RFID sensor network network architectures to integrate RFID, sensor and WSN

RFID Sensor Network

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Abstract - The Radio Frequency Identification (RFID) may be the hottest Auto-ID technology in the world, while the wireless sensors and sensor networks is one of the focusing topics in computer science and electronic engineering. More and more companies and researchers are now trying to combine these two technologies together to provide more integrated information for specific applications. In this paper we first discuss the possible hardware combinations, then three network architectures are presented and discussed for integrating RFID network, sensors and wireless sensor network (WSN). We expect these three architectures to cover most of the on-going works in this topic.

Keywords: Radio Frequency Identification (RFID), sensor, wireless sensor network, network architecture.

Introduction

RFID

The Radio Frequency Identification (RFID) is one of the Auto-ID technologies. It is a generic term for technologies that use radio waves to automatically identify people or objects[1]. The method is to store a unique serial code in a microchip; an antenna is attached to the chip so that the identification code can be transmitted. The chip and its antenna together are called a RFID transponder or a RFID tag. In order to receive and identify the information sent by tags we need a RFID reader, which can then forward the information to a computing device such as a server computer.

There are two broad categories of RFID systems – passive and active RFID systems, depending on the types of tags used. The active tags have transmitters and usually a battery as their power resource; they transmit their ID codes through transmitters, thus a wide reading range can be achieved. The passive tags, or called backscatters, have neither own power resource nor RF transmitter, they use inductive/propagation coupling to connect with the reader antenna, this means that the passive tags just simply reflect back the signal emitted by the reader. These passive tags are simpler and cheaper but have a much shorter reading range. Semi-active tags are also available now in market for specific applications[10]. These semi-active tags contain batteries that are only used to support the embedded memories and sensors. A brief comparison is given in Table 1 for the three systems.

	Passive tag	Semi-active tag	Active tag
Own power for data transmission	No	No	Yes
Own power for chip	No	Yes	Yes
Communication with readers	Backscatter	Backscatter	RF tansmit
Read range	short	medium	long
Tag cost	low	medium	high

Table 1. Brief comparison of different RFID tags

Although it emerged early in 1970s, it is only in the past decade did the RFID technology start to develop and to spread quickly due to advances in hardware industry. After having the support from world's largest retailer Wal-Mart[12] and the US Department of Defence[13], more and more companies and researchers are getting involved into this area. It is very likely that RFID will be one of the most prospective technologies for the future applications in asset tracking, manufacturing, security and access control, payment systems and supply chain management.

Combine RFID with sensor and WSN

An information system is always expected to provide answers to four questions: Who, What, When and Where. RFID provides the Who (ID). Most people usually think RFID can provide 'Where' at all the time. Unfortunately, what RFID does is tell to us where an object was the last time it went through a reader[2]. So research activities nowadays are investigating joint sensing infrastructures to provide the What, When and Where. One of these infrastructures is to make RFID systems work with sensors and sensor networks. With possible sensing capabilities an RFID system will become responsive and conscious of the asset state and environmental conditions, from which we are able to ensure that our goods are not only in specific locations, but also in appropriate conditions[3].

Generally, sensor enabled RFID networks can be used in the supply chain management to surveil two types of goods during their transportation and storage:

- The goods those are sensitive to environmental changes. These goods usually require specific environmental conditions during transportation and storage, for example temperature, humidity and vibration etc;
- The perishable goods and foodstuffs, such as fruits and vegetables, which have quality and value changes while moving in the supply chain.

Sensor enabled RFID networks can also be used in production line management. Tagging some core component/assembly and recording their specifications would lead to quicker repairs or better maintenance. Tags should be writable, active and integrated with special sensors to meet the needs of feedback status (temperature, pressure, humidity, etc) of the object tagged[4]. Such a network can also be responsible for the monitoring of manufacturing processes, tracking tagged components and status of a product. Therefore, people can ensure that automated processes are kept synchronized and product quality is under well control throughout the manufacturing processes[5].

Elder healthcare at home and patients' healthcare at hospitals are other possible hot applications for sensor enabled RFID systems[14]. People will be able to use these systems to monitors patients' medication in take, to track patient's position in real time and surveil their health conditions[6].

