All-in-one middleware for industrial human-robot-interaction

arise-middleware.eu

Coordinator

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Disclaimer

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D2.1 NGSI-LD Context Broker with native DDS Support

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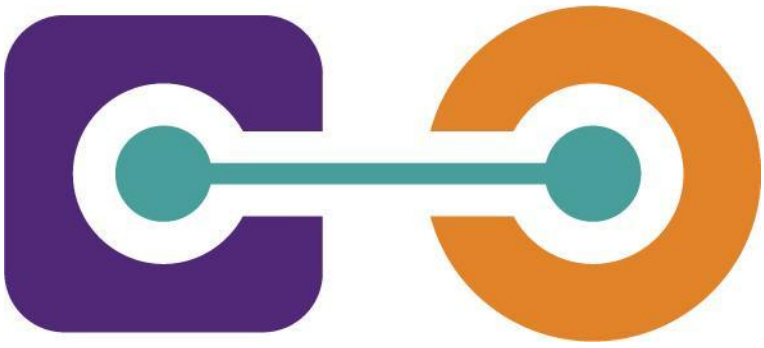

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Table of Contents

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List of Figures

Acronyms & Abbreviations

ACR.	Description
CIM	Context Information Management
DDS	Data Distribution Service
ETSI	European Telecommunications Standards Institute
HRI	Human-robot Interaction
HTTP	Hypertext Transfer Protocol
IT	Information Technologies
NGSI-LD	Next Generation Service Interface with Linked Data
OMG	Object Management Group
OT	Operation Technologies
QoS	Quality of Service
ROS 2	Robot Operating System 2
TTF	Testing Task Force

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1 Introduction

1.1 About the project

ARISE is an innovative action aimed at simplifying, reducing costs, and broadening the adoption of industrial Human-Robot Interaction (HRI) deployments across Europe. This initiative aligns with the principles of Industry 5.0, emphasizing the creation of resilient, sustainable, and human-centric work environments. In this envisioned future, companies recognize that investing in industrial HRI is not merely an expense but a strategic approach to achieving both immediate and long-term goals. By prioritising human-centric methodologies over traditional technology-driven approaches, ARISE positions technology as a tool to empower people, rather than people serving or being replaced by technology. Within this framework, industrial HRI emerges as a transformative asset, fostering seamless collaboration between humans and robots, enabling them to tackle complex challenges efficiently and work collaboratively across diverse workplace scenarios and shift patterns.

1.2 About this document

This deliverable reports on one of the core contributions that ARISE aims to achieve with its technical framework. The most important aspect of the deliverable is the functional, ready-to-use software that has resulted from the engineering, design, and implementation efforts devoted to this task. This document serves as a complement to the software repository and its documentation, providing additional context to facilitate understanding of the objectives, complexities, dedicated efforts, and outcomes achieved during the project's first year.

1.3 Intended audience

Project reviewers, solution engineers, developers and multidisciplinary innovation experts in AI, data and robotics fields which aim to understand the purpose, scope, and status of the software under discussion.

1.4 Reading recommendations

Chapter 2 provides the necessary background to help readers understand the problem addressed and the solution proposed. *Chapter 3* introduces the software and its current status from a high-level perspective. *Chapter 4* contributes with lower-level details which are more specific to the software implementation. Last but not least, *Chapter 5* presents the conclusions and next steps identified.

2 Background

2.1 About NGSI-LD Context Broker Technology

2.1.1 The NGSI-LD Standard

NGSI-LD is an information model and API for publishing, querying and subscribing to context information, based on JSON-LD and its predecessor, NGSIv2. NGSI-LD is standardized by ETSI in the Industry Specification Group CIM (Context Information Management), started in 2017 and is still very active, currently with 4 weekly meetings for:

- API
- Security
- Digital Twins / Advances Actuation
- General call, for official decision-making

Typically, there is a new release of the NGSI-LD API twice a year, the latest release being v1.8.1, from March 2024. V1.9.1 is planned for January 2025.

