Leading EDGE COMPUTING

Simulation Whitepaper

Using DDS for Scalable, High Performance, Real-time Data Sharing in Next Generation Modeling & Simulation Systems

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Table of Contents

1. Modeling & Simulation Challenges

The need to make Modeling & Simulation (M&S) environments more realistic and sophisticated so that they can support an increasingly varied and wide range of complex situations is driving the need for extremely high throughput, low latency, real-time data sharing over geographically dispersed distributed networks. This is combined with the need to provide open architecture solutions that can enable reusability and interoperability between models and simulators in Live Virtual Constructive (LVC) simulation. The key challenges facing the M&S community include:

1.1 Interoperability

- Over different networks in a system of systems scenario. This includes between multiple simulators and also between simulators & operational systems
- Between heterogeneous architectures
- Among multiple simulation standards or multiple implementations of the same standard
- Data synchronization of alternative sources

1.2 Performance

- Maintaining performance as simulation scale increases
- Low latency data requirements
- Real-time data prioritization and distribution

1.3 Security

- Confidentiality
- Integrity
- Authenticity

1.4 System evolution

- Plug and play capabilities to allow systems to evolve more easily
- Support for dynamic simulation elements so that simulations can better reflect the variable aspects of real-world operational scenarios
- Fast discovery times

1.5 Fault tolerance

- Avoiding single points of failure that can disrupt or compromise simulations

The current generation of M&S architectures are finding it increasingly difficult to meet these emerging requirements. This document discusses how the OMG's Data Distribution Service (DDS) for Real-time Systems standard is increasingly being used to address the real-time data distribution requirements of large scale, highly distributed networked simulations.

2. Current Solutions

Originally developed by the US Department of Defense the High Level Architecture (HLA) is the prescribed standard for military simulation interoperability within the US. It is also the standard for simulation interoperability within NATO. The HLA standard has also become a non-military standard through the Institute of Electrical and Electronic Engineers (IEEE) 1516. It was the first Open standard designed for LVC, providing services for any type of simulator.

The underlying HLA architecture is publish-and-subscribe based whereby elements publish data onto the bus to be picked up by other units that subscribe to that data, commonly referred to as 'federated data'. This model allows a system to be distributed, avoiding the bottlenecks of a client-server architecture and allowing the system to scale more easily.

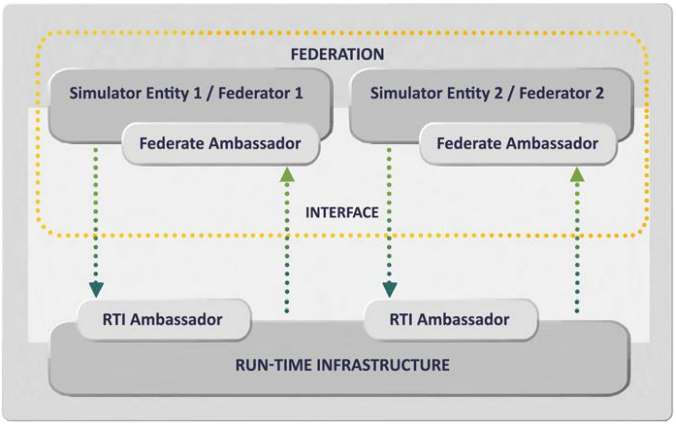

Figure 1 – HLA Run Time Infrastructure

In simulation, run-time infrastructure (RTI) is middleware required when implementing the High Level Architecture. RTI as shown in Figure 1 is the fundamental component of HLA. It provides a set of software services that are necessary to enable federates to coordinate their operations and data exchanges during a runtime execution. An RTI is the implementation of the HLA interface specification but is not itself part of specification. Modern RTI implementations conform to the IEEE 1516 and/or HLA 1.3 API specifications.

HLA supersedes several earlier standards such as Distributed Interactive Simulation (DIS) and Aggregate Level Simulation Protocol (ALSP) used in Constructive Simulation.

There is overwhelming use of HLA and DIS and together they account for more than 70% of the simulators. Other non-mainstream simulation standards include Test and Training Enabling Architecture (TENA) and Common Training Instrumentation Architecture (CTIA), which account for approximately another 15% and 5% of the market respectively.

