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ENABLING MILITARY COALITION COMMAND AND CONTROL WITH INTEROPERATING SIMULATIONS

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Abstract: This paper reports on progress in developing standardized methods for military coalitions to interoperate command and control (C2) systems and simulations as a system-of-systems, resulting in improved functionality and timeliness for participants. Command and control systems are networked software systems that commanders, staffs, and other participants use to exchange tasking information (called Orders) and status information for situational awareness (called Reports). Simulations are useful as C2 system elements for analysis and to stimulate training and mission rehearsal. C2SIM combines the two and has particular value in a coalition environment, where each nation prefers to use its own C2 system and simulation. The paper describes NATO and SISO activities in C2SIM, the technical approach used to achieve interoperability, and examples of its success.

1 INTRODUCTION

This paper reports on progress in developing standardized methods for military coalitions to interoperate command and control (C2) systems and simulations as a system-of-systems, resulting in improved functionality, timeliness and cost savings. Command and control systems are networked software systems that commanders, staffs, and other participants use to exchange tasking information (called Orders) and status information for situational awareness (called Reports). Simulations are useful as C2 system elements for course of action (COA) analysis and to stimulate training and mission rehearsal (Sudnikovich et al., 2004).

Coalitions consist of military forces from multiple nations; generally, each national force has its own C2 and simulation systems. This complicates the problem of operating as a cohesive whole. The goal of C2-simulation interoperability (C2SIM) is to enable an environment where national C2 systems can exchange information freely and each nation's military operations can be represented accurately, each operating their own simulations. In developing C2SIM technology and standards, we look toward a day when a newly-formed coalition, operating over a shared network, can "plug in" their C2 and simulation systems to the network and work together rapidly and seamlessly to train, analyze COAs, and perform mission rehearsal. As a result, they will be better able to perform as a cohesive whole and do so more rapidly and efficiently.

In such a force, the C2 systems may function as a group using a C2 interoperation capability such as the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) (Multilateral Interoperability Programme, 2007) and the simulations may function as a group using an interoperation capability such as DIS (IEEE Standards Association, 2012) or HLA (IEEE Standards Association, 2010). Alternately, it is possible for all systems to share information through the C2SIM capability, although the resulting system may have lower time resolution. We refer to the totality of systems interoperating under C2SIM as a *coalition*, just as a collection of simulations interoperating under the HLA is called a federation.

The remainder of this paper provides a comprehensive overview of the current state of work in C2SIM. Section 2 describes North Atlantic Treaty Organization (NATO) efforts to improve and validate the interoperation capability; section 3 describes Simulation Interoperability Standards Organization (SISO) activity to standardize C2SIM; section 4 describes how system components are combined to achieve C2SIM; section 5 describes recent activities that have demonstrated the potential effectiveness of C2SIM; and section 6 concludes the paper.

2 C2SIM IN NATO

The process wherein the NATO Modeling and Simulation Group (NMSG) identified and has continued to encourage C2SIM as an enabler of coalition military operations is described in (Pullen and Khimeche, 2014). Initial NMSG concerns for interoperation were largely economic. With introduction of modern combat simulations in the 1980's came a new capability: military organizations can "train as you fight" by using their operational C2 systems to interact with each other and with the simulation (Sudnikovich et al., 2004). However, interaction with the simulation required an extra human in the loop: a supporting "puckster" who transfers C2 information into the simulation system and also enters situational information from the simulation into the C2 system. In a large exercise, staffing for this role became a major expense. Furthermore, if the "puckster" was not knowledgeable in this role and diligent in transferring information, the operation of the exercise could become degraded. Therefore, automated interfaces between C2 and simulation systems were sought and in some cases implemented. However, such interfaces were implemented in an ad hoc, point-to-point manner and could not be extended readily to other systems.

Beyond the domain of training, the ability to interoperate C2 and simulation systems presents the possibility for simulation support of planning and preparation phases in ongoing military operations, by providing course of action analysis and mission rehearsal capabilities. These C2SIM capabilities also were implemented experimentally were strictly ad hoc, operated point-to-point, and could not be extended readily to other C2 or simulation systems.

