A Service-Based Methodology for RFID-Smart Objects Interactions in Supply Chain

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Abstract

Automatic Data Capture and RFID technologies (Radio Frequency IDentification) can be found in many industrial applications, mostly for product identification and traceability in the supply chain. In this paper, we suggest a methodology supported by an environment in which an RFID-tagged product is transformed into a smart object with embedded services and capable of acting by itself and conducting its destiny along its lifecycle. We use the RFID technology to assure automatic identification and communication with a product and UPnP technology (Universal Plug and Play) to allow developing product-to-process interaction, product-to-product interaction, product-to-environment and product-to-user interactions. The paper proposes a methodology based on UPnP Services that aims to give to the product the capabilities to analyze and to control its lifecycle behavior. Thus, a product can analyze each stage in the supply chain, to control its needs and to avoid the critical situations. The presented work proposes a methodology for RFID-based Smart Object design based on product's service modeling. The merging of RFID technology with UPnP framework offers the opportunity to design and implement smart object capabilities on products within the supply chain and manufacturing areas.

Keywords: *RFID-Smart Objects, RFID, Service-Based Methodology, Supply Chain*

1 Supply Chain Requirements and Context

Increasing requirements of reactivity in the supply chain topic are observed among product, processes and clients across the product lifecycle. In this context, the interactions between processes, operators and product, beginning with manufacturing level until its use, require more information and automated intelligent exchanges between partners, in a sure and relatively quick way. Specifically, the requirements that emerge in the supply chain are associated to product customization, traceability and information management along its lifecycle, and, in general, all kind of services related to the product lifecycle using Internet technologies. In order to respond to these new requirements this paper will propose an approach considering a physical object as an active actor managing its evolution in the phases of its lifecycle, cooperating with multiple actors in the supply chain (supplier, producer, distributor, and consumer).

With respect to the APICS dictionary (American Production and Inventory Control Society), the supply chain is "the processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies". The supply chain concept is review by APCIS [1] like "the global network used to deliver products and services from raw materials to end customers through engineered flows of information, physical distribution and cash". According to Panozzo [2], the logistics is the art to coordinate and manage the products and information movements from the origin to the destination. In our work, the supply chain is seen like several enterprises directly implicated in a product lifecycle. We are interested in the physical and informational flux that links these enterprises, where appear bi-directional information flows between the supply chain actors (Provider A, Producer B, Distribution Centre C, Retailer D) and unidirectional physical flow from the provider to the retailer. We can observe that the transport phase must manage both the information flow and the physical flow.

The need for augmented and enriched information about product, delivered locally to the product place and, in real time, along the product route, promotes the development of new approaches for intelligent or smart products with information electronically attached to them. As example for information management, associated to products in the supply chain, we can cite the services offered by the UPS Company. This company offers automatic means for the information management (via Internet, electronic messaging, etc.) to follow the physical objects and to inform the clients in real time the important events related to objects.

1.1. RFID and Smart Objects for Ambient Intelligence System

In this section the Smart Object and Ambient Intelligence concepts are presented. The Smart Object concept is related to an ordinary object as basic product capable to interact in an ambient environment using technologies (RFID, Wireless Communication, ...). The Ambient Intelligence concept represents an environment in which the Smart Objects are supported and can be promoted as the first layer for interactions in between objects, users and systems.

1.1.1. Smart Objects

A *Smart Object* is an ordinary object capable to communicate with its active environment, and interact with its users, other objects or processes from the supply chain. According to Kintzig [3] a Smart Object is able to acquire, to receive and to distribute information in a near or distant environment, and is able to carry out diverse actions on its own initiative or request help from others objects. The Smart Object paradigm provides an ability to embed new capabilities into an every day object as described by Kawsar [4], allowing extended access information up to complex services invocation and interaction. In addition, the *Ambient Service* is an abstract view of a system that provides information management capabilities, processing capabilities and event messages in an Ambient Network. The *Ambient Network* offers a continuous and transparent connection in an IP network (Internet Protocol) to all the actors offering and requesting services, whatever the moment and wherever an actor is.

McFarlane [5] and Bajic [6] have proposed definition of an intelligent product within manufacturing and logistics domains as a generalized Smart Object concept to be defined as a physical and informational representation of an object offering the following characteristics:

1. It possesses an unique identification;
2. It is capable to communicate effectively with its environment;
3. It can retain or store data about itself;
4. It deploys a language to display its features and its needs over its lifecycle;
5. It is capable of participating in or making decisions relevant to its own destiny;
6. It can survey and control its environment;
7. It can generate interaction by services offering: contextual, personal, reactive services.

So, in order to transform a physical object into a Smart Object, the previous characteristics must be fulfilled. This can be achieved using the ambient technologies presented later in this paper.

The smart object capabilities as presented above bring on the enhancement of product/ process/operator relationship from simple data exchange to high-level service providing and invocation at the product level. Ambient services architecture will be defined to allow intelligent product services capabilities supported by UPnP (Universal Plug and Play) technology.

By offering to manufacturing and retailing enterprises a new paradigm to interact with the handled products throughout the supply chain, the smart object transformation of industrial products is expected to enable significant gains in operational efficiencies. For example, warehouse management systems will have instant and automatic information transactions with stored and handled products. Automatic monitoring and context aware relationship with industrial products will lead to better performance in enterprise applications, such as warehouse management systems, supply chain management (SCM), and enterprise resource planning (ERP) applications. Later in the supply chain, retailers will have nearly instantaneous, rather than monthly or quarterly, data about which products have been sold. This information can be used to more tightly control inventories, monitor and control products operation and thereby reduce costs and processing times.

