Proceedings of the 2014 Winter Simulation Conference
A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.

MODELING OF COMPLEX SCENARIOS USING LVC SIMULATION

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ABSTRACT

Interoperation of simulation models is an important issue due to high level requirements of reusability, scalability, and eventually training effect. Achieving Live, Virtual and Constructive (LVC) simulation interoperability is a main goal and a major challenge for M&S community. High interoperability quality in LVC simulation environment is a technologically complex task, being affected by multiple factors, and the task is not yet satisfactorily characterized and studied. This research presents an experimental LVC simulation framework to model and simulate complex war fighting scenarios. Our experimental framework implementation discusses key issues for LVC interoperability encountered during our experimentation. A case study is presented to discuss LVC integration and interoperability challenges. Our experimental research aim is to contribute to the definition and design concepts of LVC simulation systems developments, technological considerations and adequate interoperability.

1 INTRODUCTION

Since federated simulations must be as agile, robust, and interactive as the operational environment they support, interoperation of existing LVC simulations is not easy and has some development challenges. The challenges include integrating multiple simulation platforms with different semantics, and regulating complex interactions between diverse simulation models. Large single models that enable analysis of systems of systems are not effective because single modeling cannot account for all the complexities. Instead, modeling and analysis must be done in a distributed and parallel fashion.

We are building an experimental LVC simulation framework using diverse simulation platforms and analytical tools. This framework will be utilized to present military personnel with tactical mission scenarios, validation of command and control (C2) strategies, and joint military operation exercises that represent today's war fighting scenarios with a high degree of realism and experiential learning opportunities with different levels of complexity in military operations. The objective of our developments is to provide a collaborative scenario development environment that supports the creation, execution, and reuse of simulations that are capable of integrating multidisciplinary models representing the elements of complex scenarios. Our experimental simulation framework development efforts for modeling various war fighting scenarios are based on the HLA and the Run-Time Infrastructure (RTI).

978-1-4799-7486-3/14/$31.00 ©2014 IEEE

In this paper, we present an integrated LVC training solution and show how this provides realistic command team training. The solution is composed of several fully interoperable simulators that allow users to execute realistic missions, interacting in common realistic scenarios with distributed human and synthetic players from own and other units.

1.1 LVC Simulation and Training

Current practices in complex war fighting training heavily rely on either coordinated scheduling of personnel or training assets. There are always challenges when it comes to training soldiers. Limited availability of training ranges and assets, and increasing live training costs, are challenges that make it increasingly difficult to maintain high standards. Some of these challenges can be mitigated in simulation based training. Virtual assets can easily be created and be reused, and weather conditions can be controlled to a high degree so that training is optimal. LVC systems eliminate geographical constraints and allow military personnel and commanders to train in almost any operating area. In addition, they enable commanders to be exposed to more training scenarios in a shorter period of time. There has been always a requirement for a Cost-effective mixture of simulators and the use of LVC entities operating in common real and synthetic environments.

1.2 Development of Complex War fighting Scenarios

Since joint and multi-national operations are highly demanding and complex, soldier and commander must perform different levels in very difficult environments requiring high standards, currency and proficiency. The effectiveness of their missions depends heavily on how well the scenarios are defined and the level of information or resolution that wants to be presented to the soldiers or commanders during training. The development of complex combat scenarios requires integration of several simulators. For example, for a Close Air Support training (CAS), the simulators can be composed of gunner simulators, several forward air controller and pilot simulators, computer generated forces, a number of battle field management systems, and simulated multi-channel radio communication.

As we define our experimental LVC framework different levels of information (multi-resolution), the desired level of interaction and the required different simulation environments and capabilities. The concept of aggregation and disaggregation techniques during training scenario definition enables the presentation of different level of information at different required levels of military personnel. Complex war fighting scenarios require careful hardware and software considerations to provide the adequate level of interaction, coherency and interoperability during the implementation of LVC simulation system for training military personnel at different levels.