A more generic, consistent approach to interoperability was needed. Adherents to this approach called it Battle Management Language (BML) (Carey et al., 2001). Figure 1 shows the general architecture adopted. The server provides a publish/subscribe service to its clients. Use of a server-based architecture has two advantages: it simplifies a complex development environment, since each client can be tested individually using the server; and it provides a measure of fault-tolerance, since it does not require that all members of the C2SIM system-of-systems coalition are available at all times.

The need for C2SIM is particularly compelling in coalitions, because differences among coalition partners' C2 systems and simulations make use of a single system impractical; the national forces are training to use their own C2 systems and are best represented by their own simulations. Thus, differences in organization, equipment, and doctrine result in a situation where each national simulation system may represent only that nation's forces well. In response to these concerns, organizations from France and the US that were interested in C2SIM capabilities became aware of each other's work and interests in 2005. They proposed to the NATO Modelling and Simulation Group (MSG) that a multinational Technical Activity be organized with the purpose of exploring use of the BML approach for coalitions. The resulting Exploratory Team (ET-016) led to a four-year NATO Technical Activity *MSG-048 Coalition Battle Management Language* where France and the US were joined by national representatives from Canada, Denmark, Germany, the Netherlands, Norway, Spain, Turkey, the United Kingdom (UK). The group developed prototypes, working to define solutions that could be standardized by SISO as Coalition Battle Management Language (C-BML - see below). Each year they presented a demonstration at the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) in Orlando, Florida, demonstrating the current state of C-BML at the time.

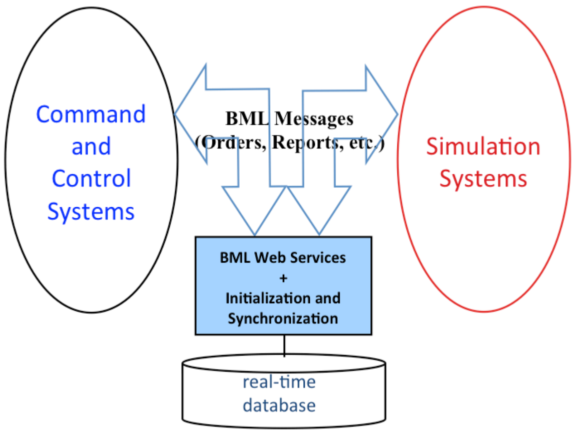

Figure 1: General Architecture for BML

As MSG-048 was preparing for its final experimentation, the NATO MSG considered a charter for a follow-on Technical Activity. It was clear even before the experimentation that Coalition

BML was a very promising approach, so a new charter was approved with no hesitation. The new Technical Activity was named *MSG-085 Standardization for C2-Simulation Interoperation* and focused on assessing the operational relevance of Coalition BML while increasing its Technical Readiness Level (TRL) to a point consistent with its operational employment. Nations participating included the original nine from MSG-048 plus Belgium and Sweden, with interest also expressed by Italy and Australia. (In NATO context, Australia and Sweden are Partner Countries but not committed to NATO collective security; the Partner Countries are welcome in MSG-085 and many other NATO activities.) MSG-085 ended in 2014 and was, to a large extent, a process of maturing the technical and operational basis for coalition use of standardized C2SIM. A new Exploratory Team (ET-038) now is working to develop a plan for a new MSG Technical Activity to establish operational military use of C2SIM.

3 C2SIM IN SISO

SISO provides a collaborative environment for exchange of information about simulation interoperability and an organization under which standards for interoperability can be developed. A creative synergy has existed between NATO MSG activities in C2SIM and the focus of SISO on standards needed to support C2SIM (Pullen et al., 2014). Various interested parties, including several ET-016 participants, formed a SISO Study Group to consider the possibility of developing a C-BML standard. After due deliberation, in 2005 that group produced a report (Blais, Galvin and Hieb, 2005) recommending that SISO charter a Product Development Group (PDG) for that purpose.

In parallel with MSG-048 investigations, the SISO C-BML PDG undertook to define such a standard. This did not go as smoothly as the work of the NATO Technical Activity did. While there was progress in drafting and adopting a standard, the overall process was slower than most stakeholders found satisfactory. The standards effort went on past the end of MSG-048; at one point, the leadership of the PDG found it necessary to publish an analysis of the reasons for delay (Abbot, Pullen and Levine, 2011). Eventually the process did produce results, as described below. In the interim, MSG-048 worked with a schema that had been developed in the US, in conjunction with an effort to increase the geospatial relevance of C-BML (Hieb at al., 2007).

