AUTO–ID LABS

Architecture Development for Sensor Integration in the EPCglobal Network

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Report Abstract: The integration of EPCglobal network and wireless sensor networking (WSN) technology explores a new technical horizon leveraging the simultaneous ID and sensor data manipulation. Although the importance of the two technologies, RFID and WSN, is widely recognized, their integration is still in its infancy. This white paper provides the fundamental classification of sensor integration to EPCglobal network, review of applications and existing and background technology to reveal the technical requirements. The ontology and a reference model, layout of roles and interfaces, of sensor-integrated EPCglobal network is derived.

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Contents

1. Introduction

IT has changed and enriched our lives in many ways. It enables us to communicate with people living on the other side of the globe via video chat system; it also make it easier, faster and more accurate to execute administrative tasks which used to take at least a few days in the absence of this technology. However, in order for us to enjoy these benefits, we first need to input information about the physical space into the information space by some means. In other words, none of those things, people and events that are isolated from the information space are able to make our life more convenient by means of IT. In order to remove this constraint and improve the quality of our life, many efforts to connect the previously mentioned physical space with the information space have been made and technologies have been proposed as a solution. The technologies that enable this connection are called ubiquitous computing technology. Two of the most important enabling technologies of ubiquitous computing are radio frequency identification (RFID) technology and sensor technology, particularly Wireless Sensor Networks (WSN).

The general application domains of RFID and WSN are different. Most WSN applications have been designed and realized to provide physical environment monitoring, while RFID applications have been applied historically for asset identification in the supply chain. These different considerations bring out different research directions although both of them use information technology to interact with the physical space.

For identification of an RFID-attached asset in the global scale supply chain, a well-designed network architecture that can handle global scale operations is essential. To realize the 'Internet of Things', which links assets in the physical space to the information space, an Internet-based architecture was proposed and developed by EPCglobal and the Auto-ID labs (previously Auto-ID Center).

Unlike RFID, WSN tends to be implemented as a separate network for dedicated services in the local (edge) domain. Thus, most research efforts on WSNs fall into developing an effective in-network data aggregation mechanism with limited resources, while connection to infrastructure networks is hardly considered.

Due to these different characteristics of RFID and WSN, they are considered to be different technologies and have been developed separately. However, according to technology research groups [1] and visionaries [2], RFID and WSN technologies will eventually be converged in the future as shown in Figure 1.1.

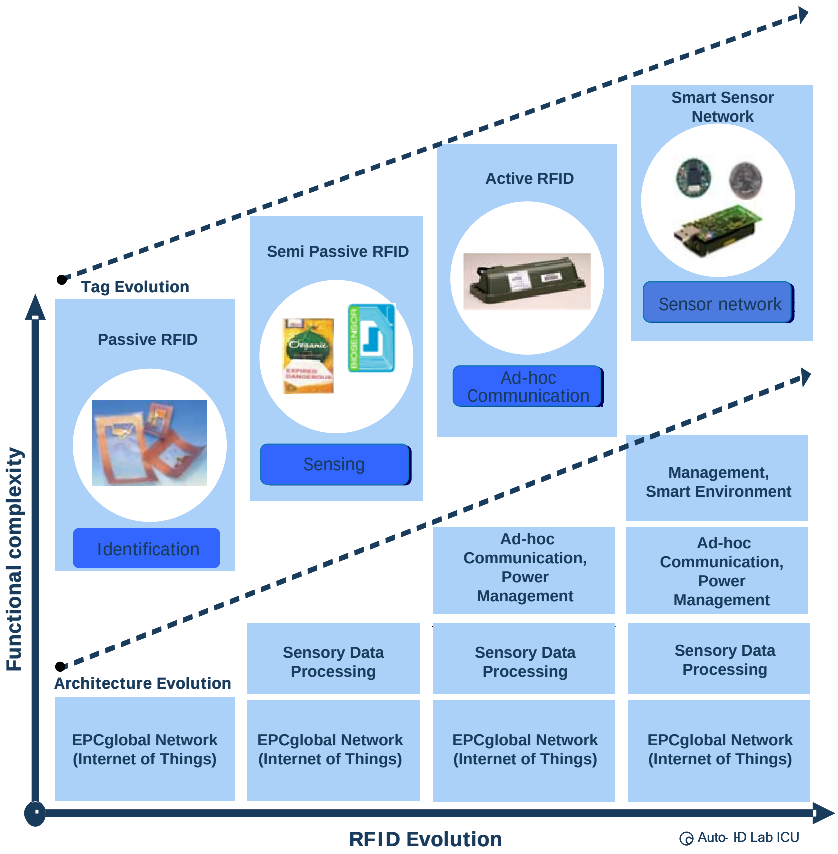


Figure 1.1: Evolution of RFID

However, the current Internet-based architecture of RFID might not be the best solution to support more complex tags such as active tags and smart sensor networks. The de-facto global standard, EPCglobal network, fundamentally supports identification of an asset with identity tags.

On the other hand, current WSNs are far from actualizing a global network vision. Although the WSN is considered as the future technology of RFID tag evolution, one WSN cannot talk to another WSN. Current WSNs are pre-configured to serve a single purpose service in a local network domain, which makes it almost impossible to share information among multiple WSNs.

The objective of this white paper is to develop the architecture for sensor integrated EPCglobal network. The term 'architecture', in this paper represents a set of roles and interfaces in and among networking entities such as interrogators, sensors, tags, applications and information services. Research efforts have been particularly focused on the classification of the sensor integration models and new roles as well as new protocols that are not relevant in the existing EPCglobal network. The goal of the proposed architecture is to provide a communication tool with concepts clearly understandable by a wide audience. It should be noted that the implementation of the architecture is outside the scope of this white paper. The foundations of this architecture development are contributed from research activities done individually inside Auto-ID Labs ([3]-[9]).

The structure of this paper is as follows: Section 2 defines the terminology in the paper and provides the fundamental classification of sensor integration. Section 3 analyzes the benefits and requirements of the sensor-integrated EPCglobal network with representative industries: healthcare, logistics and integrated system health management in aerospace. Section 4 introduces background and involved technology. Since our objective is to provide a set of roles and interface in an abstract manner, we have tried to extract all the virtue of existing proposals. In Section 5, the requirements and issues in sensor integration are derived in view of data delivery and data management. In Section 6, the architecture of sensor integrated EPCglobal network is presented in two abstraction levels, one is the ontology and the other is the reference models tailored to EPCglobal network.

2. Terminology and Classification

2.1. Terminology

Agent: A general concept describing an entity (physical, living or software) with significant independence, capacity for decision making and actions

Application: A set of procedures to produce output data from input data. The procedure is usually carried out by computers

Architecture: A set of roles and interfaces in and among networking entities such as interrogators, sensors, tags, applications and information services

Data record: A database record or memory field storing data

Database (repository): A composition of 'data' records

Entity: A logical unit representing a group of roles

Event: The occurrence of a change of significance in the physical state or information content of an agent

Functional node: General description of RFID tag, sensor node, actuator and interrogator

Information service: A software which is designated to serve another application

Interface: Standardized procedure to exchange information among entities

Interrogator: General expression for RFID reader/writer and sensor base station. Interrogator has communication capability with network entity

Message: The exchange of information between agents

Networked RFID: RFID system in which interrogators, applications and information services are communicating

Protocol: Precise description of a vocabulary and interaction method of agents over air interface or wired connection

Query: A question posed in a formal language and relating to a relevant dataset in the system

Read event: A logical unit of interrogator read comprises Time stamp, Interrogator ID, Tag/Sensor ID and additional data (sensor data)

RFID tag: A microelectronic device including a memory and antenna for wireless data communications. Each RFID tag is assigned a unique ID. RFID tags are classified into passive RFID tag, semi-passive RFID tag and active RFID tag

Role: A particular function

Sensor: A device to measure physical amount quantitatively

Sensor base station (BS): A device which provides aggregated communication between a set of sensors and applications. A sensor BS may be referred to as a sensor sink. A sensor BS is a type of interrogator.

