications are the two areas in which some progress has been made for LVC and are discussed in this paper.

PACAF OVERVIEW

Red Flag - Alaska

Red Flag-Alaska is a Pacific Air Force (PACAF) sponsored exercise. The exercise is a multi-service, multi-platform, coordinated, combat operations exercise which corresponds to the designed operational capability of the participating units. The exercise mission is to provide a realistic air defense system by including early warning/Ground Control Intercept (GCI) with Command and Control (C2) links, Radar/Infrared (IR) Surface to Air Missiles (SAMs), Anti-Aircraft Artillery (AAA), "smokey SAM launches" and aggressor-trained advanced air-to-air threats. It also provides high-fidelity target arrays and Large Mixed Force employment which includes Radio/DataLink communication priorities and discipline.

RF-A participants are organized into "Red" defensive forces and "Blue" offensive forces. "White" forces represent the neutral controlling agency. The defensive force includes GCI and surface air defense forces to simulate threats posed by potentially hostile nations. These forces generally employ defensive counter-air tactics directed by GCI sites. There are also range threat emitters – electronic devices which send out signals simulating AAA and SAM launches. The offensive force includes the full-spectrum of the U.S. and allied tactical and support units. The job of controlling the mock war and ensuring safety falls to the White neutral force.

A typical RF-A scenario involves deploying 60 aircrafts to Eielson and 40 aircrafts to Elmendorf. At the height of the scenario up to 70 fighters can be operated in the same airspace at one time. The aircraft types taking part in the scenario include: F-16C, F-15C, F-16CJ, E-3, C-130H, RC-135V, and F/A-18. The scenario would involve threats like SAMs, manned threats and Unmanned Threat Emitter systems (UMTE). The Electronic Warfare (EW) includes AN/TPS-77 radars that cover the full Yukon and Stony Military Operations Area (MOA) and training pods on aircrafts that provide Air Combat Maneuvering Instrumentation (ACMI) data. DENRO radios are used for live (voice) communication between the participants.

PACAF LVC

PACAF's approach to achieving a persistent, on-demand, LVC training capability is by integrating the global, standards-based CAF DMO architecture with the fully-instrumented, TENA-based PARC training architecture. This merging of standards-based architectures provides a "controlled" environment that is conducive for providing an efficient, repeatable LVC training environment for the warfighters.

The first CAF DMO system identified for PACAF LVC integration into the PARC was the AWACS MTC at Elmendorf Air Force Base (AFB). The primary reasons for the selection of this system was its proximity to the PARC; and the feedback received from pilots and crew members during a prior ACC LVC effort, which indicated that C2 platforms in an LVC environment were of great benefit.

The goal of the AWACS integration effort is to provide seamless interoperability among the AWACS MTC and live PARC air platforms. Accomplishing this objective requires that LVC solutions for radio communications, Federal Aviation Administration (FAA) radar feed, TENA Time and Space Position Information (TSPi), and Link-16 are implemented. We recognize that solutions for many of these capabilities have been demonstrated in the past. The PACAF LVC effort is focused on the establishment of standards-based LVC solutions for persistent LVC training.

An advantage of leveraging the CAF DMO training platforms is the well-defined nature of their system interfaces, capabilities, and interoperability. All CAF DMO platforms comply with a tailored set of SISO-based standards, which was collaboratively developed with industry representation to achieve the high-fidelity training goals of the Combat Air Force units. This set of common requirements greatly simplifies and reduces risk for the future integration of additional CAF DMO MTCs into the PACAF LVC architecture. Therefore, the PACAF LVC architecture can be incrementally extended one CAF DMO virtual/constructive asset at a time.

However, one of the major challenges in achieving a truly interoperable, near real-time, LVC training architecture still exists. Testa et al state,

"Accessing TENA data for updates is much more onerous than accessing DIS or HLA data. Also, TENA object models do not provide all the information that is required to properly populate HLA and DIS entity fields. Critical platform information such as [accurate] velocity and acceleration is not available." [2]

This fact makes it very difficult to establish "ground truth," that is, where everything is actually located, within the virtual and constructive simulated battlespace. Ground truth is essential for accurate depiction of a virtual reality to trainees. Without ground truth, the idea of representing situational awareness becomes unfeasible, because no reference of the truth can be ascertained. For effective training to occur, it is critical to completely populate the virtual/constructive simulation world with all the information available in the real world – and do it in near real time. That is the major challenge. Here, we first try to correlate the locations of live, virtual, and constructive entities in near real-time.

TIME SPACE POSITION INFORMATION (TSPI)

Figure 1 illustrates the architecture implemented in the Eielson ACMI training facility, part of the PARC range complex, and the Elmendorf MTC to demonstrate the LVC TSPi concept.

