How to Develop True Distributed Real Time Simulations? Mixing IEEE HLA and OMG DDS standards

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ABSTRACT: *HLA has been a great success to interoperate simulators but its use as the internal architecture of a real time simulator has been very limited. This paper describes the use in Simulation of other publish-subscribe international standard for real-time purpose: OMG DDS (Data Distribution Service). The DDS standard is specifically designed for its application in large critical distributed systems and federation of systems. Some of the most prestigious administrations around the world have recommended or even mandated its use. As some examples, US Navy has mandated the use of DDS as a key building block for any architecture that whishes to comply with the Open Architecture Computing Environment (OACE) directives; DISA has recommended the use of DDS as the publish/subscribe technology for distributing tactical data for supporting Network-Centric capabilities; EUROCONTROL has mandated DDS as the technology for distributing flight data plans among European air-traffic control centers; or QinetiQ, an UK company, has recommended DDS as the information backbone for the electronic architecture of next generation Vetronic Systems. This paper will introduce basic concepts of DDS then will explain how these features have been successfully applied to real time virtual and engineering simulators, enabling key trends like interoperability with Network Centric "clouds", open architectures or M&S development based in repositories. The critical issue of interoperability between these DDS based simulation systems and HLA-compliant systems is also analyzed and we propose a solution to this problem.*

1. Introduction

In previous papers and conferences ([1], [2]) we pointed the fact that whilst HLA 1516 – 2000 give a way to do distributed simulations and execute virtual exercises between simulation systems of different countries and manufacturers, it has not achieved a greater challenge: to open the internal software architecture of the simulation systems, in order to achieve reusability of simulations models and simulator subsystems between different simulators.

In this paper we propose another publish-subscribe standard, OMG DDS (Data Distribution Services) ([3] [4]), as the ideal companion of the HLA standard in real time simulation. The **DDS standard** is specifically designed for its **application in large critical distributed systems and federation of systems**. Some of the most prestigious administrations around the world have recommended or even mandated its use DDS is the middleware for some of the most demanding applications now in use, like Combat Management Systems ([5],[6]), Air Traffic Control Centers ([7], [8]), Communications and interoperability between tactical Command and Control (C2) systems or Unmanned Systems. We do believe that the **right mix of DDS and HLA standards** is the **best way to develop simulators with open architectures and fully interoperable** with other systems in Network-Centric environments.

2. Why is it needed new technologies for the simulation systems?

From our point of view, the simulation market is evolving, driven by the latest technological trends imposed on CIS (Communications and Information) systems in mil&aero markets. Concepts and new paradigms like Network Centric Warfare ([9], [10]), Services Oriented Architectures, or Cloud Computing have driven new trends and requirements in simulation[1], such as:

- Simulators as network assets in **Net-Centric federations of Systems**.
- Reusing of existing simulation assets
- Reducing costs of training by increasing operation time of the simulators and interconnecting geographically distributed distributed simulators through conventional and cost-effective IP WANs
- Extending the training systems availability beyond the classroom, thanks to Internet and new and fast data encryption technologies
- Demand for **rapid deployment** of training solutions based on **COTS** and **GOTS**.
- More **interoperability** between **simulators** and **real systems**.
- **Open Architectures** and **modular design** for Simulators, looking for more **reusability, scalability and maintainability**.
- Improve capabilities for **battlespace M&S**.

According to our research, former trends and user requirements will drive new technical requirements for M&S technology:

- **Plug&play** simulation Architectures
- **Distributed architectures** with QoS (Quality of Services)
- Interoperate with **NEC "clouds**"
- **Development based** on existing **repositories**
- **Interoperability** between live, virtual and constructive simulations

As we will explain in the rest of this paper, the use of an **open architecture based on DDS and HLA** standards covers all the former requirements (indeed the use of DDS for simulation have been already proposed in the technical literature in last years [11],[12],[13]). Our proposal is based in the next **main features**:

- **Data centric design** based on open middlewares (**HLA & DDS**)
- Use of **DDS for simulation**
- **DDS** as a **common messaging** technology
- **Model Driven** and **Rapid** Developments
- **Cohabitation** of **HLA** and **DDS** with other **mil standards**, like MIP (Stanag 5525).