1.1.2. Ambient Intelligence

Smart Objects are intended to form objects communities to create reactive and context sensitive environments to achieve the Ambient Intelligence concept (AmI) . This concept represents a near future vision where the persons are assisted in theirs day-to-day activities by intelligent technologies that are deployed in the environment, taking actively into account their presence and the context. Two definitions describing the Ambient Intelligence context are currently relevant in the scientific community:

- "Ambient Intelligence is the vision that technology will become invisible, embedded in our natural surroundings, present whenever we need it, enable by simple and effortless interactions, attuned to all our senses, adaptive to users and context and autonomously acting. High quality information and content must be activated to any user, any where, any time, and on any device" according to Lindwer [7])[1]
- "Ambient Intelligence is an exciting new concept in information technology, in which people are empowered through a digital environment that is aware of their presence and context. The environment is sensitive, adaptive and responsive to their needs, habits, gestures and emotions." ITEA Ambiance [8]

The AmI concept has been published for the first time in 1999 by Aarts and Appelo [9] and has been officially adopted by Philips in 2000[2]. Then Philips has created HomeLab[3] in order to demonstrate the AmI concept and to evaluate the feasibility and usability of future home vision scenarios, Philips HomeLab [10]. As described by Van Loenen [11] and ITEA Ambience [8], the AmI concept is the result of two large tendencies: ubiquitous computing

[1] Consensus definition given by the Philips Research, Carnegie Mellon University, Eindhoven University of Technology, European Commission, Infineon Technologies Cie.

[2] Ambient Project results 2001 – 2003 supported by ITEA (Information Technology for European Advancement).

[3] http://www.research.philips.com/technologies/misc/homelab/ - Philips Research – Home Lab.

and social user interfaces. Marc Weiser [12], from Xerox Palo Alto Research, had invented the Ubiquitous Computing term to symbolize a future vision in which the persons will be surrounded by computers (small dimensions, mobiles and small prices) to interact easily with them in a transparent, invisible and non-obstructive way (*anytime and anywhere*). In "*Media equation*", Reeves and Nass [13] argue that the communication between persons and technological resources (computers, televisions, etc.) will be made in the same way as the communication between two persons. This means that the person will interact with the machines exactly with the same inter-personal interaction rules (*face to face*), like: confidence, similitude, attraction, and inter-personal distance between the user and the machine.

Another paradigm supported by the research projects is the pervasive computing paradigm, proposed by Ark and Selker [14] at IBM in the end '90 by taking as fundamental reference the ubiquitous computing concept. Pervasive computing represents distributed informatics in the environment (*everywhere*) to make the user interact with other informatics entities in different interaction scenarios. According to Mark [15], the pervasive computing paradigm is associated to a future vision in which the computers are embedded in the environment and the interactions between users and the environment are context dependant.

In the presented work, the AmI concept is the guideline to describe and model high interactions with Smart Object being able to interact with the human users, machines, and management systems. The proposed AmI environment is composed of the Smart Objects and other actors from the supply chain using the presented ambient technologies UPnP and RFID.

1.2. RFID technologies as AmI building bricks

In order to implement the RFID-Smart Object concept we present some technologies that offer the characteristics presented before. From the multitude of technologies we have pointed out the need of automatic identification and information management technologies and also Ambient Technology Architecture, which offers services and communication capabilities in an Ambient Network. In this section we present these technologies.

1.2.1. Classification of automatic identification technologies

The automatic identification technologies (Auto-Id) allows to an object to be automatically identified, in a unique way amongst all surrounding objects. The combination of Auto-Id technologies with information management and processing technologies will permit to an object to be transformed into a Smart Object to achieve the full characteristics listed in 1.1.1.

Based on the existing technologies survey figure 1 represents a classification of the major and mature industrial automatic identification technologies: Barcode, Passive RFID, Active RFID, Smart Cards, and Wireless Sensor Network. The *Autonomy axis* refers to the capacity of the auto-id technology to work in an autonomous way, without human assistance. The *Intelligence and Information Management* axis represents the computation capabilities allowed by the technology to realize decision and action making according to the treatment of internal and contextual information. This axis reflects the technology and ownership prices.

Barcode is a well-known low cost technology that allows identifying an object using a printed code that represents the general type of the object or the product, but not the unique item. It is generally divided in two parts according to UCC/EAN coding schemas: a company code and a product type code assigned by the product manufacturer. These regulatory coding schemas cannot assure the unique coding of each object.

Passive RFID has more industrial applications for automatic identification and traceability of objects. The system, composed by a RFID tag, a RFID antenna and a controller, allows to write and to read information in the tag's memory. The Passive RFID tag is power-supplied by using the magnetic field created by the reader's antenna, allowing short distance (up to several meters) wireless communication between the reader and the passive tag without any internal energy source. Active RFID technology is the battery-assisted version of the Passive RFID, allowing communication range up to 100m. Also, the Active RFID can incorporate several sensors, allowing the object to be context-sensitive.

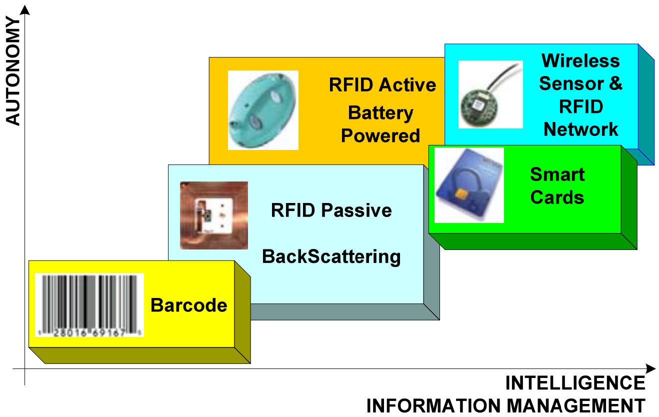

Figure 1. The evolution schema of smart object technologies

The Smart Card technology is mainly used in the systems that require secured transactions, like banking and access control. The advantage of the Smart Card is to be programmable, by embedding java applets for example.

The most recent and powerful technology Wireless Sensor Network is composed of many nodes, named Motes, which have the capacity to communicate wirelessly with each other. A Mote is a programmable microcontroller–based device with large memory, real time and multitasking embedded Operating System, offering a communication distance up to 100m, and it can also be equipped with sensors and actuators. A weakness of this technology is the need of a battery source on-board the object.