Sensor node: A device which provides communication function to sensor(s). The communications are either toward sensor base station or among sensor nodes. A sensor node may have sensor in it

Sensor tag: Tags, which have sensing capability. Examples are Class II–IV tags in EPC. The ID does not confined to be EPC

Translation: Numerical translation from the raw sensor data to the physical value (cf. 8bit data to temperature)

Unique identification number (Unique ID): A positive integer representing an entity exclusively in a particular numbering system (for example, EPCglobal, DoD and ATA have their own numbering systems)

2.2. Classification of RFID-sensor integration

There are typically five modes to correlate identification data in EPCglobal network and sensor data locations (Figure 2.1). All modes are common in view of sensor data and identification data are fed into the designate application or information service.

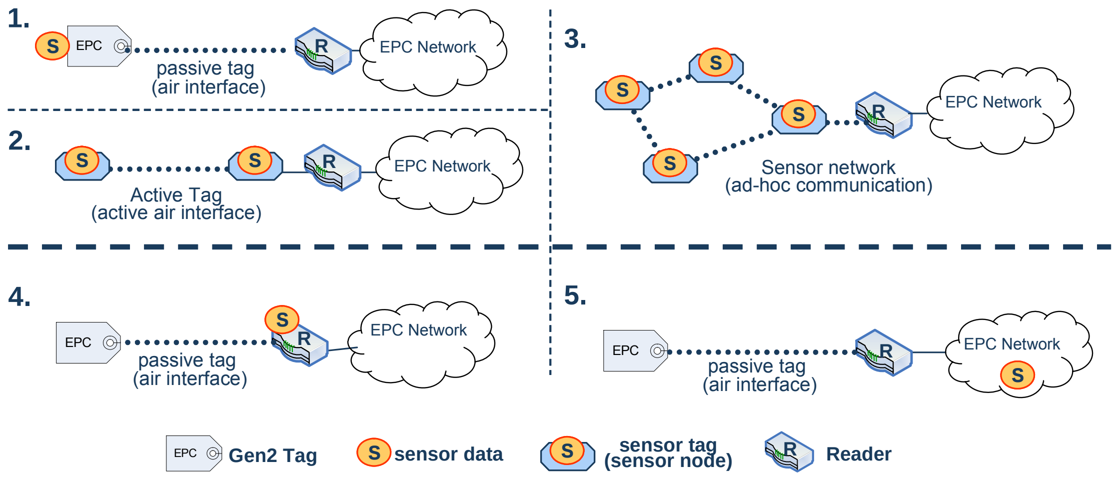


Figure 2.1: Modes of identification and sensor data integration

When we study how the sensor data is incorporated with ID data, the five modes can be classified into hardware and logical integration. For now, let us assume that RFID involves EPCglobal network but not confined to. In case of hardware integration, sensor data is associated with the identity of the sensed object at the hardware level, whereas in case of logical integration, sensor data is associated with the identity of the sensed object at the upper layers of the RFID/sensor data integration architecture (2.2).

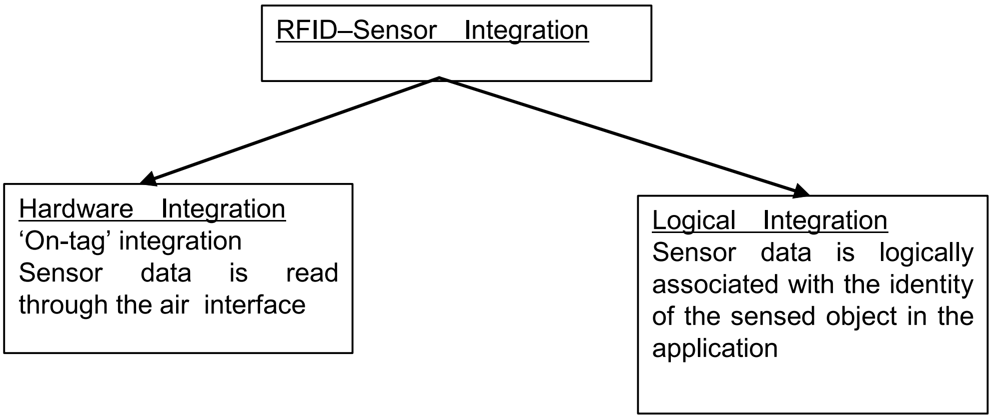


Figure 2.2: Basic classification of RFID-sensor integration

The five modes depicted in Figure 2.1 can be further categorized into logical and hardware classification forming a matrix of sensor integrated EPCglobal network.

3. Applications of the RFID- sensor integration

In this section, representative applications of the sensor in the EPCglobal network are introduced with the focus on identifying the requirements for the network architecture.

3.1. Healthcare

Integration of sensors and RFID in healthcare will improve quality and efficiency of the treatment in various ways. We assume that RFID-sensor integrated system will be used not only inside medical institutions, such as general hospital, rehabilitation facility and nursing home, but also outside these facilities while patients and equipments for treatment are on the move. There are several potential applications in healthcare.

3.1.1. Treatment quality improvement

Patients' conditions are carefully monitored inside an operating room or a sickroom but not so much while they are in, for instance, hallways or bathrooms. The same can be true when they are outside medical institutions. However, it is possible that patients' condition gets worse while they are in unmonitored areas, and this is critical. With the availability of sensors and RFID integrated systems, it is possible to monitor patients' conditions in such scenarios and to notify doctors when their conditions deteriorate suddenly. To realize this kind of ubiquitous healthcare, patients' location needs to be known, which can be done by tagging them, and their health conditions need to be monitored with vital sensors. Since the type of sensor depends on the patient, we need to provide a flexible mechanism to handle sensor in a plug-and-play manner. Application systems that monitor patients inside a medical institution collect both identification and sensory data about the patients and integrate them. If logical integration is used, location information of the patient and the sensor devices is the key for the integration. Application systems that monitor patients outside medical institutions also need to collect those data; therefore, there needs a mechanism to link captured data (both identification and sensory) with the application systems. In other words, application systems need to discover the available ID and sensor system (interrogator and sensors) while the ID and sensory system need to resolve the destinations of captured data. We also need to accommodate new applications by providing a way to discover appropriate sensors and RFID readers, which were already installed.

3.1.2. Medication error reduction

An important challenge in healthcare is to reduce medication errors. Causes of medication errors include doctors' or nurses' treatment mistakes, their order mistakes, their check mistakes, and so on. In some case, an order change is made by the doctor but not informed to nurses appropriately, and the treatment based on the old order causes a medication error. In any case, if a system identifies the patient, monitors his or her condition and verifies treatment orders, and further if the application system supports doctors and nurses when they treat patients, some of the medication errors will be prevented. These kinds of quality improvement applications require real-time transactions; therefore, integration of patient-identification information and vital data information, including the treatment order, also needs to be done in real time. What this means for a sensor device is that sensory data needs to be updated dynamically.

3.1.3. Accurate medical records

Keeping accurate medical records is a foundation of medical treatment. If records are not kept accurately, it will cause fatal accidents. In addition, drugs and medical devices that need special treatment (e.g., temperature control) require keeping accurate recordsof their condition. The integrated sensors and RFID system will enable the identification of drugs or medical devices and bind sensor (i.e. condition-) data to them. Since both drugs and devices are shipped from manufacturers all the way to medical institutions, sensor data captured by the systems need to be available from multiple application systems that are operated by supply chain companies including medical institutions. Condition history data is inquired from multiple application systems, and query type will be identification base and attribute base (for instance, “Give me the identifications of drugs that were exposed to more than 25 degrees centigrade.”). There should be a mechanism to facilitate this type of semantic modelling from myriad of sensor data and event or context generation.