NGSI-LD views the world as a series of entities. NGSI-LD Context Brokers are the reference software components which fully implement the NGSI-LD standard API to build and interact with such entities while other software components may partially implement the API to provide and/or consume entity data. An entity has a unique ID, a type and a set of attributes. Attributes have a type, a value and potentially a set of sub-attributes. The NGSI-LD offers several mechanisms (API endpoints) to create/update/delete entities, apart from the querying of entities, including filtering and projection. Subscriptions are supported as well, which is often a better approach than polling information by querying. Perhaps the most important concept in NGSI-LD is the *federation*, namely, the ability of one NGSI-LD context broker to join other context brokers or simpler context sources and "work as one". The mechanism for federation is NGSI-LD Registrations, with which one broker is made aware of entities that live on another broker, and it becomes transparent to the end user on which broker a specific entity actually resides. There is also the possibility of having an entity split up into various brokers.

2.1.2 Reference Implementations of NGSI-LD Context Brokers

As part of the FIWARE catalogue, there are three NGSI-LD context broker implementations:

- Scorpio (implemented in Java by NEC)
- Stellio (implemented in Kotlin by EGM)
- Orion-LD (implemented in C/C++ by FIWARE Foundation)

They're all open source and living on GitHub (links available in the bulleted list). Apart from these three, there are more NGSI-LD broker implementations, one being the "CityHub", implemented in Java by the Korea Electronics Technology Institute (KETI).

2.2 About Data Distribution Service (DDS) Middleware Technology

2.2.1 The DDS Standard

The Data Distribution Service (DDS) is a middleware standard developed by the Object Management Group (OMG) to facilitate real-time data exchange in distributed systems. It is designed to support high-performance, scalable, and low-latency communication for mission-critical applications, such as those found in industrial automation, aerospace, healthcare, and robotics. DDS uses a Data-Centric Publish-Subscribe model, enabling efficient and reliable data transmission with fine-grained control over Quality of Service (QoS) parameters like latency, reliability, and throughput.

2.2.2 Reference Implementations of DDS Middleware Technologies

Several DDS implementations exist, both open-source and commercial, adhering to the standard. Popular implementations include:

- Fast DDS (by eProsima): The most used open-source implementation of DDS. Due to its high performance and robust support for real-time robotic systems, Fast DDS is the default communication middleware of ROS 2. It also provides low-latency communication, advanced QoS settings, and efficient intra-process data handling, essential for ROS 2 applications. Moreover, its active community of users and its comprehensive documentation make it a preferred choice over other DDS implementations for developers seeking reliability and scalability in their systems.
- RTI Connext DDS (developed by Real-Time Innovations): A commercial implementation of DDS standard designed for real-time, distributed systems, and widely used in high-reliability systems.
- OpenDDS (an open-source project maintained by Object Computing, Inc.): A C++ and Java-based implementation of the DDS standard.
- Cyclone DDS (maintained by Eclipse Foundation): An open-source DDS implementation focusing on lightweight design and simplicity for IoT and embedded systems. However, it has demonstrated lower performance and more limited support for the DDS standard and communication features compared to other implementations, such as Fast DDS and RTI Connext.

2.3 The Problem Addressed: OT/IT Convergence in I4.0 settings

The convergence of Operational Technologies (OT) and Information Technologies (IT) in Industry 4.0 (I4.0) environments presents significant challenges and opportunities. OT systems, which focus on real-time control and monitoring of physical processes, must integrate seamlessly with IT systems, which manage data, analytics, and digital infrastructure. This integration is critical for enabling smart industry scenarios such as predictive maintenance, agile production models and industrial digital twins, which are a cornerstone to enable timely and data-driven decision-making for sales and operations units. However, differences in system architectures, communication protocols, security requirements, and organizational silos create obstacles to addressing the required technical convergence effectively.

2.4 ARISE's Solution: Native DDS/ROS 2 in NGSI-LD Context Brokers

In ARISE, the concept of an All-in-One Middleware encapsulates the integration of operational and information technologies by providing a unified platform that bridges their inherent differences. The ARISE Technical Framework proposes extending NGSI-LD brokers with native DDS (Data Distribution Service) support, thereby enabling seamless communication and data exchange between IT systems and OT systems, such as those utilizing ROS 2 (Robot Operating System 2).

