Overview of Simulation Architectures Supporting Live Virtual Constructive (LVC) Integrated Training

Yang Gao
Simulation Training Center
Naval Aviation University
Huludao, China
gy_hkdx@126.com

Yuanyuan Zhang
Simulation Training Center
Naval Aviation University
Huludao, China
109889354@qq.com

Xiaoguang Zhou
Simulation Training Center
Naval Aviation University
Huludao, China
zhouxiaoguanghf@163.com

Huan Lu
Simulation Training Center
Naval Aviation University
Huludao, China
53956090@qq.com

2021 6th International Conference on Control, Robotics and Cybernetics (CRC) | 978-1-6654-2437-0/21/$31.00 ©2021 IEEE | DOI: 10.1109/CRC52766.2021.9620135

***Abstract*—For Improving the interoperability, reusability and composability of simulation resources, creating a unified Live-Virtual-Constructive (LVC) integrated simulation architecture has always been a major goal in the modeling and simulation (M&S) field. This paper summarizes the creation process and potential architectures involved. Firstly, the developing history of distributed simulation architecture is introduced from SIMMNET to JLVC2020. Then, the simulation architectures of TENA, JLCV Federation and JLVC2020, which have great potential in the future, are elaborated. Finally, the near-to medium-term future construction plan of LVC integrated simulation architecture is given through three development routes. The related discussion has important reference value for promoting the construction capacity of joint training simulation.**

Keywords—simulation architecture, Live Virtual Constructive (LVC), Test and Training Enabling Architecture (TENA), JLVC Federation, JLVC2020

I. Introduction

Simulation architecture is the core of modeling and simulation (M&S) technology. Since the 1980s when the U.S. forces adopted computer simulation for training, the architectures of Distributed Interactive Simulation (DIS), Aggregate Level Simulation Protocol (ALSP), High Level Architecture (HLA), and Test and Training Enabling Architecture (TENA) have been proposed one after another to meet the needs of interconnection and interoperability of three kinds of simulation resources: Live, Virtual and Constructive. However, they are heterogeneous in model specification, communication protocol and time characteristics, which makes it difficult to integrate the three kinds of simulation models [1, 2]. After years of efforts, they are good interoperability in modeling and simulation (mainly refers to virtual simulation and construction simulation), test and training (mainly real simulation), but the interoperability between these two fields is still poor, and the reusability and composability of simulation resources are far from the requirements.

Therefore, creating a unified "Live Virtual Constructive (LVC)" integrated simulation architecture has become a major goal in the M&S field. LVC refers to the networking integration of real equipment, simulator and computer generated forces (CGF) system to build an integrated environment (as shown in Fig. 1) that can interoperate among real training (L), virtual simulation (V) and construction force (C), and realize the simulation tasks covering three levels of individual, system and integration [3].

Fig. 1. LVC integrated simulation environment

Distributed simulation architecture can provide basic technical support, unified communication protocol and consistent message format for interconnection and interoperability of LVC resources, which is the technical standard to realize LVC operation. To guide the construction of LVC, the U.S. forces released the LVC Architecture Roadmap (LVCAR) in 2008 [2], and then proposed to build JLVC Federation [4] and JLVC2020 [5] as LVC support environment. It can be said that the U.S. forces have carried out lots of LVC research, are the standard-setters of current mainstream simulation architectures, and represent the international advanced level in the M&S field.

This paper focuses on the developing history, composing structure and constructing plan of the distributed simulation architecture supporting LVC, which can provide important reference and guidance for developing simulation training systems and exploring large-scale joint training methods.

II. Development History of Simulation Architecture

The U.S. DoD has always listed M&S as an important defense critical technology, and established the most complete simulation architectures all over the world, as shown in Pig. 2. Although their technical characteristics and application fields are different, they all have a common goal which is to solve the problems concerning interoperability, reusability and composability of LVC assets.

In 1983, DAPRA launched the Simulation Network (SIMNET) plan, which aims to connect the scattered simulation platforms through the network for cooperative combat training. It marks the beginning of distributed simulation.

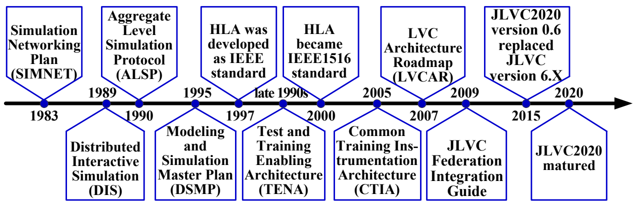

Fig. 2. Development of simulation architecture

In 1989, absorbing the achievements of SIMNET, The U.S. DoD and industry sector jointly developed DIS architecture based on the interconnection of heterogeneous networks, forming the DIS 2.X standards, which were adopted by many projects.