3. Why HLA and DDS cohabitation in simulation systems?

With **HLA 1516-2000 [15]**, **bottlenecks and technical issues** arise whenever **interoperability and reusability are required** to combine various simulation systems of different providers:

- Different RTI software are not compatible each other,
- A complete simulator can be HLA compliant but not its subsystems, therefore you only can reuse them at system level, and
- Simulators should interoperate not only with another similar ones but also with C2 and other live and real Systems in order to be able to rehearse complex missions.

The recent introduction of HLA 1516-2010 (**HLA Evolved** [16]) adds **several improvements** to the standard, addressing some but not all of the former problems:

- **Evolved Dynamic Link Compatibility (EDLC)** now guarantees that a federate built on one RTI can be used in runtime with another RTI.
- The new **Fault Tolerance and Smart Update Rate Reduction** capabilities are in fact **Quality of Service (QoS) features**, improving performance and facing the fact that simulation systems are nowadays far more dynamic and aggregated than years ago. In such environment different subsystems have different needs or capabilities to process or generate updates, and also are very more likely that some elements could fail and these failures must be handled as gracefully as possible.
- **Web Services (WSDL API)** lets the integration with real WS compliant systems

Does HLA Evolved eliminate the need of DDS?
Yes, DDS is still needed as it adds a lot of value over HLA Evolved.The main reasons are:

[1] For example the Spanish MoD R&D organization (DGAM) has included some of these items and many others in its *SP MoD **2010 Strategy for Technology and Innovation (ETID), [14]***

- HLA Evolved still **lacks of a wire protocol** that would provide real interoperability between RTI of different providers, opening the architecture of the simulators.

- **QoS in DDS** are far **more richer and fine grained** than HLA's.

- **Web Services** are not **the best way of integrating with real-time critical systems**, especially those that follow by nature and implementation a **publish-subscribe paradigm, like DDS**.

- Also there are **performance considerations**:
    - A middleware for the internal messaging of a simulator must be able to **work at frequencies of 100Hz or more** in any situation.
    - If we want to integrate external components as subsystems of a simulator or if we want to integrate the simulator in Net-Centric federations of systems the middleware must me able to manage a **large throughput over heterogeneous networks**.
    - When we think in rehearsing of complex mission or the integration of Simulators in Net-Centric federations, **scalability is essential**.

About the former parameters: **latency, throughput and scalability** DDS is more capable than HLA, due to target real time systems in critical environments. While most performing HLA RTIs can provide 50,000, sometimes more than 100,000 updates of 100 bytes per second between two hosts on a LAN and latencies about 130microseconds (based on publicly available figures from COTS RTI vendors [17]) **DDS implementations can deliver around 750 - 1000K 100byte messages per second** in similar conditions and **latencies of less than 60microseconds**. **Scalability** is also guaranteed: for **2Kbytes messages throughput** is more than **60,000 messages per second** and **latency is about less than 130 microseconds**. Latency in DDS is well bound and has little dependency on message size, also some implementations provide mechanism to keep it bound independently from system and network load.

4. The DDS standard in a nutshell.

The OMG DDS standards family is today composed, as in Figure 1, by the **DDS v1.2 API** [3] and the **DDS Interoperability Wire Protocol (DDS-RTPS v2.1)** [18]. The DDS API standard guarantees source code portability across different vendor implementations, while the DDS-RTPS Standard ensures on the wire interoperability across DDS implementations from different vendors. The DDS API standard **defines several different profiles** (see Figure 1) that **enhance realtime pub/sub with content filtering, persistence, automatic fail-over, and transparent integration into object-oriented languages**.