There are also researches and applications for RFID sensor networks in mass server maintenance, fire safety networks and real time location system. Most of these efforts are intended to identify objects or persons and also to determine their states as well.

There are a number of important issues concerning the combination of the RFID system and the sensors or sensor networks. We classify these issues from three aspects:

- RFID transponder. Combining RFID transponders and sensor node by embedding them onto one board;
- RFID reader. Sensors are also working with RFID reader devices to improve system performance or to enable new system functions;
- Network topology. RFID system and wireless sensor networks cooperate and work together.

RFID Transponder/Tag

RFID sensor tags

The first stage for a RFID system to work with sensors is to embed simple sensors into the RFID transponders. Various types of sensors have been placed onto the RFID transponder boards to achieve the sensing capability for specific applications. Many active and semi-active / semi-passive tags have incorporated sensors into their design, allowing them to take sensor readings and transmit them to a reader at a later time[6]. They are functionally less than sensor network nodes because they do not have the capacity to communicate with one another through a self-organized network, but they are functionally more than a simple RFID transponder. In this way, RFID is combined with the sensor technology. Special readers are required in these types of systems so that sensing information can be read at the same time while reading the unique ID from the RFID sensor tags.

Currently, sensors have rarely been placed on passive RFID transponders. Passive RFID sensor tags are only tested in small and special systems due to three main reasons:

- Passive RFID tags do not have their own power resource. They use inductive coupling (LF & HF tags)/propagation coupling (UHF tags) with the reader's antenna to gather energy for powering the chips in the tag and reflecting signals back to the reader. Though the current antenna technologies can support a passive

RFID tag working in all frequencies, they can hardly get enough power resource to activate a sensor, especially in the UHF band.
- The sensor in a passive tag can monitor its environment only when a reader interrogates the tag. This means they cannot be used in the event driven system, which limits their usage.
- High cost is still limiting their usage in massive applications.

Last year a UK company has announced the first passive RFID sensor tag in the world[7]. It works only under 13.56MHz HF band, which limits their reading range to up to 2 metres; and the cost is about 5 pounds per tag. Though this type of tags have illustrated an important improvement in the RFID technology, it still has the main problems mentioned above while being applied to the massive applications in the supply chain management, the biggest market of passive RFID.

RFID sensor nodes

The ability of a sensor network node in storing and transmitting a unique identifier enables it to work as a RFID sensor node. A RFID sensor node uses IEEE 802.15.4 or Zigbee to communicate with a sensor gateway. Passive or semi-active RFID tags use inductive/propagation coupling to communicate with readers. Not only the reader devices for passive or semi-active RFID should be implemented in particular fixed positions, but also the requirements for antenna direction and angle are very critical. This has reduced the flexibility of the whole system. Large directional antennas are also required and at the same time the antenna RF power increases significantly when trying to have a longer reading range. These constraints could lead to high cost and health hazard caused by HF radio radiation. Active RFID tags has already lost some of its advantages such as low cost and long life time when embedding with power resources; they do not have the positive features of the Zigbee enabled sensor network nodes, such as self-organized network, multi-hop communication and an unified power efficient protocol standard. The RFID sensor network inherits a number of features from wireless sensor networks, which may overcome the constraints faced by passive, semi-in the section 'Tag as a sensor'.

RFID Reader

Sensors can be also combined with RFID readers to improve their performance. An example is to use motion sensors together with the RFID readers at a warehouse door. While a pallet is moving through the door the motion sensor will activate the readers to read the tags on the passing objects. This could make the reading more reliable and avoid unexpected readings when an asset is passing in front of the door within the reader's reading range but not entering the warehouse.

Currently, some sensor nodes are now using RFID readers as part of their sensing capabilities. An example of a RFID reader designed to mate directly with the sensor nodes is the SkyeRead Mini M1 made by SkyeTek, which could read directly from the Crossbow Mica2Dot sensor motes[6, 11]. A sensor network gateway can act as a

RFID reader in the RFID sensor network.