In 1990, MITRE Company designed ALSP with the support of DAPRA, which extends the advantages of distributed simulation to cluster force training, so that different aggregate level simulations can cooperate with each other.

SIMNET, DIS and ALSP all realize the interconnection of similar functional simulation applications, and thus have limited interoperability and cannot meet the increasingly complex requirements of combat simulation [1].

In 1995, with the purpose of promoting the interoperability between all types of models and simulations and between them and C4I system, also promoting the reusability simulation components, the U.S. DMSO put forward Modeling and Simulation Master Plan (DSMP), the core of which is HLA. It is required that all simulation applications developed by services and arms for different fields must comply with HLA specifications. In 1997, HLA was formally developed as an IEEE standard, and final definition was completed the following year. In 2000, HLA became a series of IEEE 1516.X standards. In 2008, the proposal of HLA Evolved greatly improved the interoperability and reusability of HLA, and expanded its application scope [6].

In the field of test and training, the actual test equipments require high real-time performance, while HLA is not suitable for hard real-time application environment. In the late 1990s, the U.S. DoD launched the Foundation Initiative 2010 (FI2010) project, which defined TENA [7]. TENA provides more specific capabilities required for test and training, has also made improvements in communication mechanism, time management and other aspects, aiming to achieve inter-operability among ranges, facilities and simulations in the field of test and training, and promote reusability and composability of these resources. The development of TENA 6.0 was completed in 2008.

In 2005, the U.S. forces developed Common Training Instrumentation Architecture (CTIA), which is designed to provide test support for the Live Training Transformation (LT2) series products. CTIA is the only service-oriented architecture, and has no competition with other architectures. The main difference between CTIA and TENA is that CTIA provides source code which is not limited by government power and can be used for users in training field, to support the development of entity ground mobile training system [8].

These architectures focus on solving the problem of resource integration at different levels of L, V and C, and their applications overlap partially, but most are in different fields, as shown in Fig. 3 below. The U.S. DoD has conducted a survey on the current use of various architectures, and the results are as follows: ALSP is about 5%, DIS 35%, HLA 35%, TENA 15%, CTIA 3% and others account for about 7% [9]. So DIS and HLA are the most widely used. Although TENA is still relatively low in usage, it is increasingly getting attention.

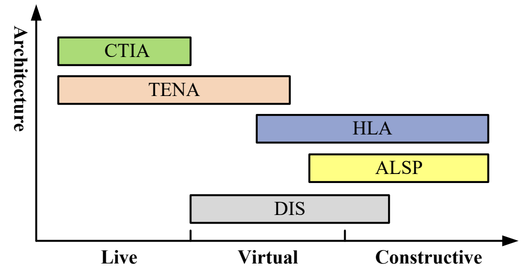

Fig. 3. Application of simulation architecture

There are many differences in time mechanism, underlying services, data format, operation management and other aspects of these architectures, which makes it difficult to achieve interconnection and interoperability among them, and bring severe challenges to the joint simulation training. Under the background, DMSO launched the research on LVCAR in 2007. The main goal is to put forward a vision and strategy to achieve a significant improvement in interoperability of multi architecture [2]. In 2010, DMSO released LVCAR implementation report again, pointing out five main tasks: LVC public support capacity building, LVC architecture convergence, common gateway and bridge, joint composable object model and LVC environment management [10].

In 2009, the Joint Operations Command (JOC) issued "JLVC Federation Integration Guide", proposing to establish a JLVC Federation as the technical support environment for LVC, thus providing more practical and effective joint training support for military activities form tactical level to campaign level [4].

JLVC Federation is constructed by traditional subsystem integration. For large-scale simulation system, integration is difficult and development is unsustainable. In order to change the original simulation environment, Cloud-Enabled Modular Services (CEMS) based JLVC 2020 is proposed to replace large-scale simulation system with small module service units with specific functions [5]. As results, a flexible, realistic, economical and efficient LVC support environment is formed to meet the present and future training needs. In 2005, JLVC2020 version 0.6 replaced the declining JLVC Federation version 6.X. In 2016, JLVC2020 version 1.0 was released.