1.3 Experimental LVC Simulation Framework for War fighting Scenarios

War fighting scenarios require different levels of information for the different live, virtual and constructive simulation systems that support the definition of complex military learning scenarios to achieve the desired level of operational effectiveness of military personnel. The integration of different type of simulation environment and platforms is a challenging task. Regardless of the different level of information or resolution presented in the training environments, a common operational picture (COP) needs to be present to enable adequate command control communications between the different military training applications and domains.

Figure 1 depicts the general experimental LVC framework for the development of war fighting scenarios for different military training applications and domains. There are a number of technological aspects and military domain characteristics that cannot be implemented in a single large scale simulator. The LVC framework adopts a systems of systems approach in which a number of different type of simulators with different levels of information enable the definition of a simulation system with a common conceptual interoperability modeling approach. Wang et al, discusses the use of the Levels of Conceptual

Interoperability Model (LCIM) as a conceptual modeling approach to achieve different levels of interoperability in the modeling and simulation domain (Wang et al. 2009). Further, it describes that a number of artifacts and components are needed to achieve the desired level of data abstraction and systems processes understanding constraints from reality to implement simulation models. These technological artifacts (i.e., middleware) and different simulator components support the definition and implementation of war fighting and military training simulation scenarios and systems.

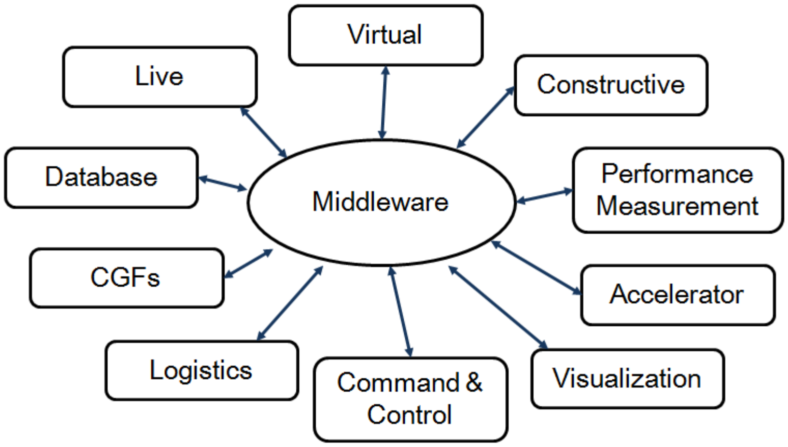

Figure 1: Experimental LVC Simulation Framework.

The conceptual interoperability modeling approach can use the common simulation interoperability standards defined in industry such as the High Level Architecture (HLA) and the Base Object Model (BOM). These standards provide the level of semantics and entity data management technique and mechanisms to develop adequate interoperation between different technological artifacts and simulation components in war fighting scenarios and military training system. In addition, the HLA and BOM standards supports the multi-resolution modeling (MRM) efforts to present the right level of information in the different simulation systems and enable adequate war fighting engagement measurement, visualization, command control and parallel computing advantages.

2 A CASE STUDY

2.1 Overview of Setup

In our experimental implementation, an LVC simulation configuration was defined to create complex war fighting scenarios. The distributed simulation configuration was based on the HLA standard with a federation consisting of six federates including two virtual simulators, a constructive simulator, a component based simulation environment, a parallel/distributed simulation engine, and an engagement measurement component. Figure 2 depicted the architecture of the simulation.