HLA was designed as a universal standard and over that last decade has been very successful. However, as simulation goals have become more challenging, limitations of HLA have become more apparent and are driving the need for the introduction of new technologies and standards in the M&S domain. Key issues with HLA and HLA RTIs include lack of support for a standardized interoperability protocol, the inability to support the low latency real-time data sharing requirements as simulation scale increases and lack of "plug and play" support for dynamic late joining federates.

3. Data Distribution Service for M&S

The OMG's Data Distribution Standard specifies a data-centric publish and subscribe model similar to HLA's which allows domain participants (publishers and subscribers) on potentially a very large number of distributed nodes to communicate with each other asynchronously and in real-time. Unlike HLA, DDS also specifies a wire protocol ensuring interoperability amongst implementations from different vendors.

DDS supports data-centric systems where the focus is on the data model. The unit of exchange in this type of system is a data value. The middleware understands the data and ensures that all interested subscribers have a synchronized and consistent view of the data. This is similar in concept to database that can provide a global view of the data and can manage its access. The infrastructure has done its job not when a message is delivered, but when all nodes have the correct understanding of that value. A domain participant may simultaneously publish and subscribe to typed data-streams identified by named "Topics" as shown in Figure 2.

DDS specifies communications interactions between publishers and subscribers that are:

- 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 or best effort and with control over available network bandwidth)

These fundamental tenets of the architecture help enable complex systems that can scale reliably. DDS Quality-of-Service (QoS) parameters specify the degree of coupling between participants, properties of the overall model and of the Topics themselves. Scalability is increased due to the multiple independent data channels identified by "keys". This allows nodes to subscribe to many (maybe thousands) similar data streams with a single subscription. When the data arrives, the middleware can sort it by the key and deliver it efficiently.

DDS has an in-built state-propagation model, so when treating data structures with values which only change occasionally, they will be transmitted only once for every update, helping reduce network load.

The DDS standard defines:

- A Data Centric Publish Subscribe (DCPS) layer providing a set of APIs that present a coherent set of standardized "profiles" targeting real-time information-availability for domains ranging from small-scale embedded control systems right up to large-scale enterprise information management systems.
- A Real-time Publish Subscribe (RTPS) wire protocol

DDS is both language and OS independent. The DCPS APIs have been implemented in a range of different programming languages including Ada, C, C++, C#, Java, Scala, Lua, and Ruby. Using standardized APIs helps ensure that DDS applications can be ported easily between different vendor's implementations.

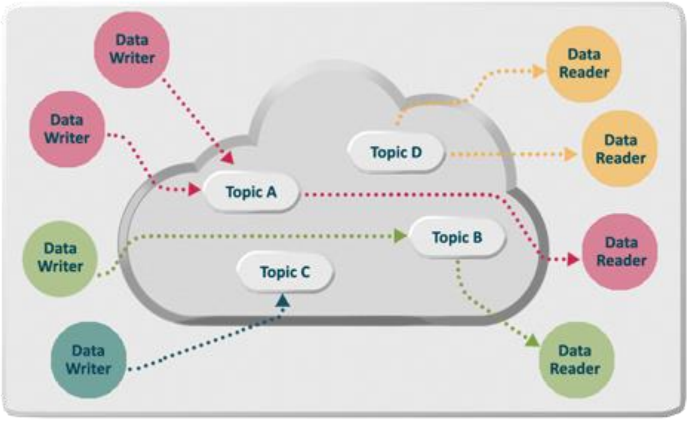

Figure 2 – DDS Global Data Space

DDS supports both unicast and multicasting IP networks to minimize data latency between nodes. It does not require a central server to broker data flows or any other special nodes. In a DDS-based system data communication occurs directly between peers. Peer-to-Peer (P2P).

Since its introduction in 2003, DDS has enjoyed rapid adoption as a standard for developing and integrating high-performance real-time systems. It is a mandated standard for publish-subscribe messaging by the U.S. Department of Defense (DoD) Information Technology Standards Registry (DISR). Programs that have adopted DDS include the U.S. Navy's Open Architecture Computing Environment (OACE), FORCEnet the U.S. Army's Future Combat Systems (FCS), and the joint Air Force and Navy Net-Centric Enterprise Solutions for Interoperability (NESI).

