Future Proof IoT: Composable Semantics, Security, QoS and Reliability

Tim Abels *, Rahul Khanna *, Kevin Midkiff $*
* Intel Corporation, Hillsboro, Oregon, USA
$ Portland State University, Oregon, USA

***Abstract*— IETF impressively defined internet interoperation across 30 years of unforeseeable syntax API. IOT needs similar future proof, but for connected things' composable semantics, security, reliability and Quality of Service (QoS). This paper overviews these with simplifying tradeoffs from a bottom up approach using Data Distribution Service (DDS). Then high level semantic additions to DDS are suggested for semantics that are backward compatible, while maintaining the security, reliability and QoS of DDS. Finally, further work is suggested toward out-of-the-box composability and interoperability between common IoT data models and compliant solutions.**

***Index Terms*— semantics, IoT, DDS, resource discovery, CoRE Resource Links**

I. Introduction

IoT is driving significant use cases for 5G and WSN. Figure 1 shows 5G usage scenarios from ITU[1]. Note that the corners are machine type communication (MTC), possibly since that is expected to grow to 100 times more than machine to human communications. Massive MTC (M-MTC) and mission critical (MC-MTC) are widespread, but we have expanded enhanced mobility (e-MBB) corner with enhanced MTC (E-MTC), emphasizing many IoT usage enhancements beyond mobility, including cognitive associations, seamless ambient and future-proof. In ITU 2020 gap report for 5G[2], network softwarization included software defined networks (SDN), network function virtualization (NFV), self-organizing network (SON) and network slicing.

Since software defined networks (SDN) centralize the control planes, this lets data owners separate their value chain semantics, from data supplier's infrastructure semantics. Table I lists the infrastructure semantics transitions that network softwarization enables. For example, SDN enables the SW design and distribution of network HW control, algorithms and flow handling for innovations, including semantics here. Overviewing the supersets of these, is beyond the scope of this paper, including software defined IoT (SD-IoT) that controls and updates any hardware, anywhere, anytime, including edge and WSN.

Long life infrastructure is rarely supported beyond 15 years and even that usually requires remote network softwarization techniques like above to avoid impossible or expensive truck rolls, downtime and on premise refurbishing. The remainder covers semantics above infrastructure and introduces future proof, including composable semantics.

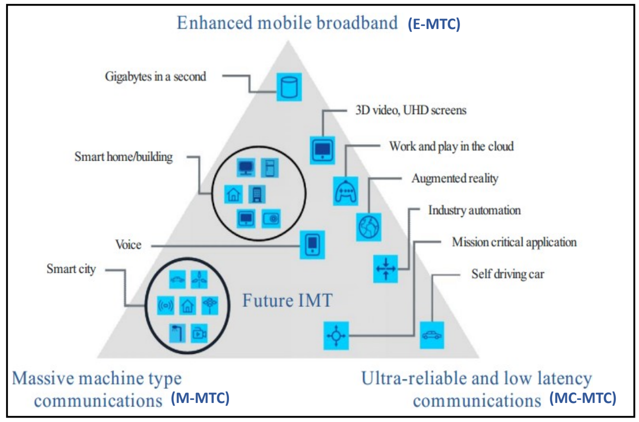

Fig. 1. ITU 5G Usage Scenarios MTC corners (Source: R-REC-M.2083-0-201509, ITU-R IMT-2020)

The enormous growth rate of IoT sensor data may dominate other data types and wireless traffic soon. Figure 2 shows end-to-end IoT network stacks with the upper application layer 7 removed. IoT was initially Things connected by Networks to the Internet (Cloud here). Note how optional Gateway brings constrained Things to the Cloud with protocol remapping and feature aggregation enabling high volume, low cost and custom Things. Similarly, optional Fog brings near real-time Cloud compute to the edge Things, whether Fog is part of the Cloud (shown here) or on-premise. We'll suggest an extension of DDS called DDS', and a subset of that to the constrained edge, of CoAP here.

