DDS White Paper

Using DDS for scalable, high performance, real-time data sharing in next generation Modeling & Simulation systems

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:

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

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

Security
- Confidentiality
- Integrity
- Authenticity

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

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.

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.

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](image)

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).

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.

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<td>Receive interaction</td>
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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 wasn’t 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 doesn’t 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 few 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.

![Figure 3 – OMG DDS Architecture](image-url)
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)

| Supported by DDS | Not Supported by DDS |
--- | ---
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 | Doesn’t scale well – in HLA the entire data model has to be 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 based so can introduce a single point of failure |
Seamless connectivity to DDS-based operational systems | No |

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 of 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.

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.

Table 2 - HLA and DDS Feature Comparison

| Supported by HLA | Not Supported by DDS |
--- | ---
Inheritance | Can be re-created b not natural |
Simulation services (e.g. Time Management) | Can be built on top of DDS |
Interactions | Can be re-created with single instance topics |

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