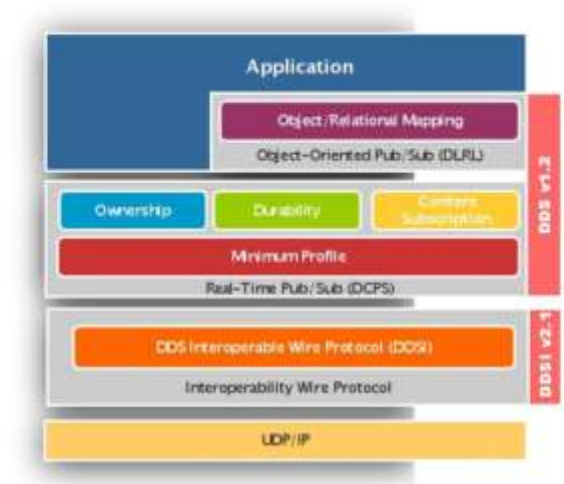

Figure 1 –OMG DDS Standard

The DDS standard was formally **adopted by the OMG in 2004**. Since then, it has become the **established Pub/Sub technology for distributing high volumes of data**, dependably and with predictable low latencies in applications such as, Radar Processors, Flying and Land Drones, Combat Management Systems, Air Traffic Control and Management, High Performance Telemetry, Large Scale Supervisory Systems, and Automated Stocks and Options Trading.

Along with wide commercial adoption, the **DDS standard has been recommended and mandated as the technology for real-time data distribution by several key administrations worldwide**. As some examples, US Navy has mandated the use of DDS as a key building block for any architecture that whishes to comply with the Open Architecture Computing Environment (OACE) directives ([19]); DISA has recommended the use of DDS as the publish/subscribe technology for distributing tactical data for supporting Network-Centric capabilities; EUROCONTROL has mandated DDS as the technology for distributing flight data plans among European air-traffic control centers;

or QinetiQ, an UK company, has recommended DDS as the information backbone for the electronic architecture of next generation Vetronic Systems.

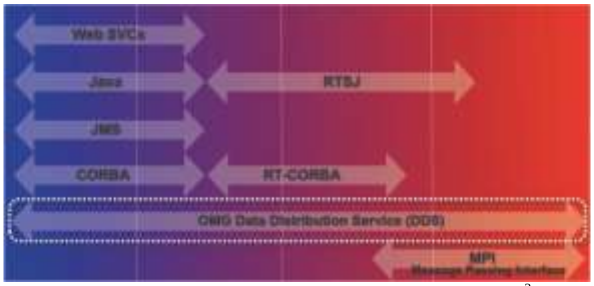

Figure 2 – DDS versus other messaging technologies[2]

This OMG standard is a pub/sub data distribution architecture which allows to connect asynchronously and anonymously very large sets of distributed nodes of a communications mesh (domain participants). A domain participant may simultaneously publish and subscribe to typed data-streams identified by some names called “topics”.

The importance of DDS relies in its reliable design. DDS QoS parameters specify the degree of coupling between participants, properties of the overall model and of the topics themselves. So, DDS defines a communications relationship between publishers and subscribers which is:

- Decoupled in space (nodes can be anywhere)
- Decoupled in time (delivery of data may be immediately after publication or later)
- Decoupled in flow (delivery may be reliable and can be done in a fully controlled bandwidth)

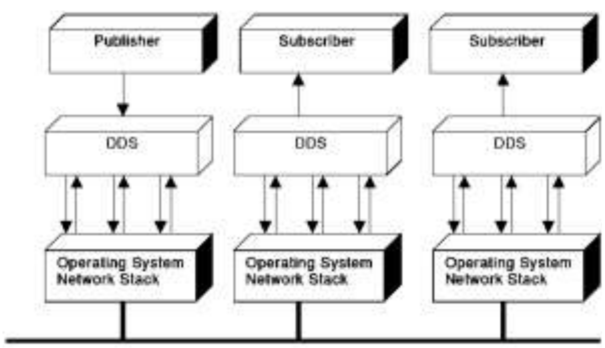

Figure 3- DDS performs the network tasks for the application

[2] Adapted from NSWC-DD Open Architecture Documentation

Scalability is increased thanks to the multiple independent data channels identified by “keys”. This allows nodes to subscribe to many (maybe thousands) of similar data streams with a single subscription. When the data arrives, the middleware can sort it by the key and deliver it for efficient processing.