The PARC is still working toward a final TENA solution. They currently use the P4 ACMI training pods with Central Computer System (CCS) data as their native protocol and await installation of the new P5 pods with the Live Monitor data system.

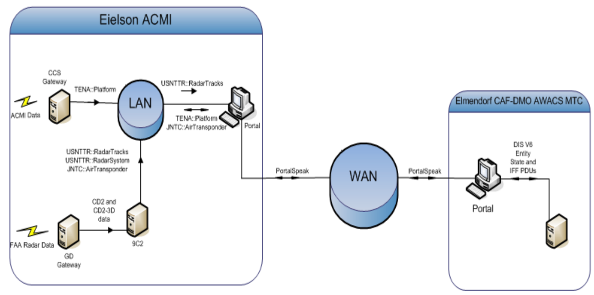

Figure 1. Live to Virtual TSPi

TSPi data from the P4 pods and CCS subsystem is routed through the Cubic Defense CCS Gateway for TENA. This gateway translates the CCS data into TENA using the Live Training - Combined (LTC) Object Model (OM) v 1.6.2. The DMO Portal receives TENA::AirPlatform messages from this gateway and translates them into DIS/HLA Entity State data to "insert" or "reflect" the live aircraft entities into the virtual-constructive world. In May 2009, several key capabilities were successfully tested between the PARC TENA network and the DMON. These capabilities include:

- TSPi data from live aircraft with ACMI pods was translated from TENA to DIS via the CAF DMO Portal connection between Eielson ACMI and Elmendorf AWACS MTC.

- TSPi data from 9C/2 radar tracks was translated from TENA to DIS via the DMO Portal connection between Eielson ACMI and Elmendorf AWACS MTC.

- Simulation data, i.e. DIS Entity State, from Elmendorf AWACS was translated from DIS to TENA via the DMO Portal connection between Elmendorf AWACS MTC and Eielson ACMI.

TSPi Data via ACMI Pods

TSPi data for training platforms with ACMI pods is communicated at reasonably fast rates, e.g. ~100 ms, and precision for real-time simulation, but with low spatial accuracy. The TSPi data from these pods does not contain reliable velocity and acceleration data. The lack of reliable velocity and acceleration data inhibits simulations' ability to estimate where a platform will be located between TSPi data updates. Therefore, a smoothing and dead-reckoning algorithm has been applied by the DMO Portal to estimate the platform's location for heart-beating, i.e. "keep alive," purposes in the simulated virtual world. Techniques similar to those used for DIS to HLA interoperability have been implemented in the DMO Portal for this TENA to DIS interoperability solution.

The major difference for the latter solution is that velocity for a platform has been averaged over time to smooth the trajectory of the platform. This approach is relatively simple and prone to errors in calculation when fast-flying air platforms are making aggressive maneuvers, e.g. sharp turns. However, this approach proved to be technically sound for this application and the results of the errors induced by such maneuvers is considered a matter of fidelity, whereby the focus of this paper is to achieve interoperability first and foremost.

This basic approach reduced the jitter problem substantially. It is left for future work to research and apply a more suitable and effective method for achieving a smoother motion trajectory based on TSPi for live air platforms being represented in the virtual world. Some suggested approaches are to apply a Least Square Fit method, a parabolic filter, or Kalman filter.

TSPi Data via Radar Tracks

All air platforms that participate in PARC exercises such as RF-A, however, will not be outfitted with ACMI training pods, which are typically only deployed on fighter aircraft. Therefore, FAA radar data is used to determine the TSPi data for all air platforms that are not configured with an ACMI pod. TSPi data for training platforms being tracked by radar is communicated at very slow rates, e.g. ~12 s, and with very low spatial accuracy. Also, the TSPi data does not contain velocity and acceleration data. The FAA radar data is provided to the DMO Portal by the combination of the General Dynamics Gateway and 9C2 systems.

The DMO Portal receives USNTTR::RadarTracks, JNTC::AirTransponder object data directly from the 9C2. Although radar data refresh is very slow, it does provide a complete Common Operational Picture (COP) of the airspace for situational awareness. It is this COP that must be provided to the Elmendorf AWACS MTC to achieve this first step toward interoperability, which is to provide all of the identified and unidentified flying objects.

Multiple TSPi Data Sources for Podded Aircraft

Due to the wide spread range of FAA radar on the PARC range complex, all platforms in the surrounding air space will be detected, including all air platforms configured with an ACMI pod. These aircraft will potentially be represented to the Portal by both the CCS TENA Gateway and the 9C2. Therefore, these platform entity representations must be correlated such that only one single representation of the live platform is "inserted" into the virtual/constructive world. This currently remains a challenge for the TENA/DIS training architecture being developed at the PARC range complex. Having the DMO Portal perform the correlation for each platform is one possible approach, but this capability can only be considered as potential future work at this time. For now, the DMO Portal successfully translates both of the TSPi data sources into DIS and HLA entity data, albeit incomplete.