3.1.4. Cost reduction

Management of both quality treatment and cost reduction is an important challenge. There are several areas for cost reduction. One potential area is to reduce drug disposal. If opened boxes of drugs are handled properly, they can be used for the treatment of another patient, which becomes possible with the integration of sensors and RFID. RFID is used to identify the drugs, while sensors monitor their condition. Since to monitoring the change of the drug state (for example, mixed or grinded) is important, semantics of the identification data as well as condition monitor data needs to be captured.

3.2. Logistics

RFID systems have traditionally been used in logistics applications to track and trace the location of products throughout different points in the supply chain. Integration of sensors and RFID is expected to bring a number of merits in logistics.

3.2.1. Accurate location tracking

RFID systems provide accurate product identity information. However, one of their basic limitations is that they offer coarse and often unreliable location information. On the other hand, other location sensors as well as tracking technologies such as GPS can accurately locate a product but not identify it. We expect that integrating RFID with other location information will enable more accurate and reliable product location tracking. In this case, RFID is used to identify the products, whereas location systems are source of sensor data. There are various ways to integrate these pieces of information. If location information is captured by GPS that is connected to an RF tag, the integration will be done at hardware level. If reader location information is used for this purpose, the integration will be done at application level. In the latter case, identification of RFID reader and providing relation information between reader ID and location information will be required.

3.2.2. Condition monitoring of products

Another application domain of sensor and RFID integration in logistics is condition monitoring of products that require careful control, such as perishable products and valuable products. Temperature and humidity are known to be the key state variables for sustaining the quality of perishable products; and vibration, shock and temperature are key variables for valuable products. Integrating RFID systems with condition-monitoring systems will enhance existing track and trace applications, enabling tracking and tracing not only of the location, but also of the condition of the aforementioned products. Moreover, the availability of product trace history data in combination with historical condition-monitoring data can facilitate numerous decision-making processes. In this case, using sensor tags that travel with the products is useful because ambient sensor data is not available all the time. When sensor tags are used, sensory data needs to be stored onto the tag memory. For reducing the amount of stored data yet preserving the integrity, filtering the data may be important especially when multiple sensors are accommodated. Since we will have other sensor devices in the future, a mechanism to accommodate new sensors is necessary.

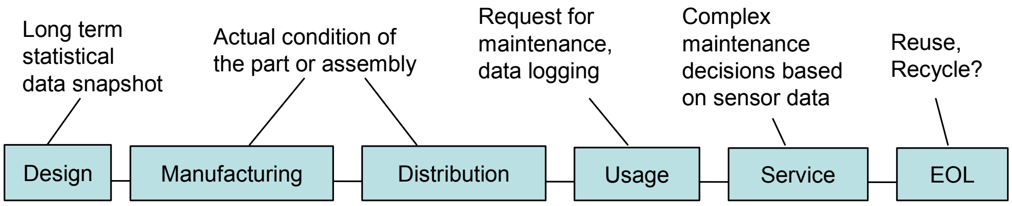
3.2.3. Automatic product tamper detection

Active RFID tags have been combined with electronic tamper-detection seals to allow automatic tamper checking of safety-critical products in transit. For instance, RFID-enabled electronic seals have been used by GE on their shipping containers. These sensor-enabled tags can be used by logistics and other companies to support the Container Security Initiative 'designed' by the US Customs Service to prevent the smuggling of terrorist weapons in cargo containers. In this case, RFID is used to identify the container and tamper-detection mechanism provides sensor data. The physical binding of RF tag and sensor device is necessary in this application. In many simple, tamper-detection applications, hardware integration is more convenient, inexpensive and less error prone. The integrated sensor and RFID information will be used by many parties in the supply chain, such as manufacturer, carrier, customs, importers, and so forth. In these systems access control and authentication have key importance. Since it is not practical for carrier and importer to have separate information systems, interrogators and information systems serving multiple industries and clients need to be developed and implemented.

3.3. Integrated System Health Management in Aerospace

One of the most promising applications of sensors and RFID integration is Integrated System Health Management (ISHM) in aerospace. The aim of ISHM is to monitor a large number of components for a long time (possibly decades in the aerospace industry) in a number of different configurations. Both private and public sectors are interested in using sensors and RFID integration system for ISHM. Examples of the organizations are DoD, Boeing, Airbus and NASA/JPL. In general, ISHM follows two steps: health monitoring and health management. Health monitoring consists of data acquisition, signal processing and detection; and health management consists of assessment, prognosis, decision support and presentation. Sensors and RFID integration systems are used in the phases of product lifecycle management depicted in Figure 3.1.

Figure 3.1: Lifecycle sensor data management



3.3.1. Design

In the design phase, long term statistical data is required. If both configuration data and maintenance history data including environmental data of a troubled part are available, designers can fix the design flaw of the part, if any, or improve the design to prevent the same problem from occurring again. In this case, RFID is used to identify the part and the integrated sensors and RFID systems provide both maintenance and condition data. Since machines, which are the collection of parts, are operated and maintained by different companies, the application system that the designers use need to get information from different organizations.

3.3.2. Manufacturing and distribution

In both manufacturing phase and distribution phase, configuration data is made. In these phases, RFID is used to identify the parts and their configurations, and sensor systems are used as a source of maintenance data such as how they are stored. This information is not only used by the manufacturer and distributor but also used by upper and lower partners of the product lifecycle.

3.3.3. Usage

In usage phase, I maintenance data requires to be logged. In this case, RFID is used to identify the parts; and sensor systems are used to record how they are maintained and what kind of environment they are used in. This information is not only used by these parties but also used by upper and lower partners of the product lifecycle.

3.3.4. Service

In the service phase, complex decisions need to be made based on maintenance history data. RFID is used to provide a unique pointer to this data, and applications built to process this data need to provide a facility for answering queries, such as:

- Sensor data related queries
- Which owner overheated a part the most?
- What had a certain mechanic done when the part was overheated?
- How will the varying lifetime of parts in an assembly influence the scheduled maintenance date?

3.3.5. EOL

In end of life (EOL) phase, decisions on whether the part can be reused, recycled or discarded need to be made. In this phase, RFID is used to provide a unique key to identify the part and to get maintenance data. Applications to support this decision also need to accommodate queries described in the previous phase.

4. Background on Involved Technology

4.1. EPCglobal network

The EPCglobal network is a set of technologies that is used to utilize automate data capturing technologies, such as RFID. The concept was originally proposed by Auto-ID Center and is developed and maintained by EPCglobal. Functions and structure of the EPCglobal network is explained in EPCglobal Architecture Framework [11]. Figure 44.1 shows the reference model. There are two types of components in the model: role and interface. Role is a collection of functions, whereas interface exists between roles. In the figure, some roles are defined separately but this does not necessarily mean that they are separately implemented in hardware or software. Also in actual implementation, some of the roles and interfaces are not implemented if they are not required the implementation. We lend ourselves to follow this customary procedure to develop the architecture, namely, defining the roles and interfaces within and among entities.

