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# Zigbee Enabled Radio Frequency Identification System

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## ABSTRACT

The Radio Frequency Identification (RFID) system is a widely used Auto-ID technology today to identify and track objects and people in manufacturing, inventory management, retailing, and security applications. The Zigbee technology, which is a recently emerged network communication protocol based on the IEEE 802.15.4 standard, provides a self-organized mesh network topology with a power-effective, low data rate and multi-hop data transmission. The RFID system could profit some of its features by introducing the Zigbee technology into the existing RFID architectures, such as having extended effective range, improving network flexibility and having compatibility with other Zigbee enabled environment systems. In this paper we first discuss the possible benefits and applications while applying Zigbee to the different parts of the RFID system. Then an integrated Zigbee RFID system architecture is discussed and a demo system is described at the end of the paper.

## KEY WORDS

Radio Frequency Identification, Zigbee, integrated system architecture, demonstration system

## 1. 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 basic components of a typical RFID system include: the transponder or the tag, which is a microchip in which a unique serial code is stored and transmitted when necessary via an antenna attached; the RFID reader, which is used to receive and identify the information sent by tags; the server with savant or middleware, where the readers forward the information to, is a computing device such as a server computer.

There are generally 3 types of RFID systems depending on the types of tags used, which are the active, passive and semi-passive/semi-active systems. The active tags have onboard transmitters and battery as their power

resource; they transmit their ID codes through transmitters, thus can have a wide reading range. The passive tags, or called backscatters, do not have own power resource and onboard RF transmitter, they use inductive/propagation coupling to connect with the reader antenna, which means that the passive tags just simply reflect back the signal emitted by the reader. These passive tags are smaller and cheaper but can only achieve a much shorter reading range. Semi-active tags are also available now in market for specific applications [2]. 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 transmit
Read range	short	medium	long
Tag cost	low	medium	high

Table 1. Brief comparison of different RFID tags [3]

Compared to the other Auto-ID technologies the RFID system has its own features: instead of typing or scanning the identification code manually, the RFID systems provide us a non-contact data transfer between the tag and the interrogator without the need for obstacle-free, line-of-sight reading; multiple tags can be read simultaneously by a RFID reader, which is known as the batch readability of tags, makes the identification work much more efficient; RFID tags are more reliable while a printed barcode is easily to be broken.

The first RFID application emerged early in 1970s, but it is only in the last decade of the century when the RFID technology started to get the attention from the various industries and spread quickly due to the advances in hardware industry. After having the support from world's largest retailer Wal-Mart [4] and the US Department of Defense [5], we can now expect a massive development in the RFID industry. Known as a possible replacement for the barcode technology, RFID could 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.

## Zigbee

Zigbee is a kind of wireless communication technology. It is provided by Zigbee Alliance, an association whose members are leading companies in the industrial. Zigbee technology dedicates to enabling reliable, cost-effective, low-power, wirelessly networked monitoring and control products [6]. Although Zigbee is a new technology (Zigbee specification draft version 1.0 was published in 2004), it is not a close one. First, Zigbee uses IEEE802.15.4 as the communication component. IEEE802.15.4 is a global standard defined by IEEE (Institute of Electrical and Electronics Engineers), its authority and opening encourage manufacturers to join and benefit from the market. Second, the designs of network layer and application management make Zigbee have potential to be generally applied for applications whose target markets are monitoring and control products. Zigbee is suitable for communication applications that require reliable low data rate within a relatively short range. The applications such as toy control, plant control, and home automation control are all belong to this kind. Zigbee promises at most 250kbps data rate which is enough for simple control (normally 40kbps can be accepted by most home automation applications and others similar [7]). Another key feature of Zigbee standard is its powerful and simple network ability. Zigbee can organize a network that can theoretically manage 65,535 network devices. Zigbee stack can be used to route messages reliably and provide strong in-built security measures [8]. Not like other network communication technologies, Zigbee is a very low-power requirement technology. Two AAA batteries can support Zigbee device working over years [9]. Compared with Wi-Fi and Bluetooth, Zigbee has unbeatable preponderance at low-data rate market.

