Ontology for Semantic Enrichment of Radio Frequency Identification Systems

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***Abstract*—**Radio Frequency Identification (RFID) has become a key technology in the emerging concept of Internet of Things (IoT). Naturally, business applications would require the deployment of various RFID systems developed by different vendors that use different data formats and structures. This heterogeneity poses a challenge in developing real-life IoT systems with RFID, as integration is becoming very complex and challenging. Semantic integration is a key approach to deal with this challenge. To do so, ontology for RFID systems need to be developed in order to annotated semantically RFID systems, and hence, facilitate their integration. Accordingly, in this paper, we propose ontology for RFID systems. The proposed ontology can be used to semantically enrich RFID systems, and hence, improve their usage and reasoning.

***Keywords*—**IoT, RFID, Semantic, sparql, Ontology.

I. Introduction

INTERNET of Things (IoT) refers to the general concept of making objects in our daily life addressable, recognizable, readable and controllable through the internet [1], [2]. Objects can, thus, interact, sense and share data in order to provide value to end users. IoT can be generally defined as a network of physical objects or things embedded with electronics, software, sensors and connected to enable objects to collect and exchange data. It allows things to sensed and controlled remotely across existing network infrastructure. It is constructed based on the pervasive presence of smart objects such as tablets, mobile phones, sensors, and Auto Identification systems.

Auto-Identification plays a central role in enabling the practical realization of IoT systems. Radio Frequency Identification (RFID) technology is one of the most promising technologies that can support identification in implementing IoT systems in practice. It has proven its practicality in several domains, especially in supply chain management operations and other applications in which identifying objects or people is required.

Many challenges are facing RFID systems today including the impact of different environmental conditions on tags, and deployment planning for readers to avoid reader collisions, tag interferences, and tag collisions [3]. Another important challenge in RFID systems is related to handling and processing the large amount and diversity of data generated by tags in real-life contexts [4]. Most of the existing techniques proposed to deal with the amount and diversity of RFID data focus on data filtering to remove unwanted/duplicated readings, data aggregation based on some parameters to filter wanted data, and report generation as done based on the concept of Application Level Events (ALE) [5]. Other techniques focus on the data itself and their meanings, and hence, address issues related to how to enrich the raw RFID data, and how to relate them to other concepts. Such approaches make use of role of semantic annotation [6] and ontologies and its ability to mix different concepts in one large linked repository. Accordingly, in this paper, we propose the use of ontologies to facilitate the analysis of RFID data and integrate various types of RFID systems. Such ontology can support the unification of concepts, which in turn, enables the interoperability of the same concepts/resources in different domains. By doing so, we can deduce relations among the various domains through a particular concept. The exposure of different knowledge domains accompanied by the unification of concepts can empower queries to obtain all related information to specific concept from the different fields. For ontologies, one can adopt, for instance, the sparql query language to perform simple first level reasoning [7].

The rest of the paper is follows. Section II, gives a brief background about the main concepts and some of the related work in RFID and semantic technology. Section III presents the proposed RFID ontology. Section IV, demonstrates a usage scenario in healthcare domain with a semantic query concept.

II. Background and Related work

In this section, we briefly review the key concepts related to the proposed ontology and its usage in practice.

A. Background

RFID is a wireless identification system based on electromagnetic field to transfer data [8]; it uses different spectrums to operate, Low Frequency (125 KHZ to 143 KHZ), High Frequency (3MHZ to 30 MHZ), Ultra High Frequency (300 MHZ to 1 GHZ) and Microwave (> 1 GHZ). It consists of two main components: the tags and the readers. Tags or transponders can be classified into three types different in their battery reliability and memory capacity which are passive, semi-active/passive and active, these tags stores the unique identifier of each object (The EPC code) [9]. A reader or transceiver is the part responsible of receiving and processing the collected data. Readers have become a very important part of most of the applications and systems that require objects identification such as in the Supply Chain Management domain.

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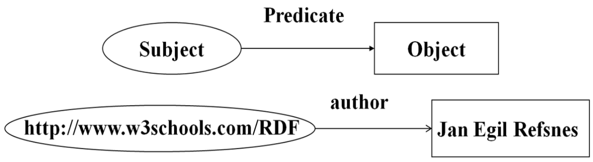

Fig. 1 RDF Data Model Graph

Data is the first layer of the well-known DIKW pyramid [10], where you can find discrete parameters about an object. This layer can be used in applications in primary scenarios; however, we can exploit data further by processing and reasoning about them to achieve information and useful knowledge to advance the application capability.

