A System Design for The Integration of RFID Systems with Wireless Network Technologies

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***Abstract*— RFID (Radio Frequency Identification) is a special type of wireless communication that allows automatic identification of objects without requiring a line-of-sight. It cannot provide the fullest benefits as a standalone technology. Efficient and successful RFID applications must be developed by smoothly incorporating RFID systems into existing infrastructures to improve business processes and data management capabilities. In this paper, a system architecture that achieves the integration of RFID systems with wireless network technologies (e.g., ZigBee, Wi-Fi, WiMAX, cellular networks) is presented. A control unit is designed to identify objects, gather and manage RFID data, and keep the track of RFID tagged objects without any human involvement from long distances. A middleware is developed to improve mobile applications, provide monitoring our system, route RFID information to the related units automatically in a faster, more efficient, secure, wide capacitated way without any limitation. Our system design resolves the problems caused by lack of information, ensures to achieve competitive advantages, has longer operating range. In our study, a system design is illustrated to show how RFID systems can be integrated with wireless communication technologies to collect and manage secure real-time information.**

Keywords- Radio frequency identification; active/passive tag; Wi-Fi; WiMAX; TinyOS; data gathering; object monitoring

I. INTRODUCTION

RFID is an automatic identification (Auto-ID) and data capturing technology that gives an opportunity to identify and monitor objects by using a tag that carries information. It provides easy, secure and quick data entry, storage and transmission. It is used everywhere, such as shops, stores, hospitals, pharmaceutical companies, logistic services, etc. where real-time data should be used. It improves data gathering and management capabilities, raises security level of information about objects and resolves problems caused by lack of information. The main feature of RFID technology is its ability to identify, locate, track, and monitor objects automatically without a clear line of sight between tags and readers [1].

Wireless networks provide the infrastructure to support mobile connectivity to all information sources with high performance and availability. They allow users to communicate and access applications and information from long distances without wires. Most wireless network technologies are license free and provide freedom of movement and the ability to extend applications to different locations. They provide significant cost savings to deploy. They offer device mobility and higher reliability because of increases in efficiencies, less error-prone cabling and less downtime as compared to a wired network. Wireless networks have several categories depending on user requirements and the size of the physical area that they are covering.

In this study, we present a system design that combines the RFID system and wireless networks. Main contribution of our study is to design and develop intelligent hardware and software components for the integration of RFID systems with wireless networks to gather and manage data, keep track of objects carrying RFID tags from short or long distances. Our design provides a cost-effective solution and economic power consumption. It also supports real-time detection of RFID tags and remote data collection through the underlying wireless network. Our system structure consists of spatially distributed devices called control units. These devices are equipped with wireless communication protocols that allow them to communicate with other devices either directly or via multiple hops. They can also use sensors to monitor conditions (e.g., temperature, pressure, motion, etc.) about objects. Having a control unit enables the network devices to identify, track and monitor a wider range of objects. Additionally, the wireless network can expand the RFID system's range and provides an RFID system in areas where a network infrastructure (e.g., Internet) does not exist.

The paper is organized as follows: Section II presents an overview of basic RFID system components. Section III presents related work discussing the integration of RFID systems with wireless communication technologies. In section IV we illustrate various examples of system designs that use our control unit and show how RFID systems are integrated with wireless networks. Finally, a discussion of new challenges and suggestions for future work are presented.

 ISBN: 978-1-61208-140-3

II. OVERVIEW OF RFID SYSTEM COMPONENTS

Main hardware components of a basic RFID system are RFID tags (passive, active and semi-passive), RFID readers, and various antenna types.

An RFID tag consists of a microchip where the information about an object is stored, an antenna connected to the chip, on-board electronics, and a protecting film layer that covers these components. It is used as an electronic data carrier, and different information can be written and read in its environment. The microchip in RFID tag can store information from 64 bit to 8 MByte. This means that the tag can carry some important information, such as shipping history, order number, customer information, company/staff information and serial number. For the purpose of tracking the movement of objects, tags can be placed anywhere, such as containers, pallets, materials handling equipment, cases or even on individual products. Tags can be classified as passive (no battery), active (with battery) or semi-passive according to their power supply. While active tags use an energy source that is integrated to a tag physically, passive tags obtain this energy from the readers in the communication field. Today, semi-passive tags that have some properties of both active and passive tags can be also used [1-3].