III. Analysis on Potential Simulation Architecture

Since DIS and HLA have been well known and widely used [11,12], we will not introduce them any more. This section focuses on the architecture of TENA, JLCV Federation and JLVC2020, which have great development potential in the future.

A. Test and Training Enabling Architecture

According to the extended C4ISR architecture, TENA establishes the overall technical framework of logical range resource development, integration and interoperability from the aspects of operation, technology, software, application and product line, as shown in Fig. 4, which mainly includes five parts [7].

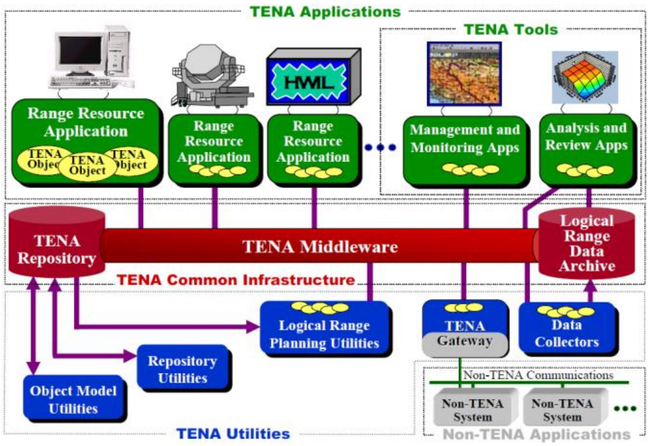

Fig. 4. TENA Architecture

1) TENA Applications: including Range Resource Application and TENA Tools. Range Resource Application refers to rang instrument or processing system compatible TENA. TENA Tools is reusable TENA application, which is used for life cycle management and monitoring of logical range events. Both interact with TENA Common Infrastructure through TENA Object Model.

2) Non-TENA Applications: including range test equipment/processing system, tested system, simulation system and C4ISR system that do not conform to TENA specifications. Although these are not compatible with TENA, they are needed for test.

3) TENA Object Model: encodes all the information transmitted during range events, and is the common language for communication between all Range Resource Applications and TENA Tools. It can be considered that TENA Object Model is a set of range interfaces and protocols defined by object-oriented packaging design.

4) TENA Common Infrastructure: is the core of TENA, including: TENA Middleware, which is the communication mechanism of all objects in TENA Object Model used for real-time information exchange; TENA Repository, essentially, is a large-scale database, which stores the information of TENA Object Model, the executable versions of all TENA Utilities and Tools, the software library of TENA Middleware, TENA architecture documents and the archive information of previous logical ranges; Logical Range Data Archive, which stores all persistent information related to logical range operation, such as scene data, data collected during range events and summary information, and provides retrieval function.

5) TENA Utilities: are application programs designed to use and manage TENA, such as repository manager, resource browser, logical range object model tool component, TENA gateway, etc.

The above five parts are divided to meet the important technology driven requirements of TENA, i.e. interoperability, reusability and composability. Among them, TENA Object Model and TENA Common Infrastructure for communication are specially used to solve the interoperability problem. The reusability problem is overcame by common infrastructure and various gateways, which can connect TENA logical range with other architectures, protocols and systems. Composability is realized by components of TENA Repository, TENA Tools based on object definition and TENA Utilities.

B. JLVC Federation

JLVC Federation builds a large-scale comprehensive simulation training environment by jointly running the federated subsystem models. JLVC Federation architecture is given in Fig. 5 below, which is mainly composed of Core Simulation and Support Toolbox, Distributed Simulation Support Technology System, Command and Communication Network Facilities, large numbers of Construction Simulation Models, and Live Training Environment [13, 14].