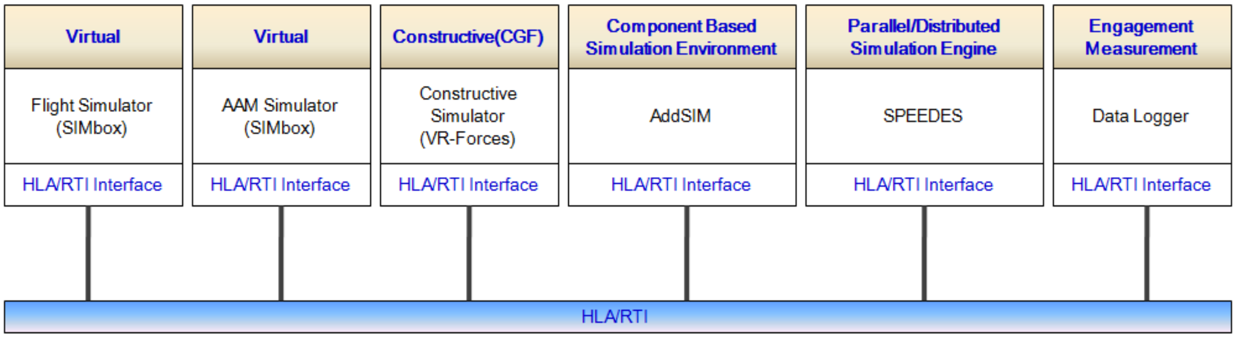

Figure 2: The Architecture of the LVC Simulation for Case Study.

Each federate resides in an individual computing node and were able to interoperate in the federation through the RTI. Details about each federate are explained in the following section.

2.2 LVC Configuration Description

In this section, we describe the different systems in Figure 2 in more detail, including functionality and how they were configured and used.

2.2.1 Virtual Flight and Anti-Air Missile Simulator

There are a virtual flight simulator and an anti-air missile simulator in the simulation framework. The simulators act as real-time virtual simulators that operators control an aircraft and an anti-air missile in real time. We used SIMbox software for the simulators. SIMbox from SIMGON is a Commercial off the Shelf (COTS) simulation system with distributed capabilities for Modeling, Simulation & Training solutions. SIMbox is a system architecture which allows users to create simulation-based training. Building a new system, such as a new engine, control systems are possible at a finer level of detail. SIMbox acts as a virtual flight simulator and a virtual anti-air missile simulator in the federation. Figure 3 shows the simulators in the SIMbox training environment.

Figure 3: SIMbox training environment for F-16 fighter and SA-8 anti-air missile launcher. This environment can be integrated with an actual cockpit (with joysticks, etc.) to provide more realism.

2.2.2 Constructive Simulation

The simulation framework includes a constructive simulation which creates and operates Computer Generated Forces (CGF). We adopted the VR-Forces to participate in the federation as a constructive simulation. VR-Forces is a COTS simulation system developed by VT MÄK as an option to government solutions. VR-Forces is mostly used for military training at the tactical level because it provides high level of details about battlefield. The scenario demonstrated diverse military situations and difficulty of military operations in a dense city. Figure 4 shows captured images of a sample military operation scenario developed using VR-Forces.

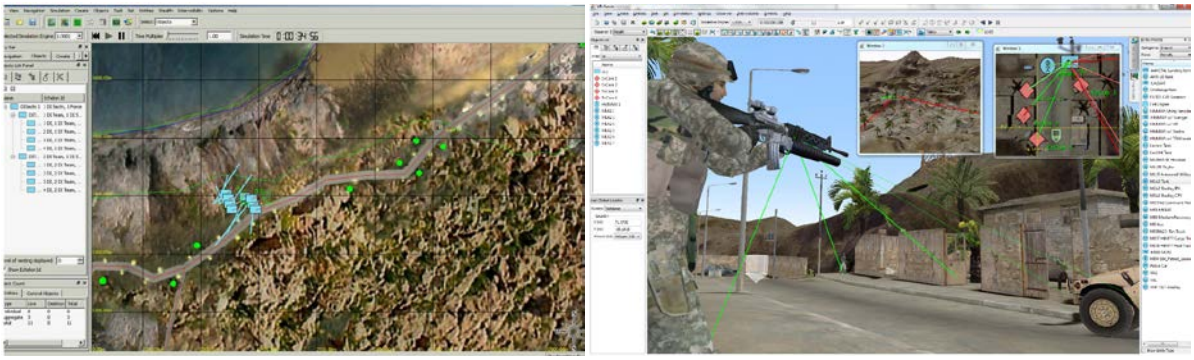

Figure 4: GUI and Sample Scenarios of VR-Forces.