Semantic technology [11] emerged from the idea of exploiting data into higher levels by building knowledge repositories using scattered discrete data. It is a general term for used for software that involves level of understanding the meaning of the information it deals with. It aims at enhancing the ability of computers to analyze and comprehend language, and making existing content more machine-readable. This can be done by representing the data in a structured from transforming it from data to knowledge. This type of representation is commonly known as *ontology*, which forms the backbone of the semantic technology.

Ontology can be defined as "a formal, explicit specification of a shared conceptualization" [12], used for facilitating interoperability of shared concepts among different domains. Ontologies can be represented using different technologies such as RDF, OWL, and RDFs ...etc.

RDF stands for Resource Description Framework, that can be understood by computers and humans for describing concepts in the ontology and relations among them in triples based on a data model graph where subject, predict, and object nodes are related by predicate arcs (Fig. 1).

SPARQL is the query language of the semantic technology that can perform complex operations on disparate repositories in a single, simple query.

B. Related Work

References [13], [14] propose an extension of the EPC global RFID standard supporting logic based formalisms for knowledge representation and enabling advanced services. RFID tags are semantically enriched by exploiting two bits in the EPC tag memory area currently reserved for future purposes. The first bit at the 15 hex addresses and it indicates whether the tag has a user memory, and the second bit is at the 16 hex addresses and it is set to mark semantic enabled tags. The Ontology Name Service (ONS) mechanism is used in order to grant the ontology support if the reader does not manage the ontology description within the tags. Our work differs from the above in that, we just need the EPC code from the tag; to be able to describe it semantically using our proposed internal ontology in addition to the linkage to external ontologies also in the application layer. We also represent the whole system via ontology to guarantee the interoperability of concepts.

Reference [15] discusses the use of the RFID technology in supply chain and its ability to automatically read data from the tags attached to items, cases, and containers with no need for line of sight (LoS). Our work proposes handling the overall system via ontologies to enrich data and have extra capabilities and functionalities, through the concept of linked data analysis on data.

Reference [16] proposes a structural ontology of RFID data for RFID system. It contains main classes that help in RFID system operations. The proposed ontology is used in the oil and gas industry to help make data collected from objects machine understandable. Compared to this work, our ontology is more general and includes a wide range of relationships and standard protocols that RFID uses.

Reference [17] proposes the combination of the IoT technologies, including RFID, with supply chain and semantic technology. They demonstrated how this combination can improve the overall supply chain system, as problems related to delays and early goods shipments can be reduced due to the unified shared concepts between organizations having different formats of data transferred through RFID. Such unifications among organizations and stakeholders in the supply chain can make knowledge understandable in a unified way as all are referring and using the same concepts with the same precise meanings. In addition, [17] proposes the proposed the EAGLET ontology, which is an abbreviation for their primitives (Event, agent, location, equipment and thing) with the goal of facilitating interoperability and visibility of objects as they move across the supply chain. In our work, we also use these primitives but in addition to other concepts that are need in RFID systems in order to make the ontology applicable to a wider domain of communications and processing capabilities.

Reference [18] proposes an ontology describing the RFID systems and data but in a small scale, it just includes the basic factors and concepts of the system. Our ontology contains these concepts besides extra concepts to improve the system and propose wider usages.

Reference [19] proposes a general framework to provide compact representation of large concept streams. In addition, the framework aims at finding informative commonalities among the concepts in order to allow automated pattern analysis and trend discovery. A case study is used to demonstrate the use of the framework in dealing with a product flow in a typical warehouse. Products are semantically described through owl language. When a product is read by a reader; the reader extract semantic annotation from tags and feed to semantic DSMS that performs extra data processing through a reasoning engine. The proposed framework allows benefiting from a semantically rich description of products and relevant process by including analytical process queries that can combine data oriented and logic based criteria with greater flexibility. Our work aims at the same purpose but in a wider scale.

Reference [20] introduces the SCORVoc vocabulary and its engineering process in the supply chain domain. They work with SPARQL query on SCOR ontology that is used to represent the supply chain process. Commonly, all activities related to the production and logistics are defined as processes. The variety in company size, industry and business models as well as different viewpoints and granularity requirements make it very challenging to define common representation formalism for these processes. Accordingly, the paper demonstrated how the SCOR ontology could be used to deal with the representation challenge in the context of the supply chain.

