A Distributed Architecture for a Ubiquitous RFID Sensing Network

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Abstract

The concept of a "Networked Physical World" originated from the Auto-ID Center, now called the Auto-ID Labs. Such a system can be realized with a combination of automatic identification technology and a ubiquitous computer network that will glue the physical world together. The ability to form a ubiquitous network of physical objects has a wide range of applications including manufacturing automation, supply chain management and collection of sensor derived data. We describe the building block system components of a distributed ubiquitous RFID network aimed at enabling ubiquitous sensing with RFID and explore the data flows within the system.

1. INTRODUCTION

Originally the architecture to build a ubiquitous item identification network commenced at the former Auto-ID Center, now the Auto-ID Labs [1] with the process of standardization issues currently managed by EPCglobal Inc [2]. The Auto-ID Center's vision was to create a "Smart World" by building an intelligent infrastructure linking objects, information, and people through computer networks oblivious to the users. The creation of the intelligent infrastructure demanded the ability to identify objects automatically and uniquely with the backbone of the infrastructure provided by a ubiquitous computing system leveraging the internet for global connectivity. The components forming the intelligent infrastructure are commonly referred to as an EPC Network where the term EPC (Electronic Product Code) is a result of the unique object identification scheme employed by the system. This new infrastructure enables object-centric computing that will allow universal coordination of physical resources through remote monitoring and control by both humans and machines. While the applications of this technology are widespread the EPC Network is expected revolutionize supply chain management.

The EPC Network is assembled upon many building blocks representing a number of fundamental technologies and standards. The enabling technology around which this network is constructed is RFID. Not only does RFID replace the more traditional barcode for logistic applications but it also provides the possibility of placing additional features on RFID ICs such as environmental sensors. This has the potential to revolutionize sensing applications as RFID is able to bridge the gap between the physical domain and the digital domain. We present the system components and technologies of the ubiquitous sensing network architecture (EPC Network) in the first section and provide architecture for extending the local area EPC Networks with an outline of the data flow within such a network.

2. EPC NETWORK

The network of physical objects is achieved by integrating an electronic Radio Frequency Identification (RFID) transponder (RFID label) into each object. Each RFID label may have added features such as sensors for monitoring physical parameters: temperature, pressure, or harmful agents: toxic chemicals, bacterial agents.

The system networks objects seamlessly by communicating with these labels at suitably placed locations: portals, mobile locations, through handheld devices, and potentially, eventually for some tags, continuously throughout the environment. A network of RFID Readers is used to collect data from tagged objects. The RFID labeled objects communicate an EPC (Electronic Product Code) code to identify themselves as a unique entity. The EPC is in essence a pointer to a database record describing the tagged object and the functionalities provided by the tag. The data originating from the network of Readers is passed to control and data collection systems that provide service layer functionalities. An illustration of the components constituting the EPC Network is shown in Fig. 1.

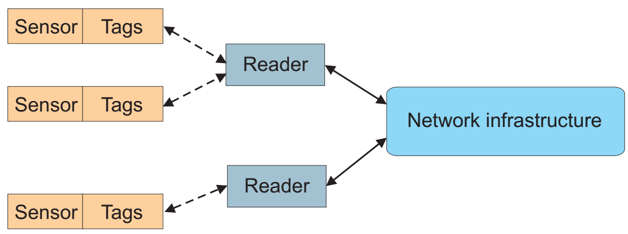

Fig. 1. An Overview of an EPC Network. The arrows indicate the flow of data from tags to network support system and the flow of control and data back to the Readers and tags.

EPC Networks are significantly different from more traditional computer networks in the sense that the flow of data and information is from many nodes (RFID tags) at the edge of the network towards a number of central servers. In RFID networks, Readers detect certain events or Readers query RFID labels to obtain event data and forward the resulting information to backend applications or servers. The application systems then respond to these events and application processes orchestrate corresponding actions; such as ordering additional products, sending theft alerts, raising alarms regarding harmful chemicals or replacing fragile components before failure.