As an innovative technology, Zigbee can be adopted to work associate with many traditional application. For example, currently the garage doors are often controlled by infrared which means the users must send out the signal when he/she is in front of the door. Using Zigbee, when the user is within the range of Zigbee network (normally the peer-to-peer communication range of Zigbee is 100m outdoor) he/she can give out the signal to open the garage door and time is saved. Zigbee technology can help products networked and improve remote management ability. In the information society, it is very interesting and considerable for manufacturers to engage the development of products based on Zigbee. Because the communication components are supported by IEEE 802.15.4, Zigbee can provide excellent peer-to-peer communication. The upper layer-network layer defined by Zigbee specification—gives Zige the ability to extend the range of the network. There are two basic and one advanced network topologies are supported, star, tree and mesh. Star topology (Figure 1 a) is the simplest one. Each device communicates with a centre device called the

coordinator. The coordinator is responsible for receiving message directly from sub-devices or relaying message from one sub-device to another sub-device. The drawback is that if the coordinator fails, the whole network will fail. Tree topology (Figure 1b) is like a reverse tree. The top node is the coordinator. Each node will have a parent node used to join the network. If one node wants to communicate with another node, it must first send the message to their common ancestor node and this ancestor node will relay the message to the destination node. The advantages of the tree topology are that it is easy to extend the network and the rule to route is easy to achieve. The drawbacks are more delay will be introduced if the range of the network is large. And those nodes, which have many sub-nodes, are the fatal nodes that will cause the same problem in star topology. In virtue of the network layer, Zigbee can support mesh topology (Figure 1c). Each node is equivalent in the network except the coordinator, which is still responsible for building and maintaining the network. Each node has ability to relaying message according to the network layer and it is faster than in tree and star topology, especially the network covers a large area.

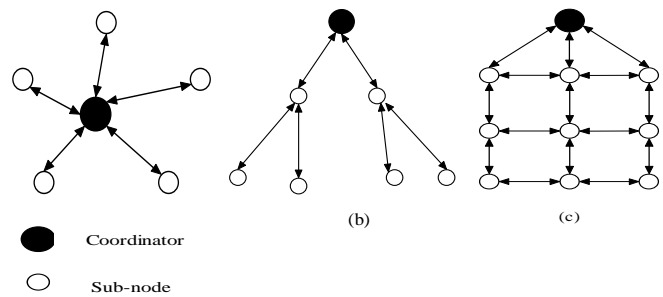


Figure 1: (a) Star (b) Tree (b) Mesh

In this paper we will discuss the implementation of Zigbee technology in RFID systems. This will be first based on the typical RFID architecture, and on a combined architecture in which RFID systems work together with the wireless sensor networks.

## 2. Implementation of Zigbee in RFID

According to the features of the different RFID, it is possible for the Zigbee technology to be implemented on most of the RFID devices.

RFID server is generally a high computing ability device such as a PC or a Laptop in order to run the complex systems such as a RFID savant software; external power source and large memory are also essential for these devices, thus there won't be any difficulty for the RFID server to work with the Zigbee technology.

All RFID readers are equipped with relatively large memory and microprocessor. Although RFID reader devices do not always have an external power source,

most of the RFID readers' power consumption is far higher than Zigbee and they are usually supported by external power sources. Some of the active readers may be powered by onboard batteries, but as they have a similar or higher power consumption level than the Zigbee devices they can still support a Zigbee module and achieve a reasonable battery life.

The components of an active RFID tag include a battery that operates the active tag, an on-board processor, small memory chip and RF transmitter. This is very similar to the components of an end device in Zigbee. Though the memory of current tags is usually not enough for Zigbee protocol stack, it can still be implemented subject to a memory upgrade or, which is the simplest way, to have a Zigbee end device act as an active tag with the programme properly developed inside. The cost of an active Zigbee tag may be slightly increased in this case. The passive and semi-passive RFID tags do not have self-powered RF transceiver, thus there's so far no way for Zigbee to work on them.