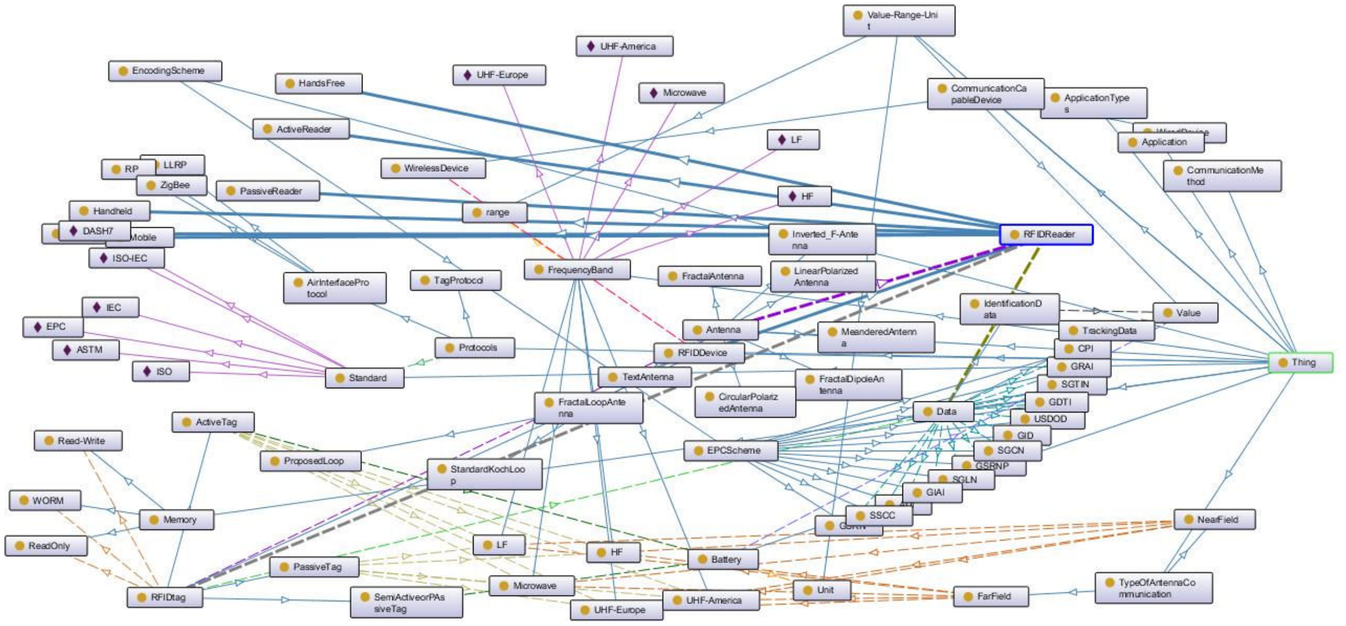

Fig. 2 The Proposed RFID Ontology

III. Proposed RFID Ontology

In this paper, we propose a new RFID ontology (Fig. 2) that models RFID systems that can be used in a wide range of domains. The ontology includes main parts of the RFID ecosystem including RFID tags, RFID Readers, Communication Methods, and RFID Applications. The ontology is developed using the well-known protégé tool (Fig. 3).

The proposed RFID ontology contains several classes that describe the various components and communications methods used in RFID systems along with their relations. The main objective is to make the ontology usable in almost any RFID-based data. In the following, we give a brief description of the various classes included in the proposed ontology.

1. Antenna: represents the conductive element that enables the tag to send and receive data. Passive, low- (135 kHz) and high frequency (13.56 MHz) tags usually have a coiled antenna that couples with the coiled antenna of the reader to form a magnetic field
2. Application: It represents software aiming at executing certain task.
3. Application Types: defines different implementations with different purposes.
4. Battery: represents physical entity responsible for charging the device with needed power.
5. Communication Capable Device: represents a device that has the capability of sending and receiving data, either through wired or wireless communication system, its subclasses wired device and wireless device.
6. Communication Method: identifies how the communication among devices will be held.
7. Data: differentiates between the types of data that can be written/ read from RFID tag. The subclasses of this class are: the identification data and tracking data.
8. Encoding Scheme: defines how data will be represented on RFID tags and in which syntax format (e.g., EPC schema).
9. Frequency Band: represents range of frequency spectrum used for communication. Its subclasses are LF, Microwave, HF, UHF-America, and UHF-Europe.
10. Memory: represents the part of the tag responsible for storing data. It is subclasses Read/Write, Read Only, WORM.
11. Protocol: identifies the way of communication between two entities so that both can understand each other. In our domain, a protocol can be divided into different types with different roles. Its subclasses are AirInterfence Protocol and Tag Protocol.
12. RFID Device: represents the physical device itself.
13. Standard: represents the unified concepts, agreed by some organizations, to control the way of communication between different entities.
14. Type of Antenna Communication: represents the types of communication (Near field and Far field).
15. Value-Range-Unit: refers to the value, range, and unit of each measurement.