An important finding under MSG-048 was that, for an effective operational capability, the SISO C-BML focus on Orders, Requests and Reports must be supplemented with another SISO standard: the Military Scenario Development Language (MSDL) (Simulation Interoperability Standards Organization, 2008) to provide effective initialization. Accordingly, in its first year MSG-085 pressed its members to implement MSDL in the simulation systems they had made BML-capable under MSG-048. This implementation was effective but it illuminated another problem: although SISO policy called for MSDL and C-BML to work together, the two were developed independently and there was no “roadmap” telling how to use them together. As a result, considerable effort went into exploring alternatives before a path forward was adopted (Remmersmann et al, 2012; Heffner, Blais and Gupton, 2012).

In 2014, SISO published the C-BML standard (Simulation Interoperability Standards Organization, 2014), with a schema that supports two major variants, called Full and Light. During development, the C-BML received considerable criticism. Ironically, while implementers found the full standard to be overly complex, it dealt with only maneuver warfare whereas the ideal BML would extend to all forms of military operations and specifically to operations other than warfare. In the same year, the culmination of MSG-085 included a new insight: a more productive path would be to base the next generation of C2SIM standards on a logical data model (LDM), standardizing the core of that LDM and the process for extending it into new domains. Schemata needed for interoperation in various domains will be derived from the LDM. Also, the second generation of initialization (MSDL) and tasking-reporting (C-BML) should form a single standard, based on that LDM (NATO Collaboration Support Office, 2014). In September 2014 SISO chartered a unified C2SIM Product Development Group (PDG) and associated Product Support Group (PSG) based on those recommendations.

4 C2SIM SYSTEMS

This section will address the technology roles of C2SIM clients (C2 systems and simulations) and servers.

4.1 C2SIM Clients

Clients generally fall in two categories: C2 systems and simulation systems. Experience to date indicates the process of interfacing clients for C2SIM operation requires only a moderate amount of time to accomplish (typically, one to three months). Client outputs (input to the server) are XML document files, transmitted via Representational State Transfer (REST) protocol; server outputs sent to the clients are similar XML document files, sent via the Streaming Text Oriented Messaging Protocol (STOMP) subscription-based protocol.

C2 systems are an essential element of modern warfare, used by commanders and their staffs to provide direction to their subordinates and keep track of the status of those subordinates. To do this, they produce Orders and consume Reports. To enable C2SIM, a C2 system must add an interface module that follows an agreed schema so the C2 system can send the server an XML document for each Order and also subscribe to Reports distributed by the server as XML documents, in order to present them as situational awareness to the commander and staff. In addition there are special requirements for working with simulations, as distinct from working with live subordinates: the C2 system must be able to clearly identify when running in simulated mode; and also support start/stop of simulated operation.

Simulation systems represent the operation of all or part of the coaltion force. Whereas most simulation systems communicate with their users via a graphic interface, under C2SIM the simulation systems communicate with their users via C2 systems. To do this, they accept Orders and produce Reports. Therefore, to enable C2SIM operation, it is necessary to add to the simulation system an interface module that sends the server an XML document following an agreed schema for each status change that requires a Report. Special requirements for working under C2SIM are that the simulation subscribes to Orders distributed by the server and follows the directions they contain; and also is able to start/stop simulation operation under C2SIM coalition control.

Examples of simulations that have been incorporated in C2SIM coalitions include APLET and OneSAF. The APLET system is used by France and is notable for its ability to support faster-than-real-time simulation, which is very useful in COA analysis since multiple alternatives generally must be considered. OneSAF was provided by the USA and is notable for its ability to represent a wide range of military forces and also as the only system that implemented the new C-BML standard completely (Wittman, 2014). A complete list of simulations used in MSG-085 can be found in (NATO Collaboration Support Office, 2014).

In addition to national C2 systems and simulations, developers of C2SIM systems have found it convenient and useful to create a special graphical user interface (GUI) client, in order to generate and edit XML documents that serve as system input and also to monitor and display the contents of such messages. Such a GUI also can be used as a surrogate C2 system where a regular military C2 system is not available. Another useful type of GUI provides for status monitoring and control in the form of a shared webpage; this is used as a coordination mechanism where multiple simulations are operated simultaneously.