2.2.3 Component Based Simulation Environment

A component based simulation environment participates in the simulation framework which acts as an independent simulation federate. AddSIM was used as the component based simulation environment. AddSIM is a component-based weapon system simulation environment using engineering models of weapon systems to enhance interoperability, reusability, and composability of weapon simulation models. The first version of AddSIM was developed by the Agency of Defense Development (ADD), South Korea from 2009 to 2011 (Lee et al. 2012).

AddSIM adopted layered architecture design to facilitate the model development and the maintenance of the software as depicted in Figure 6. The layered architecture also prevent from duplication of functions at each layer. For example, the kernel layer which is the core component of AddSIM consists of six functions including parallel/distributed management for parallel processing in distributed environment as well as the basic five functions of event management, time management and simulation management, run-time object management and persistence/rollback management.

AddSIM also provides a Graphic User Interface (GUI) for modeling high fidelity engineering level models. Users can model weapon system, atmosphere, ocean, and geography using the GUI. Figure 6 shows the GUI of AddSIM.

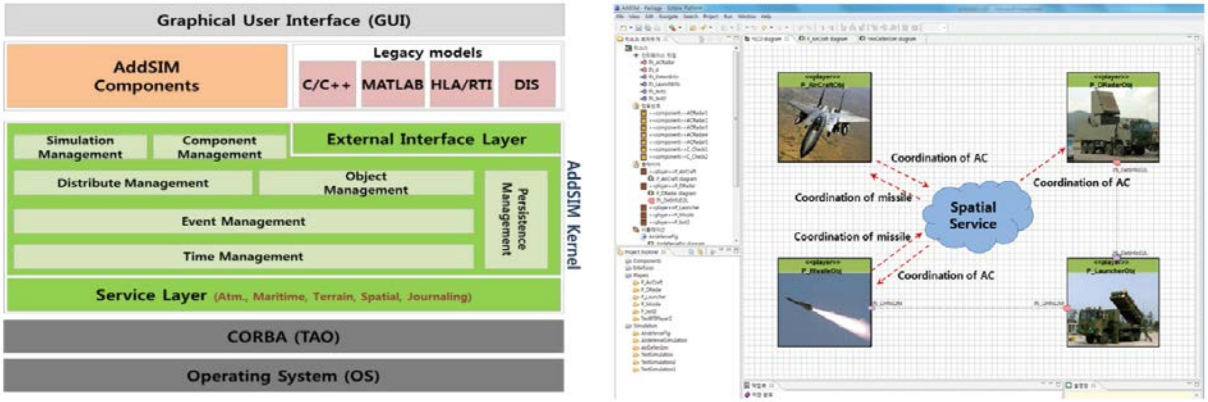

Figure 6: Architecture and Graphic User Interface (GUI) of AddSIM.

AddSIM has capability to integrate other simulations developed using C/C++ or Matlab in distributed simulation environment. The purpose of the capability is to support reusability and interoperability with other legacy simulations resources. The interoperability is implemented through standard interoperability architectures such as the High Level Architecture (HLA). For this reason, AddSIM provides three external interfaces such as C/C++, Matlab, and HLA interface.

2.2.4 Parallel/Distributed Simulation Engine

The LVC simulation framework required the addition of "accelerators" in order to improve the real-time capabilities and data integrity. We used a high-performance computing platform which is the Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES) (Fujimoto 2003; Steinman et al. 1999). SPEEDES is a general purpose discrete-event distributed simulation framework that can be used to simulate a wide variety of situations. In our experimental implementation, SPEEDES acts as a discrete event simulation model which represents the logistics life cycle of F-16 aircraft in the federation. Figure 7 shows the architecture of SPEEDES.