The above Classes have relations among each other reflect and describe the real-life RFID communication and environment. We have enriched our ontology by using some external standard ontology to enhance usability of our ontology.

IV. Usage Scenario in Healthcare

In this section, we use a simple healthcare scenario to demonstrate the value of using the concept of RFID ontology.

A. Query Language

Shared knowledge with unified resource identifiers (URIs) has widened the opportunity to obtain new relations that may not be easily noticeable even by using complex query operations. By exploiting the concept of URIs, semantic technology becomes very powerful in processing knowledge from different domains. In addition, with the power of the SPARQL Query Language, we can now obtain all the available information about a given instance, identified by a URI, from all the related /unrelated domains.

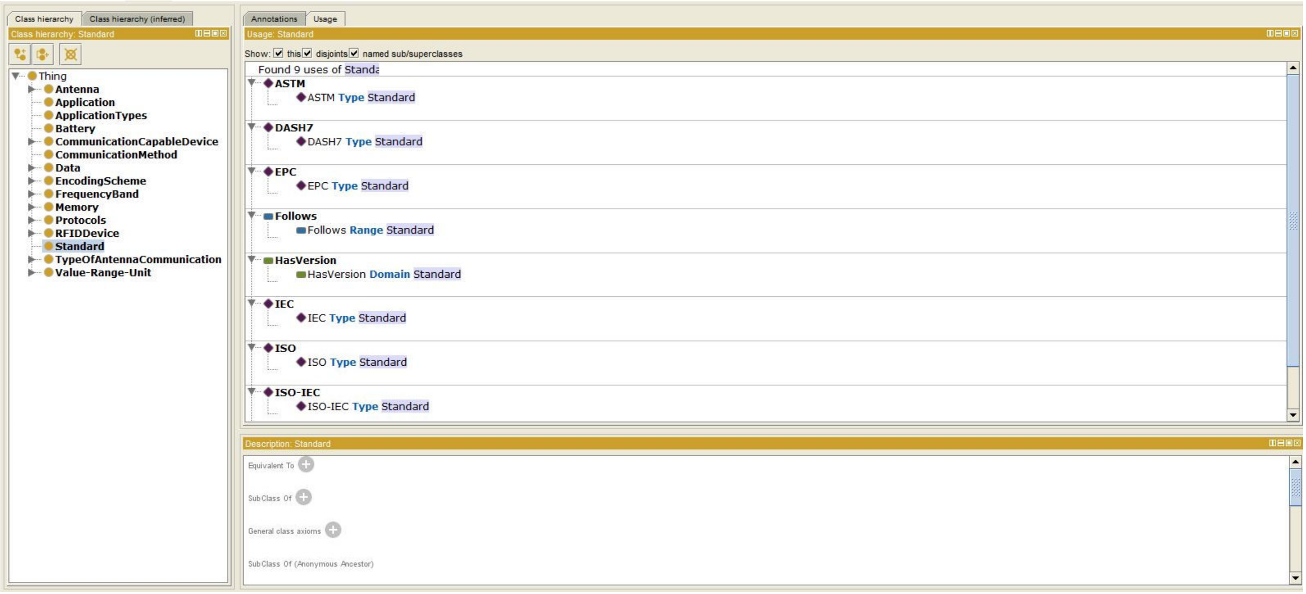

Fig. 3 Protégé Representation

SPARQL [21] can be used to express queries across diverse data sources, whether the data is stored natively as RDF or viewed as RDF via middleware. SPARQL contains capabilities for querying required and optional graph patterns along with their conjunctions and disjunctions. SPARQL also supports extensible value testing and constraining queries by source RDF graph. The results of SPARQL queries can be results sets or RDF graphs.