One additional example of incomplete data is Identify Friend/Foe (IFF) modes. IFF Mode 2 and Mode 3 data is contained in the FAA radar data received by the GD Gateway, but data for the other IFF modes is not available. Operators can configured the DMO Portal with a mapping function to provide appropriate values for the missing IFF modes. It has also been suggested that the DMO Portal could automatically get the missing IFF modes from the Link-16 data link.

Link-16 PPLI messages contain IFF data, which could be extracted to generate the corresponding IFF DIS Protocol Data Unit (PDU). However, even with this approach, the individual platforms in the seemingly correlated radar and Link-16 "pictures" must still be correlated via a unique identifier. This does not currently exist in both data sources. Some sort of external mapping between Link-16 Participating Unit numbers and IFF identifiers would have to be developed. Currently, no obvious approach for correlating native identifier fields within these two protocols has yet been developed and remains as future work.

JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS) LINK-16

Figure 2 illustrates the architecture implemented in the Eielson ACMI training facility and the Elmendorf MTC to demonstrate the LVC Link-16 concept. In May 2009, key Link-16 capabilities were successfully tested between the PARC TENA network and the DMON. These capabilities include:

- Multiple Link-16 messages from live aircraft from the Gateway Manager were transmitted to the Elmendorf AWACS via the DMO Portal connection between Eielson ACMI and Elmendorf AWACS MTC.

- Multiple Link-16 messages from the Elmendorf AWACS were transmitted to live aircraft via the DMO Portal connection between Eielson ACMI and Elmendorf AWACS MTC.

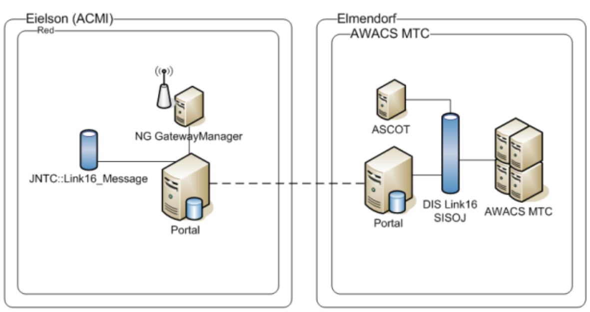

Figure 2. Live to Virtual Link 16

At Eielson ACMI, the DMO Portal receives Link-16 DIS Signal PDUs from the Northrop Grumman (NG) Gateway Manager and transmits them to the Elmendorf AWACS MTC. At Elmendorf AWACS MTC, the DMO Portal receives Link-16 DIS Signal PDUs from the Elmendorf AWACS and transmits them to the NG Gateway Manager. In both directions, the Portal can distribute the Link-16 Signal PDUs just as it does routinely for all CAF DMO training events, because the NG Gateway Manager support the DIS protocol.

This solution currently works with the NG Gateway Manager, which provides the Link-16 data translation into the readily acceptable DIS protocol. However, the TENA Working Group is working to develop a Link-16 OM. When this OM is released, the DMO Portal will potentially be enhanced to provide the TENA to DIS translation required to interface with other PARC range subsystems that provide Link-16 in the TENA protocol.

WEAPONS ENGAGEMENTS

An approach is recommended for the simulation of live-to-live, live-to-virtual, and live-to-constructive weapons engagements as future work. It can be asserted that constructive to live weapons engagement capabilities already exist. If live platforms are represented in the virtual battle space via Entity State PDUs, then they look the same as simulated entities to other simulated, i.e. constructive, entities. Therefore, a constructive entity will engage a live participant, i.e. TENA entity, as it would any entity that it detects and deems to be a member of the opposing force.

Live-to-virtual and live-to-constructive weapons engagements in the simulated battle space could be initiated by events received via CCS, and therefore TENA. When using CCS data, the DMO Portal could generate DIS/HLA Fire Interactions based on CCS MIL-STD-1553 weapons bus data received from the ACMI pod. The ACMI training facility located at Eielson AFB typically does connect the ACMI pods to the aircraft's MIL-STD-1553 weapons bus. Therefore, the weapons bus could potentially be monitored for weapons release events. This would provide the DMO Portal the discrete weapons fire event needed to "insert" a Weapons Fire interaction into the virtual world.

In the event of a weapons fire, e.g. a missile launch, a weapon server or CGF of some sort would simulate a missile entity on behalf of the live platform. This application could also perform damage assessment to determine if a live platform entity should be considered destroyed, as is does with its locally simulated constructive entities in its usual manner. If deem dead, the Range Training Officer (RTO) would notify the live participant to egress from the training airspace until further notice or even Return to Base (RTB) depending on the current situation in the training exercise.