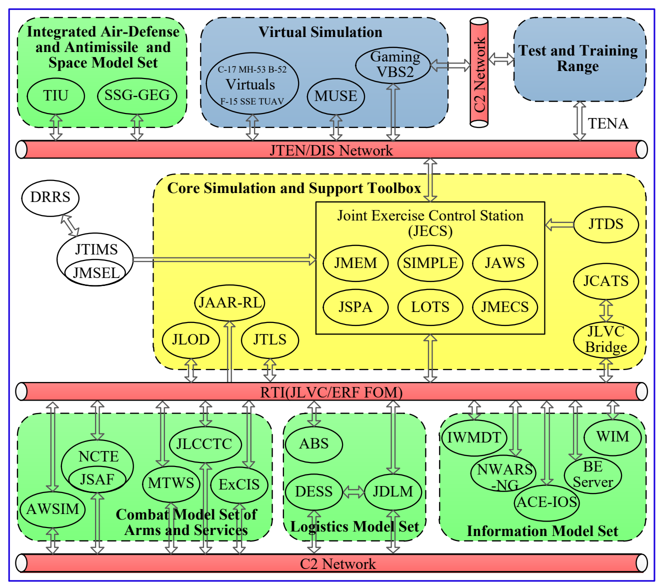

Fig. 5. JLVC Federation Architecture

1) Construction Simulation Models. JLVC Federation integrates the main existing U.S. forces construction simulation systems, including services and arms combat model set, logistics model set, intelligence information model set, integrated air-defense and antimissile and space model set, etc. These models carry out joint interactive operation to build a multi-dimensional virtual battlefield space including land, sea, air, space, electron and network.

2) Live Training Environment. The U.S. forces pay great attention to actual combat training, and take Live Training Environment as an important part of JLVC Federation. In terms of command, there is Global Command and Control System (GCCS), and in terms of operation, there are various weapon equipment simulators, Multiple Unified Simulation

Environment (MUSE), Virtual Battlefield Space (VBS) and geographically distributed test and training ranges.

3) Distributed Simulation Support Technology System. With the purpose of connecting all kinds of systems under different architectures to work together, JLVC Federation adopts an open way to absorb a variety of technology systems, including HLA/RTI, DIS, TENA and Link16, etc. By following these protocols and standards, JLVC Federation connects live weapon equipments, virtual simulators and construction simulation systems distributed in different places to support LVC training.

4) Command and Communication Network Facilities. An important hardware component of JLVC Federation, which is composed of Command and Control Network (C2N), Joint Training and Experimentation Network (JTEN) and Joint Worldwide Intelligence and Communications System (JWICS), provides command and control communication and simulation transmission services for LVC training.

5) Core Simulation and Support Toolbox. One is the theater and combat simulation system supporting joint exercise, which includes Joint Theater Level Simulation (JTLS) on account for aggregation level joint combat model, Joint Conflict and Tactical System (JCATS) based on entity combat model, and JCATS Low Overhead Driver (JLOD). The second is Joint Exercise Control Station (JECS) used for managing Master Scenario Events List (MSEL), conducting battlefield situation awareness and analysis, using Joint Simulation Protocol Analyzer (JSPA) to process relevant data, and generating Common Operational Picture (COP), etc. The remaining one is the support toolbox, such as Joint Training Data Services (JTDS) supporting exercise plans generation, Joint After-Action Report (JAAR) and JLVC Federation Bridge.

JLVC Federation, as a technical supporting environment for LVC joint training, supports loading different training courses according to different scenarios. Therefore, the model system of JLVC Federation adopts an open and tailorable structure, which makes to flexibly build a training federation for different trainers according to different needs of exercise. It is a general technical framework to be flexibly constructed and used for different training tasks, rather than a specific application system only for a certain exercise. However, JLVC Federation is still limited by some faults:

- Complexity. Each member of JLVC Federation has its own development cycle, and repeatedly federating makes the Federation increasingly complex.
- Redundancy. The independent development and the federated way lead to massive functional redundancy among federation models, which requires every effort to avoid the functional conflict between similar federates.
- High-cost. Due to the complexity and continuous development cycle of JLVC Federation, the cost of maintenance and operation is huge, and extensive funds and technician are consumed.

C. *CEMS Based JLVC 2020*

To solve the problems of JLVC Federation and improve the development level of joint M&S, the U.S. forces proposed JLVC2020 plan based on CEMS, that is, to gradually replace the large and complex simulation system by developing small Modular Service Units (MSU) with specific functions, and to finally realize the transformation from loose federation structure to modular framework.

The framework of JLVC2020 consists of five MSU [13,14]: CEMS, Scenario Management Tool (SMT), Virtual Training Interface (VTI), Correlated Data Layer (CDL) and Authoritative Source Data (ASD), as shown in Fig. 6. In the early development of JLVC2020, these units must be mixed with JLVC Federation to run interactively.