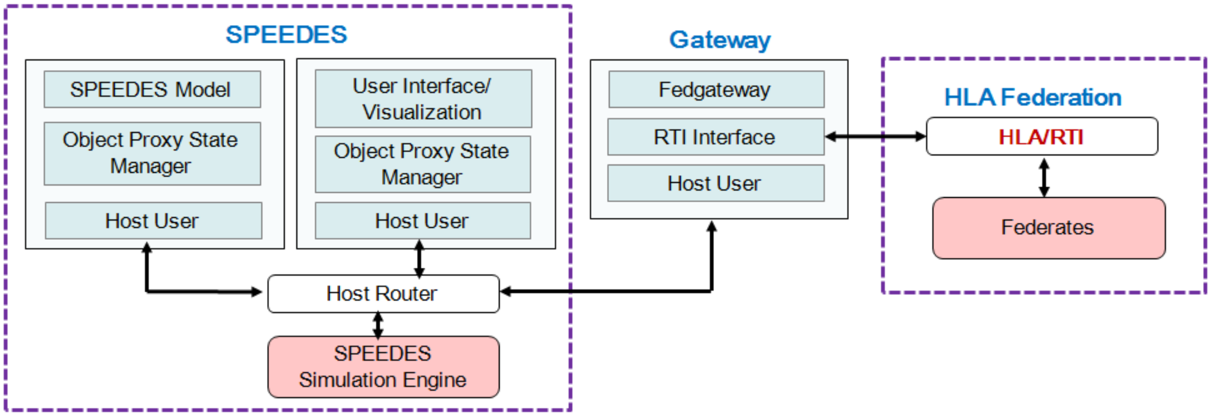

Figure 7: Architecture of SPEEDES.

2.2.5 Engagement Measurement Component

An engagement measurement component participates in the federation to provide an analysis function by recording the HLA/RTI traffic data. The component is used for after-action-review, playback/record and general engagement results. The measurement engagement component was developed with VT MÄK "Data Logger". The MÄK RTI implementation interfaces with a "Data Logger" tool developed by VT MÄK technologies. The Data Logger is composed of a series of C++ libraries that interact with the HLA/RTI API implementation. Figure 8 depicts the general arrangement/configuration of the measuring engagement interface.

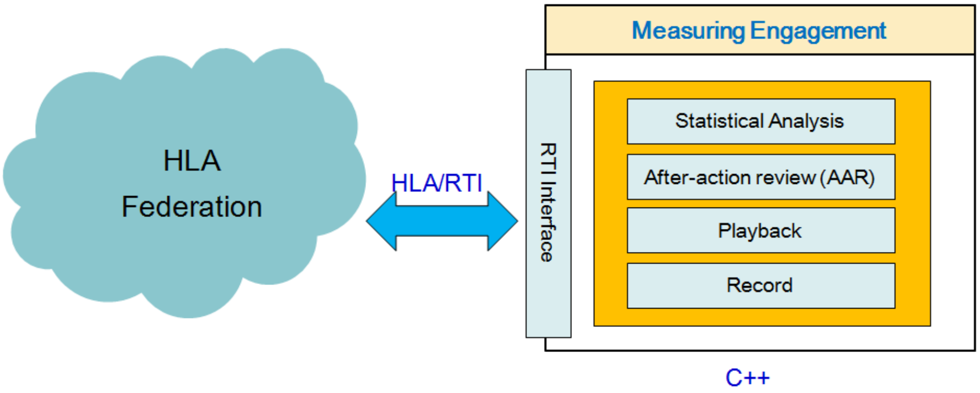

Figure 8: Measurement Engagement Component Arrangement.

3 INTEGRATION AND SCENARIO GENERATION

Finally, all federates are integrated through HLA and RTI. Total six federates are in the federation. We used HLA 1516 Evolved which is the latest version of HLA standard. Figure 9 below shows complete federation of simulation platforms.