RFID Sensor Network Topology

Based on the latest technologies of RFID and wireless sensor networks as well as the new types of hardware, various integrated system architectures can be made for the RFID systems and sensor networks to work together, so that applications can profit features from the both sides. In this section we will define and discuss three integrated architectures: the agent network architecture, the 'Reader as a sensor' architecture and the 'Tag as a sensor' architecture.

Agent network architecture

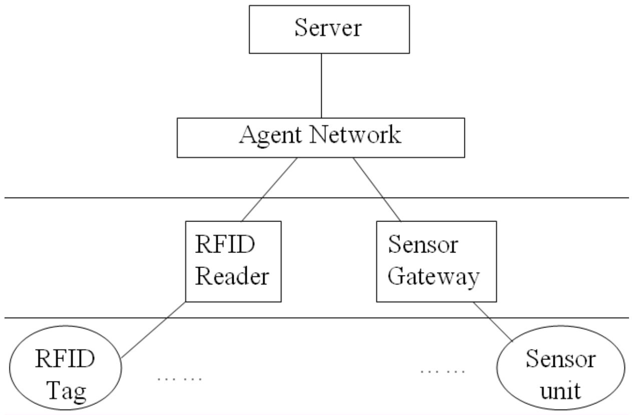

Figure1: Agent network architecture

The most common way to make a RFID system and a sensor network work together for a particular application is to implement the agent network architecture. The RFID network and the sensor network work in the same layer, but not directly connected to each other. To make them work corporately an agent network is added as a backbone frame here to link the central server and the two networks together. The structure and protocol used by the agent network can be any of the existing wireless network standards, such as IEEE 802.11 family and IEEE 802.15 family. Wired network standard can also be chosen depending on specific application.

The advantage of this architecture is that people can use typical RFID devices and sensor network devices to construct a cooperated RFID sensor network without requiring customized special hardware devices. This is especially a simple and cost-effective way for companies who want to develop a RFID sensor network based on their existing but separated RFID networks and sensor networks.

There are two ways to connect the RFID reader devices and the sensor network gateway devices to the agent network: either should the devices themselves have the interfaces compatible to these standards so that they can have the ability to construct a data network, or a network agent device, which can be connected to one or several readers and sensor gateway devices, will pursue the task of constructing the agent network backbone.

A similar example is the Sentient Overlay Network in HP Lab, which inserts hierarchy of diverse ad-hoc wired and wireless network structures and computing nodes that are capable of processing and filtering both sensor and RFID data[3]. The RFID network and the sensor networks are working completely in their standard mode. RFID readers and sensor network gateways are assumed to be wired and powered and compatible to the IP based network standards. The upper layer communication between the ad-hoc networks and the server nodes is based on standard wired IP networks and wireless LAN, which depends on the specific requirements.

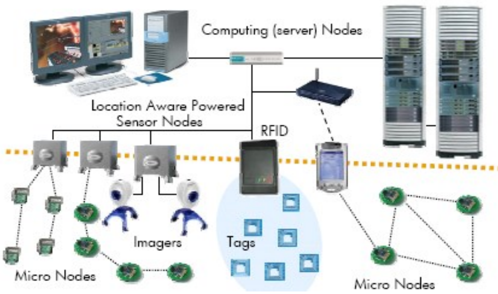

Figure 2: Hp's Sentient Overlay Network[3]

Jedermann's sensor system prototype for fruit logistics could be the example of the application using the agent network architecture[8]. In his prototype standard fruit containers are equipped with RFID readers to read the unique ID number of every freight item as well as their transport information stored on their RFID labels. In order to surveil the fruit states, sensor networks are implemented in the containers to measure temperature, humidity and ethylene production rate. The RFID networks and the sensor networks in the prototype all report to a freight agent, which could send out warnings and recommendations through the external network, such as a WLAN of a cargo ship.