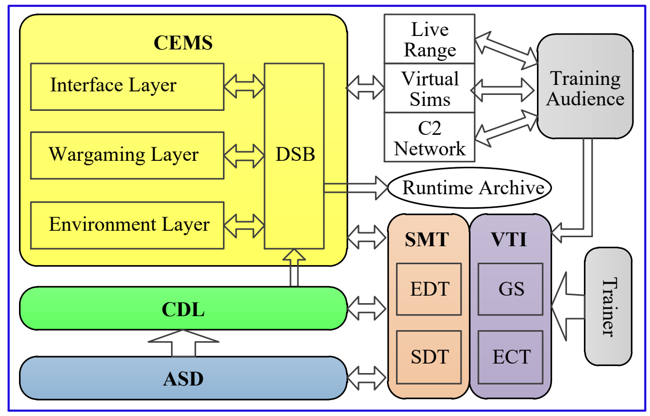

Fig. 6. JLVC2020 Architecture

1) CEMS. CEMS is mainly composed of Data Service Broker (DSB) and three modular service layers supported by cloud-enabled environment, as shown in Fig. 7. With the upgrade of JLVC2020, increasingly MSU will be added to each layer.

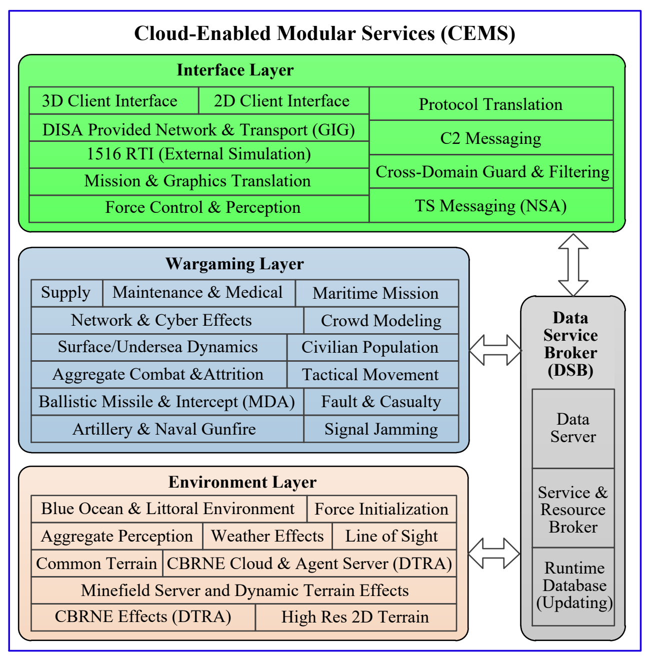

Fig. 7. CEMS composition

- DSB is the data exchange center of simulation interaction connecting modular service layers and data activities, and the core of JLVC2020.

- Environment Layer is to create a specific simulation environment stored in Runtime Database with the data of resource repository, including time, terrain, weather and simulated forces, etc.
- Wargaming Layer is to provide designers with the ability to select appropriate modules from numerous simulation models, tools and service units for combined interaction according to training requirements.
- Interface Layer is used for communication, protocol conversion and display, such as providing network transmission services through DISA, achieving data interaction, runtime coordination and distributed simulation through RTI, and realizing 2D/3D client display.

2) ASD and CDL. The key of CEMS is to build a single data layer that touches the live data sources. So ASD is created through preparation, verification and classification of the real-world data obtained from exercise, training, test, equipment R&D and intelligence operations, including data of force structure, weapon effects, terrain resource, logistics support and mission processes, etc. Meanwhile, CDL is established to solve the data problems of redundancy, divergence and error in large-scale joint simulation system.

3) SMT. SMT mainly includes Event Design Tools (EDT) and Scenario Design Tools (SDT), is the key part of realizing the dexterity and composability of JLCV 2020. Its function is to quickly build an expected scenario environment according to the training needs, which greatly saves time, manpower and other resources and shortens joint exercise life cycle. When building simulation instances, SMT requests to call specific MSU and necessary data during simulation preparation, which enables to support resource sharing management of multiple simulation training projects at the same time.

4) VTI. VTI is the connecting structure between trainers and simulation system, and the component to achieve the accessibility and discoverability of JLVC2020, composed of General Services (GS) and Event Control Tools (ECT). Its functions include assisting the trainers to approach SMT, combing the training environment and controlling M&S outputs, etc. VTI also act as the management role of Computer Aided Exercise (CAX), allowing trainers or CAX managers to integrate the events in MSEL and monitor the operation status of JLVC2020 during simulation activities.