	Server	Reader	Tag
Active	✓	✓	✓
Semi-passive	✓	✓	✗
Passive	✓	✓	✗

Table 2. Zigbee compatibility of RFID devices

The compatibility of Zigbee and the RFID devices are summarized in Table 2. The Zigbee technology can now work in reader layer and server layer of passive and semi-passive RFID systems, and in all device layers of active RFID systems. Thus it is possible for Zigbee to handle the following data communications:

- Between a reader and a server
- Between two readers
- Between a reader and an active RFID tag
- Between two active RFID tags
- Between RFID system and the devices of another external or combined system.

In a specific application Zigbee can be chosen to control one or more of these data links. Different functions and features can be achieved when different combination of data links is chosen. In the following discussion we will first choose to use Zigbee in the highest device level (server) in the RFID architecture, and then extend its usage layer by layer to reach the devices in the bottom level (tags).

**Server-reader communication**

Most of the current RFID systems in the market use serial port, such as RS-232 and USB ports, to link a single or a small amount of readers to the server in small-scale applications. A serial port needs particular cables to wire all the readers to the server, and the number of reader

device that can be connected is limited to up to 127 including the bus devices. When a large number of readers need to be connected in a more complex scenario, the Ethernet or the WIFI technologies are often chosen. Firstly we let Zigbee work only for the communication between the Savant server and the readers, which means the other data links will be like a traditional RFID system. No reader-to-reader communication is available in this case. It is essential to have the server-reader Zigbee data links first for the implementation of Zigbee between and within the reader layer and the server layer. The network topology is like a typical hierarchical star network, where the server is at the top of the network as the root node. All the readers are connected directly to the server via Zigbee enabled wireless channels. The tags, no matter active or passive, are read by readers and can be considered as the sub nodes of the reader that read from them. The role of the server in this Zigbee network is the coordinator, and the readers will act as the Zigbee end nodes.

Based on our former discussion, for all active, passive and semi-passive RFID systems, the server device and the reader devices are always compatible for Zigbee implementation, thus the Zigbee enabled server-reader communication is possible for all types of RFID systems.

**Reader-reader communication**

We now extend Zigbee implementation into the reader-reader communication. This should be based on the established server-reader Zigbee links and could be optional in specific applications. There is no reader-reader communication in almost all existing products. But having such an option will bring us new features for the RFID system. The network topology is a hybrid mesh network. The server and all the readers construct a Zigbee mesh network, in which the server will act as the coordinator and the readers will be the Zigbee routers. Particular Zigbee routers may also be implemented at proper place to help the routing in specific area depending on the application needs. The tags are still traditional ones and are considered to form the sub star networks with the reader that read them. Like the server-reader communication, the Zigbee enabled reader-reader communication is also possible for all type of RFID system.

**Reader-tag communication**

As only the active tags are compatible with Zigbee, the implementation of Zigbee between reader layer and tag layer is only possible for active RFID systems. The readers work as the Zigbee routers and the active tags will act as the Zigbee end nodes, while the server works always as the network coordinator. A hybrid mesh network architecture remains in this extension of Zigbee usage.

**Tag-tag communication**

To have a tag-tag communication may not have been much considered by the RFID manufacturers. But Zigbee can achieved this by simply allow the communication between two end nodes, that is, in the active RFID systems, to have two active tags exchanging data.

**Communication with other Zigbee devices**

The communication with another Zigbee enabled system or individual devices can be easily achieved. This will usually be a wireless sensor network. We can simply add Zigbee sensor nodes into the Zigbee RFID structure and only slight changes should be done in the application layer protocol before they can be accepted by network and communicate with the server and the other Zigbee RFID devices. These will usually be implemented in the RFID reader layer and also in the tag layer for active systems. The network topology is still a hybrid mesh as we only add new types of device in each layer.

