

Towards a Cross-domain Semantically Interoperable Ecosystem

MILENKO TOSIC, VizLore Labs Foundation, Serbia

FÁBIO ANDRÉ COELHO, INESC TEC, Portugal

BARRY NOUWT, TNO, Netherlands

DAVID EMANUEL RUA, INESC TEC, Portugal

ALEKSANDAR TOMCIC, VizLore Labs Foundation, Serbia

SASA PESIC, VizLore Labs Foundation, Serbia

The increasing number of IoT devices and digital services offers cross-domain sensing and control opportunities to a growing set of stakeholders. The provision of cross-domain digital services requires interoperability as a key enabler to bridge domain specifics, while inferring knowledge and allowing new data-driven services.

This work addresses H2020 InterConnect project's Interoperability Framework, highlighting the use of semantic web technologies. The interoperability framework layering is presented, particularly addressing the Semantic Interoperability layer as its cornerstone to build an interoperable ecosystem of cross-domain digital services via a federation of distributed knowledge bases.

Departing from a generic, ontology-agnostic approach that can fit any cross-domain use case, it validates the approach by considering the SAREF family of ontologies, showcasing an IoT and energy cross-domain use case.

Motivation: Most IoT systems and other digital services and platforms from the same domain are expected to be interoperable on a syntactic level, that is, they use the same communication protocol and common data formats. This means that interconnecting syntactically interoperable systems boils down to accepting the same data model. Once syntactic interoperability is achieved, the next level is semantic interoperability, that is, the ability of digital systems to exchange data with unambiguous, shared and agreed meaning.

Semantic interoperability is not yet established on a larger scale due to: (a) a steep technology learning/mastering curve of the paradigm based on knowledge dissemination rather than the point-to point data exchange approach widely used today and (b) the need to agree on business level interoperability between manufacturers and industry.

Smart cities establish a natural cross-sector ecosystem with knowledge exchange at its core. The provision of semantic interoperability will allow users to easily swap digital service providers, seeking the ones with the most appealing set of capabilities while avoiding privacy concerns and vendor lock-in.

Problem Statement: Cross-domain use-cases in IoT (like the ones that can be found in smart cities) require interoperability capabilities that go beyond the standard approach to exchange data based on the adoption of a strict data model. This requires moving from syntactic interoperability to a semantic approach that is geared by a knowledge-centric interface. Going forward unlocks data exchange to be tied to a strict representation and enables data exchange to be guided by knowledge concepts that are able to be queried within and across domains. The shared knowledge concepts require an ontology to be selected and utilized by and on behalf of participating digital systems. Finally, a set of enabling software components is needed to facilitate proactive and reactive data exchange between digital systems based on their knowledge offerings and capabilities.

Approach: The InterConnect project [1] delivers an Interoperability Framework (IF) capable of bridging the integration gaps “within” and “between” the IoT and other sectors, namely Energy. “Within” means that the

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interoperability is achieved among various IoT platforms and services. “Between” means that interoperability is achieved in cross domain ecosystems comprising both IoT platforms and services.

InterConnect applies the standard SAREF (Smart Applications REference) ontology (plus extensions) for modelling data coming from, exchanged between, or representing all key resources, services and systems deployed in smart buildings. This enables semantic discovery, navigation and reasoning, taking full advantage and establishing knowledge pools representing platforms of digital services.

A Distributed Semantic Interoperability Layer unlocks a series of distributed enablers that act as interoperable gateways, interconnecting all resources, platforms and services and enabling them to exchange data and instructions in a uniform and secure manner, while relying on widely adopted interface technology (RESTful). This layer is embodied by the Knowledge Engine (KE). Its main purpose is to facilitate data exchange on the basis of a common language. This common language is used to describe the capabilities of various services or platforms and these capability descriptions are then used by the Knowledge Engine to orchestrate the exchange of data. The KE fully utilizes semantic web technology to support data pull and push, while incorporating privacy and security by design.

