Airborne Network and Datalink Technology Analysis Program: A Link 16 Simulation Study

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ABSTRACT

Tactical data links are critical to network centric battlefield planning and execution. There are many legacy data links that must be optimized and integrated into modern battle spaces. Implementations of data links have been platform-centric with limited regard to how other military assets could use or process the data to be transmitted. There have been some attempts to catalog each platform's implementation, but little has been done with the data to support automated planning and evaluation of data link performance or levels of interoperability.

This paper describes an investigation into alternative methods for simulation of data links to support planning, design, and implementation of tactical data links. Data link simulations created to date have focused on performance and interoperability at the physical layer while modeling data and information flow at a statistical level only, relying on reference implementations of military standards. The methods investigated and presented in this paper seek to use existing physical layer data link models while using actual documented platform implementation data to develop accurate aircraft communication and information exchange models.

These accurate aircraft data link implementation models, when coupled with equally accurate aircraft motion and behavior models, will allow true interoperability and information flow analysis without prolonged post-integration flight testing. The approach has considerable potential impacts in the areas of platform integration, training simulations and joint interoperability testing.

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INTRODUCTION

In recent years, communications interoperability has become a paramount concern for the Department of Defense (DoD). Studies have shown a vast increase in military strike effectiveness when various platforms designed to detect, identify, track, and engage targets are able to transmit and receive data efficiently across common networks (Fabio, 2001 & Petersante, 2003). Tactical data links, such as Link 16, were developed to accomplish this task. The original concept was to allow military aircraft and ships to exchange tactical information creating a clear picture of the battle space in near real-time. The transmission protocols and message formats developed for Link 16 are defined by MIL-STD-6016C. This standard describes binary data words called J-Series messages which are grouped functionally as network participation groups (NPG).

To date, the Link 16 message standard has been adopted and implemented on many airborne platforms some of which include the F-15, F-16, E-3 AWACS, E-8 Joint STARS, RC-135 Rivet Joint, and a number of other airborne, maritime, and ground systems. While these platforms have all implemented the Link 16 message standard, tests have shown interoperability issues present when trying to perform cross-platform communications. Without an oversight body to certify a common implementation of MIL-STD-6016C, the developers of Link 16 systems are free to interpret the standard in different ways, thereby resulting in variants that, in many cases, are incompatible (Morris, 2004). The Airborne Network and Data Link Technology Analysis Program was created by the U.S. Air Force Aeronautical Systems Center's Capabilities Integration Directorate (ASC/XR), in part, to study this particular problem and develop methods to test current and future data link integration implementations to discover the existence of interoperability issues between platforms.

Most weapon system integrators perform hardware in the loop tests; but, they are normally limited to their own Link 16 implementation. System tests involving multiple Link 16 platforms are expensive to conduct and only available during interoperability testing in the test and evaluation phase of a program, well after designs have been completed and extensive resources already spent in development of a weapon system. The best way to realistically perform these types of tests prior to the system integration phase is through modeling and simulation techniques.

This Link 16 simulation study focused on the development of a proof-of-concept demonstration to determine the feasibility of using modeling and simulation to discover platform interoperability issues during the design phase of a weapon system program, where the cost and schedule impacts resulting from design changes are much less significant than during the development and testing stages of the program. Subject matter experts and simulation engineers from KIHOMAC and Southwest Research Institute® teamed together to develop the proof-of-concept study for ASC/XR. The approach used, results obtained and lessons learned are documented in the remainder of this paper.

SIMULATION APPROACH

In keeping with the proof-of-concept approach, we implemented a simple four versus four (4v4) engagement scenario as the basis for this demonstration. The 4v4 scenario represents a typical training exercise where four blue force (friendly) F-15 fighters and an E-3 AWACS, engage four red force (opposing) F-15s acting as enemy targets. The Link 16 network is simulated between the blue force F-15s and the E-3. The guidelines laid out by MIL-STD-6016C were followed; however, the message sequences, transmission rates, and message contents follow each individual platform's current implementation. The purpose of this simulation was to quickly and effectively show that platform-specific Link 16 implementations could be realistically modeled and simulated with a degree of accuracy. Figure 1 illustrates the tactical scenario concept used for the simulation.