DDS has also a state-propagation built-in model, so when treating data structures with values which only change occasionally, they will be transmitted only once for every update, so the network overload will be very low.

The standard defines **two levels of interfaces**. At a lower level, it defines **a Data Centric Publish Subscribe (DCPS)** whose goal is to provide an efficient, scalable, predictable, and resource aware data distribution mechanism. Then, on top of the DCPS, it defines the **Data Local Reconstruction Layer (DLRL),** an optional interface which automates the reconstruction of data, locally, from updates received, and allows the application to access data as if it was local.

DDS is fundamentally **designed to work over unreliable transports such as UDP** or wireless networks.

Besides, central servers or special nodes are not required, so all the communication is direct between the nodes, also known as **Peer-to-Peer or P2P**.

DDS scheme supports both unicast and multicasting IP networks, so latency of data between nodes will be insignificant.

One very important point in DDS is that **the wire-protocol is also standardized**; the **DDS Interoperable Wire Protocol (DDS-RTPS) [18]** is a fundamental component of the standard. This OMG specification defines an **interoperability protocol for DDS**. Its purpose and scope is to ensure that applications based on different vendors’ implementations of DDS can interoperate. This is a **key difference versus HLA standard**.

5. Mixing HLA and DDS standards in an open Simulation architecture.

Traditionally, a **real time simulator**, used in training as a virtual simulator or in use in a testbed as an engineering simulator, has some kind of evolution of **client-server architecture, with proprietary messaging** between the different simulator components, as showed in next figure

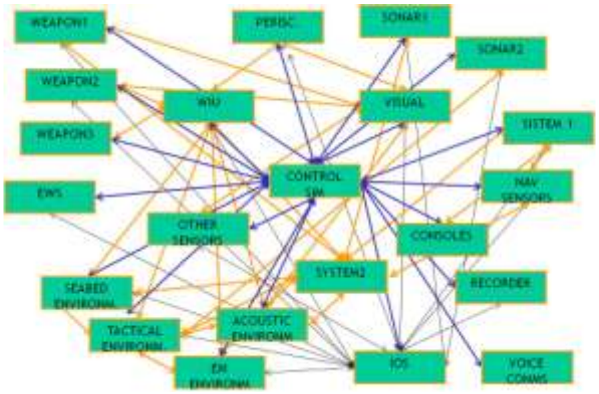

Figure 4 – Traditional software architecture for a virtual simulator

In this architecture, **HLA compliance** use to be obtained by having a special component or node, called **gateway**, that **"translates" internal proprietary messages into HLA compliant simulation data**: simulation objects and interactions. In this way, **openness and interoperability as defined by the HLA standard are only achieved in the system level**, but its subsystems remained proprietary. Reusability and interoperability collected in this way are very limited. **Maintainability of simulators designed in this way is also complicated and costly**, due to the **high degree of coupling** between components of the simulator.

NADS R&D ([1], [2], [20],[21],[22]) in last years has been focused on migrate this architecture to a new one, named **SimWare®**, based on the use of a **simulation middleware (NCWare Sim) as the backbone of the simulator**. In this new architecture, each **software component** (i.e. simulation models, image generator, IOS, etc.) is a **Simulation Asset** and the **simulator** itself is a **federation of these assets**. Hence, we are applying the **concept of HLA Federation to the internal architecture of the simulator**. In this architecture, each simulator asset is considered as a "federate". To have **real time performance and high rate messaging** in any situation, **we use DDS standard as default for messaging**, while the **middleware object model is based on HLA metadata**. The Middleware is also **compliant with the most common HLA's RTI**, making easy the interoperability with other HLA systems and avoiding gateways. **The mix of HLA and DDS features in this middleware is a very powerful and magical recipe**: HLA metadata and architecture applied over a real time pub-sub data bus, as it is DDS. In this context, usually DDS is used for high rate and deterministic messaging between internal assets or to interoperate with external DDS critical systems and HLA is used to interoperate with external simulators components or to integrate external federates as simulator assets (i.e. CGF[3] or an IOS[4] in a distributed tactical simulation federation).