In order to make large use of smart objects in supply chain with huge number of items, we need to identify the most enabling technology to fulfill the targeted functional requirements on economic, practical, and sustainable conditions. When taking into consideration the information management capabilities, the form factor to allow easy encapsulation in various products, and the cost impact, we assume that RFID is the most enabling technology. Finally energy dependency is crucial when we consider that object should be operated on a long time period and in various applications and conditions like for example point-of-sale purchases, tracking, inventory management, identification, and industrial applications. So for all these reasons passive RFID technology is the most suitable technology to achieve economically sustainable design of smart object deployment in a supply chain.

1.2.2. Ambient Services Architectures

In order to develop the interactions between the Smart Object and the supply chain actors, it is necessary to characterize the notion of service in an ambient network. The *Ambient Service* concept represents an abstract view to define high level service accessible in an ambient network, offering information management, information processing and events management capabilities as proposed by Cea and Bajic, [16].

In an ambient services context, the product is a service provider or service requester, demanding discovery mechanisms and service control that are offered in a determined service domain. The domain can have a functional or geographical dimension. For Rousseau [17], the ambient service is a communication module characterized by information treatment, offering a control interface and publishing the service description. According to Naing [18], ambient services can be *location-based-services* that are services delimited by the geographic localization.

The Ambient Services Architecture models the Services and permits transparent interactions between informational entities. The Ambient architecture framework based on Internet technologies was developed by integrating technologies such as ad-hoc network, mobility management, and service discovery as described by Duda [19]. A detailed analysis of the main functionalities of Ambient Services Architectures can be found in Bajic [6].

1.2.3. Universal Plug and Play Services Architecture

UPnP is the acronym for an industry initiative designed to enable simple and robust connectivity among stand-alone devices and computers in a distributed, open networking architecture that leverages Internet and Web technologies. UPnP is designed to enable seamless proximity networking in addition to control and data transfer among networked devices in the home, office, and factory and everywhere in between. The UPnP approach is based upon generic Internet protocols and technologies such as Hypertext Transport Protocol (HTTP), Simple Object Access Protocol (SOAP), Generic Event Notification Architecture (GENA), Simple Service Discovery Protocol (SSDP) and eXtended Mark-up Language (XML). The generic UPnP architecture includes the two following entities: Devices and Control Points. The term Device Point (dp), noted UPnP(dp), is used to define a logical container of others devices and services. The Services are logical entities providing a specific service to UPnP devices network. A service embedded in an UPnP device consists of a state table, a control server and an event server. A state table models the state of the service through state variables at run time and updates them when the state changes. A control server receives actions request, executes them, and then updates the state table and returns responses. An event server publishes events to interested subscribers anytime the state of the service changes.

Services are controlled by Control Points, noted UPnP(cp), which is a logical entity that controls Device Points. After devices discovery, a control point retrieves the device description and get a list of associated services; then retrieves service descriptions for interesting services; after what it can invoke actions to control the service; and also it can subscribes to the service's event notification. Any time the state of the service changes, the event server will send an event to the Control Point. It is expected that devices incorporate also control point functionality, noted UPnP(dp/cp), to enable true peer-to-peer interaction.

In UPnP architecture UPnP Devices are allowed to present their capabilities known as services that can be controlled by the control points. The interactions between the Control Points and Devices can be fully automated, without need of human intervention. Also, it is possible to control the UPnP devices manually by using the device's Presentation page, which is a Webpage offered by the device and loaded by an administrator using a web browser. Service interactions in a UPnP architecture are represented in figure 2 which details information and event flow based on the fundamental functions: addressing, discovery, description, control, event messaging and web page presentation.

Addressing is a basic functionality for all UPnP Devices; each Device must get an IP address before it can discover other devices or it can offer its services in the ambient network.

Discovery allows the Control Points to search Devices and Services in the ambient network and to find who matches it's searching criterions. When using the discovery feature, the devices announce their presence in the ambient network by sending multicast messages, which describe the device type, the device's unique universal identifier (UUID), and an URL to reach its XML description document.

Each Device is composed by several Services. Each Service is described by a list of state variables, which models the state of the service at runtime, and a list of actions, which can be used to interact with the service.

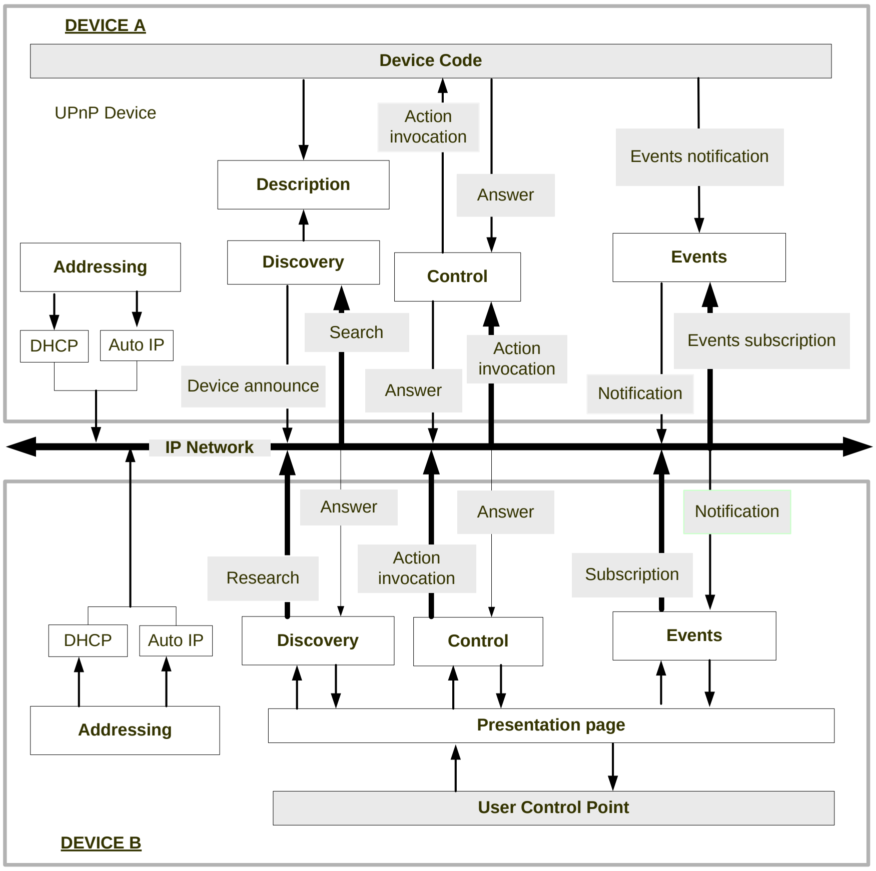

Figure 2. Information and event flow in a UPnP architecture

A Control Point can interact with a device situated in the same ambient network by means of remote action invocation, which is executed on the target device. Each action has a list of arguments that must be sent by the Control Point within the execution request. In the UPnP terminology, this call process is named Control. The execution of the action is done locally into the Service and the response will be sent to the Control Point after the execution.

