# An Information-Centric System for Building the Web of Things

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**Abstract.** In recent years, common-use devices has seen a leap transition in terms of equipped technology, introducing the so called "smart things" to the consumer market. This technological and societal revolution has underpinned the realization of the Internet of Things. To take full advantage of the opportunities arising from connectivity capabilities, smart things approached the application realm bringing the novel Web of Things vision to life. The Web, as a collaborative global space of information, is a critical asset to create value-added services. However, such a promising potential entails a number of challenges including data interoperability, data integration, information reuse and collaboration. This Ph.D. work focuses on a novel approach to take a smart thing to the Web, by representing it as graph of granular and individually addressable information called IDN-Document. IDN-Documents are simply structured web resources which can be aggregated, linked, reused and combined to build collaboration oriented, value-added services. IDN-Documents are managed by the InterDataNet middleware leveraging Linked Data and REST.

**Keywords:** Internet of Things, Web of Things, Information Modeling, Representational State Transfer, Linked Data, Information Reuse.

## 1 Introduction

The advances in electronics, informatics and communication sciences have paved the way for the widespread distribution of devices with considerable technological potential. Due to their capabilities, these objects are usually called "smart". This scenario motivates the Internet of Things (IoT) concept which is a transformation of the Internet from a network of computers to a network of heterogeneous devices [1].

Leveraging the existing Web technologies and standards including HTTP [2], URIs [3], etc., smart things can also enter the application realm, giving rise to the Web of Things (WoT) vision. To take full advantage of the WoT opportunities is essential to address issues including interoperability, data integration,

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information reuse and collaboration. These topics are definitely challenging because of the heterogeneity of smart things in a number of aspects such as device and application requirements, connection strategies, data representation, data management and many others.

This Ph.D. work proposes an approach to enable interoperability and data reuse between objects in the WoT. To this intent, I follow a two-steps methodology: first, a connection with the smart object is established via a dedicated adapter, and second the object is represented as a graph of granular, individually addressable data units called IDN-Document, leveraging an information model. Consequently, the object is put on the Web as an aggregation of information whose pieces can be dereferenced, consumed, reused, and managed with negligible effort. The smart object representation relies on the expressiveness and flexibility of the graph structure adopted by Linked Data [4], which has been chosen as the inspiring paradigm. In this work I refer to a more general interpretation of Linked Data, as the one provided by Wilde et al. [5], who define Linked Data as "the general concept of publishing interlinked data representations, without referring to the one specific way of implementing it that is often associated with that term as well".

The implementation of the IDN-Document is delegated to a middleware called InterDataNet (IDN) [6–9] which exposes RESTful [10] HTTP APIs for its management. This Ph.D. work covered the study and design of the information model, the study, design and implementation of the whole IDN core architecture, and the study, design and implementation of several applications on top of IDN, for validation purposes.

## 2 Motivation of the Work

Although the WoT is very promising, many problems remain to be solved [1]. Data should be produced and consumed easily, without worrying about formats and custom representations. Moreover, security concerns must be addressed to support collaboration around data. To fully benefit from the WoT concept, the author argues that the Web of Data [11] vision would contribute to effectively put a "thing" on the Web. Indeed, not only data produced by a smart object, but also the object itself can be represented as a graph of structured information to be exposed in the global space, where applications can use it and other objects can connect to, building a richer and more informative object. Zeng et al. [1] made a survey on the WoT and their analysis highlights several points of interest, which validate the approach proposed in this paper. First, they make a comparison of the WS-* and REST architectural styles and conclude that REST is the best choice because of its low complexity and loose-coupling stateless interactions. These features are particularly desirable because they take into account resource constrained devices. Also Wilde in [12] states that REST has substantial advantages over applications, having better performances in terms of testing, scalability, and integration with other applications with respect to state-based paradigms. Second, search and discovery capabilities are critical for

WoT, spanning from regular search to advanced search managing very transient data. In this paper, is presented a methodology for bringing an object of the real world to the Web as a graph of interlinked information pieces. Such information should be made available taking into account all the aforementioned issues. To fulfill these requirements I propose the InterDataNet middleware which leverages an adapter towards physical objects and supports a Linked Data oriented resources representation. Therefore, resources are exposed via RESTful APIs for their management. InterDataNet is also provided with transversal services such as a data-centric [13] security framework and a search service supporting semantics.

## 3 InterDataNet

InterDataNet (IDN) [6–9] is a middleware offering capabilities for representing and managing information units and their structural relations on the Web, in a RESTful way. For the sake of conciseness, in this paragraph a brief introduction of the IDN middleware is provided. Further details can be found in [6–9].

The main goal of IDN is to enable the easy reuse of globally web-addressable information units to support collaboration around data. To this end, IDN considers documents as first class entities. In the following, I refer to a document in IDN as an IDN-Document.