IV. Construction Plan of LVC Integrated Architecture

LVC construction is complex system engineering. It is not a simple combination of "L", "V" and "C", but a closed-loop system formed by the deep integration of three domains. Therefore, LVC construction involves many factors such as personnel, technology, equipment and management, and needs to be gradually and continuously evolved. The near-to medium-term future construction plan for LVC is implemented synchronously following the three lines of "L/LC", "VC" and "LVC" in combination with current projects, as shown in Fig. 8.

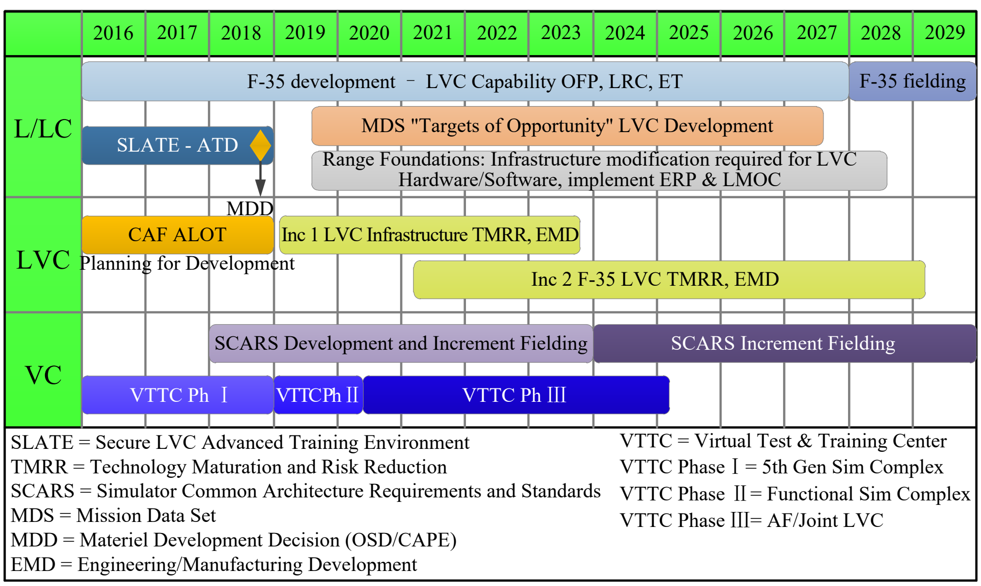

Fig. 8. Construction schedule of LVC

In "L/LC" domain, the U.S. forces stressed on supporting SLATE-ATD project in 2016-2018, mainly verifying the capacity of existing fighters and simulators to join LVC. Concurrently, planning to take 12 years from 2016 to 2027 to develop software and hardware required for F-35 to join LVC, and to test the simplified LVC function predominating Embedded Training (ET) in the F-35 Block 3F mission system in advance. In addition, MDS for LVC environment will be built in 2020-2027. In 2020-2028, create and optimize LVC hardware and software required by the test site and realize ERP management, while continuing to upgrade the Live Mission Operations Center (LMOC).

In "LVC" domain, the U.S. forces emphatically conducted the development of Combat Air Forces Advanced Live Operations Training (CAF ALOT) based on SLATE-ATD in 2016-2018. Additionally, LVC infrastructure construction has been scheduled since 2019, focusing on waveform design, frequency relocation of P5 training system, anti spectrum conflict, rule classification and multilevel security network protocol, etc. In 2021-2028, LVC capability integration for F-35 will be launched to achieve technology maturation and risk reduction.

In "VC" domain, the U.S. forces develop "VC" primarily by supporting VTTC construction. In 2016-2018, the first phase of VTTC was implemented, mainly building F-16 and F-22 series Mission Training Center (MTC) and F-35 Full Mission Simulator (FMS), and integrating Joint Terminal Attack Guidance Simulation (JTACS). In 2018-2023, the key support for development, optimization and fielding of SCARS is carried out, following the increment fielding in 2024-2029. The second phase of VTTC was completed in 2019-2020 with integrating FMS and building Airborne Warning and Control System (AWACS) operation center. In 2020-2024, VTTC will perform the third phase mission, which intends to integrate cross operational domains (including sea, land, air, space and network), and to build Joint Simulation Environment (JSE) based on LVC.