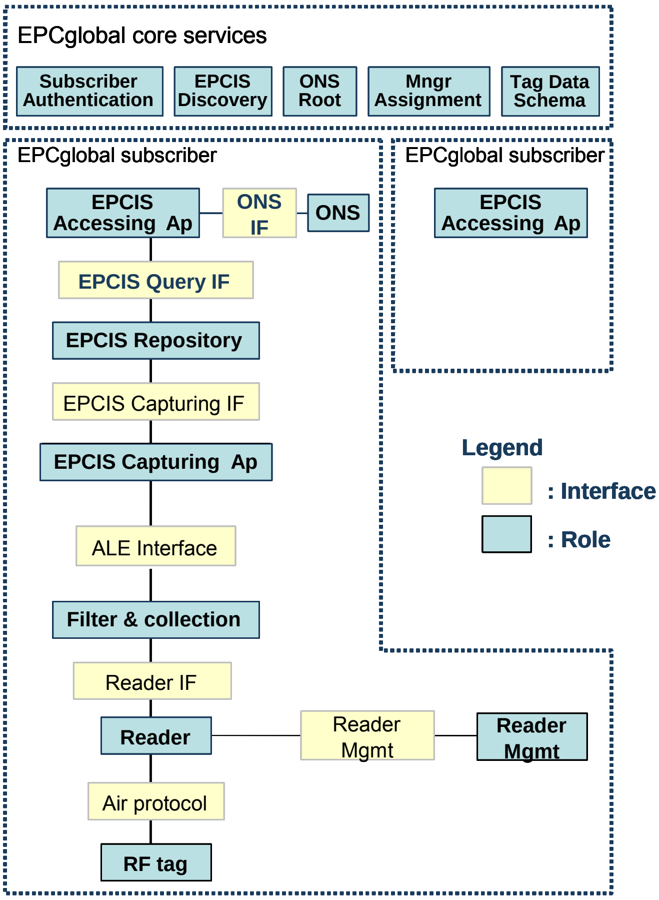


Figure 4.1: EPCglobal architecture reference model

4.2. RFID and sensor integration

Integration of sensor and RFID architectures has been an active research field. Emery [12] proposed a logical integration of sensor and RFID. The sensor data is represented as a combination of physical quantity and the time with their units. The sensor data is transported as streams and processed with relations and operations. Introduction of 'Query' to represent a state as a combination of streams and relations and various data processing roles such as filtering, inference and differentiation are worth noting. The ELIMA project [13] had been an EC-funded research endeavor that aimed to demonstrate the acquisition and management of product lifecycle data by collecting and exploiting data from products in different phases of their lifecycle including design, manufacture, use, maintenance and end-of-life product recovery. ELIMA partners built and tested a prototype Identification and Data Unit (IDU) to collect technical operational data from seven different sensors.

Deng [14] proposed Sensor Embedded RFID (SE-RFID) which could be classified as hardware integration and a type of sensor tag. The sensor data is A/D converted and are read by RFID reader as user data. In the application referred to as HEMS (Real-Time Health Monitoring), additional logical integration is stated as an extension of SE-RFID. Ranasinghe [15] overviews the EPCglobal network technology and its extension to incorporate sensors, fundamentally, at hardware integration level. He reveals the importance of introducing active tags and power-scavenging technology to realize the passive sensor tags. Zhang [16] presents the importance of RFID and WSN convergence and proposes an integration of RFID reader into WSN by means of 'smart node'. Smart node has the capability of communicating with tags and with other smart nodes forming a WSN. The read data will be multi-hopped and feed into the information through sensor sink.

4.3. Wireless sensor networks

Sensor networks (Wireless Sensor Networks [WSN]) are networks of reduced size, low power, low range, low cost wireless devices with computation and sensing capabilities. WSNs have gained more and more popularity since the beginning of this century due to their increasing number of applications and the advances on radio, microcontroller chips and software protocols for a reduced prize. The ability of the WSN to form ad-hoc networks and perform data processing represents a significant improvement over traditional sensors.

The basic purpose of wireless sensor network applications is to provide physical monitoring of targeted environment to user, and WSN have many applications which pose different technical issues that need to be addressed. Some popular applications are exposed here:

Environmental Monitoring: These range of applications involve monitoring of the environment around the sensor network and reporting its state to a central command, which will usually analyze the data-building statistic logs. Some examples include disaster monitoring [17]–[22] (fire, earthquake, wind, flood, snow, etc), animal tracking [23], crop status [24], chemical/biological detection and water salubrity.

Military: This increasingly involves monitoring of troops, hazards detection, vehicle tracking, equipment monitoring, battlefield surveillance [20], damage assessment and others [19].

Home applications: These applications use the ability of sensor nodes to share information and make decisions according to it, including the actuation of appliances due to the different conditions of the house. A general consideration inside this area is the interpretation of a wide range of sensor information to deduce a certain situation (context). This area is also called Smart Environment or Smart Spaces [26][27][28].

Health: Healthcare applications are also increasing in popularity due to the ability to monitor patient statistics without actually having the patient tied to a hospital bed [21][25]. A discussion of the capabilities of wireless sensors for health monitoring can be found in Section 3.3.

As mentioned before, many technical issues arise from the utilization of WSN. In general, since the sensor devices run on batteries, power consumption is a key factor in the design of nodes and network protocols. Power consumption affects all aspects of the WSN, from choosing low-power hardware components [29] (namely radio chip, microcontroller and sensors) to program efficient network protocols that will minimize the use of the radio, and efficient power control algorithms that will shut down hardware components when their use is not necessary. Another aspect is the limited computation capabilities of the on-board microcontrollers and the reduced memory space to run the programs. Typically, a sensor node microcontroller will run at 8 Mhz and have around 128K of flash (for code footprint) and 4K of RAM (for runtime space). The reduced memory and power restricts protocol stacks and computation algorithms, so the programming of the sensor devices has to be hardware specific.

In order to provide a solid background for developing applications, many implementers opt for building simple yet efficient operating systems that will deal directly with the hardware and provide some level of abstraction. Several WSN OS exist, but maybe one of the pioneers and best known ones is TinyOS [30]. Due to some limitation of TinyOS, other OS appeared in later years. Some notorious examples are Mantis [32], Contiki [31], SOS [33], EOS [34] and uT-Kernel [35].

Due to hardware and application restrictions, the nature of the WSN is generally data centric. In data-centric architectures, the information of the network flows towards a central processing point which usually also behaves as a gateway of the network. In WSN, this gateway is normally called Base Station or just Sink. Due to this data-centric nature, the topology of the network favours a tree configuration, where data flows from leaves to the root node. However, tree topologies are limited in that each node has only one parent, resulting in costly topology reconfigurations if one node is lost due to battery exhaustion or other issues. Many specific protocols follow different techniques, such as clustering [36], in order to cope with this and other problems. A recently popular protocol stack and standard that includes physical and MAC layers is the IEEE802.15.4. [38]. Also, an industry standard based on the IEEE802.15.4 that includes Network and Application layers is ZigBee [37].

WSNs are on the verge of producing commercial applications [39][40]. However, there are still deep gaps between real WSN implementations and the ideal vision of a self-configurable WSN, which can run without intervention of users. In most realistic applications, WSNs are statically set up for pre-defined applications with dedicated users. There is little intelligence adopted for those applications because it is difficult to model many issues in real environment. In real applications WSNs have to deal with broad issues ranging from unreliable network, low power consumption to effective data processing; and several problems occur due to the lack of standard for WSN.

Many WSN are implemented as a disjoint network for dedicated services in the local (edge) domain. Thus, most research efforts on WSNs fall into developing an effective in-network data aggregation mechanism with limited resources, while connection to infrastructure networks is hardly considered. Nevertheless, WSN will certainly have a bright future in the coming years, when standardization and massive deployments will open the doors for a ubiquitous society.

4.4. Plug-and-play technology

4.4.1. IEEE 1451 Family of Smart Transducer Interface Standards

Sensor transducers basically output a signal — electrical, digital or optical — according to the physical condition of the attributes they are designed to monitor. This signal needs to be interpreted by other devices to produce a meaningful stream of data. The meaning of the transducer output is implementation dependent, that is, each manufacturer independently specifies how to interpret the different levels of the output signal of the transducers they produce.

Due to the large number of manufacturers and sensor types, the integration of transducers into information systems can be slow and costly. The IEEE 1451 family of standard [41] aims to provide a standard way of accessing any type of transducer regardless of the type, manufacturer and underlying information network. The IEEE 1451 comprises seven different standards that deal with the different aspects and interconnection possibilities among existing networks and transducers.

The incorporation of sensor in RFID has also been studied in ISO/IEC group. The current working drafts [61], [62], part of which involves tag data structure and air protocol, are largely consistent with IEEE 1451 standardization.

4.4.2. Alternative technology for plug-and-play functionality

Other possibilities for achieving plug-and-play functionality include Zero Configuration Networking ‘Zeroconf’ (implemented by Apple as Bonjour, previously Rendezvous), Universal Plug-and-Play (UPnP) or Sun Microsystem's Jini (recently moved to the Apache River open source project). Just as in case of USB, these standards provide many ideas and tools for developing plug-and-play sensors and can also be partially implemented.