TENA TO DIS INTEROPERABILITY ISSUES

Throughout the course of integration and testing, no Link-16 related issues were observed. However, several TSPi-related issues were observed when interfacing TENA with DIS simulations. The TSPi data related issues are:

1. position update frequency and dead-reckoning mismatches,

2. real world data measurement inconsistencies, and

3. entity definition and battle space removal.

These issues occurred because live protocol norms were still used when the Cubic CCS/TENA Gateway translated CCS data to the TENA protocol. An overview of these issues is provided below:

1. Live entities are not dead-reckoned in the TENA protocol so they require frequent updates (~10 Hz). DIS and HLA entities update much less frequently due to the use of dead-reckoning in simulation. To address this in the live domain, a translator for converting live to virtual protocols needs to derive dead-reckoning parameters and implement thresholds to minimize update rates. Translating this data to CCS would involve heart-beating at a 100 ms rate using dead-reckoning parameters.

2. Measurement resolution of live aircraft position produces jitter and may result in loss of tracks. Translation to the virtual world needs to smooth this data to minimize jitter. It also needs to detect when pod tracking is inadvertently dropped and dead-reckon the entity until pod tracking resumes. When pod tracking does not return in a timely manner, the simulated entity corresponding to the live aircraft would need to be removed from the battle space. The Cubic gateway used in this architecture contained no algorithm to cease publishing TSPi data for aircraft that had RTB, i.e. departed the range. The DMO Portal was able to work around this interoperability issue, but more work needs to be done in the DMO Portal to provide a comprehensive solution.

3. Virtual world representation of entities is governed by a well defined set of international standards. In the live world, this is not the case. Entity representation is skewed in some cases due to incorrect data translations resulting in misplaced or additional battle space objects. Translators need to only translate valid range entities to the virtual protocol(s).

Additionally, CCS update rates must be considered as a technical risk to the simulated battle space. These rates can be up to 2 orders of magnitude greater than Entity State updates for DIS and HLA entities. Dead-reckoning algorithms must be implemented to provide consistent and smooth TSPi updates for the live aircraft. The DMO Portal solution accounted for these disparate update rates to avoid entity flickering and jumping, i.e. jitter.

The live CCS protocol and the virtual TENA protocol have different operating assumptions. For the two protocols to interoperate, more needs to be done than a direct translation between fields. The reason for this is that simulation protocols assume perfect knowledge of a simulated planes position, velocity, and acceleration at all times. In the existing Live Range implementations, only a live aircraft physical attributes are measured. At best this provides an approximation of attributes such as position. Some of these attribute measurements (e.g. reliable velocity) were unavailable on the TENA network, which can result in a jittery representation or momentary dropout of a live entity in the virtual battle space.

FUTURE WORK

In addition to the future work discuss throughout this paper, a cross-domain audio communications capability must be developed between the Elmendorf AWACS MTC and live aircraft to achieve a complete training venue. This future work involves the integration of the Virtual Tactical Bridge (VTB) subsystem, which will be installed at the Eielson ACMI training facility in the near future. When this subsystem is installed, an audio communications solution will be integrated with the DMO Portal and demonstrated.

With the near-term integration of the Elmendorf AWACS MTC, LVC DMO training will potentially become a routine occurrence. Support for such a training capability has been expressed by both ACC and PACAF ranges, along with the CAF DMO Joint Surveillance and Target Attack Radar System (JSTARS) aircrews. Site preparation is currently underway for JSTARS integration, which will potentially expand the PACAF LVC solution to interface with Army ground systems. With the realization of this capability, our focus will shift to the Air-Ground platforms in the CAF, e.g. F-16CJ. Where the JSTARS C2 platform integration will be similar to the AWACS, the F-16CJ integration will bring new challenges related to Out-The-Window (OTW) visualization of the real world in the virtual world – and correlation of these worlds, i.e. terrain, will be difficult. Additionally, at that time, an advanced jitter-reduction method will have to be applied to prevent potential negative training impacts for F-16CJ pilots caused by flickering and jumping air entities.

CONCLUSION

Several capabilities for providing a complete LVC solution for PACAF and CAF DMO training were demonstrated at the Eielson ACMI training facility and the Elmendorf AWACS MTC. This paper demonstrates marked progress toward a TENA-to-DIS interoperability solution required to achieve a truly persistent, standards-based LVC DMO capability. Specifically, TSPi data from ACMI pods and FAA radar tracks was used to represent live training platforms in the virtual/constructive simulation. The issues related to the update rates for these TSPi data sources were discussed and mitigation strategies were presented. Link-16 data was successfully translated and transmitted between live and simulated training platforms. No Link-16 issues were observed. Brief proposals were presented for a live-to-simulated weapons engagement solution and an audio communications solution based on the use of the VTB. Finally, potential future work was discussed, including the integration of additional CAF DMO training platforms, e.g. JSTARS and F-16CJ, with the PACAF LVC TENA training architecture.

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