4.2 C2SIM servers

The primary functions of a C2SIM server are:

- Accept push/post C-BML Orders and Reports and MSDL scenario files, in REST format
- Accept client subscriptions, by Topic (e.g. all General Status Reports)
- Publish the XML documents to subscribers via STOMP as they arrive and be prepared respond to get/pull for them

A C2SIM server may have other functions:

- Namespaces: XML tagnames can be qualified by addition of a "namespace" code or example <bml:Report> indicates a namespace "bml" is to be used; this allows tagnames from different sources to work together safely without previous disambiguation.
- Schema validation: the server confirms that each document received conforms to the schema, in order to identify possible incompatibilities. Since this slows the service, normally it is done only during initial testing.
- Filtering data: the server can restrict delivery, based on user-defined criteria.
- Logging/replay: to achieve this, the server writes a file containing every transaction it receives, with time stamps for each. The server is capable of replaying this file to recreate the original sequence of Orders and Reports at original time intervals.
- Bridged servers: multiple servers can be tied together into a distributed server system in order to increase load capacity and increase network efficiency of a C2SIM coalition (Pullen et al., 2015). Figure 2 shows a three-

server system that was demonstrated in December 2014.

- Aggregating MSDL inputs from participating systems: In a coalition each C2 and simulation system can have different initialization requirements. A consolidated MSDL initialization file is needed for consistency; the server can aggregate them automatically, so that all systems receive common initialization data.

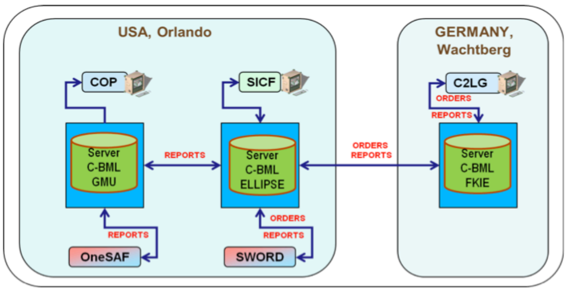

Figure 2: Three-Server Architecture.

4.3 Server Schema Translation

A translation capability is needed because developing organizations are reluctant to change their interface each time a new schema is developed, with the result that the coalition finds itself with C2 and simulation systems interfaced to different (but largely equivalent) schemas. To achieve translation, the server parses the XML document according to appropriate schema, saves the input in an in-memory database, and draws on the database to produce output conforming to different designated schema. (This is possible only where data support the same semantics.) A server with this capability, developed by George Mason University in cooperation with Saab Corp, allowed MSG-085 to interoperate C2 and simulation systems that had been interfaced under various previous schemas (Pullen et al., September 2013).

4.4 Example of server operation

The server is the heart of the interoperation capability in the C2SIM architecture. It provides the critical publish/subscribe function and can enable by translation, as was done for MSG-085, operation over multiple compatible schemata that otherwise would not be capable of interoperation. This section will highlight the methods used by the author's development team to produce a server capable of doing these things at production message rates and also of working with other servers to form a distributed, interoperating server system. A more detailed exposition is available in (Pullen et al., September 2013).

Saab Corporation is in the business of providing software for military command and control. They were active in the Swedish delegation to NATO MSG-085 and offered use of their Widely Integrated Systems Environment (WISE) for experimentation support. WISE is built on commercial technology and supports a robust, high-performance information switching capability with a graphic setup editor. In 2012, discussions between the GMU C4I Center and Saab concluded that the general approach used in GMU's open source Scripted Battle Management Language (SBML) server could be productively re-implemented in WISE. This capability enables fundamental research at GMU, prototyping a new generation server that is expected ultimately to transition to operational military use as described in (Pullen et al., June 2013).

Saab also provided to MSG-085, through GMU, access to its 9LandBMS command and control system, intended for use with touch-sensitive tablet computers at battalion/brigade levels. This system had an existing interface to WISE; thus it was capable of interoperation with C-BML capable systems using the WISE-SBML server, without going through the usual process of building a C-BML interface.

Figure 3 shows the architecture of the WISE-SBML server. WISE appears to SBML as an in-memory, non-persistent database. The "BMS" system in Figure 3 represents the 9LandBMS or any other system directly interfaced to WISE. This approach enables a great improvement in performance over the previous SBML server, measured at over 10X, and is well suited for deployment in the high-performance cloud computing environment.