In the aerospace industry, a modified version of the USB standard is being developed and called ‘Space Plug-and-Play Avionics (SPA)’. It is motivated by the need for responsiveness and aims at using new technologies while they are ‘still new’.

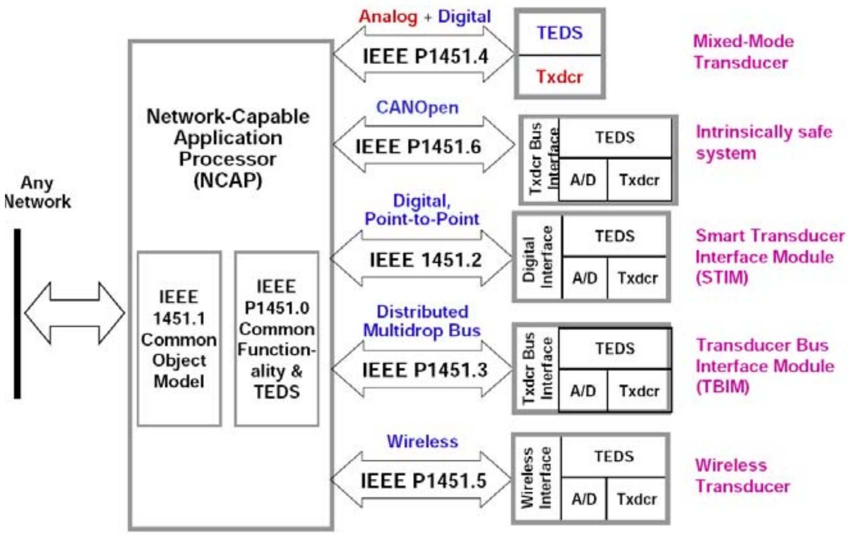


Figure 4.2: Structure of IEEE1451 standard

Standard	**Description**
IEEE 1451.0	Defines common functionality for interoperability among the IEEE 1451 family
IEEE 1451.1	Specifies a common object model to communicate with underlying networks and various transducer modules
IEEE 1451.2	Wired transducer interface over point-to-point links, including RS- 232, RS-485 and USB
IEEE 1451.3	Transducers are located in a number of Transducer Bus Interface Module (TBIM), connected to the NCAP[1] by a multi-drop bus
IEEE 1451.4	This portion of the standard specifies the requirements for TEDS[2] connected to the NCAP through a mixed-mode interface (analog or digital)
IEEE 1451.5	This section of the standard specifies information that enables 1451 compliant sensors and devices to communicate wirelessly, eliminating the monetary and time costs of installing cables to acquisition points. Wireless technology examples are 802.11, Bluetooth and Zigbee
IEEE 1451.6	Information required for the consolidated auto network (CAN) bus

[1] Network Capable Application Processor
[2] Transducer Electronic Data Sheets

4.5. Sensor tags

There are two streamlines of technology on sensor tags. One is fixed function sensor tags and the other is variable function sensor tags. A fixed function sensor tag focuses on one or multiple fixed function such as enhancing the read range and embedded sensors. On the other hand, variable function sensor tags can change their functions by, for example, changing the air protocol and state model inside the tags. In this paper, tags which work as RF modem, or data transport, are categorized as fixed function tags. Data transport means that the tag resides between the sensor device and the reader/writer, acting as the gateway to feed data from the sensor device to the designated server.

A fixed function sensor tag may be a battery assisted (BAP), battery powered (active) or even a passive tags. Products from PowerID feature read range enhancement with paper-thin battery called PowerPaper [42]. Alien [43] has a line of products on BAPs to enhance the reading performance, and features such as large memory and embedded sensors. External analog and digital I/O can be used as optional functions. Redemske [44] proposes a battery-assisted tag equipped with field power detector for RFID testing and data transport. The extreme form of fixed function tag are the passive sensor tags. Opasjumruskit [45] presents their 125 kHz RFID transponder with embedded temperature sensor for animal healthcare. The work features the digital on-chip calibration. Cho [46] proposes a Gen2 compatible passive transponder with embedded temperature sensor. The temperature is measured by charging time of a capacitor. The calibration needs to be done on network side. Meiners [47] proposes a smart pressure sensor with 125 kHz RFID technology to detect improperly placed bandages, which is a cure for venous ulcer. In α-wisp proposed by Philipose [48], objects are equipped with a number of off-the-shelf passive tags. A mercury switch connecting to the tags choose the actively operating tag in accordance with the inclination. By doing that, the ID data may represent one-bit accelerometer. Ubiquitous ID centre proposes that its 128 bit ID (Ucode) may represent geographical locations [49] [50]. These can be categorized as passive and fixed function sensor tags. Low-cost active tags may be fixed function tags [51] [52] [53].

The variable function sensor tags in BAP arena are reported by and Mitsugi [54] and Mori [55]. They have programmable logic device (FPGA, CPLD, Microcomputers) inside. Because of the capability to re-programme, they can be conveniently used in testing, adding new functions such as combination of sensors, data processing and data loggings. Raskar [56] proposes an interesting combination of photo-sensor enabled BAP to identify its location. With the advent of commercial chips, which can communicate with the existing passive RFID protocol, for example product from Intelleflex [57], the development of variable function sensor tags in BAP are expected to increase particularly in the R&D arena. The representative variable function sensor tag, which may be conceived as sensor node, in the active tag arena is Smart dust as explained in Section 4.3. Kobayashi [60] presents a low power and small variable function active tag. It features the adoption of pT-Engine, which is a single-chip computer with active wireless communications functionality. This is also an illustrative example of variable function sensor tags (sensor node).

5. Requirements and Issues for the Sensor-integrated EPCglobal Network Architecture

In this section, the requirements and issues needed to be incorporated to establish sensor-integrated EPCglobal network architecture are investigated, reflecting the exemplary application usage modes detailed in Section 3 and the examination of the existing technology development in Section 4. We have observed that the representative requirements for sensor-integrated EPCglobal network are as follows:

- Accommodation of various type of functional node
- Increased importance of semantic modelling
- Multi-service interrogators

Requirements and issues tailored to sensor-integrated EPCglobal network are categorized into two. One is how to deliver identification and sensor data into application or information service (data delivery). The requested work in data delivery can be done without knowing the semantic of data. The other is how to process the delivered data (data management) requesting the serving entity to understand the semantic of the data.

5.1. Requirements and issues for data delivery

5.1.1. Sensor plug and play

Sensors and sensor nodes need to be administrated by designated entities according to the type of integration explained above.

In sensor-integrated EPCglobal network, it is expected that heterogeneous tags would need to be incorporated. There may be passive ID tags, sensor tags or active tags furnished with sensors. The data may come from wireless sensor network through sensor BS. In case of sensor tag, for example, reader/writer needs to identify the type of sensor tag and read the requested sensor data, which is typically mapped into tag user memory. The sensor data types can be classified into static and dynamic. In this paper, "static" sensor data represents the data length and data types are consistent throughout operations. The fixed function sensor tags usually include static data. Dynamic sensor data, on the other hand, has variable data length. Variable function sensor tags usually demand dynamic sensor data handling. It is therefore important to resolve sensor tag memory schema depending upon the types of sensor.

5.1.2. Public and private functional nodes

The networked RFID usually starts inside an industry. In this case, RFID tags, reader/writers, even information systems and applications are owned by the industry. It is up to the industry's decision to add or to delete applications. This is the private system. When the industry appreciates the power of RFID it may expand the application to the upstream and down stream affiliations. In this case, the read data needs to be shared among the group of affiliates to enhance its visibility in the whole supply chain. That is, even in this private system, a part of the data should be shared by the affiliations, in a sense be made public data. There are systems where tags are public. An example is where tags represent geographical places. Application may be produced to particular geographical places, the registration of such application needs to be easily added as an information service. Similarly, there may be a public interrogator. If the owner of a RFID tag or sensor node permits, a part or whole of read data could be disclosed. Involvement of public tags and public reader, therefore, entails sophisticated discovery sensor data delivery.