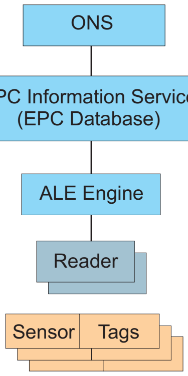

Fig. 2. The component based structure of a local area EPC Network.

The EPC Network is a component based architecture with six primary components, some physical, some, logical: (1) RFID tags, (2) RFID tag Readers (interrogators) (3) Electronic Product Code (EPC), (4) Application Level Events Engines, (5) Object Name Service (ONS), and (6) EPC Information Service (EPCIS) . Fig. 2 shows the structure of a typical EPC Network.

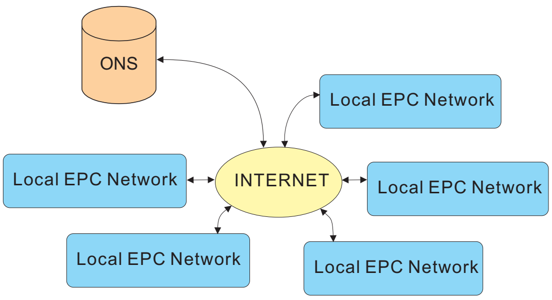

Fig. 3. Wide area EPC Network overview. The local EPC networks are able to route their information and requests to remote and unknown locations using the translation services provided by a network of global public ONS servers.

The EPC Network shown in Fig. 2 is a local area EPC Network akin to LANs. This model captures the architecture of the system at a local site: company or organization, or a private network. Nonetheless, local EPC Networks can be linked together through the already established backbone of the Internet to achieve a global flow of information and data while extending the outreach and the usefulness of the EPC Network. Fig. 3 illustrates such an architecture where a global public ONS (Object Name Service) system may be used to connect public local area EPC Networks. The subject of ONS is considered in Section 5 of the paper.

3. RFID COMPONENTS

The RFID aspects of the EPC Network consist of RFID tags (the miniature computing devices forming an interface to the physical world) and RFID Readers. The following is an overview of the RFID components of the EPC Network while a more complete and thorough coverage of the topic may be obtained from [3].

RFID tags, when coupled to a Reader network, form the link between physical objects and the virtual world in the EPC Network. RFID tags have a small radio antenna that transmits information over a short range to an RFID tag Reader [3]. RFID technology may use both powered and non-powered means to activate the electronic tags. Powered devices use batteries to actively transmit data from the tags to more distant Readers. Electronic highway toll systems are good examples of active RFID tags. Passive RFID devices literally harvest energy from the electromagnetic field of an active Reader to both power the tag and transmit the data. Modern RFID labels are fabricated using standard CMOS technology and are interrogated by the process of RF backscatter [4]. In the most cost effective and popular technology, the tags are passive and in consequence the ranges of operation are limited (few meters) [5]. Passive systems are well suited for use in the EPC Network due to their low cost.

The architecture of the network does not place a restriction on the tags that can be employed as tags with substantially enhanced functionality will extend the depth of the application layer. Such functionality can be provided with active RFID labels. The most common objective of an active RFID label is to obtain a long read range using battery-assisted backscatter. An active backscattering label will modulate the powering carrier or a subcarrier to establish a communication link with the Reader while using the battery to power the logic circuits of the label [3].

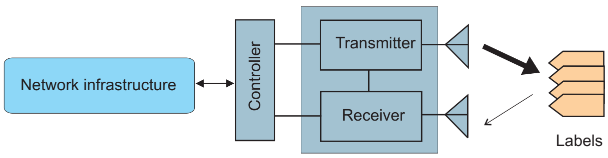

Fig. 4. RFID System overview. The transmitter, Receiver, and the Controller forms the RFID Reader. Here a transmitter of interrogation signals which is contained within a Reader communicates via electromagnetic waves with an electronically coded label to elicit from the label a reply signal containing useful data characteristic of the object to which the label is attached. The reply signal is detected by a receiver in the interrogator and made available to a control system.