'Reader as a sensor' architecture

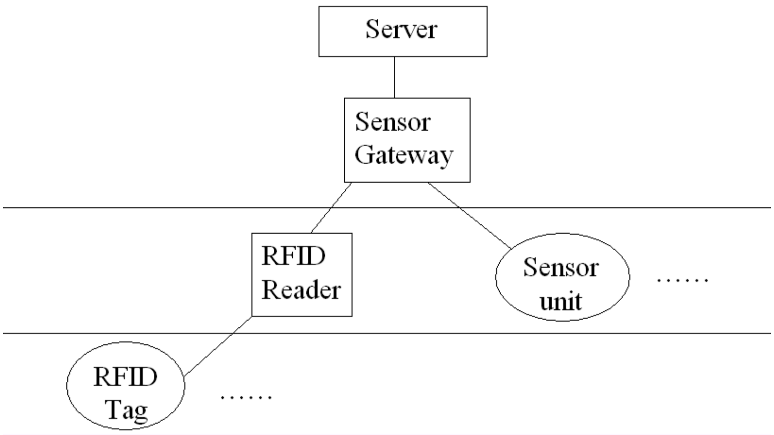

Figure 3: 'Reader as a sensor' architecture

In order to achieve a combined architecture for RFID systems and the sensor networks, the conception of a ‘sensor’ need to be extended. Generally a sensor is a device that responds to a stimulus of a particular type of environmental condition or pursues a specific physical measurement. In this combined structure the concept of the sensor is extended to involve the RFID reader device as a sensor. What a reader device ‘sense’ is the appearance, the approaching or the passing of a RFID transponder/tag within its reading range. In this case, the RFID readers and the sensor motes (units) of the sensor networks are considered to be in the same layer in the system architecture. The sensor network gateway device, such as a sensor coordinator, will also act as the gateway device between the RFID readers and the central server/network. All information generated by the readers will be sent to the central server via the sensor network gateway device.

Although various interfaces and protocols such as RS-232, RJ-45 or WiFi are applicable to bridging the readers and the sensor network gateway devices, the Wireless Sensor Networks protocols (802.15.4 or Zigbee) are recommended for the following reasons. Firstly, we can make the whole architecture be more integrated by using a unified network protocol between every two layers, therefore design and development of the system could be simplified in this case. Secondly, sensor network protocols allow multi-hops between readers and sensor network gateway device for data transfer, which means that the readers are not obligatory to be placed near the gateway, and could be installed anywhere within the transmission range of any sensor node. Thirdly, sensor network protocols support self-organizing and self-healing in network topology, which make their communication be more reliable. Fourthly, WSN protocols are for low speed and power-efficient communication, while the data transmission speed (20 ~250 kbps) is sufficient for RFID information, reader devices can profit the power efficient feature of the WSN protocol as some of them may be battery driven.

This ‘Reader as a sensor’ architecture can integrate active, semi-active or even passive RFID networks as the reading procedure or the communication between the tags and readers are very similar to the typical RFID systems.

C. Englund and H. Wallin’s work has a similar but special structure with this ‘Reader as a sensor’ architecture[9]. They gave the RFID readers the radio frequency ability, and used a network protocol that is very similar to the wireless sensor network protocols to construct a wireless RFID reader network. Their work expanded the reading range limit of the short range RFID system, and at the same time implement the ability of reading RFID tags from distances that are well beyond the range of ordinary RFID readers.

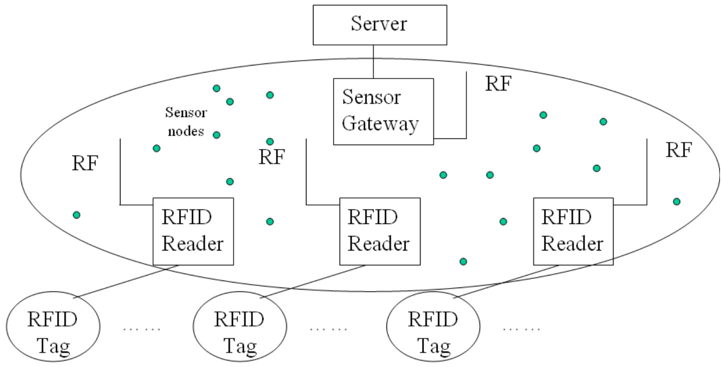

Figure 4: Example application for 'Reader as a sensor' architecture

An integrated example application of this architecture is shown in Figure 4. A number of RFID readers are implemented in a warehouse to perform object identification, access control and real time location tracking tasks; each of them has been given a RF transceiver and a RF antenna to achieve the wireless communication ability. Wireless sensor nodes are also implemented in the warehouse to surveil environmental conditions and accidents. Wireless sensor network protocol is applied to the wireless ad-hoc network constructed by the RFID readers and the sensor nodes. It is more likely in this architecture that a RFID system has been integrated into a wireless sensor network structure in the upper layer.