DDS is the major transport in life and mission critical medical, aerospace, energy and military. DDS specification goal[3] is enabling the "'Efficient and Robust Delivery of the Right Information to the Right Place at the Right Time."' Table II compares major IoT transport options

[1] www.itu.int/rec/R-REC-M.2083-0-201509-I/en - ITU-R IMT-2020

[2] IMT-2020 focus group, http://www.itu.int/en/ITU-T/focusgroups/imt-2020/

[3] www.omg.org/spec/DDS/1.4/ for current version 1.4 of DDS

TABLE I

NETWORK SOFTWARIZATION INFRASTRUCTURE SEMANTICS TRANSITIONS

SDN	Hardware (HW) gains software (SW) semantics, including reprogramming data, management and HW, and remote control plane that's functionally centralized
NFV	SW deployment gains file copy semantics, including file move/copy, create/delete, pause/resume, chaining files/flows and package once for common binary guest SW to common host HW.
SON	Networks gain service semantics, with execution and organization at local levels, to control by exception or policy
Net	Slicing Workloads gain grouping of isolation and concurrency units for QoS, security, reliability, etc. and we add composable semantics

TABLE II

COMPARE IOT MESSAGING WITH DDS

	AMQP	CoAP	MQTT	HTTP/REST	XMPP	DDS
Transport	TCP/IP	UDP/IP	TCP/IP	TCP/IP	TCP/IP	UDP/IP, TCP/IP unicast & multicast
Messaging	Point-to-Point Message exchange	Request-Reply (REST)	Publish-Subscribe	Request-Reply	Point-to-Point Message exchange	Publish-Subscribe, Request-Reply, Queueing, Deterministic middleware, Distributed Real Time
Scope	Device-to-Device, Device-to-Cloud, Cloud-to-Cloud	Device-to-Device	Device-to-Cloud, Cloud-to-Cloud	Device-to-Cloud, Cloud-to-Cloud	Device-to-Cloud, Cloud-to-Cloud	Device-to-Device, Device-to-Cloud, Cloud-to-Cloud
QoS	Limited	Limited	Limited	N/A	N/A	Extensive
Interoperate	Structural	Semantic	Foundational	Semantic	Structural	Semantic
Security	TLS + SASL	DTLS	TLS	HTTPS	TLS+SASL	TLS, DTLS, DDS Security
Fault Tolerance	Implementation-specific	Decentralized	Broker is SPoF	Server is SPoF	Server is SPoF	Decentralized

with DDS including: flexibility, scope, QoS, semantics, security and fault tolerance. For example, there are over 20 user-configurable QoS defined by DDS including data availability, data delivery, data timeliness, resource limits, system availability data configuration and grouping. Note the issues of non-DDS, including single point of failure (SPoF), unencrypted HTTPS and limited quality or flexibility. Beyond this table's comparisons, only DDS has hard real-time, sufficient content awareness with content-based routing queries, and sufficient data prioritization with transport priorities and automatic discovery.

We don't assume detailed knowledge of DDS or semantics, so we reference their specification sections for more completeness, since only our extensions are detailed. We do not modify an existing, adopted specification, but only add functionality. For customization needs, there are popular open source DDS[4].

DDS provides a middleware layer for deterministic, fault tolerant, real-time distributed systems of systems essential for IIoT. DDS primarily uses publish-subscribe, building on a global data space and model, with publishers contributing data objects and alerted subscribers accessing their values. This data flow is regulated by QoS contracts between the DataWriters and the DataReaders, independent of platform or language. A proven, hardened low level that we think combines well with the highest expressive level, strong semantics, avoiding intermediary syntax, structure and taxonomies, by integrating directly with OWL, based on DARPA agent markup language (DAML).

[4]https://github.com/objectcomputing/OpenDDS

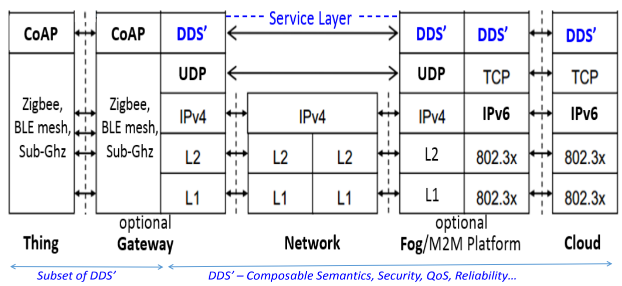

Fig. 2. End-to-End IoT Network Stacks with DDS'

II. RELATED WORKS

Semantically rich sensor network, providing spatial, temporal, thematic events and entities, and their essential value for discovering, analyzing, and contextual sensor data interpretation was detailed by Sheth [1]. A modeling space of semantic types and lifecycle stage for Cloud computing was offered, but it was sparse, did not include IOT Gateway and Fog, and did not align data with non-functional semantics [2]. Four types of application and service semantics were identified, but that also did not align data with non-functional semantics [3], unlike our table III.