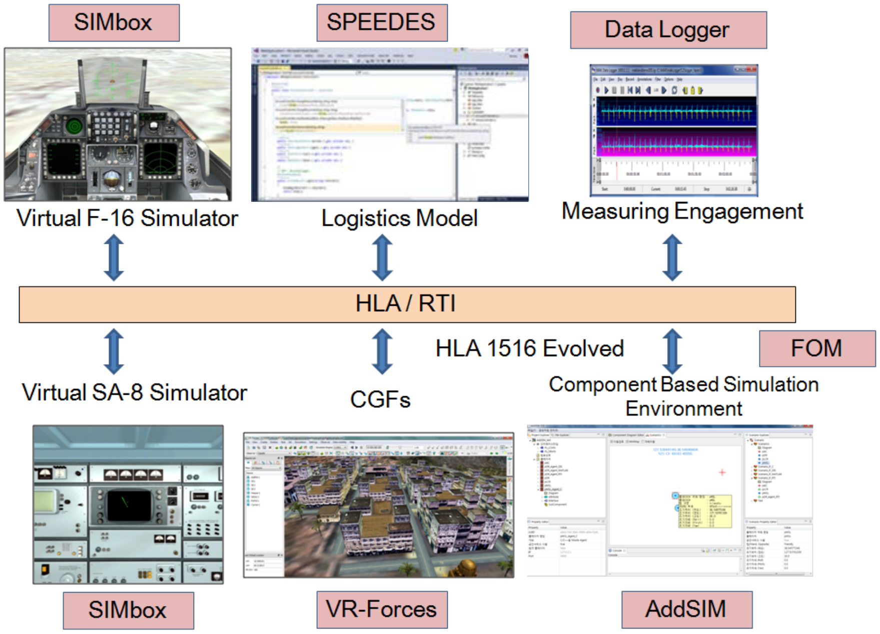

Figure 9: Interoperability through HLA.

After the integration, complex sample scenarios were created. We created common synthetic environment where all the simulations entities participate in to conduct engagements. The purpose of the scenario generation is to evaluate whether the models properly follow the designed setting. We located the CGFs, created routes and waypoints, set Artificial Intelligence (AI), and configured other parameters. In the scenarios, players and components implemented air-to-air engagements and air defense scenarios. The scenarios execution showed successful compliance to the designed setting. Figure 10 shows the setup of the engagement scenarios.

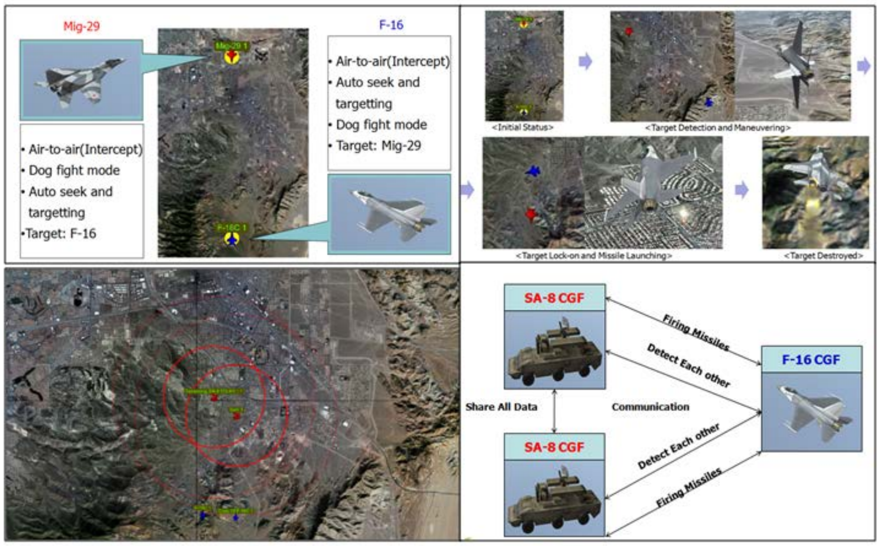

Figure 10: Engagement Scenarios.