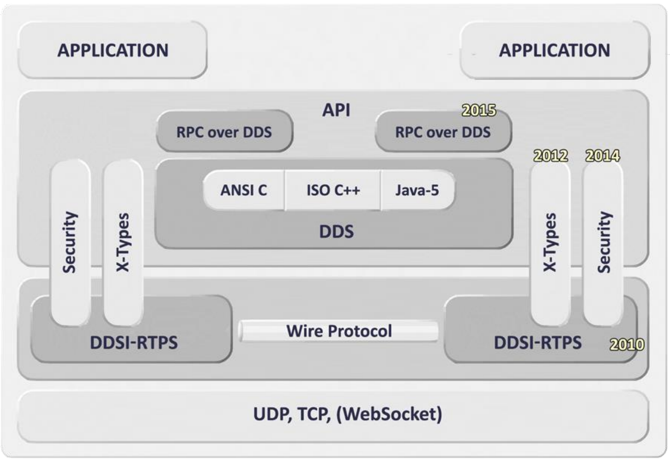

Figure 3 – OMG DDS Architecture

4. DDS Comparison with HLA

DDS is already deployed in many operational systems ranging from large-scale network centric system of systems, to supervisory control and data acquisition (SCADA), transportation, healthcare, finance, and as the data backbone supporting the next generation of smart cities.

HLA	DDS
HLA-OMT	DDS-DLRL
HLA-RTI	DDS-DCPS
HLA-Rules	-
Federation	Domain
Federate	Participant / Application
RTIAmbassador	DomainParticipant, Publisher, DataWriter, Subscriber, DataReader
FederateAmbassador	Listener classes
Object class	Keyed Topic
Interaction class	Topic (no keys)
Update attribute	Write "keyed" instance
Reflect attribute	Read/Take "keyed" data samples
Send interaction	Write "non-keyed" instance
Receive interaction	Read/Take "non-keyed" samples

Table 1 – Mapping Between HLA and DDS Concepts

DDS is also increasingly being used in large-scale high performance simulations. DDS is suitable for a large subset of scenarios targeted by HLA and can provide a number of benefits over current HLA implementations to the M&S community. Table 1 provides a comparison between key HLA and DDS concepts.

HLA was developed as a standard whose initial focus was to address functions and services common to simulation systems and was not designed to address communication problems and issues such as interoperability. The standard also considered systems to be static in nature and does not adequately support dynamic scenarios with late joining simulations.

DDS on the other hand was designed to support large-scale real-time publish-and-subscribe communications in a networked environment. It does not provide all of the services tailored specifically for the M&S domain. However, it does provide the necessary functionality to support the communication scenarios common in simulation systems and the user has the ability to build any missing services on top of DDS should they be required.

Over the past six or seven years there has been a growing recognition by the M&S community that DDS can bring a number of benefits to HLA based systems including:

1. A high performance integration technology to support interoperability between HLA implementations from different vendors over heterogeneous networks
2. A HLA-DDS gateway between simulation and operational worlds
3. A high performance real-time deterministic equivalent of an HLA-RTI

In fact, the Simulation Interoperability Standard Organization (SISO) that maintains the HLA standard has created the Layered Simulation Architecture (LSA) Study Group. This group has been tasked to explore and develop a consensus view of the applicability of modern principles of network centric interoperability and Open Systems architecture. In particular the definition of different layers to enable looser coupling among simulation applications will be addressed. The architecture resulting from this study may better define a modular, loosely coupled structure that enables more flexibility and performance than current approaches. The latest proposed architecture will use DDS's DDSI wire protocol to support interoperability between simulators, with HLA also formally adopting other DDS key features as part of the standard. Table 2 provides a high-level comparison of key features supported in DDS and HLA.

Supported by DDS	Not supported by HLA
DDS provides a rich set of QoS (22 in total) to control all aspects of networked communications: • Time • Space • Lifecycle • Resources	HLA Evolved only supports 2 (reliable delivery and message order)
Standardized wire protocol supports interoperability between vendors	No interoperability between vendors
Fast dynamic discovery	No discovery service
Scales easily to Support large system-of systems	Does not scale well – in HLA the entire data model has to distributed to every participant
Performance – low latency, high throughput	No QoS control over data latency or throughput
Predictable data sharing	No support for Real time QoS
Plug and play	Not easily
User friendly API	API difficult to use
Security	No security service
Fault tolerant	HLA is broker base so can introduce a single point of failure
Seamless connectivity with DDS-based operational systems	No
Supported by HLA	**Not Supported by DDS**
Inheritance	Can be re-created but not natural
Simulation services (e.g. Time Management)	Can be built on top of DDS
Interactions	Can be re-created with single instance topics

Table 2 – HLA and DDS Feature Comparison

5. Vortex DDS OpenSplice Edition

ADLINK's Vortex DDS OpenSplice edition is the most advanced, complete and widely used Commercial and Open Source DDS implementation. It has been designed to optimally address the real-time information distribution and management challenges posed by traditional high performance real-time data-processing systems as well as next generation big-data systems.