### 3.1 IDN Information Model (IDN-IM)

The IDN-Information Model (IDN-IM) defines the rules for organizing data in an IDN-Document.

**Definition 1.** An IDN-Document is a directed graph $G = (V, E)$ where $V$ is the set of vertices and $E$ is the set of edges. The elements of $V$ and $E$ are the nodes containing the granular information (IDN-Nodes) and the relations between IDN-Nodes, respectively. IDN supports two types of relations between IDN-Nodes: aggregation (i.e., containment) and reference.

**Definition 2.** An IDN-Node is a set $S = C, P$, where $C$ is the set of content elements (i.e., data) and $P$ is the set of properties (i.e., metadata) that characterize $C$.

**Definition 3.** The Aggregation Link represents a container-content relation. The node where the edge starts from aggregates and therefore contains the node the edge points to.

**Definition 4.** The Reference Link represents a pointer towards the referred resource. To better understand the Reference Link role, it could be somehow compared with the HTML `href` attribute.

Through the IDN-Information Model (Fig. 1) is possible to define an IDN-Document as an aggregation of data provided by different information sources. Indeed, an IDN-Node can be referred to by more than one IDN-Document, thus favoring the reuse of information across different applications. This is possible since each IDN-Node is associated with an information provider which is authoritative for the information the IDN-Node refers to. It is worth to mention that many efforts have been made to keep the IDN-IM as simple as possible, to lower the entry barriers for WoT developers. It is possible to see the IDN-IM as a projection of a RDF graph in an extremely reduced dimensional space (containment and reference dimensions). The definition of the container-content relation (Aggregation Link) serves well for the scopes of document composition, still not burdening the formalism. Consequently, data can be managed without requiring a query language such as SPARQL for RDF. Of course, when such simplification is not sufficient, it is possible to lift an IDN-Document to the RDF representation. That's why IDN-Documents support semantic annotations.

In addition, IDN-IM can be extended with metadata enforcing privacy, licensing, security, provenance, consistency, versioning and availability properties attached to IDN-Nodes and affecting IDN-Documents. Such features are crucial to support effective and trusted collaboration on real world scenarios.

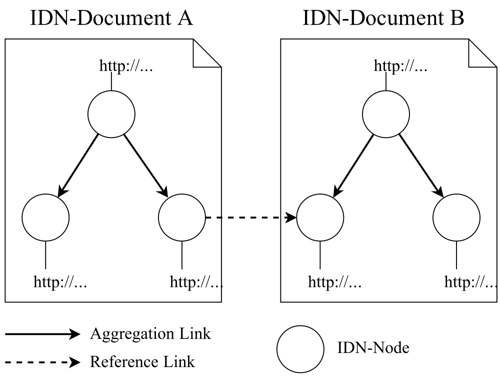


**Fig. 1.** The InterDataNet Information Model

### 3.2 IDN Service Architecture (IDN-SA)

IDN-Documents are exposed as resources through the IDN-Service Architecture (IDN-SA) API. The IDN-SA API is a set of generic REST interfaces for addressing, resolving and handling IDN-Documents. IDN-SA is the architecture that implements services needed to enforce the IDN-Documents properties and capabilities. IDN-SA has been designed with the separation of concern principle in mind and is organized according to a modular architectural pattern. IDN-SA has three main modules: Virtual Resource (VR), which provides RESTful APIs for accessing, creating, and modifying IDN-Documents; Information History (IH), which implements information versioning capabilities; Storage Interface (SI), which offers persistence capabilities. In addition, a set of horizontal services, including search and security management are defined.

A key role is played by the IDN-Adapter (ADPT), which is implemented as an independent module, detached from the core architecture. Its main task is to connect to external data sources and prepare the information with custom format to be used by the IDN-SA. As a consequence of the IDN-Adapter mediation, the IDN-SA can treat outer data as its own, and enable all the properties characterizing IDN-Documents, acting as a decorator. The IDN-Adapter is also designed with a modular approach, and includes three components: 1) a Transformer module that refines data served by the outer source (e.g., demultiplexing the information to achieve a more granular representation); 2) a Document Manager that assembles the outer information in a specific structure (associating it with a specific IDN-Document); 3) a Command Manager that translates commands coming from the IDN-SA interface in commands appropriate for the original data-source interface (e.g., a PUT request to IDN-SA could map to a POST request to the data-source).

From a system point of view, IDN is organized as a network of peers. Indeed, the top layer of the architecture, the Virtual Resource, is able to contact different instances of the same module to realize the distributed graph of information. In such way, IDN-Documents spanning through various domains can be interlinked and managed from a single access point. Fig. 2 shows a comprehensive picture of the InterDataNet system.