Integrating a new capability into WISE requires creating a software interface element and then using the WISE graphic editor to configure information mappings between that interface and the WISE internal database. These configuration elements must be maintained as changes to the schema occur. It is noteworthy that the second step in particular can be achieved more quickly than developing an SBML script.

As shown in Figure 3, the WISE-based Web service accepts XML inputs through a REST interface and publishes one or more XML documents (the original plus translations) through a STOMP interface. Therefore, to build a server based on WISE, the GMU team had to complete two important steps:

- Build a WISE driver, shown in green on the figure, for each major information flow to be interfaced: C-BML/MSDL Web service (one for each schema version); publish-subscribe service; persistent recording interface; and the 9LandBMS WISE interface, adapted for C-BML/MSDL.
- Use the WISE graphic editor to specify all information flows between the WISE data repository and these drivers.

The second of these steps represents an added capability provided by the WISE approach and requires only drag-and-drop in the WISE Connectivity Designer. However, there remains a sequence of steps to be programmed in conjunction with the specifics of the application (in the case at hand, C-BML and MSDL) for XML documents, both incoming from the REST interface and outgoing to the STOMP interface for publication.

Further, when the client is subscribed to a topic using a different schema, a translation must occur. This takes place as follows:

- Accepting incoming XML from REST:
  Parsing: using the open source DOM parser, the interface extracts each data element from the input XML file to an internal data structure.
  Building: the internal data structure is pushed into the WISE database.
- Producing outgoing XML through STOMP:
  Receiving: a matching internal data structure is extracted from the database.
  Generating: XML output is generated from this data, in accordance with the appropriate schema.

The WISE driver software generated for this purpose, written in C++, is available as open source at http://c4i.gmu.edu/OpenBML. WISE itself requires a license from Saab, which may be available at no cost for development purposes. Also available via the OpenBML site are Java client software, replay logger, and replay client.

5 EXAMPLES OF C2SIM USE

As described above, C2SIM coalitions are expected to support interoperation of the C2 systems and simulation systems of the participating nations, requiring interoperation of all parts of a heterogeneous system-of-systems. This section will describe the two most significant such coalitions assembled to date, at the culminating major events of MSG-048 and MSG-085. The diversity of systems involved illustrates the scope and flexibility of the C2SIM approach.

While it would be possible to use only C2SIM interoperability methods to couple the simulations in a coalition, the primary intention of C2SIM is not simulation-to-simulation; it is sharing information among C2 and simulation systems, and for this the frequency of information update required is on the order of once per minute. Experience has shown that it is quite possible for simulations to send updates more frequently than some C2 systems are able to accept them. Therefore, in the coalitions reported here, the simulation-to-simulation interconnection was via DIS (use of HLA was considered, but determined to require more complex setup than warranted by the circumstances).

The MSG-048 Technical Activity set out to show the technical feasibility of the C2SIM approach. It culminated in a one-week period of exploratory experimentation, conducted with operational military subject matter experts (SMEs) in 2009. Intensive preparation for this activity took place over the Internet, which at the time was a new way of working for most of the participants. In addition, two physical integration events were held: September 2009 in Portsmouth, UK and October 2009 in Paris, France. These events proved to be a successful risk reduction mechanism. The system-of-systems architecture used is shown in Figure 4.

It would not be accurate to say that all MSG-048 development went smoothly. Despite all the risk reduction, there were technical problems even during the experimentation. Nevertheless, interoperability was achieved, many of the experimentation goals were met, and we learned a great deal about how BML would need to be supported in MSG-085. Considering the complexity of the system of systems assembled (as reflected in the variety of subsystems described above) and that an entirely new paradigm was implemented, the fact that the MSG-048 final experimentation ended with all subsystems demonstrating interoperation was a significant accomplishment. As a "proof of principle," the process followed was basically successful and showed that the technologies used, and the overall BML concept, provide a sound basis for future work. This was confirmed by the participating military, who were not part of the MSG-048 development team and therefore were able to view the results objectively (Heffner, Khimeche and Pullen, 2010). Evidence that others also were convinced can be seen in the fact that

MSG-048 received the NATO Scientific Achievement Award in 2013.