In short, the standardization and networking of simulators is the key aspect of LVC construction. Before the completion of SCARS, the U.S. forces rely heavily on Distributed Mission Operations Network (DMON) to communicate between different simulation frameworks (mainly DIS, HLA, ALSP, TENA and CTIA). The gateway of DMON can adjust network traffic by using reckoning technology to reduce state update. Also the problem of multilevel encryption needs to be solved to allow data nodes with different security levels to interact during training, which is an important driving factor for LVC construction in the future.

V. CONCLESIONS

The U.S. forces regard M&S technology as the multiplier of military spending efficiency and strategic technology. Due to lack of long-term planning, the early development has formed the situation of coexistence of multiple architectures. Moreover, due to the poor interoperability resulting from the incompatibility between architectures, it is difficult to meet the requirements of joint operations training in network-centered environment. Therefore, the U.S. forces focus on improving the interoperability, reusability and composability of M&S, energetically construct LVC integrated simulation environment, reuse existing simulation resources, avoid redundant construction caused by independent "chimney" development, and finally realize the major transformation of simulation training field. Learning from the experience and lessons of them building LVC integrated architecture, we should pay attention to the following aspects of LVC construction:

- Building the joint common object model to support the efficient data exchange between different rang systems.
- Building the metadata model coving simulation, test, training and other heterogeneous resources to provide the basis for the rapid discovery and effective reuse of resources.
- Establishing reusable and composable basic simulation resource database.
- Establishing common infrastructure for the requirements of multi range test operation environment, communication mechanism and time management to provide interoperability support platform.

REFERENCES

[1] G. A. Wainer, K. Al-Zoubi, “An Introduction to Distributed Simulation,” In Book: Modeling and Simulation fundamentals: theoretical Underpinnings and Practical Domains, John Wiley & Sons, 2010, pp. 373-402.

[2] Amy E. Henninger, D. Cutts and M. Loper, “Live Virtual Constructive Architecture Roadmap (LVCAR) Final Report,” Institute for Defense Analyses, 2008.

[3] D. D. Hodson and R. R. Hill, “The Art and Science of Live, Virtual, and Constructive Simulation for Test and Analysis,” Journal of Defense Modeling and Simulation, vol. 11, no. 2, pp. 77-89, 2014.

[4] “Joint Live Virtual and Constructive (JLVC) Federation Integration Guide,” United States Joint Forces Command (USJFCOM), 2010.

[5] M. G. Edgren, “Cloud-Enabled Modular Services: A Framework for Cost-Effective Collaboration,” in Proc. NATO STO Modeling and Simulation Croup Conference, 2012, pp. 1-10.

[6] B. Möller, K. L. Morse, M. Lightner and R. Little, “HLA Evolved - A Summary of Major Technical Improvements,” in Proc. Fall Simulation Interoperability Workshop, 2008, pp. 1-9.

[7] G. Hudgins, K. Poch and J. Secondine, “TENA and JMETC, Enabling Technology in Distributed LVC Environments,” American Institute of Aeronautics and Astronautics, 2010.

[8] R. Saunders, “Live-Virtual-Constructive Architecture Roadmap Implementation-Legacy Architectures Reference Model,” National Security Analysis Department, 2009.

[9] X. Chen, L. Xu, Q. Kai and J. Feng, “Research on Simulation Architecture Development State and Trends,” Computer Engineering and Applications, vol. 50, no. 9, pp. 32-36, 2014.

[10] G. W. Allen, R. Lutz, R. Richbourg, “Live Virtual Constructive Architecture Roadmap Implementation and Net-Centric Environment Implications,” ITEA Journal of Test & Evaluation, vol. 31, no. 3, pp. 355-364, 2010.

[11] B. Jayaprakash, A.Shenbagamoorthy, “Design and Analysis Using Distributed Interactive Simulation (DIS) Concept for Armoured Flight Vehicle Training Simulators,” in Proc. IEEE International Conference on Emerging Trends in Robotics and Communication Technologies, 2010, pp. 216-219.

[12] A. Falcone, A. Anagnostou, A. Garro and S. J. E. Taylor, “An Inroduction to Developing Federations with High Level Architecture (HLA),” in Proc. Winter Simulation Conference, 2017, pp. 617-631.

[13] J. Li, N. Ji and X. Liu, “Study of JLVC2020's Framework for U.S. New Generation Joint Training,” Computer Simulation, vol. 32, no. 1, pp. 463-467, 2015.

[14] S. Bai, J. Hong, “Development of U.S. LVC Joint Training Technology,” Command Control & Simulation, vol. 42, no. 5, pp. 135-140, 2020.