The distributed configuration of the KE prevents the use of a central triple store, keeping home and service owners in control of their data. This is achieved through a Knowledge Base, a central concept for the KE, defining a logical unit where knowledge flows to and/or from. Each KB instantiates a Smart Connector (SC) which allow to register its capabilities and exchange data with other KBs connected to the Knowledge Network (KN). The SC handles all communication primitives and allows Knowledge Interactions (KI) to be registered and handled. Each KI defines a knowledge capability for data via a graph pattern representation, governed by the SAREF ontology. KIs allow to reactively or proactively interact with data, via one of the four types: Ask, Answer, Post and React. Both the Ask/Answer and Post/React are opposites of each other where the Post and Ask Knowledge Interactions represent the capability of the KB proactively posting or asking data to/from the KN. While the React and Answer KIs represent the capability of the KB reactively reacting to or answering a question from a Post or Ask, respectively.

These types of KIs together with the graph patterns cover most data exchange scenarios necessary for realizing the InterConnect cross domain challenges. After a KB has registered its capabilities using KIs, the data exchange starts depending on their types. In case of an Ask KI, the KB is expected to proactive trigger the Smart Connector to ask the registered question, optionally providing bindings for the variables in its graph pattern. Any KB that can answer such questions will be involved by the SC. In case of an Answer KI, the KB will be contacted by its SC whenever another KB asks the type of data it can provide. In case of a Post KI, the KB can post data to its SC whenever it sees fit. Any KB with compatible KIs will get a chance to react to the publication of data. In case of a React KI, the KB will be contacted by its SC whenever another KB posts data to which it wants to react. In short, a SC of KB A will involve any other KB B that has compatible capabilities with any of the capabilities of KB A.

Beyond the Distributed Semantic Interoperability Layer, the IF comprises two other components, namely the Service Store and the Generic Adapter. The Service Store serves as the repository of all interoperable services available in the ecosystem. Moreover, it also provides security control by establishing a user base and sandbox for instantiating and test interoperable digital services. The Service Store pairs up with the Generic Adapter, that deploys the gateway adopted by digital services to integrate with the framework’s services and interfaces.

Demonstration and Future Work: The IF will be demonstrated in 7 large scale pilots across Europe, in real-life Smart City conditions. In Portugal, the incorporation of Flexibility¹ in SAREF will enable SAREF-enabled smart appliances to exchange knowledge with an Energy Management System (EMS). The exchange of knowledge through the interoperable ecosystem will allow energy stakeholders (e.g., Distribution System Operators and Aggregators) to operate optimization procedures to forecast and plan ahead of time the energy demand via the interoperable knowledge centric interface. Energy stakeholders can also exchange Flexibility needs and other data for third-parties to consume and use in data-driven energy and non-energy digital services.

¹From the Energy domain, defining the capability of a user to adjust/shift energy consumption in time, according to demand.

Future work will unlock more than 62 digital energy and non-energy services to be integrated with the IF knowledge interface, in real Smart City conditions, establishing an interoperable ecosystem for IoT and Energy Stakeholders.

CCS Concepts: • **Theory of computation** → **Semantics and reasoning**; • **Information systems** → *Web searching and information discovery*.

Additional Key Words and Phrases: Interoperability, Semantics, IoT, SAREF

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BIOGRAPHY

Milenko Tomic is Director of Innovation at VizLore Labs Foundation. He has been active in R&D projects in domains of IoT, Distributed Ledger Technologies (DLTs), Communication Networks and Artificial Intelligence (AI) for 12 years. His research spans topics such as application of AI and DLTs in IoT, optimization of processes in highly distributed systems, edge and fog computing and context aware resource management in communication networks. He has led architecture specification and implementation tasks in 6 different collaborative projects under the H2020 program. Most recently his research focuses on achieving semantic interoperability in cross-domain challenges, which is one of the main objectives of the H2020 project InterConnect.



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