Resource discovery extending CoAP[5] and CoRE Link Format[6] for Wireless Sensor Networks [4] was offered, but that lacked DDS benefits and general IoT, including composable semantics and extensibility for future proof.

[5]http://tools.ietf.org/id/draft-ietf-core-coap-13.txt,(CoAP)
[6]www.ietf.org/id/draft-ietf-core-link-format-14.txt

The semantics were focused on constrained edge, and not the end-to-end IoT system of systems that include Gateways and Fog.

The Spitfire project developing applications that span and integrate Internet with embedded Things via linked open data, SPARQL query and RDF triples toward an easier Semantic Web of Things [5] and similarly Phouc et al [6], but no guarantees for QoS or its semantic compositions.

III. Proposed Solution

Table III makes simplifying tradeoffs from prior model spaces, for consistency and density, including per column:

Combining data with non-functional since DDS provides the base and extensible profiles for aligning data with non-functional semantics. It also provides IDL pre-processor for platform independent data representation, bindable to platform specific for deterministic, real time, QoS performance considerations, with flexible DDS profile extensions for access control, logging, or adding new profiles such as functional safety (FuSa), regulatory or domain-specific compliance.

SysML-Systems **M**odeling **L**anguage-[7] is used as orthogonal subset of UML, but adds: hardware modeling to UML, composable SysML ports for completeness, and tagging sub-blocks and flows with both real world IoT constraints and requirements for correctness. Open source SysML have solid functionalityhttp://sysml.tools/review-modelio/ and use XMI standard to exchange XML with commercial products and tools. Logic and Process is simplified with thin, applications, remote API and management that maximize DDS for state per Agirre, et. al. [7] [8] [7]. A SysML equivalent to FUML[8] semantic execution could help model remaining lifecycle.

System of Systems, models collaboration across distributed, unattended, heterogeneous but integrated sensor collections (fusion), by adding DDS Service Plugin Interfaces (SPI) for deployment and management of DDS semantic systems.

Obrst summarizes the levels of semantics expressivity and associated application interoperability [9], where we connect the extremes of low level, managed shared data model, with high level semantic interoperability, disintermediating much complexity.

A semantic model for DDS, called DDS', defines users, objects to extend with semantics metadata following Semantic Web of Things (SWoT) formalisms [10], and the composition operations on those semantics. Semantic DDS means providing:

- Registration and discovery of semantic data objects. DDSI-RTPS[9] includes discovery, metadata sent, all protocol message and handshakes for reliability, and message assembly.
- Composability of data objects and the messages that contain them, with semantic metadata added to managed DDS Global Data Space, accessed via Service Plugin Interface (SPI)
- Maintain DDS specified security, QoS and reliability of DDS data, readers and writers, i.e SPI does not disruptive QoS.

Example actions include maintain DDS unique QoS, while integrating above with large-scale sensor web standards, such as the Open Geospatial Consortium (OGC), which developed several semantic metadata models to standardize sensor data, devices and services. Note their web service intermediaries are compatible with DDS real-time publish subscribe:

- Sensor Alert Service: publish and subscribe sensor alerts
- Sensor Observations Service: intermediary for client subscribers of published observation repository
- Sensor Planning Service: intermediary for client subscribers of sensor collection management environment
- **SensorML**: to register and discover sensors and their taskable properties

DDS' would not need to change prior OMG specs:

- **DDS**: carry additional semantic information, compatible with existing DDS 1.4 spec.
- **DDSI-RTPS**: no modifications, but brownfield implementations will not interoperate with other DDS' without adding DDS' extensions to brownfield.
- No modifications, but dependence on OMG-IDL (Interface Definition Language) [10] 4.0 compliance levels and OMG-IDL syntax in DDS-XTypes[11] 1.1 extended CDR, an IDL preprocessor syntax for representing data types in a machine neutral format.