5.1 Vortex DDS OpenSplice Edition Benefits for M&S Systems

Vortex DDS OpenSplice edition has a number of unique features that make it particularly well suited for use in M&S systems. In particular, Vortex DDS OpenSplice edition has been designed to offer exceptional scalability and real-time network performance. Both of these are key challenges in the M&S domain.

Vortex DDS OpenSplice edition is the only DDS implementation that gives users the choice of selecting the deployment architecture that best suits them by simply configuring the software at runtime. This allows users to change from a standalone 'single-process' deployment (where the middleware is linked as libraries into your application) to a 'federated' deployment (where multiple applications on a computer share information via shared memory and where network-traffic to/from that federation is arbitrated by a unique network-scheduler based upon urgency & importance of each exchanged piece of information).

The Shared-memory based deployment option shown in Figure 4 features ultra-low latency inter-core communication along with extreme nodal scalability. This architecture results in better scalability, more efficient data-sharing and better peer-to peer determinism. This differs from other DDS implementations, where library-based deployment prevents nodal arbitration of data-flows and related usage of nodal communication resources.

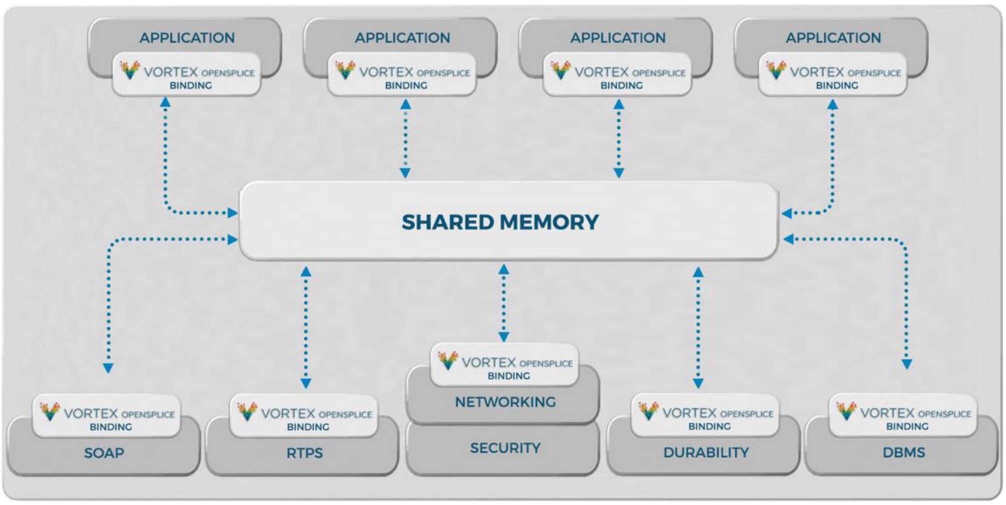

Figure 4 – OpenSplice Shared Memory and Real-time Networking

Vortex DDS OpenSplice edition real time networking service allows users to fine-tune, prioritize, and bundle data across topics and applications to ensure optimal throughput, reduce CPU utilization and maximize the use of network bandwidth. Vortex DDS RTNetworking provides native real time network-scheduling for deterministic large scale systems. Vortex DDS SecureRTNetworking is a secure version of RTNetworking that supports transparent encryption of information in selected partitions. Vortex DDS also provides an enhanced version of the core DDSI2 interoperable networking service; DDSI2E, offering better determinism and scalability enhancements whilst preserving interoperability with other OMG DDSI Rev2.1 implementations.