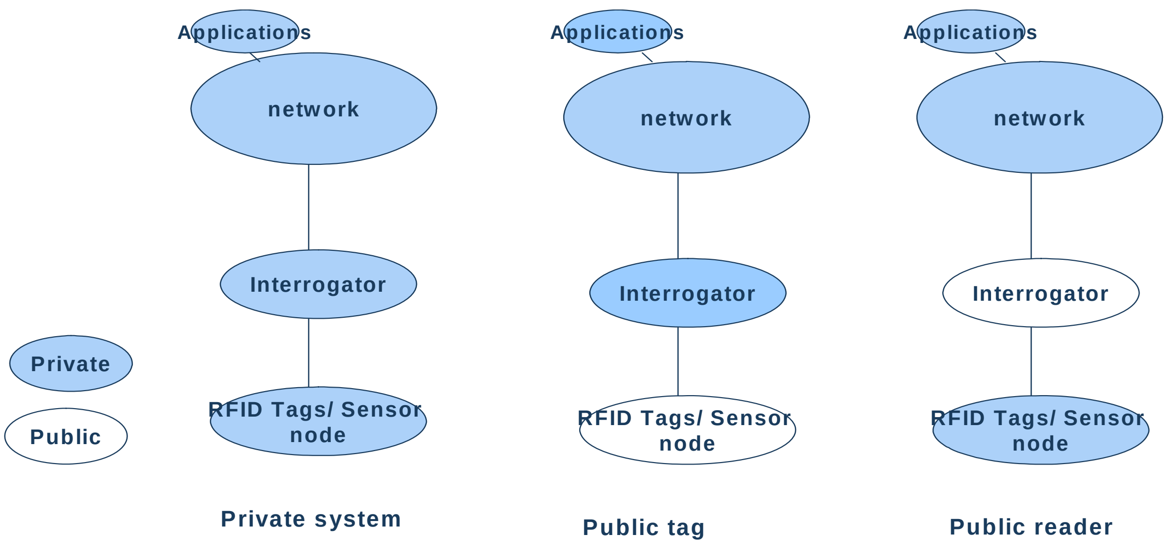


Figure 5.1: Service domains

5.1.3. Data filtering

EPC and sensor data filtering (smoothing) may be required in order to transmit only the changes to the existing state and reduce the communication overhead. The idea is powerful in that it may condense streams while conveying the same amount of information. This 'data filtering' role is an extension of filter and collection role of EPCglobal network. Since the sensor data source can be anywhere, the flexibility of data filtering location needs to be incorporated.

5.1.4. Enhanced air protocol

Short sensor data could be handled by the exiting tag read/write command. When it comes to large data, particularly on BAP, active tags and sensor nodes, it is desired to achieve high-speed reading. This could be done by extending the air protocol by increasing the tag reply bit rate by simply increasing the clock or multiple bit modulation technology. For fast data reading, FEC should be considered to be benefited from coding gain.

5.1.5. Enhanced tag data standard

In order to accommodate dynamic sensor data, which may reside in sensor node or sensor tags, tags user data needs to be structured such that the corresponding interrogator can identify the start and end address. This could be realized by defining the fundamental memory schema of user data. In [61], tag memory structure composed of the pointers to sensor data written in TID memory and their data entries are proposed. In [7], a tag data structure, which can accommodate sensor data, is presented featuring the seamless operation with ID tags and sensor tag.

5.2. Requirements for data management

5.2.1. Semantic modelling

A semantic data model on EPC and EPC-related data, such as sensor data, will enable to define the events and queries relevant to business-important entities. This should be of importance since incorporation of sensor data entails myriad of business logics triggered by sensor data. The following functions need to be accommodated for sensor data.

Event generation: Depending on the nature of the application, sensor data might need to be filtered by a threshold, in order to generate events relevant to the condition of products. Ancillary relational data will be required for this data processing function. It is clear that event generation needs to take place after data integration. A series of events may be aggregated to compress the total amount of data flow or may generate an event which represents a context of tagged object.

Data translation: Raw sensor data will need to be transformed into knowledge, in order to generate more meaningful events with business context. TEDS in IEEE1451 [41] is a representative implementation of raw data translation into physical quantity with calibration.

Data processing: EPC and sensor data may need to be processed before they are further processed and analyzed. Data processing involves data correction, which cleans sensor data by, for example, filtering out of non-realistic values from the series of data and Sensor Fusion in which multiple sensor data are fused to provide more accurate and reliable data than a single sensor.

5.2.2. Directory service

Importance of directory will be increased when public type functional nodes prevail. Representative bindings are as follows.

ID and information service binding: By specifying Unique ID, an application obtains information services related to the Unique ID. ONS and discovery service are existing ID and information service bindings. Another type of directory particularly needed for public interrogators is data distribution directory. By notifying the retrieved Unique ID, an interrogator obtains information regarding where to distribute the identification and sensor data.

Interrogator directory: When public type interrogators are abundant, directory of interrogators is indispensable. The directory holds the interrogator IP address and the attribution of the interrogator including the position of installation.

6. Sensor-integrated EPCglobal Network Architecture and Reference Models

The integration of RFID and sensor systems involves a great number of entities – including hardware, software, concepts, relationships – and a number of technically and commercially viable combinations of these. Due to the characteristics of the industry currently shaping the future of RFID-sensor systems, it is very likely that at least a few different networked systems will coexist and will need to be integrated with each other.

Without considerate planning and system design it is foreseeable that these systems will not be interoperable and significant overlaps in development projects will exist. In order to avoid this kind of confusion, we provide a robust, abstract architecture that will be helpful for end users to refer to when designing and developing sensor-integrated RFID systems. This deliberate design process is shown in Figure 6.1.

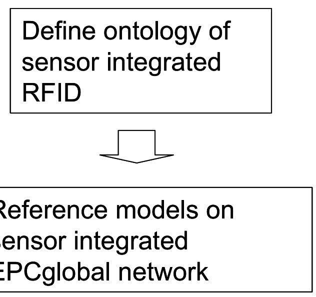


Figure 6.1: Architecture presentation

In order to accommodate various characteristics of the systems and guarantee the robustness, we first focus on developing an ontology which consists of functions (roles) necessary for the sensor-integrated EPCglobal network architecture in Section 6.1. Through abstraction of system components, we only need to deal with functions that are required to the architecture.

This ontology is then used as an establishment in the initial phase of a sensor-integrated EPCglobal network reference architecture development in Section 6.2. These reference models are not only beneficial for companies that implement sensor integrated EPCglobal network systems but also useful for researchers/engineers when they identify roles (and interfaces between roles) that are defined in the models but not studied in the industry.

6.1. Ontology of sensor-integrated EPCglobal network

Table 6.1 shows the ontology of sensor-integrated EPCglobal network reflecting the requirements deduced from applications in Section 3, involved and background technology in Section 4 and the requirement and issues described in Section 5. Shaded rows indicate unique roles in sensor-integrated EPCglobal network.