'Tag as a sensor' architecture

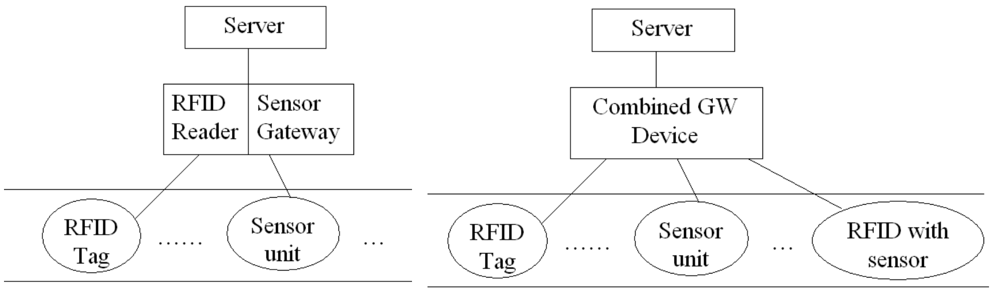

Figure 5: 'Tag as a sensor' architecture

In the 'Tag as a sensor' architecture the 'sensor' conception is extended to treat the RFID transponder/tag devices as a sensor. What a transponder device 'sense' is the unique identification code stored in the tag's memory. When a tagged asset or person goes within the reading range of the reader device, the tag senses the identification code of the asset or the person and transmits the identification code to the reader device. In this case the RFID tags and the sensor units are considered to be in one layer of the architecture. The reader devices and sensor network coordinators are in another layer, in which a combined gateway device, the sensor units, the RFID tags and the RFID sensor tags/nodes communicate with each other. An example of this type of combined gateway reader device has been given in Section 'RFID reader'.

When we are using only RFID sensor nodes in the network, as they work very similar to the typical sensor network nodes, the combined gateway devices could be just the sensor network gateway with slight modification.

As shown in Figure 5, one of the significant features of this architecture is that a unified and simplified structure is implemented, where the RFID sensor tags/nodes discussed in Section 'RFID transponder' could be easily integrated into the system. The other features of this architecture when using RFID sensor nodes include:

- The reliable and power efficient communication brought to the tags/nodes by sensor network protocols, which is more important in this case as tags have much limited power resources;
- The possibility for server and reader devices to interrogate a tag as long as it is in the covered area of the whole sensor network. Due to this feature a real time object/person state interrogation function and the real time location system function will be available.

An example application that may use a similar architecture is the work from UC Berkley. They are constructing a mesh network in a hospital or a warehouse. In the network they implement only 2-3 access points, which are similar to the combined gateway devices in our architecture. The access point will then lead to an interrogator and then to the server devices. Numerous nodes with ID, which can be considered as RFID sensor nodes, will then come in and form a mesh network topology. These RFID sensor nodes start to communicate and report their nearest range, measuring the distance from one node to the next. The researchers are now investigating algorithms through which the location of every node could be calculated.

Conclusions

In this paper we have discussed the combination of RFID systems and wireless sensor networks. After discussing the possible hardware combinations for transponders and readers respectively, we presented three integrated architectures in the network topology level for RFID systems and wireless sensor networks to work together or even to be combined. These architectures may cover most of the applications, if not all of them, in this field nowadays. Most of them are still on-going researches. It has been recognised that there is a great potential in combining the two technologies to achieve a system that has the features from both sides. Some real applications based on these ideas are expected in a few years. We hope this article has painted a picture of describing what is happening in the near future in RFID industries.

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