Integration of RFID and Wireless Sensor Networks into a Supply Chain Management System

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***Abstract*— Wireless Sensor Networks together with Radio Frequency Identification are promising technologies for supply chain management systems. They both provide supply chain players with goods tracking and monitoring functions along the chain. Whereas RFIDs are rather focusing on identification of goods (e.g., identification, classification), WSNs are meant to monitor and control the supply chain environment. Nevertheless, despite the interest for the supply chain management systems, their integration is often deterred due to the lack of interoperability. In this paper, we propose a software framework which makes easier the integration of both RFIDs and WSNs into supply chain management systems.**

Keywords - RFID; Wireless Sensor Network; Supply Chain Management

I. Introduction

A. Context

Both WSN (Wireless Sensor Networks) and RFID (Radio Frequency IDentification) are very promising technologies for supply chain management as they introduce automation of product tracking and monitoring, and as such, they reduce the cost of the whole supply chain [19]. Today, there are only few attempts, mostly from industrial initiatives, that aim at integrating WSN and passive RFID tags [7, 8, 11].

Similarly, in the scope of the RESCUEIT project [14], we address the integration of RFIDs and WSNs into supply chain management systems. Together with major industrials such as K+N [15], Group Casino [16], REWE [17], Dr Oetker [18], we identify a clear need of secure and efficient tracking of goods along the supply. Supported by the integration of WSNs and RFIDs either within packaging or at pallet level, good tracking empowers supply chain players with tools for risk assessment along the supply chain, but also with mechanisms for identification of responsibility in case of incident.

B. Motivation

The benefit of such integration for supply chain management could be significant as data collected from RFID and sensors are complementary and could serve for enriching the range of supported services like monitoring and real time traceability. Whereas RFID is rather focusing on identification of goods (e.g., identification, classification), WSNs are meant to monitor and control the supply chain environment. To some extent, RFID are not restricted to unique identification of goods along the supply chain, but can be associated to information related to the classification, and dangerousness of goods. Based on those classifications, and with regards to the regulations (e.g., safety [20], quality), the handling, storage, and transport constraints are identified. In this context, WSNs are meant to enforce those constraints (e.g., incompatibilities with other products, flash points). Based on the sensed supply chain context at runtime, sensors tend to evaluate mismatches between the constraints defined by regulations and the current context. Any mismatch is therefore reported to the supply chain management system as a risk of incident.

As depicted in Figure 1., we propose a distribution of sensors into the supply chain, as foreseen in RESCUEIT [14]. Figure 1. shows an integration of RFID and sensor nodes only at pallet level. This assumption has been validated with end users of the project, like K+N [15]and the Casino Group [16]. In this case, we are addressing only low valuable products (e.g., household, gardening products), which explain the fact that neither goods nor packages are equipped with RFID or sensors. Nevertheless, goods and packages are still identified with barcode. In addition, depending on the value of the product, RFID and sensor can be integrated either at package or even product level.

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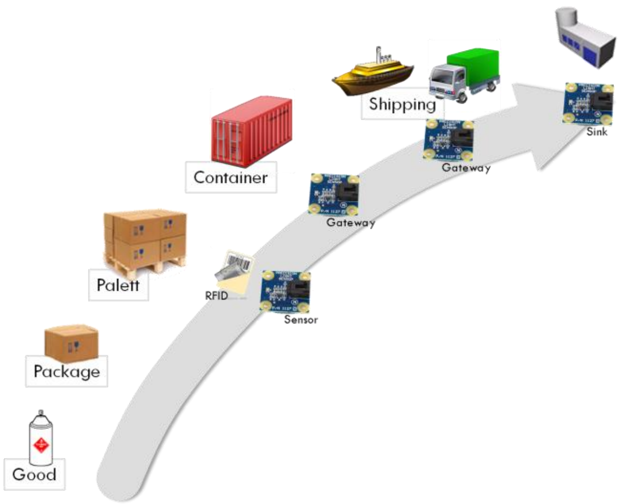

