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# Internet of Things Research on Semantic Interoperability to address Manufacturing Challenges

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*ABSTRACT: This paper gives an overview on interoperability challenges and in particular for semantic interoperability addressing manufacturing within the Internet of things research cluster (IERC). In the Internet of Things area, business and manufacturing aspects have not been clearly taken into account yet but there is an important need to include requirements and challenges from this area as there are a lot of common issues and additional values that current experience and deployments in manufacturing can be relevant. More specifically it is discussed semantic discovery and interoperability issues related to intangible assets and to products-services manufacturing ecosystems. The IoT challenges in semantic interoperability presented in this paper are also defined in a EU position paper to be published in 2014.*

*KEY WORDS: Internet of Things, Semantic Interoperability, Intelligent Manufacturing, Smart Industries*

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## 1- Introduction – IERC activities

The European Research Cluster on the Internet of Things<sup>1</sup> (IERC) has created a number of activity chains to initiate close cooperation between the projects addressing the IoT related topics and to form an arena for exchanging ideas, to have an open dialog on important research challenges and to disseminate the ideas and best practices in the areas around the IoT to other communities. The activity chains are defined as work streams that group together partners or specific participants from partners around well-defined technical activities that work on addressing the IERC objectives. Out of eight activities, there is the fourth one dedicated to Service Openness and Interoperability (IERC AC4) which is for about more than 2 years active in addressing Semantic Interoperability.

The design of the Internet and The Information and Communication Technology development relies on the convergence of Software Engineering and Technology (infrastructure). A common practice is required to think/design cross solutions between software and infrastructure in order to provide integrated solutions for some of the complex problems in the current and future Internet systems. In Information Technology and Communication (ITC) systems this convergence is evident, and the continuous evolution generates more and more devices or Internet connected objects (ICOs) that are becoming embedded with sensors and their respective associated services defined under the umbrella term: “Internet of Things” (IoT).

However the conceptual realization of Internet of Things is far from achieving a full deployment of converged IoT services and technology. Current ITC research is focused on providing integrated solutions and primarily on the feature that enable convergence or what is called as “Interoperability”. Interoperability can be generalized as the feature for providing seamless exchange of information to, for example, personalize services automatically or simply exchanging information in a way that other systems can use it for improving performance, enable and create services, control operations and information processing. This type of scenarios requires increased interoperability in service management operations.

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<sup>1</sup> <http://www.internet-of-things-research.eu>

The IERC AC4 in the Internet of Things Cluster is planning to release by mid 2014 a European position paper on semantic interoperability. In this document we review the recent trends and challenges on interoperability in IoT domain, discuss physical versus virtual sensors and while addressing technology interoperability challenges in parallel, discuss how, with the growing importance of data understanding and processing, semantic web technologies, frameworks and information models can support interoperability in the design of services in the Future Internet. The objective of this position paper is to identify relevant issues and challenges that need to be taken into account in the coming and future projects and H2020 and to identify synergies across the participating FP7 projects. This can be used to define an overall framework to address the interoperability challenges.

Interoperability is a global issue and semantics is a relevant approach that has emerged as a realistic approach for solving some of the issues for interoperability. Semantic interoperability is currently demonstrated and used in extensive Internet (Web) domains and with the use of the already deployed semantic technologies there is a lot of common challenges to share with manufacturing areas and therefore common actions might also be envisaged.

## **2- Internet of Things Research and Innovation on Semantic Interoperability**

Internet of Things (IoT) is an emerging area that not only requires development of infrastructure but also deployment of new services capable of supporting multiple, scalable (cloud-based) and interoperable (multi-domain) applications. IoT has been considered as part of the Future Internet architecture and in the race of designing IoT, academia and Information and Communication Technology (ICT) industry communities have realized that a common IoT problem to be tackled is the interoperability of the information and services. In this paper we review the recent trends and challenges on interoperability, and discuss how semantic technologies, open service frameworks and information models can support data interoperability and particularly in the design of the Future Internet, taking the smart industries (manufacturing) as reference example of application domain.

IoT refers to objects (“things”) and the virtual representations of these objects on the Internet. It defines how the things will be connected through the Internet and how those things “talk” amongst other things and communicate with other systems in order to expose their capabilities and functionalities “services”.

IoT is not only linking connected devices by using the Internet; it is also web-enabled data exchange in order to enable systems with more capacities to become “smart”. In other words, IoT aims to integrate the physical world with the virtual world by using the Internet as the medium to communicate and exchange information.