The proposed middleware solution directly addresses the primary barriers to OT/IT convergence by harmonizing their distinct protocols and architectures within a unified, open, and extensible framework. This approach promotes improved operational efficiency, enhanced scalability, and fosters innovation in smart industrial settings.. Therefore, by integrating DDS/ROS 2 capabilities into NGSI-LD brokers, the middleware fosters a fully integrated data environment that serves as a central hub for managing IT data while ensuring compatibility and interoperability with high-performance, real-time OT networks. This integration effectively decouples the specific challenges of OT and IT systems, streamlining the development, deployment, and management of I4.0 applications.

In short, the major strengths of integrating DDS/ROS 2 capabilities into NGSI-LD brokers include:

- Real-time data handling from OT devices becomes feasible within broader IT infrastructures.
- Bidirectional communication ensures that insights from IT systems, such as analytics or digital twins, can influence OT processes in real time.
- Adherence to open standards like NGSI-LD and DDS supports standardization and scalability, allowing for flexible and extensible solutions across heterogeneous environments.

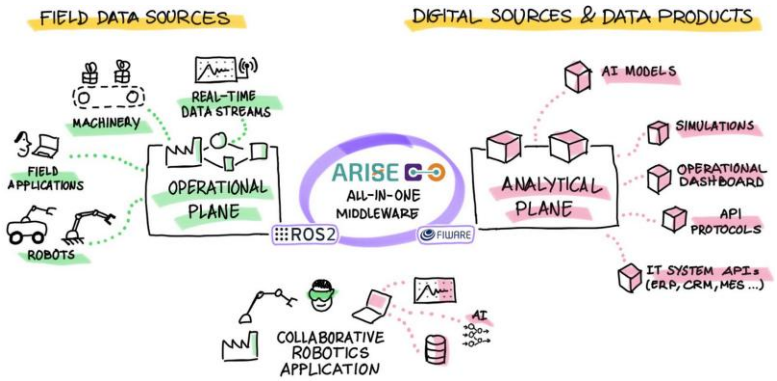

Figure 2.1 The ARISE's middleware solution enables seamless OT/IT convergence by leveraging an advanced NGSI-LD technology which natively supports DDS/ROS 2

3 ARISE's Broker: Fast DDS + Orion-LD

ARISE has developed a version of Orion-ld, a powerful software component for efficient data brokering, which natively supports ROS 2 and FIWARE (NGSI-LD) interfaces. In short, the ARISE version of Orion-LD is equipped with native FastDDS, a collaborative initiative between eProsima and the FIWARE Foundation to bridge DDS/ROS 2 and FIWARE ecosystems together. The foundational idea is that the context broker translates the data published in the DDS topics into NGSI-LD entities and attributes and data providers and consumers can interact with those entities using HTTP or DDS based indistinctively. In practice, this requires a series of conventions on how to connect an NGSI-LD context broker to a FastDDS system and open up HTTP access to the FastDDS system via the context broker. Developing a comprehensive binding for ETSI's NGSI-LD standard to use DDS as a transport layer has proven to be a complex and time-intensive task. This complexity could jeopardize the timely delivery of high-quality software to TEFs and experimental projects. To address this, ARISE has adopted an implementation-driven approach, where conventions are iteratively defined, discussed, and formalised with ETSI. This process ensures standardization and maximizes reusability. The roadmap designed for ARISE brokers consists of two main phases, detailed as follows.

3.1 Phase I - Legacy Mode (M12)

Phase I or "Legacy Mode" is for the broker to be able to connect to already running DDS systems, without any modification whatsoever to the already running DDS system. Basically, the broker listens to the DDS communication, receives every DDS sample and translates those samples into NGSI-LD entities/attributes, adding that to its current state. Applications can then access those entities/attributes coming from DDS via normal HTTP NGSI-LD queries/subscriptions. That's about the "read-only" mode, which is already working as of release 1.7.0 of Orion-LD. For the "Write mode" that is to be supported by January 2025, any update of an NGSI-LD entity/attribute will be pushed onto DDS. As earlier stated, every pushed DDS sample is (by convention) seen as an NGSI-LD attribute, so the NGSI-LD broker needs a translation table from the DDS topic to the NGSI-LD entity ID, entity type, and attribute name. In the Legacy mode, as we need it to be 100% non-intrusive on the already running DDS system, a configuration file of the broker supplies this information