Figure 1. RFID and WSN integration

C. Problem statement

Even though the integration of RFID and WSNs appears to be promising for supply chain management systems, it can be deterred due to a lack of interoperability. First they are considered as disjoint networks. The EPCglobal network is designed for supporting RFID only; there is no standard targeting the integration of RFID and WSN into one network. Second, from a technological point of view, RFID are rather supporting single-hop communication between tag and reader, while WSNs supports a larger variety of communication (e.g., single to multi-hop communications). Third, they have different objectives. RFID are used for products identification and traceability. They rely on the information stored within the EPCGlobal infrastructure [10]. This information is related to the characterization of tagged assets. On the opposite, sensors have the objective to control and monitor the physical environment of assets, but not specifically associated to assets. Moreover they are able to self-store the useful information and regularly report that information to some supervision platform.

Due to different technological capabilities and uses and different objectives, a direct communication between RFID and sensor nodes is barely conceivable. That is why, we propose a software architecture that supports both RFID, especially very low-cost RFID systems, and WSN with the objectives to control, supervise and monitor both the environment of assets and the assets themselves.

D. Overall Approach

Our technical approach aims at integrating both WSN and RFID at the software layer. For that purpose, we propose to use EPCIS (Electronic Product Code Information Services) for RFIDs management and a mediation layer for the WSNs management. EPCIS is usually in charge of giving the list of all the features associated to an RFID product. In order to ease the interaction of RFID and sensor nodes, we use a mediation layer, Middleware for Device Integration (MDI), a SAP Research prototype. It serves for the activation of adequate monitoring and controlling mechanisms on the sensors, and to implement interactions with RFID.

As described previously, RFID and sensor are meant to be associated to a single product, package or pallet. In that context, RFIDs have two major roles: (i) identifying automatically goods along the supply chain - as made possible by the EPCglobal standard [10] for RFID but not with sensors - and including their classification, (ii) and tracing RFID for keeping sensors informed of the activity along the supply chain (e.g., storage, transport). As such, RFID are used for their fundamental identification and traceability functions, but also through EPCIS data basis to automatically raise the awareness of sensors about some (transport, storage) constraints (e.g., humidity, temperature) for the tagged good, with respect to the effective regulations. In addition, the traceability function enabled by RFID makes it possible to dynamically inform the sensor of any change of activity in the supply chain (e.g., transport, storage), so sensors can automatically adapt its constraints. Together with classification of goods, and update on supply chain activities, sensor nodes can therefore adapt their monitoring and controlling mechanisms according to regulations.

In this context, both EPCIS and MDI are considered as agents, each having interactions with RFID tags and sensors. As such, this architecture is of great help to make RFID and sensors systems interact through the MDI which handles data from RFIDs and sensors. Note that this approach is very attractive as no new integrated nodes are needed since the whole collaboration process between RFID and sensors is done at the software layer.

E. Outline

The remainder of this paper is organized as follows. We present the related work in section II. We describe our approach in section III, together with a architecture for the integration of RFIDs and WSNs into supply chain management systems. Finally, we conclude in section IV, with an outlook on our ongoing activities.

II. RELATED WORKS

To the best of our knowledge, integration of RFID and WSN did not attract the interest of the research community. RFID and sensor networks are both under development but with no interactions in between. Sensors are generally an open system contrary to RFID passive tags that are generally considered as a closed system where modification of their behavior is barely possible. Moreover, whereas sensors support multi-hop communications, current RFID systems are affording only single-hop communications, so no communication among tags is possible. Many issues are to be solved before integrating RFID technology with sensor networks. These

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issues include protocol design, energy consumption, security and privacy [13].

Moreover, the RFID technology benefits from the standard framework EPCglobal Network [10] that defines a network architecture for managing the RFID product information. This framework serves for trading partners to share product data. It is based on several key network elements including: EPCIS (EPC Information Services) and ONS (Object Naming Service). EPCIS hosts and facilitates access to serialized product information generated by EPC-tagged products. ONS is a centralized authoritative directory that routes information requests about particular EPCs likely to the well known Domain Name System (DNS).