However other types of active labels may not use backscatter but instead use a battery (such as a paper battery) for powering and transmitting requirements (independent reply generating labels). This distinction is more apparent in the range of operation of the label. Under RFID systems operating under the US regulations for the ISM (Industrial, Scientific and Medical) band of 902-926 MHz (allowed transmit power in this band is 4W EIRP), a backscattered reply can be correctly decoded in the range of several tens of meters while an independent reply generating label will work in the range of several hundred meters

A simple illustration of the concept of a Radio Frequency Identification (RFID) systems used in the EPC Network are shown in Fig. 4. Currently there are standardization efforts to produce a harmonious air interface for low cost RFID tags that requires a minimum of functionality implemented on the microchip. However there are existing protocols for an RFID air interface in the ISO standards (ISO 18000).

Communication between a Reader and a label (via a radiofrequency interface) may involve interrogating the label to obtain data, writing data to the label or beaming commands to the label so as to affect its behaviour. The Readers possess their own source of power, processing capability and an antenna. A ubiquitous Reader network will allows continuous tracking and identification of physical objects. Reader arrays can be fabricated and integrated in floor tiles, carpeting, shelf structures, cabinets and appliances. Similarly to cellular phone grids, the Reader network may provide seamless and continuous communication to RFID tags. A data collection and control system must support the Reader network to enable efficient use of the continuous, or at least very frequent, object communications. Additionally, in order to access and identify these objects, a scheme is required to uniquely name and identify objects.

A. Unique object identifier

MSB | | | LSB

Header	General Manager Number	Object Class	Serial Number

Fig. 5. Bit level representation of an EPC general type identifier format.

The unique object identifier must have a global scope that is capable of identifying all objects uniquely and act as a pointer to information stored about the object and the functionalities of the tag somewhere over the network. The Electronic Product Code (EPC) is a scheme designed for universal object identification with the associated standards developed by EPCglobal Inc. A binary representation of the EPC is shown in Fig. 5 [6]. The Header identifies the EPC format used by the tag; 96-bit, 64-bit or 256-bit. The General Manager Number identifies an organizational entity. These numbers need to be unique and thus need to be assigned by a standards body such as EPCglobal Inc. while Object Class is used by a General Manager to identify a specific object class. The Serial Number is a unique number within each Object Class. The identifier encoding format is one of many possible schemes. A more suitable scheme for sensor networks may be envisioned.

It is important for serial numbers to be unique for objects labeled by a particular organization within a object class. However, different objects may reuse the same serial numbers, as the difference in object codes will ensure unique identification of the product. Hence, the triplet of General Manager Number, Object Class, and Serial Number uniquely identifies an object.

The unique identifier format defined as the EPC is a flexible data structure. The format provided in Fig. 5 is only one possibility that might be suitable for a sensor network. However, the flexible framework provided by the EPC permits organizations to integrate its own standards based numbering format.

B. Extending RFID to Sensing Applications

The mechanism used by RFID Readers to obtain information stored in the E^2PROM memory of an RFID label can be applied directly for the collection of data obtained by sensors. This will require extending a simple RFID chip interface to log sensor derived data [7 and 8] in its memory.
However there are number of engineering challenges that needs to be overcome. Passive RFID systems do not have an onboard power source and thus the sensors on passive labels can not operate while the label is not in a Reader range. Passive RFID labels are also power constrained systems that function by deriving its power from a Reader interrogation signals thus the available energy for a sensor is limited and is dependent upon the proximity to the Reader.

Nevertheless this is not a serious inherence to the development efforts as active RFID labels [3] provide a suitable and cost effective alternative. In addition it is possible for a Reader network to frequently power a distributed network of RFID sensors or to power when required, to regularly obtain sensor derived data. However in the future energy scavenging systems on board passive RFID labels may power the sensors and provide sufficient power to store sensor derived data in a E^2PROM memory [9 and 10].