The execution of actions within a Service can modify the state variables. A Control Point can choose to receive any modification in the state variable in order to react to device changes. The UPnP Event management allows Control Points to subscribe to event servers in order to receive messages when Device's states change.

2 Methodology for RFID-based Smart Object design

The interactions between RFID-based Smart Objects and supply chain actors demand effective communication standards and interoperability. In that respect, a methodological offer is proposed so as to create an effective integration between physical objects and their virtual representations. This offer is applicable all along product lifecycle in multiple services domain.

2.1 Principle of Service-based relationship for RFID-Smart Objects

Once an RFID-smart object has entered the ambient architecture, it is detected by an RFID ambient interface. Then the object is mounted in the ambient services architecture as a service provider entity UPnP(dp) ubiquitously accessible by any existing control point UPnP(cp). So the Physical Product is transformed in a UPnP(dp) Device providing and performing transparent services called RFID-smart object's services.

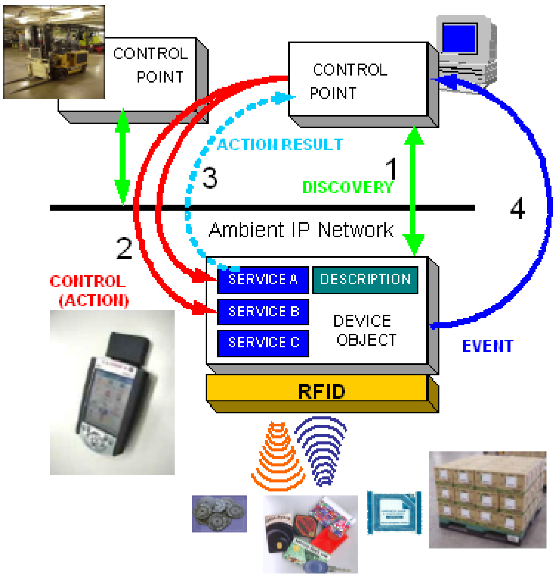

Figure 3. Service based relationship between product and actors in a supply chain

Figure 3 depicts the generic principle of a Service based relationship between RFID-smart products and actors in a supply chain:

1. The RFID-smart object (dp) announces its presence to the ambient IP network. Control point entities automatically discover new mounted device points. The device and service description files are broadcasted in the IP network by the (dp) to inform the ambient environment of its capabilities.

2. Any control point (cp) in the ambient network can invoke the device point services.

3. When a (dp) service is requested by a (cp), the device point executes the corresponding invoked action and returns an acknowledgement or action's result to the requestor.

4. A (dp) figuring a Smart Object can perform automatic and spontaneous eventing to the ambient partners without any preliminary request in order to provide bottom-up reactivity from the product to the system.

2.2. RFID-Smart Object's implementation cases

In order to present the conceptual solution for a Smart Object achievement, three generic cases for implementation are considered, depicted in figure 4, and detailed below:

1st implementation case: UpnP-assisted Passive Object

Case one on figure 4 represents a physical object carrying a RFID tag, which is interfaced to the UPnP architecture by an UPnP (dp) middleware composed of a PDA or a microcomputer with a RFID Reader. Process begins with the automatic identification of the object by the RFID-UPnP (dp) reader. As soon as the device identifies the physical product, services embedded in the product are mounted in the (dp) memory by means of XML files. A XML file summarizes the information about the object's services, including actions and state variables. Thus the services available in the UPnP (dp) represent a virtual image of the product parameterized by the information stored in the tag. At that time, all the services associated to the product are known and can be remotely invoked by all UPnP (cp) in the ambient network. Conceptually, the merging between the RFID-tagged object and an UPnP (dp) plugged in an UPnP network forms an entity called **UPnP-assisted passive object**, acting as a service provider. The UPnP (dp) middleware is either a PDA or a micro-computer. The service provider carries out a passive role responding to high-level requests from supply chain actors plugged in the IP network such as automatic identification of the tagged object, related information about lifecycle of the tagged object, contribution of the tagged object in decision making. This implementation case represents a low-cost industrial solution for RFID-smart object with a versatile technological integration.

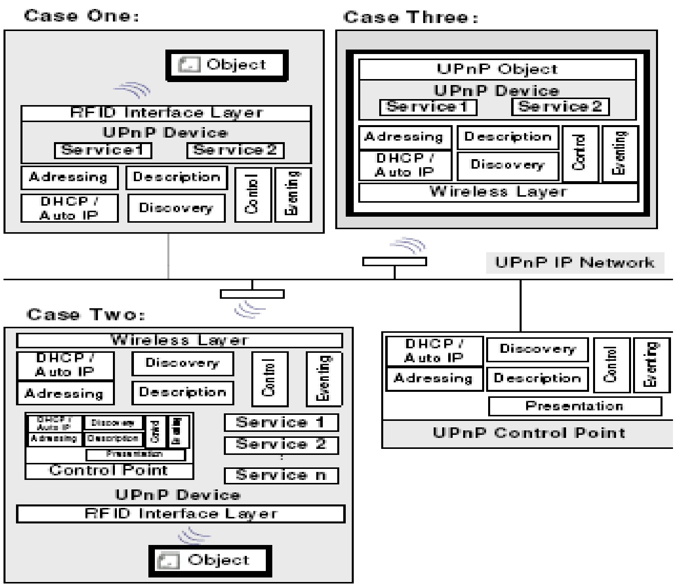

Figure 4. From RFID to Smart object: three integration cases

2nd implementation case: UpnP-assisted Active Object

The UPnP(dp) is enriched with Control Point capabilities to form a UPnP(dp/cp). The RFID-tagged object and an UPnP(dp/cp) middleware plugged in an UPnP network form an new entity called **UpnP-assisted active object**, acting as a service requester and provider. The UPnP(dp/cp) middleware is either a PDA or a micro-computer with RFID reader. This UpnP-assisted active object, is more intelligent than a passive object as it can moreover make requests to other services providers (dp) in the UPnP architecture and thus makes its own decision process according to the answers. A software layer in the (dp/cp) is parameterized according to RFID-information, so a (cp) algorithm manages the RFID-smart object decision-making and performs corresponding services calls to other actors in the UPnP ambient architecture. This implementation case still represents a low-cost industrial solution for RFID-smart object with a versatile technological integration but with advanced programming embedded in (dp).