IoT is mainly supported by continuous progress in wireless sensor and actuator networks and by manufacturing low cost and energy efficient hardware for sensor and device communications. However, heterogeneity of underlying devices and communication technologies and interoperability in different layers, from communication and seamless integration of devices to interoperability of data generated by the IoT resources, is a challenge for expanding generic IoT solutions to a global scale.

In a coming position paper we present various parallel and inter-related interoperability challenges ensuring that technologies deliver information in a seamless manner while this information is understood whatever the context and can be efficiently processed to deliver the potential of innovative services that IoT is aiming for.

To provide seamless communication and interaction between and with the real world objects, at anytime and anywhere in future, we need to solve today’s complex interoperability issues.

### **Semantics and Technology**

IoT environments for Internet-connected objects facilitate the deployment and delivery of applications in different domains and will enable businesses and citizens to select appropriate data and service providers rather than having to deploy physical devices. At the same time, they will provide capabilities such as on-demand large scale sensing beyond what is nowadays possible.

It is important to highlight the origins of IoT are found in the area of Radio Frequency IDentification (RFID) domain where RFID tags are extensively used for data collection. The static information, a group of RFID tags, can generate the quick development of RFID middleware frameworks to the extent that nowadays RFID frameworks provides added functionality beyond the data collection, by means of filtering, event generation, as well as translation of tag streams into business semantics, etc.

At the Internet of Things, additional to the limits of physical devices (e.g. sensors) there is also a notion of “Virtual Sensor” that refers to virtualization of an element of the IoT platforms representing new data sources created from live data. These virtual sensors can filter, aggregate or transform the data. From an end-user perspective, both virtual and physical sensors are very closely related concepts since they both, simply speaking, measured data. In order to handle the measured data, an information model has to be used, thus the Semantic Sensor Network (SSN) ontology, provides the most important core vocabulary for sensing data: which defines the notion of sensor and physical devices in general, and therefore formally the concept of a virtual sensor as a subclass of the sensor concept are defined in the SSN ontology. Due to the rising popularity of IoT technologies and applications the emergence of a wide range of platforms that enable users to build and/or use IoT applications is unavoidable. In general there is a clear trend towards the convergence of physical worlds and virtual solutions by using IoT technologies.

In all cases either Physical or Virtual sensors, a middleware framework is the core element to be used for providing baseline sensor functionalities associated with registering and looking up internet-connected objects, exchanging messages between objects, as well as fusing and reasoning data from multiple-objects. Some features of these implementations are:

1. Integrate ontologies and semantic structures, in order to enable semantic interactions and interoperability between the various objects, which will be a significant advancement over the existing syntactic interactions.
2. Provide Open Linked Data interfaces (e.g. SPARQL (SPARQL Protocol and RDF Query Language) over ontologies for internet-connected objects within the physical world middleware to interact with virtual world).
3. Define techniques for the automated data configuration of filtering, fusion and reasoning mechanisms, according to the problems/tasks at hand.

Taking a broader view of state-of-the-art and current developments in interoperability and in converging communications, many of the problems present in current Internet will remain in the Internet of Things systems and mainly generated by interoperability problems, thus there are three persistent problems:

1. Users are offered relatively small numbers of Internet services, which they cannot personalise to meet their evolving needs; communities of users cannot tailor services to help create, improve and sustain their social interactions;
2. The Internet services that are offered are typically technology-driven and static, designed to maximise usage of capabilities of underlying network technologies and not to satisfy user requirements per se, and thus cannot be readily adapted to their changing operational context;
3. Network operators cannot configure their networks to operate effectively in the face of changing service usage patterns and rapid networking technology deployment; networks can only be optimised, on an individual basis, to meet specific low-level objectives, often resulting in sub-optimal operation in comparison to the more important business and service user objectives.

As the move towards Internet of Things, the convergence of communications and a more extended service-oriented architecture (SOA) design gains momentum, worldwide there is an increasingly focussing on how to evolve communications technologies to enable the “Internet of Things”. The aim is directed mainly by pervasive deployment of Internet protocol suites and VoIP is a clear example of this.

By addressing evolution of networking technologies in isolation is not enough; instead, it is necessary to take a multi-domain adaptable holistic view of the evolution of communications services, their societal drivers and the requirements they will place on the heterogeneous communications infrastructure over which they are delivered.

By addressing information interoperability challenge issues, Internet of Things systems need to exchange information and customize their services. The Future Internet can reflect changing individual and societal preferences in network and services and can be effectively managed to ensure delivery of critical services in a services-aware design view with general infrastructure challenges.