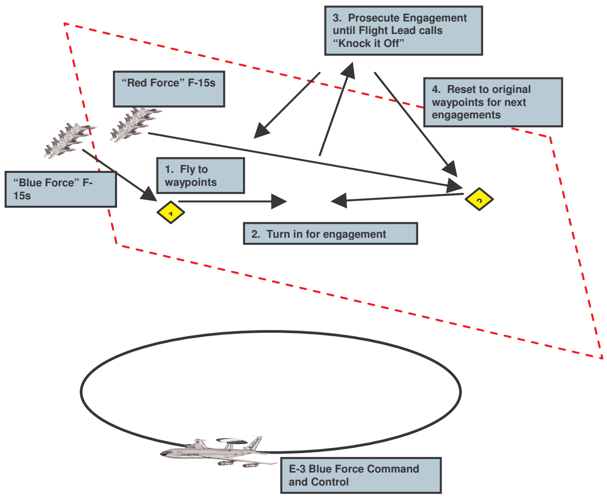

Figure 1: Engagement Scenario Overview

Aircraft Simulation

The Aircraft Simulation consists of two separate simulation components to model the aircraft and their communications for this experiment. The first is a discrete event simulation implemented to model the physical aircraft locations and movements. This physical simulation was used to determine movement and locations of the aircraft. Composable Behavior Modeling (CBM) technology, which provides pilot decisions for flying the aircraft in the simulation, is an integral part of this physical simulation. Tactics and procedures are determined dynamically by the decision models associated with each aircraft. The simulation determines entity state data throughout the mission based on decisions for aircraft movement, targeting and range calculations. Decisions are also made to trigger asynchronous Link 16 messages, based on the situation and relative positions of the aircraft. These messages would normally be generated from human operator inputs on each aircraft.

The second Aircraft Simulation component is a Link 16 simulation engine that was originally developed to model the MIL-STD-6016C transmission and reception rules. This engine was modified to replicate actual F-15 and E-3 implementations. The automatic (synchronous) messages begin transmission for each aircraft at the start of the scenario and continue based on the transmission rules. The operator driven (asynchronous) messages are triggered from the discrete event simulation's CBM, based on the current scenario situation and relative locations of the aircraft.

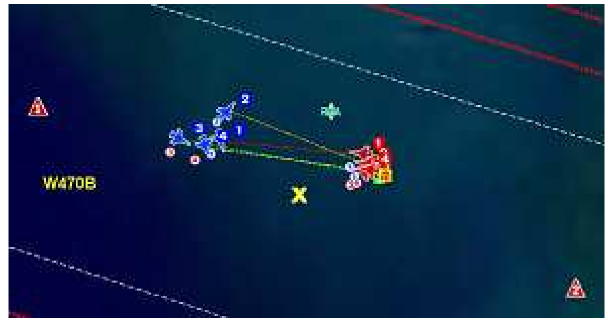

Figure 2: Aircraft Simulation Display

The network analysis requires that information about the aircraft position and the Link 16 message traffic be captured within the Aircraft Simulation. This information can be captured in two different ways. The first means of data capture is to collect the data and store it in static text files. The second data capture method consists of sending it, via the High Level Architecture (HLA) protocol, to an external analysis application. The Link 16 message format for the HLA interface complies with the Link 16 Simulation Standard SISO-STD-002.

NETWARS Application

The final simulation component used in this effort was the NETWARS application, which provides an external network simulation environment via the HLA protocol. The NETWARS program was selected by the Military Communications-Electronics Board (MCEB) in 1998 to be the DoD modeling tool of choice for communications modeling and simulation projects. The NETWARS program, built as a wrapper around OPNET's Modeler, continues to create and maintain vast libraries of communication models from every branch of the military along with a core set of commercial off-the-shelf (COTS) models. Its ability to assess current and future military networks has made it an integral part of many DoD analysis, acquisition, and operational activities. These COTS data link and radio models were deemed ideal for the proof-of-concept demonstration as a way to leverage significant existing model development investments.