3rd implementation case: Full UpnP Object

UPnP(dp/cp) is directly embedded into the physical object, with no need of any RFID tag on the object. It figures the most complex entity represented in our methodological proposition. But, a PDA with both WiFi and RFID communication capabilities, or a WSN mote can play this role of Smart Object. Nowadays, such industrial products do not exist mainly due to high cost and implementation complexity.

2.3. RFID-Smart Object's Service Classes

To extract real profit from our methodological proposal, it is necessary to identify and to define the interactions between all actors of the supply chain - including the product - for every stage of the product's lifecycle. The actors' interactions during invocation or execution of services represent the key element in the modeling process. Therefore, the characterization of innovative services will contribute to a significant added value for the supply chain.

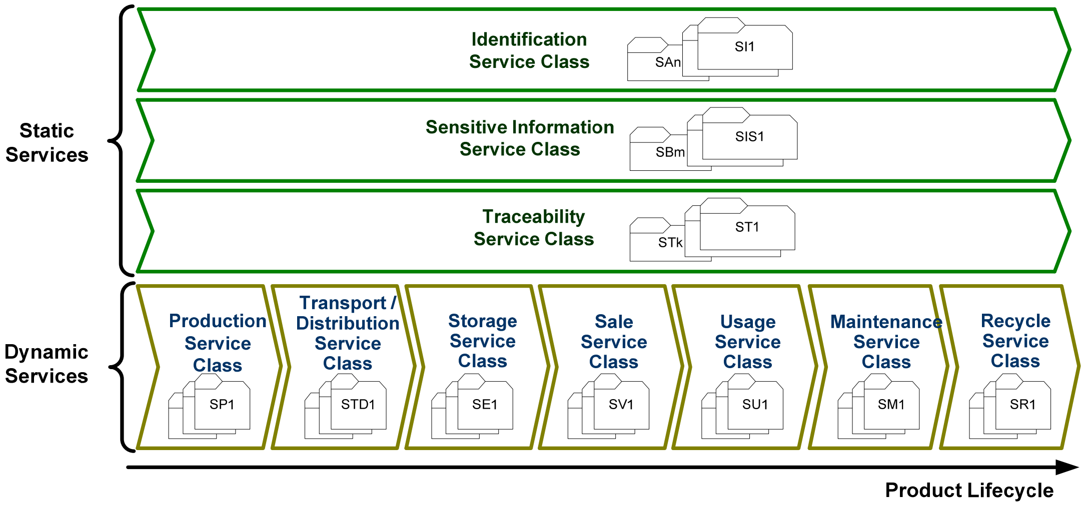

Figure 5. Services classification along the product lifecycle

Modeling of interaction between intelligent product and supply chain processes is thus supported by definition of a set of service classes associated to different stages of the product life cycle according to the capabilities of the Smart Object.

The services associated to an RFID-smart object can depend on contextual information, i.e. the object's physical nature, and also depend on the object's interaction domain and the supply chain actor's profile. We recommend making services clustering according to the object lifecycle phases. Wong [20] adopted this approach to explore the possible applications for a RFID tagged object that points to a remote informational system (ePC approach). Loke [21] proposes another service classification approach based on the object's geographical position, with services' access rights according to the requester's profile.

We propose to classify the RFID-Smart Object services by considering the static or dynamic character of the services throughout object's lifecycle. We propose three classes of static services: object identification, sensory information, and traceability services. The static services do not depend on external factors and are permanently available during the lifecycle. The dynamic services depend on the object lifecycle and the contextual information (object type, interaction domain, and the actor's profile). These services can be classified in 7 categories presented in figure 5: production, transport and distribution, storing, sales, usage, maintenance, recycling services.

The UML language is used to model the services and the interactions between an intelligent product and the actors of the supply chain. The UML Class Diagram in figure 6 summarizes the relationship between device, services, state variables and actions.

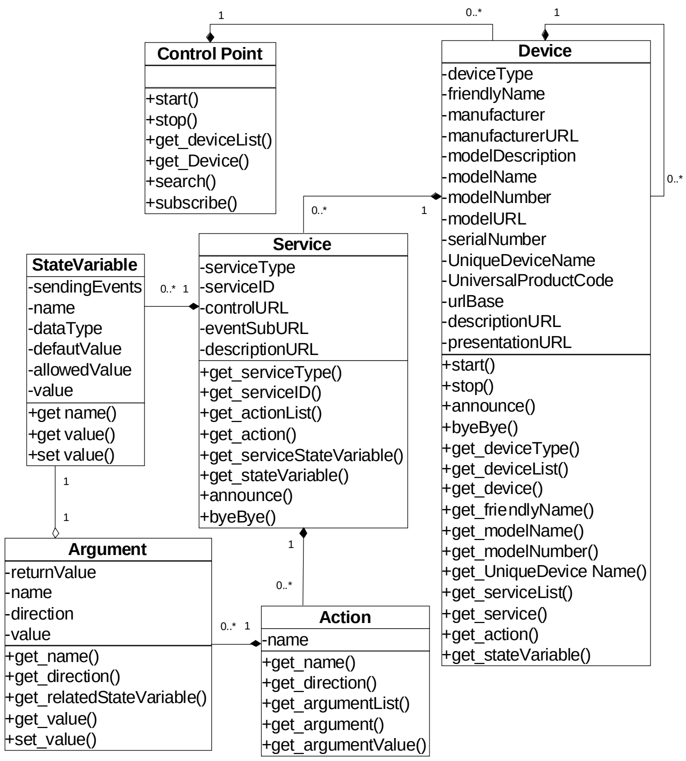

Figure 6. UML Class Diagram of UPnP Device

2.4. RFID-Smart Object's Interaction Model

The general mechanism used by an RFID-Smart Object acting as a control point is represented in figure 7. Inspired from the *Contract Net* protocol, standardized by FIPA[4], this interaction begins with a service request (e.g. use of a resource, transportation, etc.) sent by a control point (e.g. WMS or an active RFID-Smart Object) to all ambient service providers (M). Providers respond by asking for the desired characteristics of the requested service (storage conditions, transport conditions, etc ...).