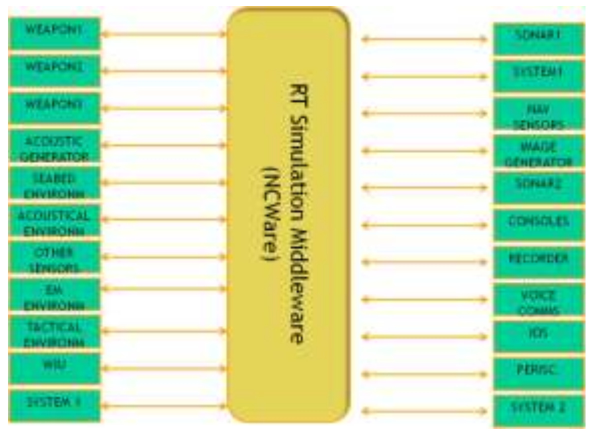

Figure 5 – An Open Distributed Simulation software architecture

With the **right cohabitation of HLA and DDS features** in SimWare we have achieved a much **decoupled architecture** with the next **main advantages**:

- **Make easy the System level Design**. A data centric design is a very powerful way of doing the system engineering of a simulator. The specification and system design is based on the development of the Simulator Object Model (the equivalent to the HLA FOM) and its assets models (like the SOM).

- **Rapid design and development based on repositories and COTS**. The openness of the architecture and the data based interfaces make easy the use of assets already develop in-house or the integration of customized COTS with HLA or DDS interfaces. Indeed FEDEP process could be used as a complete framework for the simulator development.

- **Less risky and more cost-effective integration and testing**. In our experience, using standard interfaces and data-centric design facilitates the integration of components and their corresponding tests.

In summary, in our experience, above advantages can save costs and speed up time to market up to 50%.

[3] Computer Generated Forces

[4] Instructor Operator Station

6. Interoperating with other DDS critical systems or other HLA simulations.

6.1. Interoperating with HLA simulations and federations.

The interoperability with other HLA compliance systems is very easy because of:

- **Middleware API and its object model are based on HLA API and metadata** (simulation objects and interactions). **OMT templates are also used** to design the object models.
- NCWare Sim middleware can **use any RTI for messaging** between internal assets or with any external HLA federation.
- A special tool, **NCWare Data Modeller**, is provided to **map in a visual way the Simulation Object Model with any other HLA FOM**. In this way you could design without any coding a "virtual gateway" to any HLA federation.

In this context, **HLA interoperability could be used** not only for doing the traditional "gateways" with HLA federations, but also for a much more powerful feature: **to integrate as simulator assets external federates or even small specialized federations** (for example to provide synthetic forces, or specialized simulation models). The integration of HLA federates as simulator assets allows you to move the concepts of Cloud computing or Saas (Software as a Service) to the real time simulation.

6.2. Interoperating with DDS critical systems.

Due to the rise and expansion of the DDS standard as the base technology for many critical distributed systems, the **interoperability with other DDS systems** is also a very powerful tool. Open **new uses for the real simulators systems, like decision support tools for tactical C2, embedded training in avionics** or Vetronic systems or other similar applications.

With SimWare architecture, **every object model and its attributes and interaction and its parameters are translated to DDS topics with QoS**. Standard DDS wire protocol, DDS-RTPS is used to transport messages in any network. Due to this design feature, the **interoperability with any other DDS compliant system is very easy**. The Data Modeller tool could be also use to map visually the DDS data model of the external app and the Simulation Object Model.

Interoperability with other DDS systems can be also achieved for **legacy HLA federates**, that are **not using SimWare** as their internal software architecture. Imagine that you are the system integrator of a DDS based system and that you would like to reuse some HLA code that have been developed in the simulation department of your organization. You could use NCWare Sim and the Data Modeller tool for doing a gateway between the HLA code and the DDS system, as showed in next figure

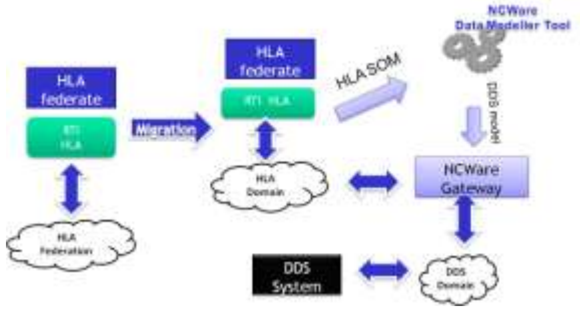

Figure 6– Reusing HLA legacy code in DDS systems

Versus other design alternatives for this integration, the main advantage of this approach is that **no change it would be required in the source code** of any system.