An RFID reader is a specialized radio transmitter and receiver that act as a central location for the RFID system. It reads tag data by the help of the RFID antennas at a certain frequency. The RFID reader is basically an electronic device that emits and receives radio signals. It is designed for fast and easy system integration without losing performance, functionality and security. The reader has a real-time processor, an operating system, a memory, and a transmitter/receiver unit. The reader is usually classified into two types: (1) Fixed reader also called RFID gate is set to a definite place. (2) Mobile RFID reader includes a wireless interface, precisely Bluetooth, ZigBee or Wi-Fi. This device uses short or long-range radio links. It can identify, read/write, remotely control and monitor RFID tags over wireless communication. It contains some software tools to communicate with other mobile RFID readers, PDAs, laptops, etc. The Mobile RFID reader facilitates the identification of the tags that are in dangerous fields where the reading process is difficult [2], [3].

An RFID antenna is used as a medium for the purpose of tag reading and data collection. In many situations, the use of an antenna is important because tag-reading ranges are generally small. Although an antenna has very simple structure because of its concept, it must be able to receive the best signal in low power and adapt to special conditions. Antenna must be designed in different sizes, shapes and frequency intervals according to the properties and distances of the environment where the application will be implemented. The antenna can be designed considering several factors, such as reading distance, particular product types, specific operating conditions, known orientation, speed of the tagged objects, reader/controller, arbitrary orientation, antenna polarization, environmental changes, etc. [2], [3].

III. RELATED WORK

In this section, we present several related works and projects that are taken place in industrial and academic research areas.

In a study performed by Intel Corporation [4], a Wireless Identification and Sensing Platform (WISP) has been developed. This platform consists of passive RFID tags and includes sensors that provide a very small-scale computing platform. It is a viable alternative system for smart dust applications, such as monitoring and recognizing human indoor activities, tracking items, informing of disasters, detecting poisonous gas or radioactivity, etc.

In [5], researchers from Intel Corporation have presented a method and its requirements, design and early experiences to obtain and use knowledge of human-object interactions. They have developed, built and deployed hands-on RFID readers that are embedded in wearable gloves and bracelets for detecting use of tagged objects. These autonomous readers are connected to sensors, gather data and report sensed events wirelessly to a base station. This method serves to support real-time analysis of data streams and can be applied to activity-based applications, such as health monitoring.

In [6], researchers in NESL (Networked and Embedded Systems Laboratory) in UCLA (University of California, Los Angeles) have presented a method that provides a cost-efficient solution for object recognition using the integration of RFID systems with mobile sensor networks. They have created an application called Ragobots (Real action gaming robots) that use small RFID readers. The Ragobots are wirelessly collaborated and coordinated to achieve a final goal while navigating in a terrain. They move in a random walk, search for tags, detect the tags and determine the object type based on the information stored on the tags.

In [7], Bluesoft, a company building Wi-Fi-based wireless security and location RFID technology, has deployed its real-time location system called AeroScout within Legoland Denmark, one of Europe's largest amusement parks. In this system, company's active tags operate using 802.11b wireless LAN technology and can be tracked over much larger areas with much fewer readers compared with traditional active RFID systems. In the Legoland deployment, readers consist of 38 Bluesoft AeroScout location receiver units. These units can read an AeroScout tag's 2.4 GHz signal and any other 802.11b-enabled device. Bluesoft's system's capability to use their preexisting Wi-Fi infrastructure allows AeroScout location receivers to be connected to the same cabling used for Wi-Fi access points. KidSpotter, a theme park application developer, has provided two different software programs. One of them links the AeroScout system with mobile phone networks while the other one enables the park to analyze tag location data to optimize the distribution of visitors within the park in real time.

In study [8], the authors have proposed a prototype that combines the RFID systems with wireless communication technologies for an in-home health care system to gather data and monitor the medication of patients. The prototype includes two parts: an RFID reader node and a base station node used for wireless communication.

There are numerous other real-world applications related to the integration of RFID with wireless networks. Examples consist of US Navy's wireless RFID system to monitor the condition of valuable aircraft parts in storage [9], Siemens IT Solutions and Services' cargo-tracking system that combines RFID, wireless sensors, GSM and satellite services [10], ZigBeef 's long-range RFID system that helps ranchers and rodeos track animals from various distances [11].

Most of the related works presented above are the applications in which RFID systems are used together with wireless sensor networks. However, our study handles this issue from a different point of view. The aim of our study is to demonstrate how active and passive RFID systems can be integrated to wireless networks that contain different communication technologies, such as ZigBEE, Wi-Fi, WiMAX, and cellular networks. In our implementation, several alternative systems that comprise different network topologies were designed to accomplish RFID integration. Moreover, a microcontroller based adaptable control unit that uses intelligent techniques to effectively operate in various integrations of RFID with wireless networks were developed.