The integration of RFID technology and wireless sensor networks provides promising perspectives as both of them can be used for tightly coupling the physical and virtual worlds.

Few research works are targeting integration of RFID passive tags and sensors. We distinguish two types of integration: hardware and software. On the hardware side, several commercial solutions are provided, which integrate RFID and WSNs in a single device (see Section II.A). On the other side, and similar to our approach, existing research works address the integration of RFID and WSNs at the software level (Section II.B).

A. *Hardware integration*

Integrating sensors into an RFID tag is used only for sensing few parameters. These sensor tags can be passive, semi-passive or active depending on the monitored phenomena. Generally, they only support single-hop communications.

The sensor passive tags draw power from the reader to perform operations. They are activated only when sensing data are required. They can be used to sense photo detection [4], acceleration [5], temperature [4, 6], etc.

The semi-passive sensor tags contain an on-board battery that is exclusively utilized for computation (and not for communication). They can perform measurements independently of the reader, but the energy supplied by the reader is always necessary for communication.

SensTAG [7] is a highly configurable semi-passive sensor tag. It operates at 13.6 MHz, and can be used to monitor a variety of sensor options, like temperature, humidity, strain, shock and light, etc.

The sensor active tags contain a battery from which they draw power for computation, sensing functions, and for communication to readers. They may be compliant with RFID standards, or they can use protocols based on wireless protocols such as ZigBee or WLAN.

Evigia [8], Savi [11] and Crossbow [12] develop many active sensor tags that integrate many embedded sensors like temperature, humidity, light sensor, etc.

Several companies ([11] [12]) also provide active RFID tags embedded with sensors nodes (e.g., temperature, light, presence detection). In the best case, those devices are equipped with GSM/GPRS communication capabilities which make them totally independent from supply chain player’s IT infrastructure.

B. *Software integration*

In [3], the authors propose a new architecture made of RFID tags and sensors. It consists in adapting the Application Level Event middleware (ALE) within the EPCglobal Network so that the filtering originally done over tag data is extended to sensor data. The main idea of this architecture is to distinguish data and control mechanisms in both RFID and WSN by introducing a reader management component that provides a uniform interface. This component is able to include WSN by adopting a Universal Plug and Play (UPnP) and the Simple Network Management Protocol (SNMP). As such, the WSN data are delivered to upper layers exactly like for RFID data, because the reader management component is able to handle data coming from RFID and WSN.

C. *Conclusion*

Regarding hardware integration within a single device, the exposed approaches often lack of integration with business applications. Those hardware solutions still require specific development for their integration into supply chain management specific.

Our solution belongs to this category, this type of integration offers advantages, as no new integrated nodes are needed. Moreover this solution provides a common infrastructure to link RFID system and WSN together.

So far, there are no standards proposing the integration of separate RFID and WSN into one network. To the best of our knowledge, our approach is the first combining sensors and RFID passive tags for specific needs for securing supply chains.

III. Our Approach

As introduced in Section I.D, our approach aims at integrating RFIDs and WSNs through the establishment of a communication channel between EPCIS, for RFIDs, and a mediation layer, the Middleware for Device Integration (MDI), for WSNs.

For that purpose, we use the MDI as an interface between RFIDs and WSNs. The main idea of our approach is to integrate RFID and sensors at the software layers. To do this, we make interacting two software elements: the EPCIS (designed for RFID as part of the RFID standards) and the MDI middleware (originally designed by industrials specifically for WSN). These elements support authentication of the tagged products and activation of the monitoring mechanisms within the sensors.

The integration at the software layer is necessary within this solution because we use very low-cost passive RFID tags with existing standards like EPC [10] to authenticate the products whereas we use WSN to monitor products along the supply chain.

A. *Architecture*

As depicted in Figure 2., our architecture is organized in three main components: (i) a palett equipped with an

RFID and a sensor node, (ii) an EPCIS component, and (iii) the MDI.