The providers that are available and capable to offer the desired service (P) will inform the requester of their availability, and propose the execution of the service (meeting point, execution time, etc…). By this way, the service requester can choose amongst the providers the most adequate one for its needs. After the service execution is done, the service provider will send a response message with the execution status.

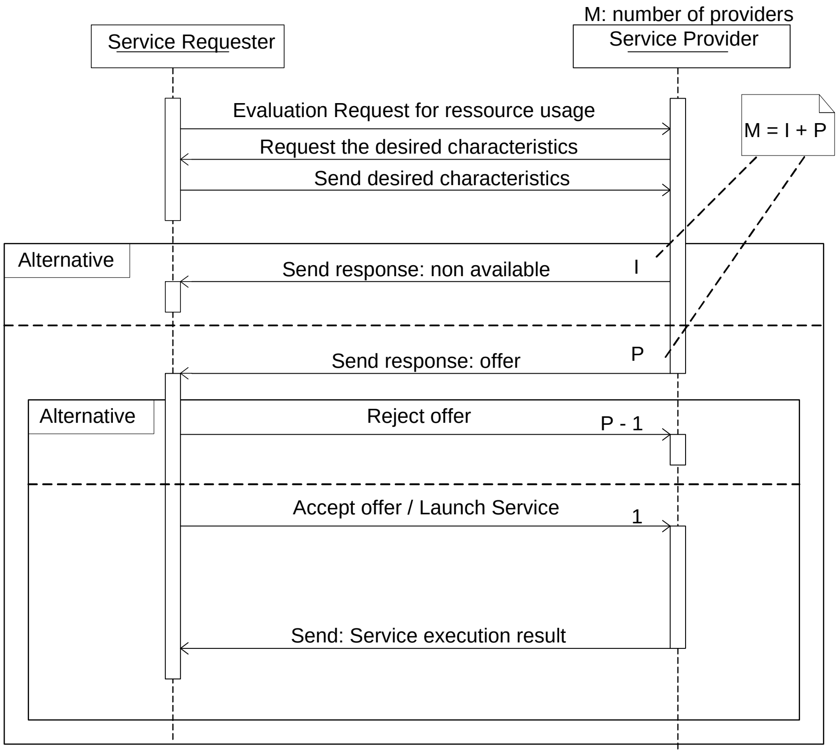

Figure 7. UML Sequence diagram describes object-to-object action invocation

3. Practical Achievement of Smart Object capabilities

The methodological proposition aims to transform a physical object into an RFID-smart object assuring intelligent interactions based on service invocation in an IP ambient network.

3.1. RFID and Services in a warehouse use-case

We validate our methodological proposition in a supply chain context with use-case applied to warehouse management. Producer companies, import/export companies, transport

[4] FIPA : Foundation of Intelligent Physical Agents : http://www.fipa.org/

and logistic companies, etc… commonly use warehouses as temporal storage places for large quantities of physical products. The common goal of these companies is to store products for short time before they are transferred to the next client of the supply chain, like the distribution, the retailer or the final client.

Figure 8 presents an example of how the resources are disposed in a warehouse. We can observe an entry zone, a storage zone, an exit zone, a Warehouse Management System and a wagon parking lot.

In figure 9 we show the proposed architecture to manage the interactions between the supply chain actors and the RFID-based Smart Objects. Three physical object families represent the physical part of the Smart Objects: the pallets, the box of products and the individual products. Boxes of physical products compose the pallets. RFID electronic labels equip these physical objects.

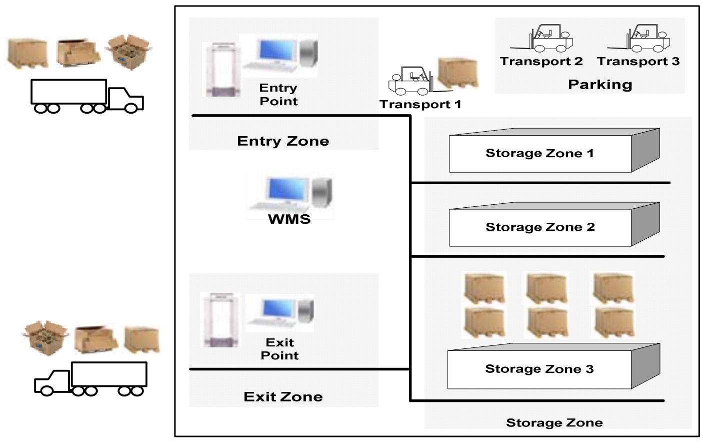

Figure 8. Typical layout of a Warehouse

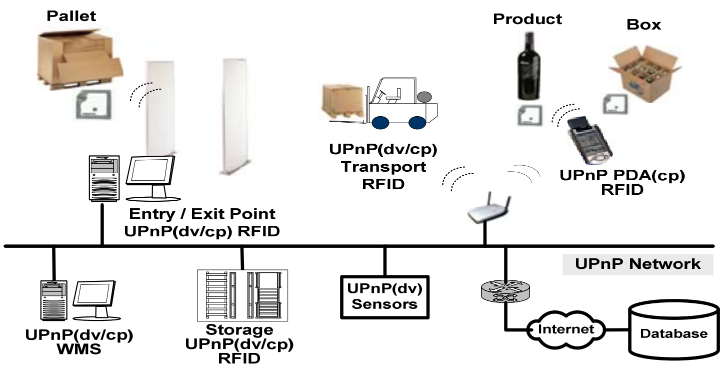

Figure 9. RFID-Smart Objects' Architecture view of a warehouse management

The devices interacting with the physical objects are:

- **Entry / Exit Point RFID/UPnP**: UPnP devices equipped with RFID readers located at the entry and the exit of the warehouse given the possibility to automatic identify the physical objects that arrive and leave the warehouse. At the identification moment, the Smart Object with its services is created in the UPnP ambient services network.