IV. OUR SYSTEM ARCHITECTURE

Our system architecture offers an effective, a reliable, comprehensive, and low-cost solution to facilitate automatic detection and identification of objects from long distances. It comprises of one or more control units, a wireless network infrastructure, and a middleware. Fig. 1 illustrates our basic system architecture.

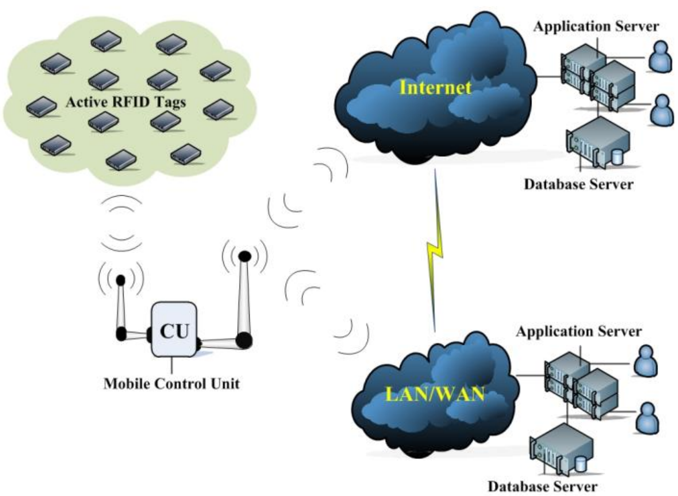

Figure 1. Our System Architecture

A. Our Control Unit

Our control unit is the brain of our system. It has long reading/writing ranges. It serves as a mobile mini application server between the RFID system and a wireless network. It gathers data from tagged objects, processes tag information and sends this information to related remote system that consists of computers, servers, or base stations. It has more advanced specifications than current RFID readers. It runs an open-source operating system (TinyOS) [12] which is designed for low-power wireless devices. Our control unit has several properties:

- operating anti-collision protocols
- monitoring RFID system
- rerouting data about objects to related units on which database management system or application software works (if necessary)
- collaborating with wireless network devices and other control units
- remote controlling and management by users
- ensuring a safe data transfer between RFID tags and the back end system
- real-time data capturing and analyzing
- sensitive object tracking and localization

B. Wireless Network Infrastructure

The wireless network infrastructure can use different communication technologies, such as Bluetooth, ZigBee, Wi-Fi (IEEE 802.11 a/b/g/n), WiMAX (IEEE 802.16/x), and cellular networks (e.g., GSM, GPRS, EDGE, CDMA, etc.) to provide fast data communication, larger coverage area, and Internet access. This infrastructure can be a cloud that consists of various network topologies (or clouds) and many spatially distributed devices that produce convenient communication among themselves. Using a wireless network infrastructure will offer several important advantages for our system architecture as below:

- It will enable exchange of communication between clouds owned by multiple service providers and system resources.
- It will expand the RFID system's range and enable the RFID system in large areas where a network infrastructure (e.g., Internet) does not exist.
- It will enable both RFID and wireless network devices operate collaboratively and coordinately to provide the best services and applications.
- It will create a heterogeneous wireless environment to serve the purpose of different requirements, such as mobile automatic identification, human-object interaction, remote data collection, object monitoring and tracking, etc.
- It will ensure a safe and compressed data transfer, information sharing, real-time data management between our control units and the back end systems.

C. Our Middleware

For our system architecture, we developed a middleware that combines active RFID tags, our control unit, the wireless network and the back-end system. As shown in Fig. 2, our middleware has six modules as follows: data management, device management, process management, application development, communication, and administration. Eeach module does specific tasks on its own.

 ISBN: 978-1-61208-140-3

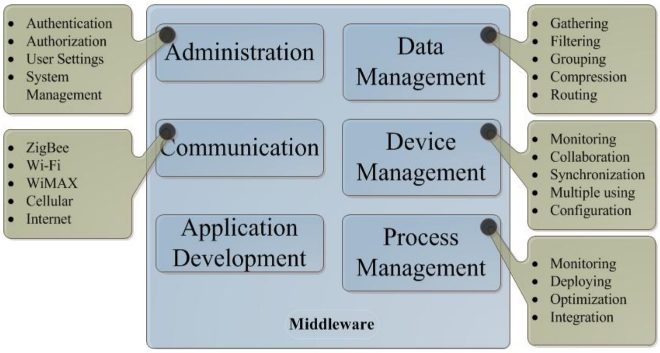

Figure 2. Our Middleware Architecture

Data management module has built-in rules and provides gathering, filtering, grouping, and routing of RFID data. Gathering helps us to gather data from RFID tags using our control unit. Filtering is used to extract definite data that we need. It checks data source when data contains unknown or undesired data. Grouping uses a clustering algorithm to classify data and allows splitting data into groups based on identical values in a field. Compression ensures a safe and compressed data transfer between the control unit and the back-end system. Routing allows to route information to related back-end system in a network.