NETWARS simulates the Link 16 transport layer, but does not adequately simulate the MIL-STD-6016C message transmission protocol. NETWARS and the Space and Naval Warfare Systems Command (SPAWAR) Link 16 models are statistical representations of the network, meaning no actual bit information is passed as part of each simulated Link 16 message. For these reasons, our Aircraft Simulation that resides outside of the NETWARS environment was used to model realistic flight dynamics, logic decisions, and J-Series message transmission. To model platform-specific Link 16 message implementations, Interoperable Systems Management and Requirements Transformation (iSMART) data, which defines the message standard implementation details for specific airborne platforms, was incorporated into the Link 16 engine.

To create the proof-of-concept demonstration, the Aircraft Simulation and NETWARS components were integrated in two stages. The first stage was a sequential simulation stage where the Aircraft Simulation was run in a stand-alone mode and an output file was generated that was later used to stimulate the NETWARS simulation. The second stage was a distributed simulation where the Aircraft Simulation and NETWARS executed in parallel via an HLA interface.

SEQUENTIAL SIMULATION

The sequential simulation was used to develop and test the Aircraft Simulation and to also gain a better understanding of NETWARS' capabilities, operation and Link 16 network simulation accuracy. An initial study of NETWARS determined that the Link 16 model created and maintained by SPAWAR would be a good starting point for simulation development. The SPAWAR model library includes a Joint Tactical Information Distribution System (JTIDS) radio model which accurately models the time domain multiple access (TDMA) transport layer and Time Slot Block setup, and a Link 16 Host Processor model which sends and receives J-Series messages.

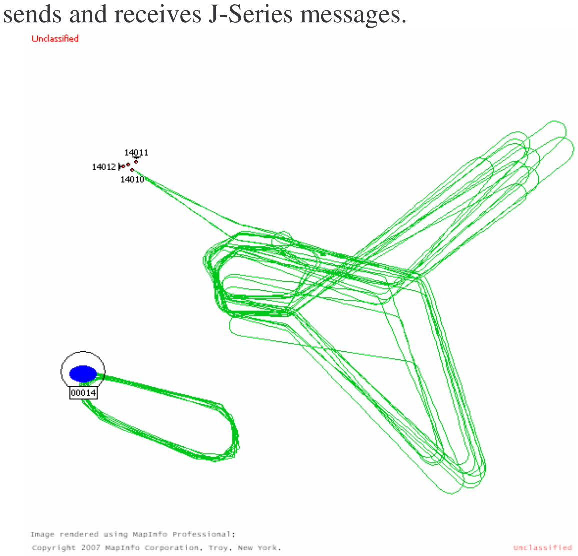

Figure 3: NETWARS Scenario Display

NETWARS simulation development requires a user to create a NETWARS Scenario using the Scenario Builder applet. Figure 3 shows the NETWARS display after a sequential simulation scenario run. The four small Operational Facilities (OPFAC), in the upper left corner, represent the four blue force F-15s and the larger OPFAC, in the lower left corner, represents the E-3. Each of the OPFACs in Figure 3 contains the same configuration of Link 16 components shown in Figure 4.

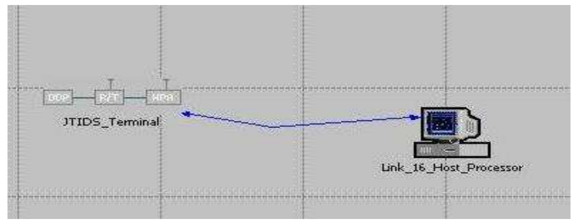

Figure 4: SPAWAR Link 16 Models

To specify the JTIDS Time Slot Block setup for each OPFAC, we used the Gulf Common Network configuration, which is a commonly used training network operated from Eglin AFB and active over the Gulf of Mexico. To simulate transmitting data across this network, NETWARS Information Exchange Requirements (IER) were used, which provide the simulation with data traffic information. For Link 16 communication, these IERs utilize a classification field to indicate the NPG and type of J-Series message that is being transferred. IERs can either be input manually or imported from a file.