4. APPLICATION LEVEL EVENT (ALE) ENGINE

An ALE Engine system is a middleware system providing real time processing of RFID tag data. Conceptually an ALE Engine occupies the space between a Reader (or multiple Readers) and the applications systems (Fig. 6). Networked ALE Engine systems form a framework to manage and react to event generated by tag reads by interrogators. The ALE Engine passes requests from the applications to the Reader(s) and receives unique tag identifiers and possibly other data from sensors, and passes that information to the applications. The ALE Engine has several fundamental functions integrated into its design, some of which are data filtering of received tag and sensor data, aggregation and counting of tag data and accumulation of data over time periods. These fundamental functions are required to handle the potentially large quantities of data that RFID systems are capable of generating through continuous interrogation of tags. For instance ALE Engines enable local applications to state the significance of specific data obtained from RFID tags (for instance a record of temperature variations over a time period) and to report accumulated data using a standard format defined by an XML schema (an existing XML schema definition can be found in [11]). Thus the ALE Engine framework may implement an application specific XML schema (such as that more suited towards a specific sensor application) or a number of such schema to allow the capture and reporting of physical world events and measurements.

The ALE Engine consists of two primary interfaces that allow it to communicate with external systems: the Reader Interface and the Application Level Event Interface. The former provides and interface between the ALE Engine and Readers, and the latter between the ALE Engine and external applications [11]. An ALE Engine is composed of multiple ALE Engine Services each of which has its own functionality. The ALE Engine Services can be visualized as modules in the ALE Engine. These modules can be combined to perform certain functions for specific applications. Hence one or more applications may make method calls to the ALE Engine resulting in an operation being performed (collection and return of temperature readings from a sensor) and the return of results. Other than ALE Engine Services interacting with each other to perform certain tasks, ALE Engine Services can also interact with services such as the EPC Information Service (EPCIS) to provide services for framework of global applications. Fig. 6 shows the basic architecture of the ALE Engine system.

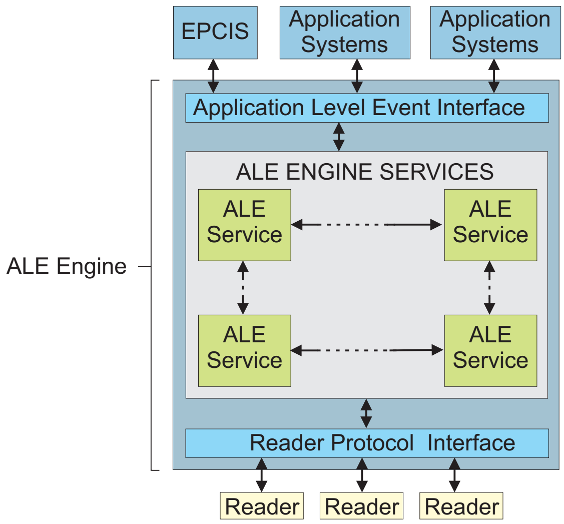

Fig. 6. Architecture of a ALE Engine System and its interaction with EPC Network components; EPCIS and Readers [11].

Event management is a primary service provided by ALE Engine services. A common event management function is filtering, which is particularly useful in situations where there is heavy data traffic. For example, Readers may read data coming in from multiple RFID tags, repeatedly. Not all of the data from all of the tags may be of interest to the application. Filtering of that data can eliminate information, that is either redundant (multiple reads of the same data) or that is not required (tags read but not of interest to that application), from reaching the specific application.

A. EPC Data Encapsulation and Reporting

The unique identifier on RFID labels serves as a reference to information however the storage, transport and description of that information requires a structured and universal body that can be easily understood, stored and transported across the internet. Previously the Auto-ID Center defined the Physical Markup Language (PML) (PML Core specification 1.0, Sept. 2003) to encode captured object information. However recent developments have retreated from such a rigid definition to the characterization of two instances: `ECSpec` and `ECReports` instances using a standard XML depiction. Thus requests to the ALE Engine are sent as an `ECSpec` object while data from the ALE Engine is returned as an `ECReports` object. The XML schema for these objects are defined with extensions to accommodate different application or manufacture specific XML schema (such as that suited for a specific sensor application) or a number of such schemas to allow the capture and reporting of physical world events and measurements. The core XML schema is tailored specifically to describe common attributes of physical objects and observables, such as the expiry date, manufacture date, weight, or the time an object was seen at location *X*. XML promises a universal means for encoding structured information while the core XML schema is rigid, simple and use elements that can be understood easily because the definition uses long descriptive tags.