Device management module is used to configure our control unit without having direct access to the device. It allows monitoring RFID system, collaboration with network devices and other control units, synchronization to manage data flow between control unit and mobile devices. It enables multiple users to share mobile devices and access RFID data.

Process management module offers monitoring, deploying, optimizing, and integration our system. It determines the resources required to operate at the back-end system and collect information for carrying out subsequent activities of deployment process. It consists of a set of services that allow interaction of multiple processes running on one or more RFID system.

Application development module involves creating a set of program modules to perform our future tasks. It supports an open-source programming model which mobile RFID applications can be developed on TinyOS operating system. It provides adding new functionalities in the form of loadable modules.

Communication module provides various wireless communication protocols to gather and manage data, monitor objects due to wireless network infrastructure. It also supports RFID anti-collison protocols for best Tag readings. It makes the platform independent of both the control unit and the wireless network. Several mobile devices such as Smart phones, Personal Digital Assistants (PDAs), laptops are supported by communication module.

Administration module defines a set of rules (read, write or change) for users to access specific data in every mobile application. Depending on the user rules and logon data, the end user can make changes in the following settings: number formats, language, time zone, control and monitor processes, manage user/group policies and applications, etc.

V. IMPLEMENTATION

The objective of our study is accomplished by integrating hardware and software components. The hardware components are divided into two parts. The first part consists of active RFID tags, our control unit, and other RFID equipment that are shown on the left sides of Fig. 5 and 6. For the RFID equipment, we used several RFID evaluation kits [13-15] which includes the RFID reader, active and passive RFID tags, antennas, sensors, adaptors, etc. Second part is the wireless network that is shown on the right sides of Fig. 5 and 6. For creating a wireless network, we used a wireless router and network evaluation kit [16] which includes various wireless network devices. The Motorola development kit [17-21] that is shown at the center of Fig. 5 and 6 acts as a bridge to combine these two parts. The software part consists of a program module developed in NesC [22] using Eclipse with NESCDT plug-in [23] to control the Motorola development kit and our control unit, and a database management system to manage the RFID tag IDs of objects attached to them. We used TinyOS operating system in our control unit to achieve several operations such as sending commands, running anti-collision protocols, controlling data signals and communication between RFID system and wireless network. Our research has the potential of being adapted for use with secure real-time data gathering and management applications involving wireless network and RFID technologies.

Figure 3. Motorola G24 Developer Kit (exterior)

 ISBN: 978-1-61208-140-3

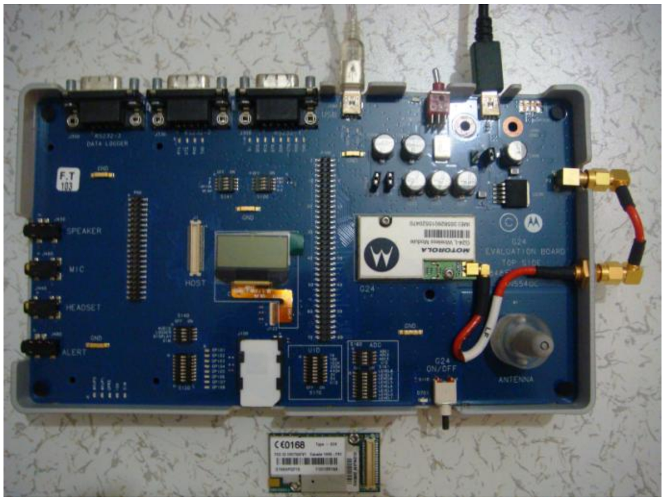

Figure 4. Motorola G24 Developer Kit (interior)