SimWare DDS compliance could be also applied for **integrating DDS services as special assets of the Simulator**. As an example, NADS has been working with the Spanish Army since 2008 in the adaption of DDS for its use as the data interface between C2 systems in tactical environments. As a result of these works, **DDS have been introduced in the new C4I reference architecture of the Spanish Army** (named ARET). In the next future every C2 systems in the SP Army will provide a DDS interface to external systems. This interface will provide special services like FFT (Friendly Force Tracking) information in DDS format. **This kind of services could be integrated in the simulator for providing other entities information**, in a LVC (Live-Virtual-Constructive) federation.

7. Example of Use of SimWare: M&S Development Environment.

In 2010, the Spanish MoD R&D organization (DGAM) has selected **SimWare framework as the core technology for the implementation of a M&S Development Environment**. The scope of the project is to provide to the MoD with **a simulation infrastructure that allows the design, development, deployment and maintenance of Simulation Assets** that could be provided to MoD simulator's integrators or to integrate directly in HLA or DDS federations.

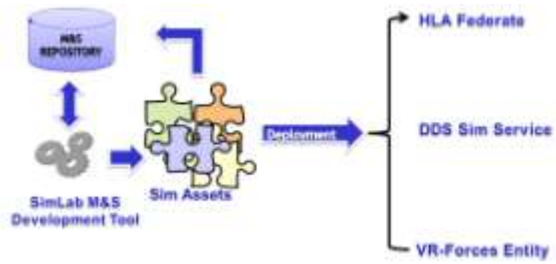

Figure 7– M&S Development Environment for SP MoD

SimWare features are ideally fitted to the requirements of this project:

- **Design and Development of simulation assets** with an **open architecture**, with independence of simulation runtime infrastructure.
- **Easy maintenance and configuration** management of Simulation Assets in **M&S Repositories**.
- **Deployment of Simulation Assets in different platforms**, using HLA and DDS features as main connectors.

In a first stage of the project, this environment has been tested conducting a proof of the concept experimentation based in a test bed for missile decoy strategies. Based in the concept of system/subsystem specification, different models for IR and Radar missiles, chaff and flares, EW equipment, atmosphere and different targets have been built. The objective is to create simulations to be used in ship defense strategies scenarios, in operational research conducted by Spanish navy. The models have been designed with three mayor constraints: generic design and reusability, clear system/subsystem specification and platform independence.

The missile simulation model has been divided in several components: aerodynamic, atmospheric, detection, movement, guidance, mass and propulsion. The components were designed to be generic enough to be reused but they fitted the missile simulation. Models have some assumptions and simplifications because the unclassified rated. Some of the components are generic and parameterized but other used data extracted from publications representing unclassified data.

The simulation is being made at two different levels:

- Model (system) interoperability: using HLA and RPR-FOM, where interoperability between missiles, targets, and EW systems can be used by existing standard data models and can be interconnected with third party simulations.
- Subsystem interoperability: using DDS, where real time performance is critical and rates beyond 100 HZ are needed and critical for simulation.

Some conclusions apart from the experiment have been extracted:

- **Models can be easily evolved and reused** with no overall impact in the development process. The introduction of new parameters and constraints can be made an almost real time process.
- **High reusability,** the models built can be used to develop future improvements as static and dynamic behavior using engineering language. Models contain all the details needed to execute it, and transformations can be made to run it in different platforms.
- **Deployment** of the models in an execution environment is a **short operation**.
- **Models can be executed** in a state of the art desktop PC at **rates higher than 100 Hz with no performance penalty**.

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