Table 6.1: Sensor-integrated EPCglobal network ontology

Roles	Description
Functional node	A function that communicates with interrogator. It usually has a unique identifier and a memory, and it may have computational resources and functions to sense the environmental conditions
RF tag	See Section 2.1 with Enhanced air protocol and enhanced tag data standard
Sensor node	See Section 2.1
Sensor tag	See Section 2.1
Interrogator	A function that is able to exchange data with functional nodes through a wired or wireless data channel. It also communicates with interrogator controller
RF R/W	See Section 2.1
Base station	See Section 2.1
Sink	See Section 2.1
Interrogator control	A function that administrates the read/write function of interrogator(s)
EPC reader protocol	See Section 4.1
EPC ALE	See Section 4.1
Data Filtering	A function to filter and collect the data captured by functional nodes. The data is sent from interrogator
EPC F&C	See Section 4.1
Sensor data filtering	A function to aggregate the sensor data
Interrogator management	A function to manage interrogator
EPC reader mgmt	See Section 4.1
Semantic modelling	A function that gives semantic to the captured data
EPCIS Cap App	See Section 4.1
Tag data translation	Mutual translation of tag code system
Sensor data translation	A function that manages the relation between identifiers of the sensor tag/node and data sheet information of the sensor
Data processing	A function to process acquired sensor data before

Roles	Description
	forwarding to the application
Application	A set of procedures to produce output data from input data. Usually the procedure is done in computers
EPCIS Repository	See Section 4.1
EPCIS Accessing App	See Section 4.1
Directory	A function that provides relationship with identifier and information that is used in the system. The information includes network address (e.g., URI)
ID – information service binding	A function that manages the relation between identifiers of the RF tag and location of the information services related to the identifier
ONS	See Section 4.1
EPC discovery service	See Section 4.1
Data distribution directory	A directory service that manages the relation between identifiers of the RF tag and the addresses of the applications that require the data of the identifier
Interrogator and attribution binding	A function that manages the relation between identifiers of the interrogators and their attributions
Sensor plug and play	A function to accommodate myriad of sensors
Memory schema resolver	A function that manages the relation between identifiers of the sensor tag and schema information of the tag

6.2. Reference models for sensor-integrated EPCglobal network

This section explore reference models for sensor-integrated EPCglobal network. These reference models also accommodate requirements analyzed in the Section 5. We present four types of reference models, which are aligned with the classification of integration introduced in Section 2.2.

6.2.1. Logical integration at application level

The first type of integration is where the application combines the identification data fed by EPCglobal network and the local sensor data. In this case, some type of sensor identification is needed particularly when multiple sensors are incorporated. Data translation and sensor management roles are handled by the application side. An example of this model is cold chain control application that collects temperature and moisture sensor data in warehouses while collecting inventory data from EPCglobal network. This type of sensor integration can be done by introducing the sensor networking technology locally to applications and information services.

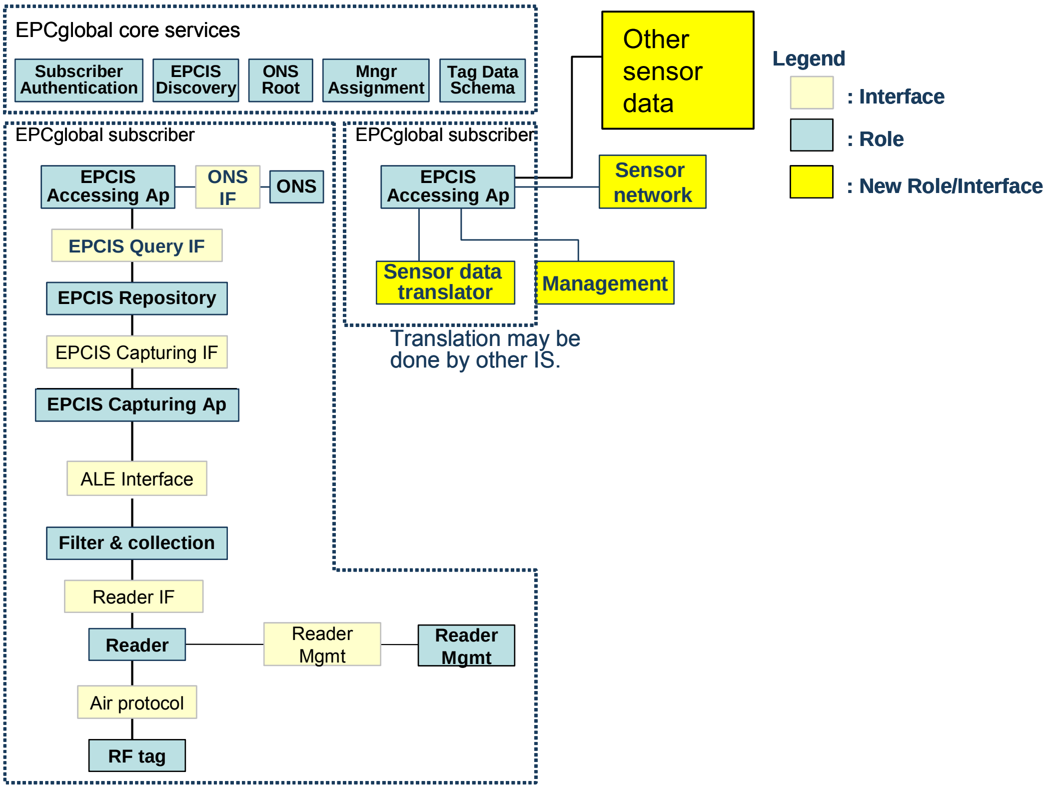


Figure 6.2: Logical integration at application level

6.2.2. Logical integration ALE level

The second type of integration is logical integration at the ALE level. When products with RF tags travel through multiple facilities and each facility is equipped with sensor networks, collection of sensor data will be facility based and collection of product location information will be networked RFID system based. In order to realize global level sensor and RFID integration, long haul data collection will be taken care by EPCglobal network and local level data collection will be taken care by both EPCglobal network and sensor network. The process should be the same as retrieving EPC and sensor data from a remote reader. The protocol between sensor BS and sensors may be sensor networking protocol or even wired connection. The communication between interrogator and the functional nodes is not necessarily facilitated by RFID protocols. An example may be a cold chain control application that collects temperature and moisture sensor data at a factory, distribution centre warehouse, and retailer, simultaneously collecting inventory data from the EPC network.

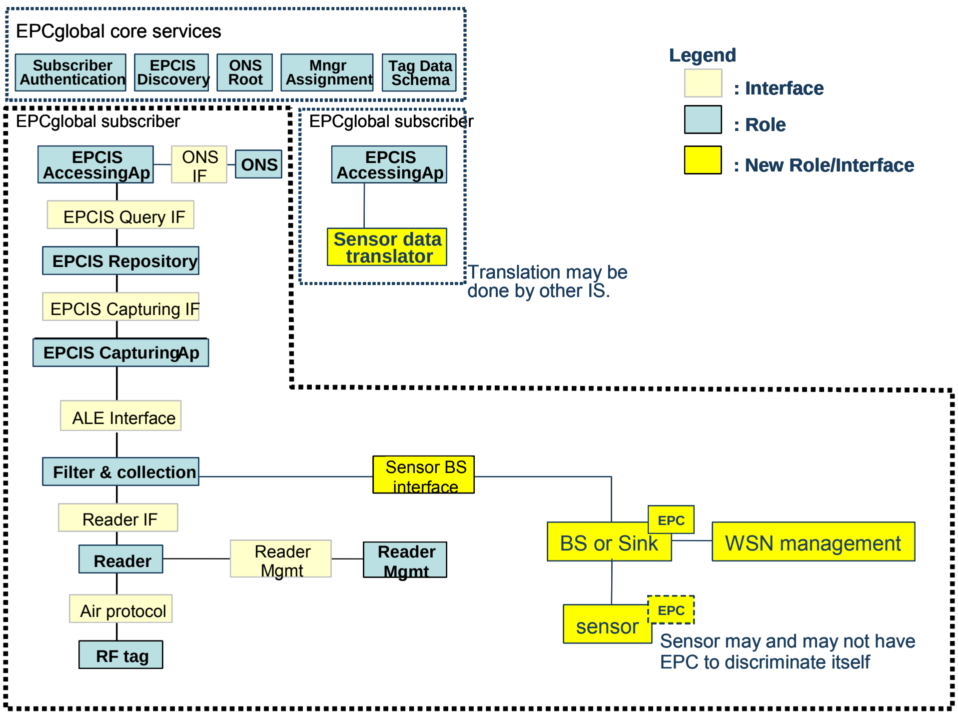


Figure 6.3: Logical integration at ALE level

6.2.3. Hardware integration in a networked system

The next type of integration is both application integration (logical integration) and hardware integration. The integration of RFID data and sensor data is taken care at the interrogator level. The situation is the same as the second type, but we assume to use sensor tags that can store the environmental information while products are not under RFID or sensor network control. The new role required in this type is memory schema resolver. Reader/writer may be required to read ID tag, sensor tag and sensor node, and in order to read appropriate data, the interrogator needs to know the memory map according to unique identifier. In order to retrieve sensor data from sensor tag efficiently, we may need to enhance the air protocol and tag data structure. An example is a cold chain control application that collects temperature and moisture sensor data at a factory, distribution centre and warehouse, and retailer, simultaneously. An EPC tag may have the capability to measure and store a part of the required sensing data. A reader may have communication channels to WSN through sensor BS.