Once the basic NETWARS scenario was designed, data was needed to test actual simulation accuracy. First, each NPG was tested by manually creating simple IERs with basic information and transmitting them from one OPFAC to another. Although this step seems rudimentary, we were able to discover several issues with the NETWARS Link 16 model which were then addressed by the NETWARS support staff. Two of the major issues were a problem with the TDMA process code and a Link 16 Host Processor coding problem which caused termination of NPG 6 precise participant location and identification (PPLI) messages. We also discovered that several key Link 16 features, such as contention access and multicast, were not modeled. However, none of these NETWARS Link 16 limitations prevented us from completing the proof-of-concept demonstration.

For the next part of the sequential simulation stage, the Aircraft Simulation was used to simulate aircraft flight patterns and message traffic during the course of the

4v4 engagement scenario. Each aircraft platform's state data was translated into a NETWARS trajectory file; and, the Link 16 traffic data was converted to a single importable IER file. The trajectories of the aircraft are represented by the lines seen in Figure 2. These files were then imported and used to stimulate the NETWARS network. To run the simulation, an OPNET Discrete Event Simulation was used to drive the NETWARS scenario. Statistics were gathered using the built-in tools in NETWARS to determine network performance. The results from the sequential simulation (shown in Figure 5) parallel those from a simulation exercise where real-world data collected from training exercises performed at Tyndall AFB was imported into and run as a NETWARS simulation.

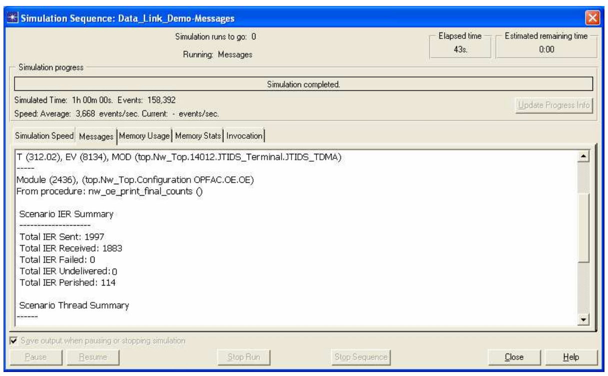

Figure 5: Sequential Simulation Results

The sequential simulation helped confirm the accuracy of the Link 16 models, but fell short of our objective of developing a simulation to discover interoperability issues between platforms. The sequential method did not allow the Aircraft Simulation to make decisions and take actions based on the transmission or non-transmission of data link messages. A feedback loop was needed to exchange IER information between the Aircraft Simulator and NETWARS Link 16 network.

DISTRIBUTED SIMULATION

The distributed simulation method provided the necessary feedback loop between the Aircraft Simulation and NETWARS. Aircraft state data and J-Series messages, created in the Aircraft Simulation using platform-specific aircraft implementation data from the iSMART, were transmitted to NETWARS. NETWARS returned the status of these messages (i.e. whether they were received or not) to the Aircraft Simulation. The Aircraft Simulation then processed this status to determine the timing of subsequent messages to be sent. The top level design for this distributed simulation is shown in Figure 6.

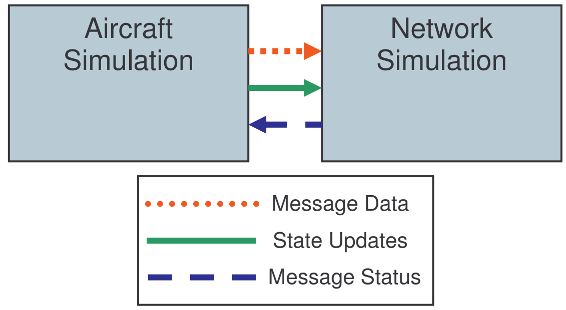

Figure 6: Distributed Simulation Concept

While developing the distributed simulation, a few technical challenges arose. The two major challenges involved creating an interface between the two simulation environments and transmitting J-Series bit information across the NETWARS simulated network. To create the simulation interface, we utilized the OPNET HLA module. To address the message bit data, an IER field called the IER ID was used. While this field can contain real data, it acts as a zero-bit field and does not affect any NETWARS simulation processes. Although this method will not show any bit errors or processing errors, it is adequate when trying to discover platform interoperability issues.

The NETWARS program has integrated several additional external OPNET modules, allowing them to be used during simulation. The OPNET HLA module allows NETWARS to communicate with outside simulations by utilizing a special HLA OPFAC embedded into a NETWARS scenario. To understand the internal processes involved, it is important to have a basic understanding of HLA.