MSG-048 set the stage for MSG-085, which was intended to show the operational military utility of C2SIM. The final demonstration of MSG-085 took place in the US at Fort Leavenworth, Kansas in December, 2013. MSG-085 partnered with the US Army Mission Command Battle Laboratory there to engage in a short integration session. The featured capability was Joint and Combined Mission Planning. The architecture of the demonstration system-of-systems that was assembled is shown in Figure 5.

While the complexity of the MSG-048 and MSG-085 final events was roughly similar, there were some striking differences:

- *Network sophistication*: The MSG-085 network included two remote participants and operated with two linked servers and three schemata (C-BML Full, while available on the WISE-SBML server, was not used by any of the systems). This models the sort of operation expected in operational BML use.
- *Setup process*: The MSG-048 setup was somewhat chaotic, with some of its capabilities becoming usable only on the last day of experimentation. By contrast the MSG-085 systems came together smoothly. There were a few problems but mostly they "just worked".
- *Audience impression*: The MSG-048 final audience got the message "We have an exciting new capability. It's not working very well yet but it has great potential for the future." In contrast, the MSG-85 final audience got the message "We have an exciting new capability and it works very well to improve some unmet needs of coalition C2, using interoperable simulations."

In short, where MSG-048 succeeded in proving the principle that C2SIM could be used effectively in coalition operations, MSG-085 succeeded in harder goal: improving the Technical Readiness Level of C2SIM in the form of MSDL and C-BML and proving the concept that C2SIM is ready to be tested in real coalition operations. Currently the NATO MSG has chartered a new Exploratory Team (ET-038) to plan new Technical Activity toward that end.

6 CONCLUSIONS

The ability to interoperate C2 systems and simulations in a coalition context represents an exciting new capability for NATO military elements. Experience in activities of the NATO Modelling and Simulation Group is that every system brought forward for interoperation by participating national groups has been able to be interfaced to the C2SIM coalition, requiring a relatively modest effort to do so, and that currently available servers will support the sizeable configurations tested to date, with rapid delivery of Orders and Reports to the participating group. Server systems have progressed to the point where heterogeneous distributed server systems and on-the-fly translation to support mixed-schema systems are available.

The SISO C2SIM PDG is working on an integrated second generation standard, based on a logical data model with standard core that is designed for extension and can be used to generate schemata tailored to individual domain needs. The C2SIM community is looking forward to bringing this new technical approach into military operations, enabling coalitions to seamlessly interoperate a collection of national C2 systems with each force being represented by its own national simulation. This will enable such coalitions to perform training, course of action analysis, and mission rehearsal in a straightforward way, interfacing via their own C2 systems.

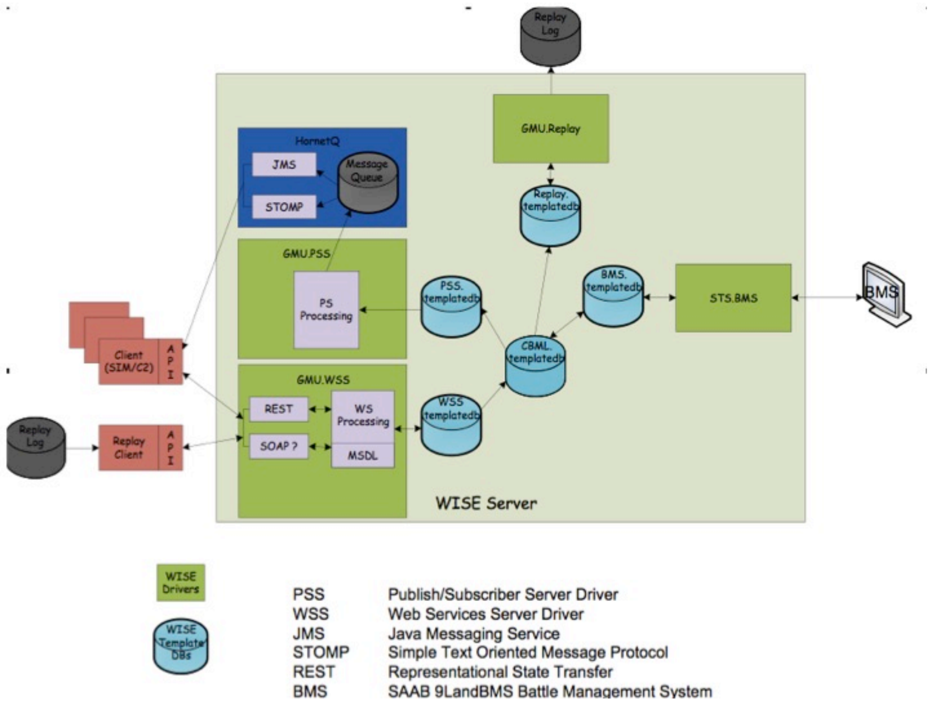

Figure 3: WISE/SBML Server Architecture.