### 3 - IERC challenges in Interoperability

In reference to the most common challenges for interoperability, and in reference to the manufacturing domain, (however in this respect and for having a more clear perspective it is recommended to read the full position paper) it is identified at first high level challenges as follow:

- **Integration of multiple data-sources:** This describes the necessity to be interoperable at the data/event level so that it becomes easier to combine/aggregate data/event coming from heterogeneous data sources. This raises also the challenge of being able to look up/discover data source and relevant data.
- **Unique ontological point of reference:** Semantic interoperability also means having a unique point of reference at the ontology level. This can be solved by third party responsible for translating between different schemes or via ontology merging/mapping. There could be also protocols for agreeing upon a specific ontology.
- **P2P Communication:** This describes the necessity for applications to communicate at a higher-level through exchange of “business” knowledge. Interoperability can be ignored at lower-levels and can be implemented at a higher-level.

Other main challenges in Semantic Interoperability and foreseen needed research:

- Data Modelling and Data Exchange
- Ontology merging / Ontology matching & alignment
- Data/Event Semantic Annotation (and dedicated ontologies)
- Knowledge Representation and related ontologies
- Knowledge Sharing
- Knowledge Revision & Consistency
- Semantic Discovery of Data Sources, Data and Services
- Semantic Publish/subscribe & Semantic Routing
- Analysis & Reasoning

### 4 - IERC AC4 position and envisioned solutions

The current position paper also in investigating the existing solutions has shown that:

- *Often there is no general agreement on annotating the IoT data*
- *There are several models, each having their own semantics and their own schema*
- *In addition to the schema, it is also important to decide how the annotation will be done (according to the chosen schema)*
- *The models are often complex and express-ability vs. usability can be an issue in using complex and very detailed models (especially in large-scale deployments)*
- *Using different representation formats can also cause interoperability issues at the serialisation level*

The following summarises a set of recommendations to enhance the interoperability and to provide common solutions for semantic interoperability among various providers and users in the IoT domain. Some of the technical solutions that can be proposed to address the above issues are:

- *Providing alignment between different and using ontology Mapping/Ontology Matching solutions*
- *Using coordinated efforts to designing common specifications and core schema/reference models*
- *Providing metrics, tools and interfaces for annotations, test and validation and integration*

Using linked-data can be also an effective solutions to link descriptions from different domain and models, to link resource descriptions to external metadata, and to use common vocabularies and taxonomies to describe different attributes of the data; e.g. Location (e.g. GeoNames), theme (e.g. DBpedia)

At the community level, setting up special taskforce among the projects can be considered to design a common (and minimum set) specifications that can be used for semantic descriptions of IoT data (i.e. observation and measurement data), resource descriptions (i.e. devices, network resources), command and interactions (i.e. actuation commands, publish, subscription, discovery and other similar messages), services (i.e. interfaces, application and higher-level services). The result of such an effort will be a set of basic models that can be used (and accepted) across different projects, tools for publishing and validating the descriptions according to the designed model and a set of best practices to annotate the legacy data according to these models.

## 5 - IERC Semantic Interoperability and Manufacturing challenges

Manufacturing (smart industries) is a privileged domain for applying the semantic interoperability technologies that are researched and produced in the scope of IERC. In particular, semantic technologies are key enablers for developing Virtual Factories (VFs), which allow the establishment and realization of complex and effective supply chains comprising several manufacturing plants around the world. The formulation of VF supply chains is a key enabler for realizing innovation driven transformations in the manufacturing domain, which is fully in-line with major trends associated with the future of manufacturing such as globalization, resource scarcity and the global knowledge society.

In particular, VF supply chains allow manufacturing stakeholders to monitor complex material flows in real-time, to optimize the use of manufacturing resources, to track (tangible and intangible) manufacturing assets, to deploy and operate advanced services (e.g., timely proactive maintenance), and overall to provide new and efficient ways for collaborating across the supply chain.

The importance of semantic web technologies for VFs (e.g., ontologies, RDF, LinkedData) stems from the fact that they can enable all stakeholders across the VFs supply chain to register and discover manufacturing assets and services in a uniform interoperable and web based way, which ensures semantic power, interoperability, versatility, flexibility and ease of use. In particular, a semantic web infrastructure for manufacturing assets and processes could empower the management of rich metadata, which facilitates the representation and management of (distributed) knowledge-intensive assets and processes.