DDS' and its semantics can also be extended into constrained Things with micro versions of DDS, gateways to connect non-DDS transports and into Cloud with Fog data exchanges[12]. Remaining non-DDS constrained edge and brownfield protocols' metadata can be mapped to DDS manager for some of DDS benefits.

IV. Summary

This paper introduces a SSN framework that combines the semantic endpoints of data-centric with strong semantics, supporting resource discovery for semantic sensor and event annotations. This initiates composable semantics, while extensions remain DDS compatible for continuing data security, QoS and reliability. RWW2017 presentation

[7] www.omg.org/spec/SysML/1.4/
[8] www.omg.org/spec/FUML/1.2.1/
[9] DDSI Wire Protocol v2.2 www.omg.org/spec/DDS-RTPS/2.2/
[10] www.omg.org/spec/IDL/4.0/
[11] www.omg.org/spec/DDS-XTypes/1.1/
[12] Examples:www.prismtech.com/vortex/vortex-gateway

TABLE III

MODEL SPACE: LIFECYCLE ROWS X SEMANTIC TYPE COLUMNS

	Data & Non-Functional	**Logic & Process**	**System of Systems**
Develop & Configure	DDS with security, QoS, or add FuSa and compliance	SysML Requirements & Constraints	Develop DDS SPI plug-ins
Deploy	IDL	FUML-like	SPI Deploy Profile
Manage	Data Lifecycle	Simplified with thin applications, API and management	SPI Manage Profile

expands on this work in progress with additional implementation details, radio and wireless features. Future work could include realizing the composable semantic service plug in (SPI) and extending it to align with the common data model (across OpenConnectivity.org, IoTivity.org, UPnP.org, OneIoTa.org and AllseenAlliance.org[13]), and the post-beta version of DDS-Security[14] SPI for information assurance.

REFERENCES

[1] A. Sheth and M. Perry, “Traveling the semantic web through space, time, and theme,” *IEEE Internet Computing*, vol. 12, no. 2, pp. 81–86, 2008.

[2] A. Sheth and A. Ranabahu, “Semantic modeling for cloud computing, part 2,” *IEEE Internet Computing*, vol. 14, no. 4, pp. 81–84, 2010.

[3] A. H. RANABAHU, “Abstraction driven application and data portability in cloud computing,” Ph.D. dissertation, Wright State University, 2012.

[4] F. Gramegna, S. Ieva, G. Loseto, and A. Pinto, “Semantic-enhanced resource discovery for coap-based sensor networks,” in *Advances in Sensors and Interfaces (IWASI), 2013 5th IEEE International Workshop on*. IEEE, 2013, pp. 233–238.

[5] D. Pfisterer, K. Römer, D. Bimschas, O. Kleine, R. Mietz, C. Truong, H. Hasemann, A. Kröller, M. Pagel, M. Hauswirth, *et al.*, “Spitfire: toward a semantic web of things.” *IEEE Communications Magazine*, vol. 49, no. 11, pp. 40–48, 2011.

[6] D. Le-Phuoc, H. N. M. Quoc, J. X. Parreira, and M. Hauswirth, “The linked sensor middleware–connecting the real world and the semantic web,” *Proceedings of the Semantic Web Challenge*, vol. 152, 2011.

[7] A. Agirre, M. Marcos, and E. Estévez, “Distributed applications management platform based on service component architecture,” in *Proceedings of 2012 IEEE 17th International Conference on Emerging Technologies & Factory Automation (ETFA 2012)*. IEEE, 2012, pp. 1–4.

[8] A. Agirre, J. Parra, E. Estévez, and M. Marcos, “Qos aware platform for dependable sensory environments,” in *Multimedia and Expo Workshops (ICMEW), 2014 IEEE International Conference on*. IEEE, 2014, pp. 1–5.

[9] L. Obrst, “Ontologies for semantically interoperable systems,” in *Proceedings of the twelfth international conference on Information and knowledge management*. ACM, 2003, pp. 366–369.

[10] M. Ruta, F. Scioscia, and E. Di Sciascio, “Enabling the semantic web of things: Framework and architecture.” in *ICSC*, 2012, pp. 345–347.

[13]https://openconnectivity.org/press-releases/allseen-alliance-merges-open-connectivity-foundation-accelerate-internet-things

[14]DDS-Security 1.0 Beta2 www.omg.org/spec/DDS-SECURITY/1.0/Beta2/