1) Description of EPCIS

The EPCIS module is a special web service interacting with the whole RFID system (reader, tags, and database) and serving as an RFID system interface by the rest of our platform. That is, it gives access to serialized product information generated by EPC-tagged products and available in the backend database. In other words, the EPCIS module is like a gateway between any requester of tag information and the database containing that information. EPCIS is able to handle large volumes of tag data coming from numerous RFID readers.

2) Middleware for Device Integration.

As mediation layer between EPCIS and sensor nodes, we use a mediation layer called the Middleware for Device Integration (MDI). MDI is a mediation layer developed by SAP Research [21] for the integration of smart items (e.g., WSNs, RFID) into business applications. Based on an OSGi Service Platform [22], MDI is an agent-based middleware which enables both monitoring and controlling of smart items. In Figure 2., the MDI hosts three agents: the sensor interface, the update, and the alerting service. The sensor interface enables communication with nodes, and the alerting service triggers alerts to users.

In addition the updater agent is in charge of the update of monitoring and controlling constraints on the sensor nodes. Depending on the classification and activity update from RFID, this agent updates on the nodes the constraints to be evaluated. For example, an alert whenever temperature reaches a given threshold can be activated. The same alert can be further on deactivated, in case of activity changes along the supply chain. For example, pallet fall alerting must be evaluated during storage in warehouse, but deactivated whenever the pallet is manipulated.

In Figure 3., we identify the following relationships: constraints, based on regulation, depend on asset's classification and activity along the supply chain execution. In addition, risk is depending on mismatch between constraints on goods and their context in the supply chain. If a constraint on temperature is defined, the probability on incident occurrence is depending on a mismatch with the context of the asset.

To that purpose, our updater agent enablement service is in charge of maintaining a monitoring database, based on the nature of the products, and the status of the supply chain process. Accordingly constraints to be evaluated are pushed to sensor nodes.

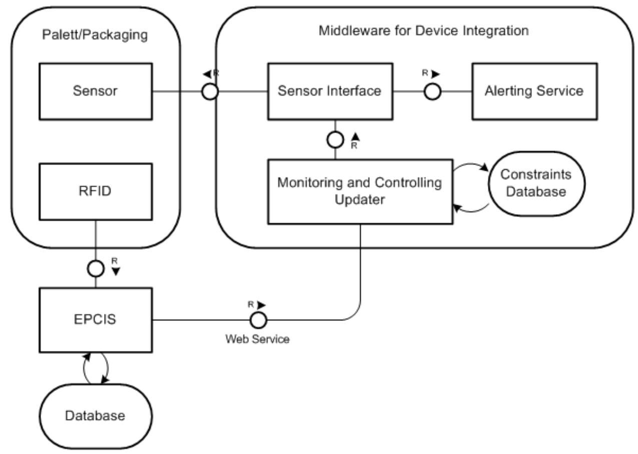

Figure 2. Architecture

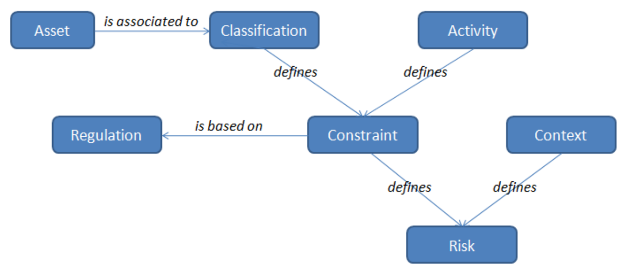

Figure 3. Risk Assessment

B. Interactions between RFID/Sensor Systems

The sensor node on the pallet is capable of in node processing, and is able to measure different contextual information (e.g., temperature, humidity). On the other hand, RFID is passive. As explained in Section III, the EPCIS service stores in its database all the information relative to the RFID tagged pallets: i.e. the SSCC [25] information (e.g. identifier of the pallet along the supply chain), CLP classification of goods (Classification, Labeling and Packaging of substances and mixtures) [24]). Also, the RFID identification is mapped manually to the identifier of the sensor attached to the pallet during the initialization phase of the EPCIS database. Table 1 gives the adopted EPCIS data model.