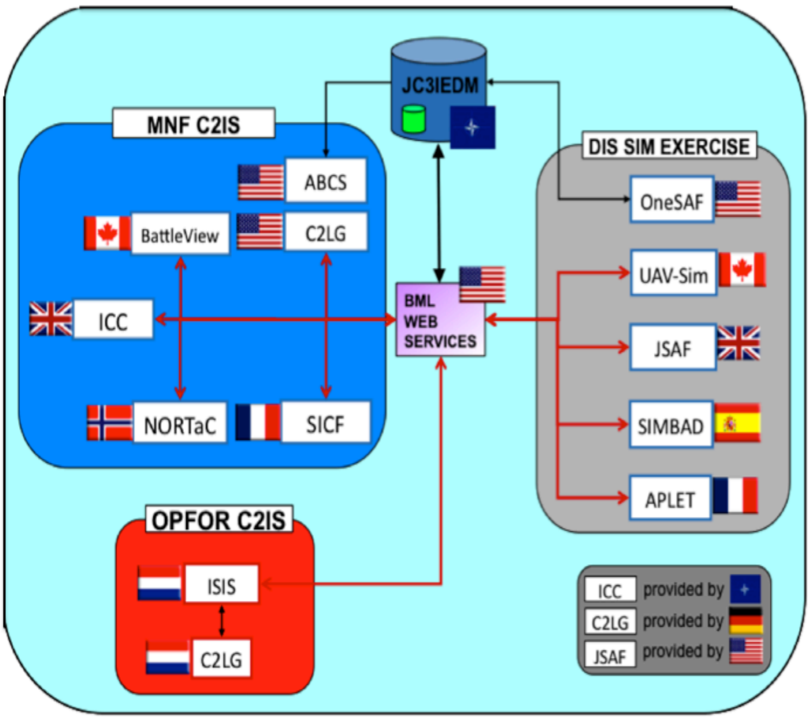

Figure 4: Architecture for MSG-048 Final Experimentation.

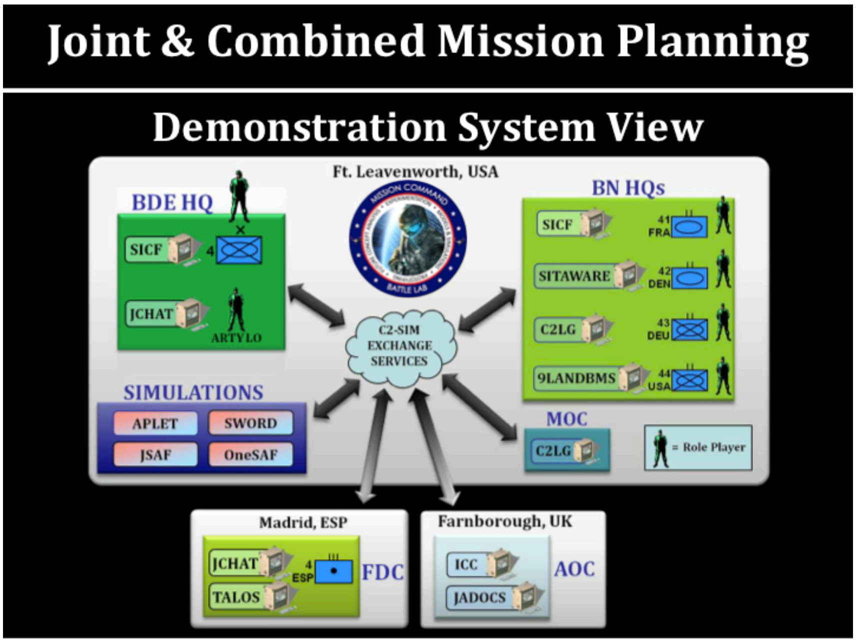

Figure 5: MSG-085 Final Demonstration System of Systems.

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