HLA is a general-purpose architecture for distributed simulation systems. It allows simulations to communicate regardless of computing platform. It accomplishes this by developing a set of data interaction rules called a Federation Object Model (FOM) that is managed by a runtime infrastructure (RTI). Figure 7 shows the basic HLA interface overview for our Link 16 distributed simulation.

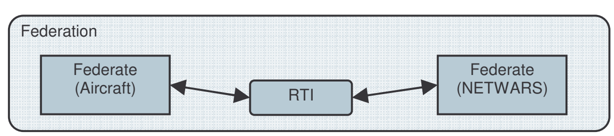

Figure 7: HLA Architecture

Within this architecture, the complete simulation is called a Federation; and, each simulation component within is called a Federate. Our final proof-of-concept distributed simulation used RTI NG v6, created by the Defense Modeling and Simulation Office (DMSO), to provide the common services to the Federates. There are several newer RTI programs available; however, the Aircraft Simulation was written in Java and required the Java bindings provided by the original DMSO RTI. The FOM created for our simulation was a simplified form of the NETWARS FOM provided with the OPNET HLA module. The three key interactions required to complete the simulation were: 1) SendLocation, 2) TriggerNewIER, and 3) IERInfoUpdate. The SendLocation interaction sent new latitude, longitude, and altitude state data from the Aircraft Simulator to NETWARS. The TriggerNewIER interaction sent J-Series message data as an IER from the Aircraft Simulator to NETWARS. NETWARS then processed incoming IERs and transmitted the status of these messages using the IERInfoUpdate interaction.

These HLA interactions are handled within the NETWARS scenario by two models: 1) the HLA_Interface model and 2) the Nw_hla_interactions model. The HLA_Interface model handles communication to and from the RTI, while the Nw_hla_interactions model packages data from the HLA_Interface model and distributes it to the NETWARS Operating Environment (OE). The OE relays the data and events to the corresponding NETWARS OPFACs. For the Aircraft Simulation, Java-based HLA implementations were added to the code to handle RTI interactions.

This HLA implementation phase of the project presented new technical challenges. Although aircraft state interactions were working properly, IER interactions were causing simulation termination. We discovered the Link 16 models developed by SPAWAR were not compatible with HLA. The modifications made to the classification field to allow for NPG selection were not being handled correctly by the OE_IERS process module, which interacted with the NW_hla_interactions model. To correct this, we modified the OE_IERS process model using OPNET Modeler to allow the SPAWAR classification modifications to pass through. Figure 8 shows the OE_IERS process model.

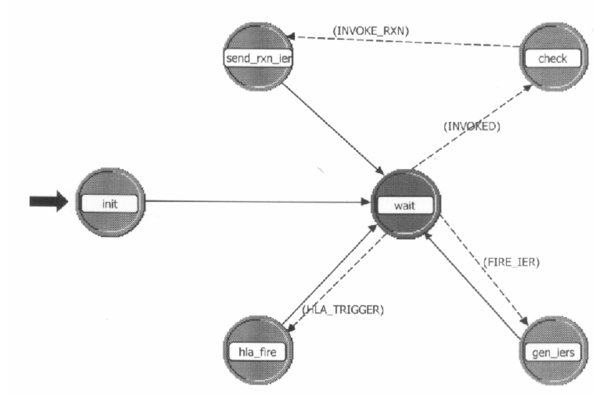

Figure 8: OE_IERS Process Model Diagram

Having solved the problem preventing HLA IER interactions, the next step was to determine how to regulate simulation time for both Federates. To accomplish this task in the shortest amount of time possible while maintaining the scope of the project, we decided to utilize a NETWARS provided federate application called HLA Commander. The HLA Commander acts as the Master Federate and creates the federation which is joined by NETWARS and the Aircraft Simulation. It provides time regulation for the simulation and provides a display that tracks NETWARS OPFACs and message transmission. The program also allows user input during the course of the simulation. Figure 9 shows the final distributed simulation architecture and the associated data interactions.