RFID Id	SSCC	CLP	Sensor Id

TABLE I. EPCIS DATA MODEL

Upon reading a tagged pallet, an RFID reader must send the RFID Id to the EPCIS service. EPCIS is then in charge of informing the MDI that the sensor identified by sensorId monitors a good classified according to the CLP norm. Based on that classification, the service enablement within the MDI extracts a set of constraint to be enforced on the sensor Id node. Those constraints are described in the constraint database, as shown in Table 1. Finally constraints are pushed to the sensor nodes via the MDI.

For example, for a chemical and anytime along the supply chain, a flash point of 13 Celsius degrees is defined

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by safety regulation. In addition, and only during storage, a constraint on acceleration of the pallet is activated, in order to prevent any pallet fall.

Classification	Status	Set of constraints

TABLE II. SERVICE ENABLEMENT DATA MODEL

Also upon detecting a status change along the supply chain, the RFID system registers that information to its own database and forwards the new status with the RFID Id to the MDI. Status change is then pushed to the sensor nodes.

C. Implementation

Our architecture has the advantage of leveraging standardized XML messaging frameworks for communications between EPCIS and MDI.

1) RFID and EPCIS

EPCglobal/ISO 18000-6C [10] is the RFID standard for supply chain. It defines a standard interface to enable EPC-related data; it does not specify how the service operations or database should be implemented. RFID tag communicates with the reader using the EPC Generation 2 protocol. The reader communicates with the EPCIS using the Reader Protocol. EPCIS has specific interfaces like EPCIS ALE (Application Level Event) interface, EPCIS Query interface.

EPCIS database stores all the product information like the traceability information, etc. In our solution, EPCIS works and exchanges information with MDI through a common interface thanks to web service.

2) EPCIS and MDI

When the EPCIS/Database authenticates the products, it informs the MDI about the nature of the pallet content, but also other tag data (e.g., sensor ID associated to the same pallet than the tag ID) and the product location (e.g., truck, warehouse, latitude, longitude). Then the MDI is enabled to activate adequate monitoring mechanisms on the sensors. This way, the logistician is able to monitor products along the supply chain. The MDI is able to handle large constraints coming from different EPCISs. Our approach consists in distinguishing the data and control mechanisms in both RFID and WSN in two different software layers. The proposed architecture has the advantage of leveraging standardized Web Service messaging frameworks [23] for communications between EPCIS and MDI.

The monitoring and controlling updater exposes a web service method for the update of a good, based on its classification and its status in the supply chain. The web service method signature is defined as follows

ErrorCode updateSensor(Integer SensorId, String GoodClassification, String Activity);

3) Middleware for Device Integration and Sensors

As depicted in Figure 2., three agents are running into the MDI. The updater agent is in charge of the update of constraints to be evaluated on nodes. An additional alerting agent is dedicated to the collection of alerts form the nodes, and the forwarding of alerts to end users. Finally a dedicated agent enables the communication between sensors and the two former agents. With respect to the targeted sensor node, a dedicated agent has to be implemented. In our case, we are focusing on crossbow [12] sensor node, which requires a dedicated agent. This agent has to be able to: (i) acquire information (e.g., alert, raw sensor data) from sensor nodes, and (ii) to push information (e.g., commands, constraints) to nodes.

IV. CONCLUSION AND FUTURE WORKS

As a conclusion, this paper proposed a framework for integrating RFID and sensor within the supply chain management systems. With this approach, we firstly aim at demonstrating the benefit of integrating RFID and WSNs. RFID are in charge of identifying good, their classification, and the status within the supply chain process. WNSs, embedded with monitoring and controlling capabilities, are meant to mismatch between regulation on goods, depending on their classification and on the status in the supply chain process. Therefore, WSNs depends on RFID information in order to run adequate alerting service on nodes.

We are planning an evaluation of our approach through a prototype in the scope of the RESCUEIT project. In addition, we are currently working of the design of security mechanisms for mutual authentication between RFID and tags reader, risk assessment delegations to nodes, and secure and efficient tracking of goods along the supply chain. Our goal is to address security requirement regarding the integration of RFID and WSNs for supply chain management systems.

V. DISCLAIMER

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