5. OBJECT NAME SERVICE

The functionality provided by the ONS system is similar to the services provided by the Domain Name System (DNS), however instead of translating host names to their underlying IP addresses for user applications, ONS translates an EPC into a URL(s). The Object Name Service (ONS) in an EPC Network identify a list of network accessible service endpoints that pertain to the EPC in question. The ONS functions like a “reverse phone directory” since the ONS use a number (EPC) to retrieve the location of EPC data from its databases. The ONS is based on existing DNS systems and thus queries to, and responses from ONS adhere to DNS standards. Fig. 7 shows the overview of an ONS system.

The ONS need to revolve to a greater depth than an IP address. An IP address is only sufficient to discover a location but it is not sufficient to locate a particular service needed by an application. It is possible to serve one service at each IP address and avoid the complications in the resolution process. Alternatively an IP address may host a number of other services. In a scenario where multiple services are provided at a specific IP address the ONS will need to resolve down to a unique URL with the exact path and name of the service (such a service provided by an EPCIS).

A challenging aspect of the resolution process is the ability to select the required URL since a list of URLs corresponding to a particular EPC may be returned by the ONS server (as shown in step 5). The format of the choices returned by ONS is defined in the Naming Authority Pointer (NAPTR). The complete definition of NAPTR can be found in [12]. In essence, NAPTR is a collection of information that points to a location on the World Wide Web when only an URI is provided. The NAPTR formatted as [Order] [Pref] [Flags] [Service] [Regexp] [Replacement] where the URL is located in the field [Regexp] while [Order], [Pref] (Preference), and [Flags] are used to state the preference order of a list of URLs. [Service] is used to specify the type of service that is offered, such as HTML or PML, while [Replacement] is reserved for future use.

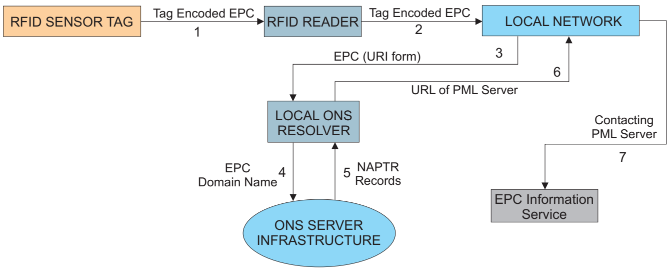

Fig. 7. An overview of an ONS system functionality [13]. An EPC encoded in an RFID label is read by an RFID Reader where the different functionalities associated with the EPC or services provided by an EPCIS associated with the tag is resolved through a query of the local ONS server. In the event that the local ONS sever is unable to satisfy the requests it is forwarded to a global ONS sever for resolution.

TABLE 1. OUTLINES A DESCRIPTION OF THE OBJECT NAME RESOLUTION PROCESS ILLUSTRATED IN FIGURE 5

	Description
1	A reader interrogates a tag and obtains the EPC in binary form.
2	The EPC obtained (as a binary number) is passed to the local network application processes.
3	The EPC is then converted into URI form (converting binary into integers) Example: [urn:epc:id:gid:2.24.400]
4	URI is converted into domain name form. - Remove urn:epc Example [id:gid:2.24.400] - Remove serial number Example [id:gid:2.24] - Invert the string (replace ‘:’ with ‘.’) Example [24.2.gid.id] - Append “.onsepc.com” Example [24.2.gid.id.onsepc.com]
5	The ONS will generate a set of possible URLs that point to one or many services (such as those provided by a EPC-IS) Example: [http://bar.com/epcis.php http://advark.com/sensor_is.asp http://foo.com/epc_is.wsdl]
6	The correct URL is picked and extracted from NAPTR record Example: [http://www.foo.com/epc_is.wsdl]
7	Application systems send a request to the URL.