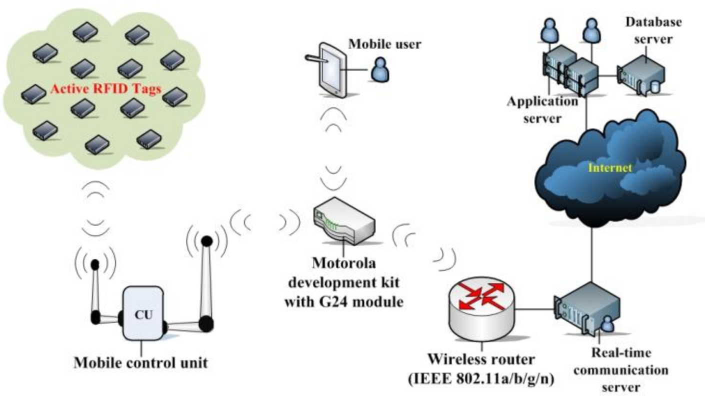

Figure 5. Integrating RFID Systems with Wi-Fi Networks

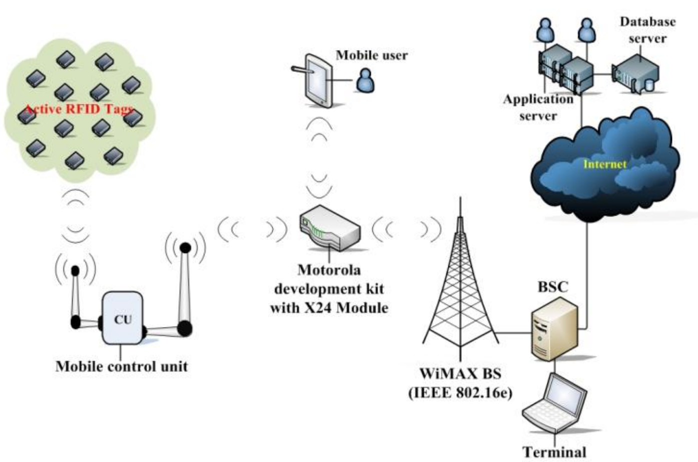

Figure 6. Integrating RFID Systems with Mobile WiMAX

VI. RESULTS

RFID systems are the best choices if the area that will be monitored is small. If the requirement is to monitor a small number of locations, these systems can be instrumented with RFID readers at a low cost. In case of long ranges, it is essential to have high coverage as possible. An important disadvantage of RFID readers is that these devices do not have a communication network to enable exchange of information. Therefore using wireless communication technologies will be good choices in terms of infrastructure costs since costs associated with Wi-Fi are minimal.

Because Wi-Fi is widely available, more standardized and used across a broad variety of mobile devices, we chose to integrate it with our system. During the integration of Wi-Fi to our systems, we had challenges. These challenges were related to the operating system that we are using in our control unit.

As we discussed in previous section, we used TinyOS as our base operating system. Although TinyOS has extensive networking support, it does not support Wi-Fi technology. To overcome this challenge, we used TinyWifi [24] as an extension of TinyOS [12]. In TinyWifi, applications from highly resource constrained sensor networks can easily be compiled for resource rich Wi-Fi based networks [24]. This solution opens the rich protocol repository of TinyOS to the researchers who are studying in wireless communication area.

As a result, TinyWifi enabled us to develop necessary TinyOS applications and protocols and execute them directly on Linux by compiling for the TinyWifi platform. Using TinyWifi as a TinyOS replacement, we successfully evaluated the wireless protocols that are originally designed for sensor networks. Our evaluation was based on the test applications of TinyOS that demonstrate the functioning of radio communication, serial messaging. By using TinyWifi, we were able to receive demo sensor measurements, display them and build routing trees, which are the variations of examples presented in [25].

In our future work, we want to evaluate the Zigbee protocol stack in our system once Zigbee protocol is fully supported by TinyOS. Zigbee protocol stack for TinyOS is currently under development and [26] provides open source tools for IEEE 802.15.4 and ZigBee.

VII. CONCLUSION

Combining RFID systems and wireless communication technologies is a promising solution that can increase the productivity and give a competitive advantage to those that begin to use it first. However, there will be some standardization issues. These issues need to be solved before the technology sees wide acceptance.

Even though there are issues with combining RFID and wireless technologies, we successfully evaluated the wireless protocols that are originally designed for sensors in our system. In our study, we proposed a system architecture that is designed to provide RFID users flexibility of wireless networks at lowest cost. Additionally, this paper has discussed the ways to combine RFID systems with wireless communication technologies and its advantages such as cost reduction. As a future goal, we want to evaluate the integration of Zigbee technology with our system, when it is fully supported by the operating system we are using.

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