- **Transport UPnP/RFID**: Transport vehicles capable to identify automatically the physical objects and to instantiate Smart Objects from them. Transport vehicles will move the physical objects inside the warehouse.
- **PDA UPnP/RFID**: UPnP mobile devices integrate a RFID reader to identify the physical objects at different storage places in the warehouse, and permit to manage and control the objects services.
- **UPnP management**: warehouse management software entity with UPnP functionalities that have a global vision about the physical and informational flux between the warehouse actors to optimize the movement of the physical objects.
- **Storage UPnP/RFID**: UPnP devices that are placed in the storage area allow the automatic identification of the physical objects that are stocked.
- **UPnP sensors**: UPnP devices sensors for temperature, humidity level in the warehouse, especially in the different storage zones where the objects can survey theirs environment.
- **Database system:** Remote database in the UPnP network, providing augmented information about the physical products.

Table 1. Capabilities of a Smart Object in warehouse management

Smart Object Capabilities	Method	Example
Possess a unique identification	Automatic identification of a product using radiofrequency.	Physical product tagged with 13.56 MHz RFID tag
Memorize and manage its own information	The physical product stores its information on both RFID tag and remote databases.	The product stock its identification code, its fabrication date, its weight, etc.
Have a dialog language	The object communicates using the UPnP potocols by announcing its presence and services, and requesting the distant services.	The Smart Object uses the SOAP and GENA protocols to communicate with other entities in an UPnP network.
Communicate with its environment	The object can communicate with UPnP devices, UPnP control points and other Smart Objects.	A physical product communicates its arriver and departure in an ambient network.
Offer services related to its lifecycle	The passive Smart Object is a service provider.	Smart Object offers information about its identification, its fabrication procedure, its recycling procedure,…
Demands services at its lifecycle actors	The active Smart Object is a service provider and a services requester.	Smart Object can request services from other UPnP entities: resource availability...
Survey and control its environment	The object can communicate with distant UPnP sensors in order to receive son environment characteristics information.	In the application layer it is possible to implement the comparison between product essential variables with external variables: temperature, humidity...
Participate at decision process during its lifecycle	Smart Object include appropriate decisions-making rules, with application layer integrated in its UPnP representation	Implementation of auto-evaluation and auto-diagnostic mechanisms, in the Smart Object's application layer

Table 1 presents the capabilities and services of a RFID-Smart Object and the methods to achieve them in a warehouse management application.

Using this warehouse representation, we have validated the smart object concept in warehouse management by creating the described entities. This validation has been possible by the use of a test platform composed by three applications and the associated technologies. Next, we will present our test platform.

3.2. Development and Demonstration Platform

A laboratory test platform has been developed, allowing to a physical product to be transformed into an RFID-smart product through the use of advanced services in an ambient intelligent network. The experimental platform supports Smart Objects' interactions related to warehousing activities. Service domains and objects' types differentiate the services.

We used Intel[5] software tools to support the design of Services and UPnP Devices. After the code generation of each Service and Device in C#, we have developed proprietary UPnP applications [22] to realize **UPnP-Assisted Passive Object**. The platform architecture is presented in figure 10, and is composed of three applications interacting together to demonstrate high-level object-to-object interactions and also user-to-object interactions.

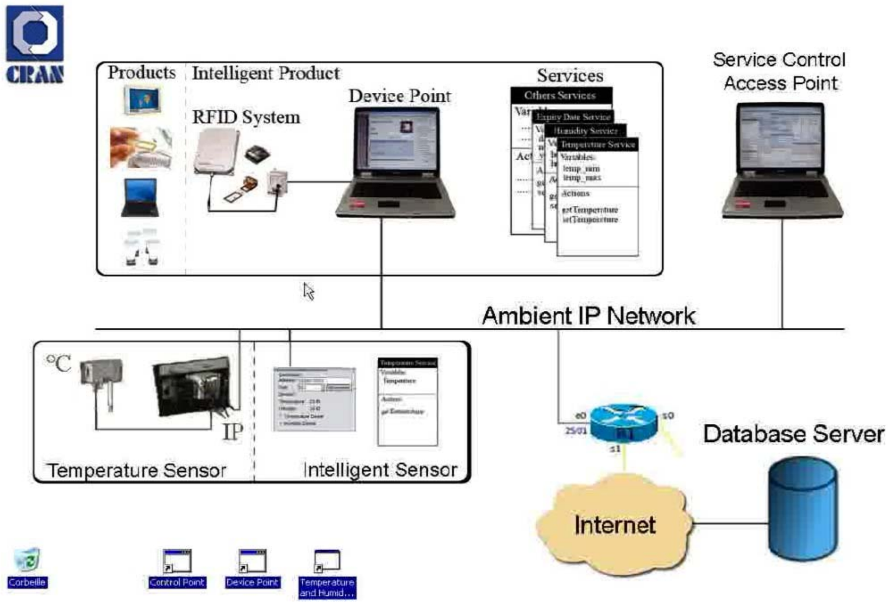

Figure 10. Advanced Services Architecture with RFID-Smart objects approach

The mechanism of transformation of a physical product into a smart object begins with the attachment of a RFID tag to product. This gives to the product the capacity to memorize personalized services information and to interact with the Supply Chain environment through the RFID Device Points that can read and write to it. The first component of the platform is the *RFID Device Point*. This is a middleware device represented in the upper left corner, composed of an RFID reader and an UPnP Device Application. The aim of this component is

[5] Intel UPnP Technology (2006) - http://www.intel.com/technology/upnp/

to generate the RFID-Smart Object from a RFID tag acting as a distributed virtual services entity in an Ambient Network. The role of the UPnP Device Point application is to detect all objects that are in the range of the RFID reader, and then after reading of discovered RFID tags it generates the Services associated to the products (See figure 11). These services will be available to any control point in the ambient architecture. We used Philips ICode1 RFID transponder technology, which has a unique 64 bits code and can store up to 48 bytes of user data for services coding. Using the first page of 4 bytes, we separate the Services in families, representing the application case like supply chain management, then the services are binary coded in the tag memory. As so, we can manage up to 255 application families (1 byte) of 24 services each (3 bytes). The last 44 user's bytes are dedicated to code product information and services parameters.