3.1 LVC Simulation Entities Mapping

Our experimental framework needed adequate simulation entity mappings to achieve proper interoperability and the required interaction in the defined war fighting scenarios. Adequate interoperability and interactions between components were implemented through the HLA distributed simulation standard and using the "Real-time Platform-Level Reference" (RPR) federate object model version 2.0. The LCIM semantic (L3) and syntactic (L2) prescriptive roles of interoperation as described by Wang (2009) were implemented adopting the HLA 1516 Evolved with the RPR FOM 2.0 standards for information exchange and data structure in our simulation component implementations. In particular, our LVC component simulation engines allowed the HLA entities definition and interactions handling thru a "DisEntitiesMap" XML file that contains both generic translations as well as specific translations. Figure 11 depicts the part of default XML entities mapping scheme provided by the SIMbox simulation engine. New XML files with generic and specific entities mapping schemes can be created to implement the High Level Architecture (HLA) compliance of all the acting live, virtual and constructive simulation components developed and their corresponding scenarios in a distributed simulation exercise.

```
<DisEntitiesMap>
  <GeneralTypeMap>
    <GeneralDisEntityMapping hlaEntityTypeName="Aircraft" simEntityTypeName="F-16C" disBridgeSimEntityTypeName="DisBridgeAircraft"/>
    <GeneralDisEntityMapping hlaEntityTypeName="Aircraft" simEntityTypeName="AH-64" disBridgeSimEntityTypeName="DisBridgeAircraft"/>
    <GeneralDisEntityMapping hlaEntityTypeName="Munition" simEntityTypeName="AIM-9" disBridgeSimEntityTypeName="DisBridgeWeapon"/>
    <GeneralDisEntityMapping hlaEntityTypeName="SurfaceVessel" simEntityTypeName="Merchant_Vessel" disBridgeSimEntityTypeName="DisBridgeShip"/>
    <GeneralDisEntityMapping hlaEntityTypeName="CulturalFeature" simEntityTypeName="Aircraft Shelter 1" disBridgeSimEntityTypeName="DisBridgeBuilding"/>
    <GeneralDisEntityMapping hlaEntityTypeName="Human" simEntityTypeName="HLAMan-M16" disBridgeSimEntityTypeName="DisBridgeGround"/>
    <GeneralDisEntityMapping hlaEntityTypeName="GroundVehicle" simEntityTypeName="Hummer" disBridgeSimEntityTypeName="DisBridgeGround"/>
    <GeneralDisEntityMapping hlaEntityTypeName="GroundVehicle" simEntityTypeName="Sam" disBridgeSimEntityTypeName="DisBridgeGround"/>
    <GeneralDisEntityMapping hlaEntityTypeName="Aircraft" simEntityTypeName="MiG-29" disBridgeSimEntityTypeName="DisBridgeAircraft"/>
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  </GeneralTypeMap>
  <SpecificTypeMap>
    <SpecificDisEntityMapping disEntityKind="1" disDomain="2" disCountryCode="225" disCategory="1" disSubcategory="9" disSpecific="0" disExtra="0" hlaEntityTyp
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    <SpecificDisEntityMapping disEntityKind="1" disDomain="2" disCountryCode="225" disCategory="1" disSubcategory="3" disSpecific="3" disExtra="3" hlaEntityTyp
```

Figure 11: SIMbox HLA Entities Mapping.

In addition to the simulation entities, simulation attributes and simulation events mapping the SIMbox simulation engine has a particular way to handle "Weapon Loadout Data". The creation and deletion of weapon entities and their data handling and translation mechanism in the HLA distributed simulation environment are implemented similar to the Distributed Interactive Simulation (DIS) entity mapping required for the "SIMbox HLA Entities". The loadout properties defined in the simulation engine scenario definitions have to be mapped to an XML file called "LoadoutAuxiliaryData.xml" in the SIMbox HLA content extension implementation. The weapon "Loadout Auxiliary Data" is required for proper interoperability between simulation engines. The required HLA entity data mappings were implemented and adequate interoperation and the desired level of interaction between simulation environments were accomplished in our defined war fighting scenarios.