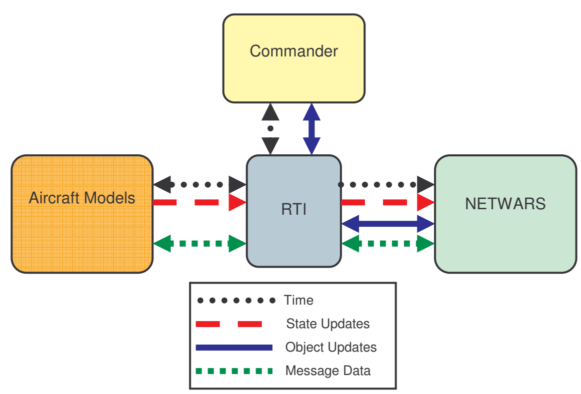

Figure 9: Distributed Simulation Diagram

Time is transmitted from the Commander to the RTI and then relayed to both NETWARS and the Aircraft Simulation. Platform state data flows from the Aircraft Simulation to NETWARS and then to the Commander (for display purposes). Message data in an IER form is transmitted from the Aircraft Simulation to

NETWARS and returned in the form of message status. If the message was sent and received properly in the NETWARS network simulation, the status sent to the Aircraft Simulation will indicate "received" along with the IER ID field containing the actual J-Series message bit data. This data will be processed by the Aircraft Simulation using each platform's Link 16 message implementation as verified by data from iSMART. If the message is interpreted correctly, the Aircraft Simulation will determine the next course of action and messages to be sent. By using HLA, we were able to close the feedback loop and complete the proof-of-concept demonstration.

RESULTS

The Airborne Network and Data Link Technology Analysis program proved that NETWARS could be used in conjunction with external simulations and iSMART data to provide insight into the interoperability of platform data link integrations. The level of data used was similar to that available during the planning stages of a new data link integration and showed that the methodologies used here could be applied to a weapon system during the system design phase of development.

The work described in this paper resulted in a body of experimental methodology data showing successful ways of integrating disparate modeling and simulation sources across an open architecture. It also demonstrated a need for a consolidated set of analysis tools and criteria for grading data link interoperability integration.

The data and simulations developed here could be used to visually verify the operation of a given network and scenario. The simulations provide feedback during the operation if messages are unsuccessful or are not processed as intended. This feedback provided immediate understanding of interoperability issues in an operational context.

The simulation could also be used to validate fielded data link integration through the use of recorded mission data link traffic and automated comparison with the recorded output of a simulation of the same mission. For use by platform integrators, however, a more structured, automated approach to analysis with many other platforms is indicated and warrants further research.

CONCLUSIONS

We have presented the methodology used to develop a proof-of-concept demonstration designed to discover platform to platform interoperability issues. The initial demonstration was performed using Link 16 as a case study; but, the framework could be used to test any number of future data link technologies. By using NETWARS and the OPNET HLA module, new radio models and new data models can be easily added to create accurate simulations for platform interoperability assessments.

Our recommendations for subsequent research efforts include creating more precise aircraft decision models, expanding to large-scale force engagement simulations, creating new open architecture interfaces, and developing a more robust HLA interface. The technical challenges that remain include determining a way to speed up the NETWARS HLA interaction process, updating the OE_IERS process model for other high speed tactical data links, (e.g. Flexible Access Secure Transfer and Tactical Targeting Network Technology), radio model compatibility, and updating NETWARS to allow statistics gathering from multiple consumers. Efforts continue with NETWARS and OPNET support staff to solve these issues. NETWARS and the HLA OPNET modules made the Airborne Network and Datalink Technology Analysis Program proof-of-concept demonstration possible and will form the backbone of the Airborne Networking Simulation Environment (ANSE) project. ANSE will focus on the expansion of the work shown here into a flexible, open-architecture simulation environment tailored to interoperability assessment. This approach provides easily extensible networks, platforms and data link waveforms. This effort will directly build on the work presented here and extends it beyond proof-of-concept and into a production setting.

Our clients deemed the Airborne Network and Datalink Technology Analysis Program a "success story." As a demonstration of a rapid proof-of-concept simulation integrating multiple off-the-shelf systems in an open-architecture framework, the effort broke new ground and explored new territory with NETWARS, HLA and iSMART.

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