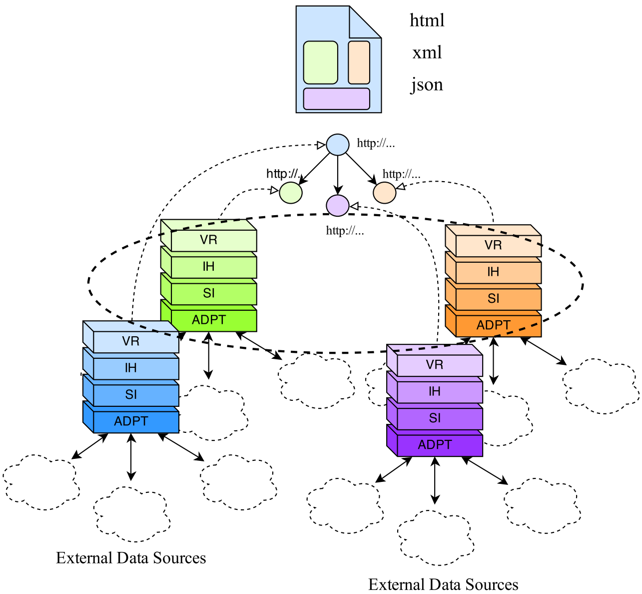


**Fig. 2.** An overall view of the InterDataNet system and the document resource

The system representation depicted in Fig. 2 includes outer data sources, components of a single InterDataNet instance, the network of peers, the information model and a representation of a document resource. The dashed clouds at the bottom represent outer data sources which provide information to the architecture in their own custom format. The adaptation layer (ADPT) interfaces with these data sources and performs a transformation of the information to comply with the InterDataNet formalism. Such information proceeds through the architecture up to the Virtual Resource (VR) layer, which implements the document abstraction. At this level, data are exposed as documents which can be composed to build new richer graphs (i.e., other documents).

InterDataNet is not limited to management of data coming from external sources. In fact, is possible to create InterDataNet native data using the RESTful interface. Analogously to the case of information coming from outer providers, these data will be exposed by the architecture in document form. The IDN-Document is depicted as a graph with four vertexes coming from different Virtual Resources to emphasize the distributed nature of the model. Finally, on top of the model, there is a representation of the document in one of the three data formats currently supported by the implementation: HTML, XML and Json.

## 4 SmartSantander: Enabling a Web of Sensors

This use-case is part of experimentation within the SmartSantader European project [14], where a number of different sensing devices were installed in the urban territory of Santander, Spain. The goal of the experimentation is to take a sensor and put it on the Web as a graph of resources manageable in an easy way, to support novel applications development such as the Virtual Sensor explained in the following.

The IDN-Document depicted in Fig. 3 represents a general sensor as an aggregation of structured information (web sensor). Leveraging this model, is possible to easily reach all the useful resources related to a particular sensor, e.g., measured data, accuracy, sensor location, and much more.

Since the chosen architectural style is REST, interacting with resources is straightforward: to get the representation of a particular sensor is sufficient to invoke an HTTP GET on the sensors name (i.e., the URI). The output of a particular sensor can be retrieved analogously. For example, the sensors output data could be retrieved issuing the following GET request:

```
http://.../sensor/{id}/data_production/data
```

while the location could be retrieved with an HTTP GET invoked on the URI:

```
http://.../sensor/{id}/location.
```

By leveraging the IDN-Document sensor representations I designed a new IDN-Document consuming sensors data. It is a Virtual Sensor, i.e. a sensor whose IDN-IM comprehends web sensors data and an analytical model which can be combined to produce new information. For instance, IDN-Documents representing temperature and humidity sensors can be combined to create a new heat-index virtual sensor IDN-Document.

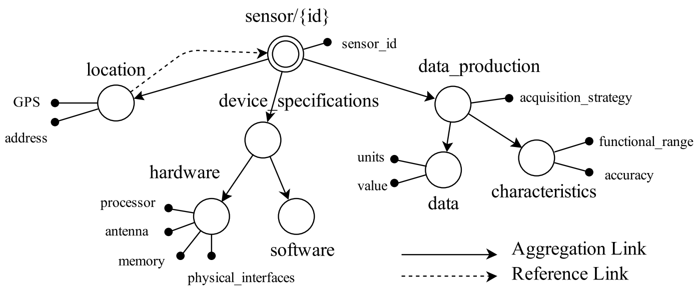


**Fig. 3.** IDN Information Model of a web sensor

## 5 Conclusions

In this paper, I propose an approach for enabling data interoperability and reuse in the Web of Things. To accomplish this task, I adopt a two-step methodology: 1) provide a connection with smart objects via a dedicated adapter, and 2) represent objects as graphs of granular, individually addressable data units. Expected benefits include easy sharing of objects related data and models across the Web, and support for the development of scalable applications. These principles have been put in practice by the InterDataNet RESTful middleware which leverages 1) an adapter for the connection to smart objects and 2) the IDN-Document formalism to turn objects into graphs of information.

Future works will include the integration of semantics into the IDN-IM and subsequent development of the IDN middleware to support semantic exploration of IDN-Documents as long as a security framework to secure information grains.

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