At the same time, the use of common semantics for assets and services could facilitate the semantic interoperability of diverse enterprise systems (e.g., ERP (Enterprise Resource Planning), MRP (Manufacturing Resource Planning), MES (Manufacturing Execution Systems)) operated by different manufacturers across VF supply chains. Furthermore, semantic infrastructures can be distributed and are accessible over the web, which boosts collaborative processes involving geographically and administrative dispersed plants, factories and stakeholders.

The application of IERC semantic interoperability technologies in manufacturing is motivated from the fact that these technologies have been successfully applied in other segments of the Future Internet such as the internet-of-things (IoT) and the web-of-things (WoT). Indeed, several projects of the IERC cluster have selected and deployed semantic web infrastructures for the semantic interoperability of different IoT services, as well as for the dynamic discovery of sensors and ICO (Internet-Connected-Objects). Hence, the use of semantic infrastructures for the dynamic registration and discovery of sensors and IoT services is a successful paradigm, which could be replicated in the area of VFs and related manufacturing assets and processes. Under this prism, the IERC semantic web technologies could enable:

- Semantic discovery of assets for VFs, notably intangible assets such as people CVs, product catalogues, marketing plans and quality control processes. To this end, a semantic discovery infrastructure could be deployed in the cloud in order to facilitate on-demand access and management of assets from manufacturers engaging in VF business scenarios.
- Semantic interoperability for VFs with particular emphasis on the semantic interoperability of diverse enterprise systems (notably ERP (Enterprise Resource Planning), MRP (Manufacturing Resource Planning), CRM (Customer Relationship Management) and MES (Manufacturing Execution Systems)) with manufacturing assets and processes engaging in the supply chain and related collaborative processes.

The implementation of the above listed infrastructures for semantic discovery and interoperability can be realized based on the following steps:

- The semantic modeling of manufacturing assets and services in a way that can support the interoperability of enterprise systems (such as ERPs). This entails the development of models (i.e. ontologies), which will bring together the world of enterprise semantics / context modeling and Linked (Enterprise) Data with other relevant counterparts i.e. services, application and the Internet of Things (IoT) for optimizing manufacturing and Virtual Factories domain(s).
- The development of a semantic discovery infrastructure for manufacturing assets and services, which shall take into account existing semantic web discovery techniques successfully applied in the Internet of Things (IoT) domain.
- The integration of the semantic modeling and discovery infrastructure with tools and techniques for managing descriptions for manufacturing assets and services with Linked Unified Service Description Language (LinkedUSDL).
- The design and offering of APIs, which will allow VF applications and services to discover and manage resources, services and processes associated with VF applications.
- The deployment of the discovery infrastructure in a cloud-based environment, where data about manufacturing assets and services used in VF scenarios will be stored and managed on demand. This will facilitate the establishment and validation of a Manufacturing-as-a-Service model across VF supply chains.

As already outlined, a possible implementation of the above technologies in the manufacturing domain could leverage readily available blueprint implementations of semantic infrastructures for other areas (such as IoT), which have been already realized by IERC projects (e.g., the OpenIoT open source cloud-based discovery infrastructure for IoT resources, which is available at: <https://github.com/OpenIoTOrg/openiot/>).

## 6- Conclusion

In this paper we have introduced the research results and main efforts of the IERC cluster towards designing and building semantic interoperability systems for the Internet of Things in the framework of Smarter Industries as implementation main scenarios in Manufacturing.

The IERC cluster has been taking advantage of existing ontologies (such as the W3C SSN) and standards (e.g., RDF), but also of emerging technologies (such as Linked Data). On the basis of this technologies the IERC has produce a semantic interoperability manifesto<sup>2</sup>, which includes/describes more detailed research challenges for semantic interoperability and additionally to that the main building blocks required in order to build semantically interoperable systems can be found in the manifesto. This manifesto is supported by a set of concrete blueprint semantic interoperability implementations for IoT and smart cities applications. At the manifesto we have illustrated how the building blocks could be used to support interoperability in manufacturing and related application domains (Virtual Factories and related supply chains).

The introduced semantic interoperability concepts for VFs could greatly boost collaborative and interoperable manufacturing in a globalized environment, where the exploitation and collaborative management of both tangible and intangible assets in becoming more important than ever before.

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<sup>2</sup>IERC-AC4-SemanticInteroperabilityManifesto  
[http://www.probe-it.eu/wp-content/uploads/2013/10/IERC-AC4-SemanticInteroperabilityManifesto-V1\\_130830-Final1.pdf](http://www.probe-it.eu/wp-content/uploads/2013/10/IERC-AC4-SemanticInteroperabilityManifesto-V1_130830-Final1.pdf)