Many M&S systems require the ability to capture and then replay simulation data. The Vortex DDS RnR (Record & Replay) Service enables effortless recording and replaying of any data in a DDS system.
In M&S systems the requirement to publish hundreds of thousands of small data samples per second is quite common. Vortex DDS Streams provides unprecedented throughput of millions of samples/sec for typical periodic 'stream' data.

The Vortex DDS Tools greatly simplify the modeling, testing, and tuning of DDS-based M&S systems. They enable total control over an Vortex DDS based distributed environment with support for automated testing and debugging of the system

5.2 Business Benefits and ROI

Vortex DDS OpenSplice edition can provide a powerful, high performance infrastructure for real-time data sharing for M&S systems. In addition to the technical benefits of using Vortex DDS OpenSplice edition a number of commercial benefits can also be realized.

The costs to build, maintain, and update an M&S system that uses Vortex DDS OpenSplice edition can reduced by enabling the system to evolve more easily and more dynamically.

Vortex DDS OpenSplice edition makes it much easier to support the federation of different simulators from the same or different vendors and also simplifies the integration of M&S systems with DDS-based operational systems.

Using Vortex DDS OpenSplice edition as the COTS data backbone for an M&S system can significantly reduce the amount of time and investment required to support homegrown simulation infrastructure and tools. A single interoperable simulation architecture based on Vortex DDS OpenSplice edition can be built to support an entire suite of M&S products.

In today's non-DDS-based simulators, developers often have to create proprietary protocols to support data distribution with adequate scalability and real time performance within the simulator. These protocols are costly to develop and costly to maintain. Vortex DDS OpenSplice edition features such as temporal QoS, data prioritization, and support for unreliable networks have been proven to provide significant scalability and performance benefits for next generation high fidelity M&S systems.

Standardizing on a single publish-and-subscribe protocol in contrast to having different simulators running different proprietary protocols can also help to reduce the number of engineering resources required to support multiple complex architectures.

Vortex DDS Tools for monitoring a DDS-based environment help make it much easier to develop, debug, support and maintain an M&S system using DDS. For new systems, this means being able to be deliver products to market more quickly.

The Vortex DDS OpenSplice edition licensing model is designed to provide a very sensible reduction of the Total-Cost-of-Ownership (TCO) for customer's middleware infrastructure. This is particularly important in today's market due to the renewed attention to technology expenditure raised by the recent financial crisis. Traditional software licenses have a very cash-flow unfriendly nature, as they demand the significant investment at the beginning of a projects life-cycle. Vortex DDS OpenSplice edition subscriptions are cash-flow friendly and ensure customers can exploit the full power of the technology from day one.

ADLINK also provides a wide range of training courses ranging from beginner level up to advanced users. Our trainers and consultants are world-class domain experts and deliver great ROI by ensuring that attendees get an understanding of the technology and how to fully exploit its capabilities

6. Summary

With the increasing need to be able support a more sophisticated and wider range of scenarios, M&S environments are becoming more complex. This is driving the need for very high throughput, low latency, real-time data sharing in heterogeneous networked environments. In order to maximize ROI there is a growing need within M&S to provide Open architecture solutions that can support reusability and interoperability between models, simulators, and operational systems. Existing M&S architectures such as HLA are finding it increasingly difficult to meet these challenges.

DDS is emerging as an important technology that can be used to address many of the challenges faced by the M&S community. Like HLA, DDS supports a publish-and-subscribe communication model and importantly was designed to support large-scale real-time data sharing. It is already used in many demanding types of mission-critical system. DDS also defines a wire-protocol so that interoperability between data producers and consumers is guaranteed even if they are based on different vendor implementations.

There is increasing use of DDS in next generation of M&S systems to provide interoperability between simulators and DDS-based operational systems. With better support for plug-and-play a DDS-based system can evolve much more easily. Better plug-and-play support also enables simulations to be much more dynamic.

Vortex DDS OpenSplice edition is the leading Commercial and Open Source DDS implementation. It provides a fully interoperable solution that has been designed to offer exceptional scalability and real-time network performance. These are all key challenges for next generation M&S systems. It is field proven and widely deployed in many mission critical systems. It has a success record of being used in systems ranging from multi-processor single-board computers, to large scale system of systems.

Finally, the LSA initiative at SISO is pushing for the formal adoption of DDS to provide an interoperable publish-and-subscribe solution for future versions of HLA. This work is indicative of the fact that DDS is becoming increasingly important to the M&S community.

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