3.2 Live Component

The integration of the live component to the LVC simulation experimental framework was implemented with a tablet PC using a SIMbox thin client. The application of tablet computing provided the flexibility necessary for the implementation of command control type military operations to simulate communications with military ground tactical units to coordinate air to ground engagement operations. The live simulation model consists of two sub-components: a live server and a live client (SIMbox thin client). Figure 12 shows the live simulation model.

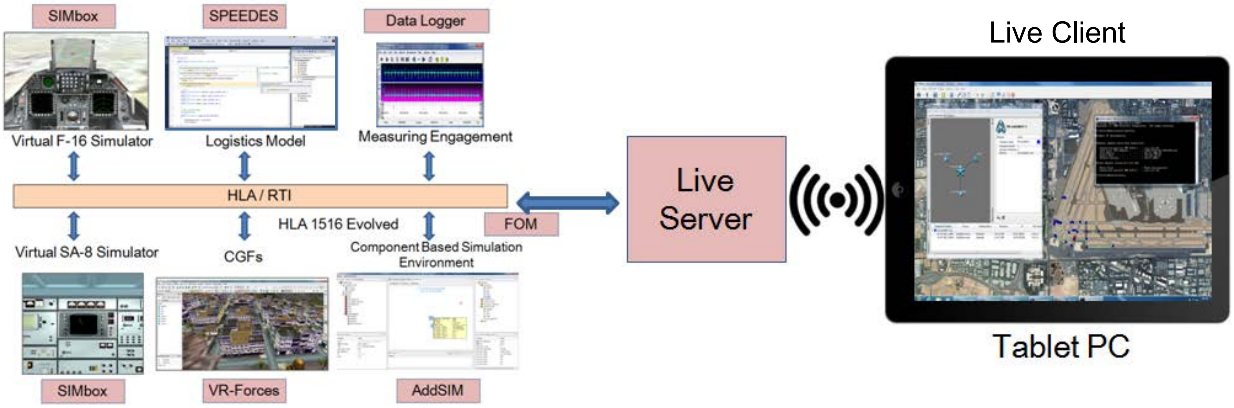

Figure 12: Live Component in the Test bed.

The live component interoperation was implemented through the integration of the table PC using a WIFI communication protocol. The information was delivered through the live server and HLA/RTI. The updated information from the simulation framework also was transmitted to the live client through the HLA/RTI and the live server.

4 CONCLUSION AND FUTURE WORK

In this paper, our experimental LVC simulation framework was used to model and simulate complex warfighting scenarios. We used different virtual and constructive simulation platforms to establish the LVC architecture and provide the adequate interoperation of different level of information as required to define the war fighting scenario and military training applications. The experimental framework was able to provide high fidelity environments that can represent different military operational situations that trainees could encounter. Also, the simulation engines utilized in our framework provided a high level of visualization to simulated realistic training environment in which trainees can acquire combat skills and experiences.

We added a live component into the experimental simulation framework using a tablet pc. After the experimentation with the framework, it was realized that LVC simulation system implementation required a high level of integration to achieve the adequate level of interoperability. In our experimentation we were able to utilize an FLT type terrain database file developed by SIMbox. However, simulation terrain environments are an essential part of LVC simulation implementations and to maintain the required level of coherency between different simulation platforms. The results of this experimentation provide a good understanding of the design concepts of LVC simulation systems development, their technological considerations and the level of integration required to achieve an adequate level of interoperability among participating simulation environments. In the future, we expect to integrate additional simulation platforms to expand the range of possible scenarios. Consequently, new simulation platforms will require expanding the existing integration of the simulation framework. These enhancements should allow for greater scenario flexibility and reduced development, configuration, and operational costs.

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