The UPnP Service Architecture allows easy management, developing and execution of ambient services. One property of the application is the transparent and dynamic loading of services, which gives to the user the possibility to develop new services and to generate application-specific family of Services.

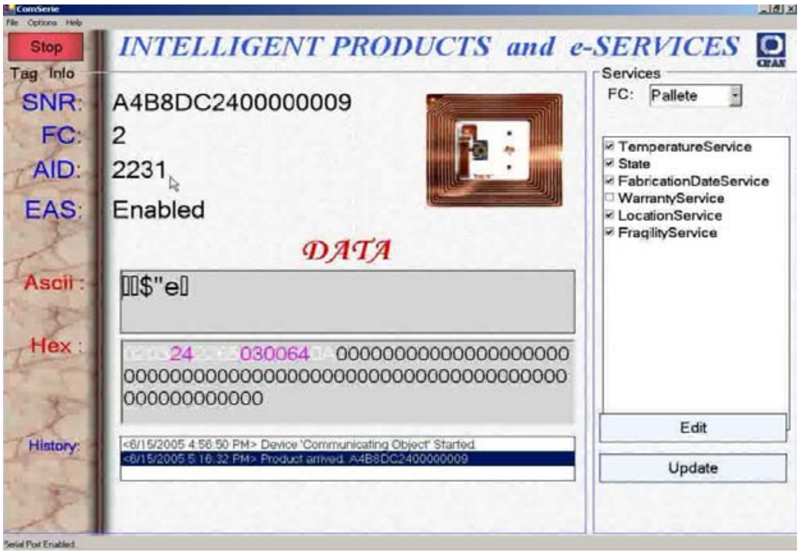

Figure 11. RFID Device Point middleware transforms RFID data into Smart object Services

For a representative example of industrial warehousing activity in the supply chain management, we have developed the following services: Electronic Product Code, Dimension, Quantity, Fragility, Expiry Date, Humidity, Temperature, Location, Origin and Destination Code, etc... Using these services, the RFID-Smart object can participate to the ambient network with high-level services about its state and behavior, and also contribute to decision-making with the Warehouse management system. Because of the limited tag's memory, an information database is linked to the architecture to offer augmented information to the object. Thus the union of the physical product, the RFID system, the UPnP Device Point and the Services represents the RFID-Smart Object concept. UPnP also helps in the distribution and distant execution of services to allow interactions between RFID-Smart Objects and machines or users.

Service Control Access Point is the application used to interact with the Smart Objects in the Ambient Network, developed to easily manage UPnP Services. We have enclosed special features as for example a color classification of the different UPnP Devices available, and the executions of background processes, which react to events received from the Ambient Network, so to execute specific user-defined scenarios though figuring product-to-product interaction. The application has been developed for PC and PDA to increase mobility [23].

As an extension of RFID-smart object concept we have diverted the functionality to a non-product entity, i.e. to peripherals and sensors situated in the warehouse environment. Ambient Services like temperature and humidity can offer additional information to WMS and RFID-Smart object to manage their states and behaviors. The services are generated by the *Intelligent Sensor* application. This application enhances a normal sensor with UPnP capabilities. In the lower left part of the architecture we represent the two components: the physical sensor, from which we read the values and which is connected to the Internet, and a service provider application. The communication between the application and the sensor uses industrial Ethernet Modbus-TCP protocol. The Intelligent Sensor device has the role to read the values from two sensors, temperature and humidity, and to create two UPnP Devices that provide the real-time values of the physical ones. So, we have included UPnP Control Point capacities in RFID-smart object to request information related to the environment in which they are placed. The UPnP control points receive the modifications of the values as events; so, the two services from the Smart Object can check and send alarms if necessary. Other application case is the surveillance of a physical environment, where sensors are deployed.

With the combination of RFID Device Points, Service Control Access Points and Intelligent Sensors the implementation of RFID-Smart Object concept is made feasible and demonstrated hereby. An RFID-based Smart Object is able to interact with its environment, with the supply chain actors and with others Smart Objects on a high-level services basis. Currently, the presented prototype is being applied in supply chain experimental cases.

4. Conclusion

This paper proposes a methodological approach offering a high level of integration of a physical object into an IP ambient network to develop wireless communication and intelligent interactions with the supply chain actors during product lifecycle. An RFID-based Smart Object design methodology is proposed to provide objects with high level services management capabilities in both roles of provider and requester allowing fulfilling intelligent interactions in supply chain. RFID technology permits to identify and seamlessly link the physical object to its virtual image depicted in a Smart Object for maximizing the use of the product information and knowledge along product lifecycle. Ambient services architecture based on IP technologies provides high-level standards functionalities for discovering and learning about product's services in a services domain. UPnP as an open networked architecture layered on Internet technologies allows the transparent communication and interactions between services-based devices situated in an ambient network.

With the merging of RFID and UPnP technologies, the implementation proposal aims to transform physical objects into smart objects interacting within reactive and context-sensitive environment, in which products are empowered through a digital environment based on services instead of elementary data.

A laboratory test-platform validates the proposed methodological approach promoting RFID-Smart Objects concept in a warehouse management application thus providing real benefits and efficiency in the treatment of the product storage conditions. By offering to manufacturing and retailing enterprises the new paradigm of RFID-smart object to perform transparent interaction with products handled throughout the supply chain, the transformation of industrial products is expected to enable significant gains in operational efficiencies. This can be used to more tightly control inventories, monitor and control products operation and thereby reduce costs and processing times. Automatic monitoring and context aware relationship with industrial products will lead to better performance in enterprise applications, such as warehouse management systems, supply chain management (SCM), and enterprise resource planning (ERP) applications.

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