3.2 Phase II - NGSI-LD "Aware" Mode (Next Release, M24)

Phase II of the "Native DDS in NGSI-LD brokers" is meant for DDS systems created with NGSI-LD in mind from scratch. The definition of phase II is still a work in progress but the idea is that the topic name is the NGSI-LD longname of an attribute and the entity ID and optionally the entity type are part of the sample. Thus, no config file is needed. Well, the part "dds:ngsild:topics" is not needed. Phase II should be implemented and fully working in Orion-LD before the end of 2025.

4 Implementation Details

4.1 Codebase

4.1.1 Core Features: Orion-LD and Fast DDS

- Official Link to Orion-LD Repository: https://github.com/FIWARE/context.Orion-LD
- Official Link to Fast DDS Repository: https://github.com/eProsima/Fast-DDS

4.1.2 The DDS Enabler

- DDS Enabler: https://github.com/eProsima/FIWARE-DDS-Enabler.git

4.1.3 Orion-LD + DDS

- Link to Orion-LD + DDS: https://github.com/FIWARE/context.Orion-LD/issues/1696

4.2 Documentation and Additional Resources (*)

Structure:

- Guide to NGSI-LD entities and attributes
- Guide to the JSON-LD @context
- Installation Guide
- Quick Start Guide
- External Libraries
- Temporal Representation
- The Broker as Context Server
- Roadmap

Additional Resources:

- NGSI-LD Overview
- NGSI-LD in 30 min
- NGSI-LD in a Nutshell
- Examples of **NGSI-LD** payloads can be found in ETSI.

Test Suite for NGSI-LD compliant brokers:

- A Test Suite for NGSI-LD-compliant brokers can be found here. This test suite is deprecated in favour of the newer ETSI NGSI-LD API Conformance Test Suite (Orion-LD passes about 95% of the test cases of this older deprecated test suite). About the ETSI-funded conformance test suite, a third TTF (Testing Task Force) is currently in progress, to improve overall coverage and to aggregate conformance tests for distributed operations. This third TTF is expected to finish in February 2025 and by then, the ETSI NGSI-LD conformance test suite should be fully operational, and thus test results for Orion-LD can and will be published.

5 Conclusions and Next Steps

The work carried out during the first year to design and implement the initial version of the NGSI-LD Context Broker with native DDS support has been a success. Despite the significant differences in approaches and patterns specified by the two standards, the high quality of the initial software components (Orion-ld and Fast DDS) and their development teams has enabled the timely delivery of functional software that both the TEFs and ARISE experiments can fully leverage.

Along the way, two key strategic decisions have been made, both of which have proven to be effective:

1. **Adopting an agile and pragmatic implementation-driven approach to align the NGSI-LD and DDS standards.** Practising the technology, evaluating potential alternatives, and learning from experience were identified as critical preliminary steps before applying more theoretical and formal methods to such a complex problem with unknown dimensions.
2. **Establishing a structured roadmap in two phases.** The first phase aims to make any ROS 2 system plug-and-play with the context broker technology. This allows the open-source robotics community to benefit from interoperability starting from the first release. The second phase will build upon the first by focusing on the reverse direction: enabling FIWARE systems, whose interfaces are based on NGSI-LD, to appropriately inject data into ROS 2 systems.

Regarding the next steps:

- Short term - The first phase has now been successfully completed, with only a few tests and adjustments remaining for the write functionality from NGSI-LD to ROS 2. This functionality is expected to be fully operational by January 2025.

- Mid-term - The next steps will focus on preparing and launching the second phase of development, which has a milestone set for December 2025, when the second release of the ARISE Context Broker will be published.

- Long-term - It is yet to be decided whether the third release of the broker will extend the second phase or initiate a new third phase. A set of highly relevant ideas and functionalities have already been identified, such as developing functionality not based on HTTP for an ultra-efficient federation of different context broker instances. These decisions, which will influence development plans for 2026, will be clarified during 2025.

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