6. EPC INFORMATION SERVICE

The EPC Information Service (EPCIS), which is the gateway between any requester of information and the database containing that information. It responds to queries for data from authorized entities in a format that can be described using a standard format while the persistent storage of that data by the EPCIS may in any format or standard. The EPCIS is the “interpreter” communicating between database(s) and application(s) and provides a standardized interface to the rest of the EPC Network for accessing EPC related information and transactions.

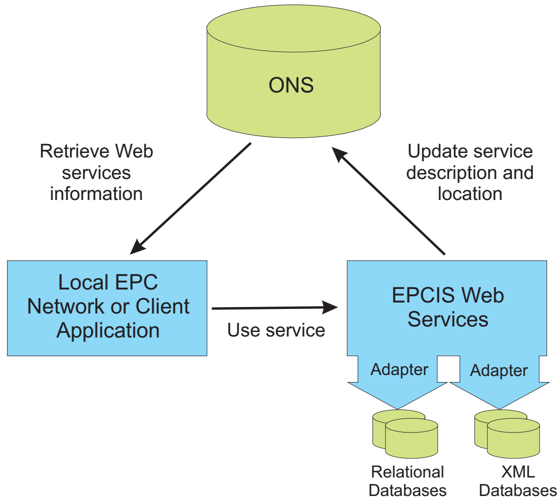

Fig. 8. Interaction between EPCIS, ONS and external applications

A possible and a common interface for an EPCIS can be defined by adopting we services technology. A web services interface allow applications in the wider area network to utilize services provided by local EPCIS using remote method invocation paradigm (Fig. 9). Such architecture has the advantage of leveraging standardized XML messaging frameworks, such as that provided by SOAP (Simple Object Access Protocol) and the description of services provided defined in terms of a WSDL (Web Services Description Language) file. Hence an application requiring information is able to access a WSDL file with a description of the available service methods, input and output parameters to the methods as well as obtain binding information to invoke those methods.

EPCIS provides a model for the integration of RFID networks across the globe. However it is important that EPCIS provides a secure communication layer so that local EPC Networks can retain the authority to determine access to information. WS-Security is a candidate proposal that describes enhancements to SOAP messaging to provide message integrity and message confidentiality [14] while proposed architectural extensions to the existing WS-Security profile [15] can provide access control as well as a federated security model for EPCIS.

Information about a particular RFID tag or sensor (with a specific EPC) may be spread across a number of local networks. The ONS does not resolve to the serial number level of the EPC and the DNS technology upon which the ONS is based also does not allow the fine grain resolution down to serial number levels. Resolution down to serial level (to a specific RFID tag or sensor) is handled by the EPCIS Discovery Service (EPCIS-DS). EPCIS-DS provides a method for custodians of a particular RFID tag data to update a register within the EPCIS-DS to indicate that that they are in possession of data related to that particular RFID tag. The register may contain a list of EPCIS URLs where such information may be obtained [15]. This may be an important consideration in a mobile RFID sensor network that may move from its origin to various local networks.

7. CONCLUSION

This paper has introduced the technology and concepts of the EPC Network that can form a ubiquitous RFID sensor network. The EPC Network as a ubiquitous item identification network has applications in supply chain management, while as an sensor network may have applications in monitoring physical conditions such as temperature, product tamper detection, toxic chemical detection such as in subways, and also as a noninvasive monitoring system such as the use of RFID sensors for long term monitoring of a patients heart condition. The EPC Network is still a concept under constant development to realize a Networked Physical World. Extending the functionality of RFID chips to include sensors will enhance the usefulness of that network while providing an array of possible applications. The functionality of an RFID sensing network can be summarized as providing the linkages between all physical objects and the environment with RFID tags where the network components of the EPC Network provide the management of the vast volume of data generated by Readers and the provision for secure access and sharing of sensor derived data on a global scale.

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