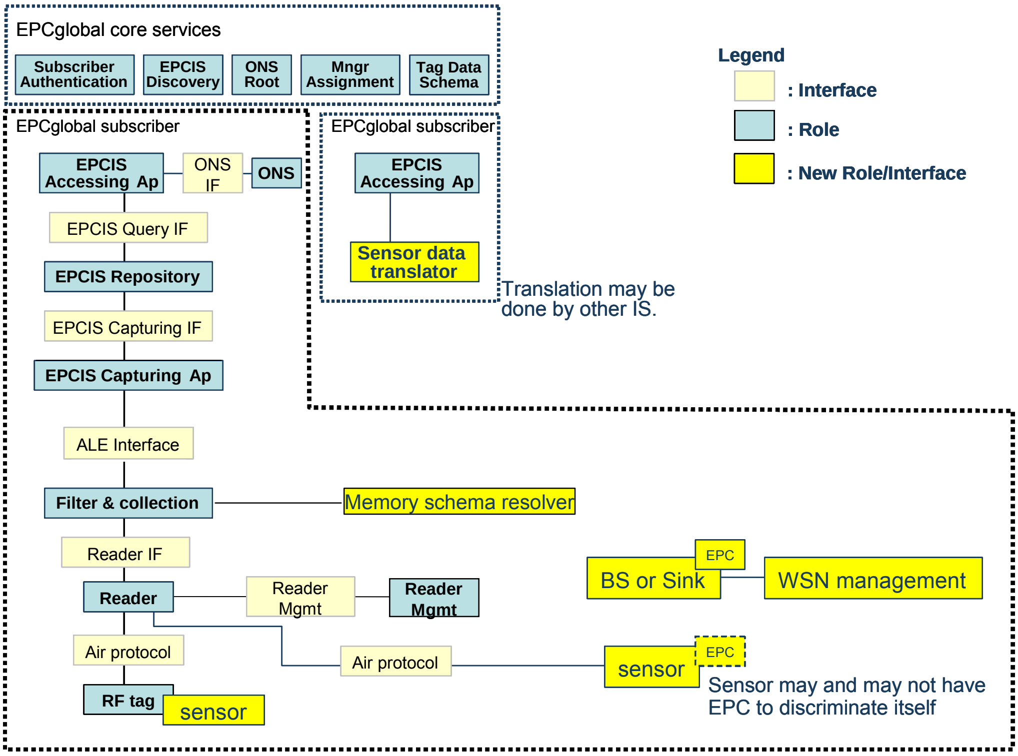


Figure 6.4: Hardware integration in a networked system

6.2.4. Logical integration at EPCIS level through aggregated transport

The forth type of integration is logical integration at EPCIS level through aggregated transport interface. This type accommodates multiple applications that may be known and may not be known at the initial implementation of the sensor RFID integration system. This is realized by defining a new role, aggregated transport, which bridges all the interrogators and applications and takes care of data transport without knowing the contents of the data except EPC. If an interrogator acquires ID or sensor data with a help from memory schema resolver and data distributor, it sends the data to the designated applications. Application can discover suitable interrogators through reader/SINK directory residing in the aggregate transport.

An example of a situation is a retailer who deploys multi-service reader/ sensor BS to accommodate myriad of application requests from manufacturers, repairers, recyclers and consumers. The retailer knows that its trading partners need RFID data and sensor data, but do not know all their future expectations when implementing a sensor integrated RFID system.

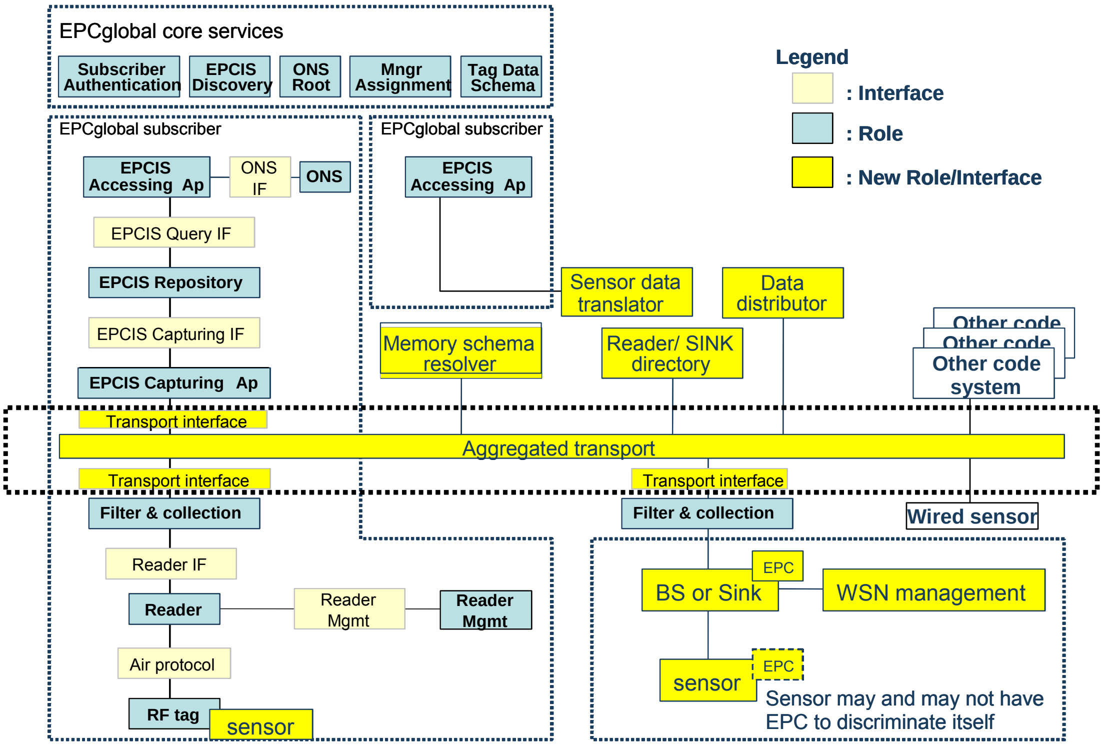


Figure 6.5: Logical integration in aggregated transport

7. Summary

The integration of EPCglobal network and wireless sensor networking (WSN) technology explores a new technical horizon leveraging the simultaneous ID and sensor data manipulation. The applications are abundant in the fields of healthcare, logistics and product health monitoring. Although the importance of the two technologies, RFID and WSN, is widely recognized, their integration is still in its infancy. This white paper addressed the required roles and interfaces in sensor integrated EPCglobal networks in an abstract manner and provided the fundamental classification of sensor integration in the EPCglobal network. Also, it reviewed applications, existing and background technology to reveal the technical requirements. We have provided an ontology and provided several reference models in four scenarios of the sensor integrated EPCglobal network architecture. We have identified the following roles and interfaces in sensor integrated EPCglobal network.

- Sensor memory schema resolver for sensor plug and play functionality
- Data translator to translate raw sensor data to meaningful data to applications
- Aggregated data transport may be effective to handle multi-service interrogator and logical integrations
- Enhanced air-protocol and tag data structure

8. Acknowledgments

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