Query results differ from one data source to another. Major differences in results can be noticed despite using the same query. Queries can be divided into the following three main stages depending on available data source (ontologies, tables…etc.).

- Database: Query can only obtain local available database tables (fixed) that are related to each other;
- Local Ontology: Query can obtain all available information related to your subject even if not related/linked to each other; and
- Standard/Open Ontology and Standard and Local Ontology: Query can obtain all the available information about your subject from any data generated depending on this ontology from anywhere in the world, also any change in this ontology can reflect your results instantly.

B. Sample Application Scenario

The following scenario shows how semantic enrichment can be useful in a simple RFID system in a Hospital. The system is used for monitoring medical stocks and identifying objects/people via the EPC unique identifier.

In this scenario, each patient is assumed to have a hand bracelet with RFID tag identifier used to identify him and to obtain him Electronic Health Record (EHR).

We also assume that there exist ontologies of description for medications (e.g., components, side effects ...etc.) and medical components and their interrelations linked to each other.

As shown in Fig. 4 (a), a doctor would first identify the patient via the tag, and perform the medical check to take a treatment decision. The doctor enters the diagnosis into the patient's record, and then he starts to check for the proper medications to be added to the patient's medication list Fig. 4 (b). Here comes the role of the semantic technology based on some specific SPARQL queries and reasoning as mentioned in Fig. 4 (c), where the system checks if the proposed medication is available in the stock or not. In case it is not available, it will recommend an alternative medication that has the same effect. This will be done based on the results of SPARQL queries applied on the EHR of the patient and using external diseases' and drugs' ontologies Fig. 4 (d). The system can also sends a notification for the person in charge to request additional supplies for the medication to cover the shortage in the stock. All the information about the stock is obtained from the readings of the reader. In addition, the system compares the medical record with the components of the medication to make sure of avoiding any component that may cause allergy to the patient. In order to make this decision, it uses the ontologies to obtain the components and to compare similarities of components' side effects with the history. For example the patient is allergic to component x , the medication proposed contains component y, the ontology has the knowledge that if you are allergic to x then you are also allergic to y, so the system can avoid this medication and all similar ones before proposing the medications to the doctor to add it to the patient's medication list.

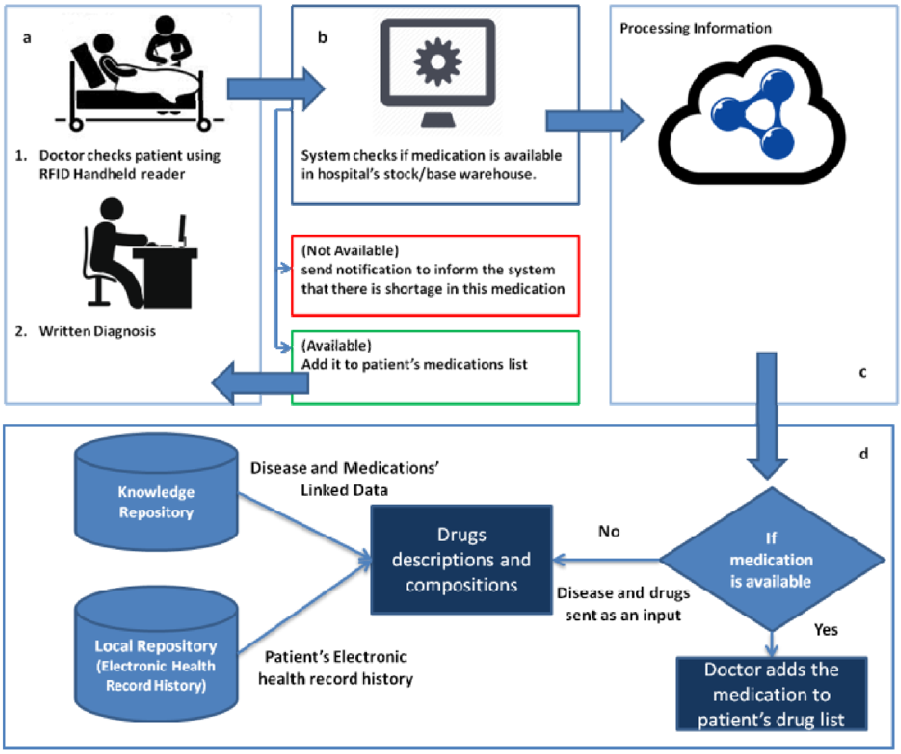

Fig. 4 Healthcare Scenario

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