**Integrated Zigbee RFID system architecture**

Based on our discussion above, we present an integrated Zigbee enabled RFID architecture for both passive/semi-passive systems and active systems. As shown in Figure 2, Zigbee is chosen to support the server-reader and reader-reader communications. Data transfer between reader and tag as well as between two tags are optional in active RFID systems. New types of device, such as the sensor network nodes, are applicable in both reader layer and tag layer. They will simply join the Zigbee network formed by the Zigbee readers and even active Zigbee tags.

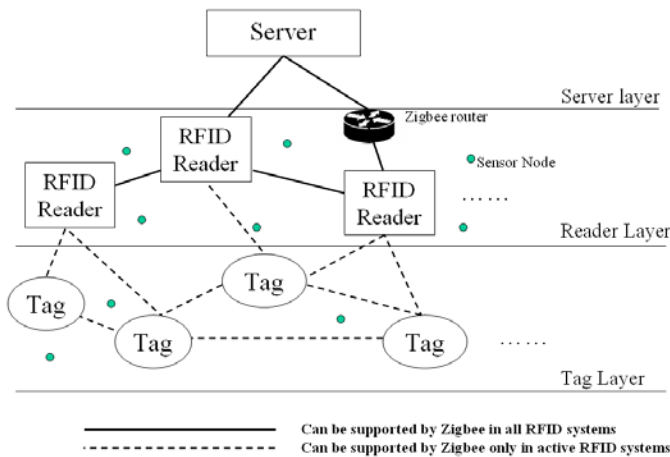


Figure 2: Integrated Zigbee RFID system architecture

**3. Features of Zigbee in RFID**

Zigbee is actually a wireless network technology concerning mostly about the architecture and the data transport inside the network. It allows a wireless communication between all the devices within its network. With the implementation of Zigbee technology in the traditional RFID system, the server, the RFID

readers and even the active tags can construct a wireless network with a hybrid mesh architecture. In our paper if a RFID system uses Zigbee for at least both server-reader communication and the reader-reader communication, we call it a Zigbee RFID system. The advantages of using Zigbee network in RFID systems are discussed below.

**Lower power consumption.** Zigbee is designed for low data rate and power-efficient communication. With a low data rate RF transmission and a relatively simple network protocol stack, a Zigbee device can work for years with only one normal AAA size battery. While the data transmission speed of Zigbee (20 ~250 kbps) is sufficient for transferring RFID information, this makes the devices in the reader layer possible to be supported by an internal battery and to have a reasonable lifetime. For example the handheld readers may benefit from Zigbee implementation as the current products are using WIFI and bluetooth whose power consumptions are far more than that of Zigbee [9]. The active RFID tags can also profit such feature to have an even longer battery lifetime.

**Multi-hop reading.** One of the most important features of Zigbee is its multi-hop routing protocol based on a mesh network topology. Zigbee allows multi-hop between readers and the server device for data transfer, which means that the readers are not obligatory to be placed near the server, and could be installed anywhere within the transmission range of at least one other Zigbee reader device or a Zigbee router [2]. As long as the server can connect with at least one Zigbee reader or router device, and at least one multi-hop path can be found between each reader and the server, the whole system will be workable. The self-organizing and self-healing routing technology supported by Zigbee, which means a new path will be generated automatically to maintain the data communication if one of devices in the path between two devices is down, makes their communication even more robust.

**Working with other Zigbee devices.** As shown in the Figure 2, Zigbee provides the possibility for a RFID system to communicate or even to combine with a wireless sensor network. A RFID sensor network can be used in many different applications such as to surveil the required environmental conditions during the transportation and storage of the perishable goods and foodstuffs, such as fruits and vegetables, and the goods those are sensitive to environmental changes; to tag the core component/assembly and recording their specifications in production line management in order to achieve quicker repairs or better maintenance; for elder healthcare at home and patients' healthcare at hospitals to monitor patient's medical intake and surveil their conditions; for mass server maintenance, fire safety networks and real time location system etc. Sensor nodes can be added directly into the Zigbee RFID systems subject to slight changes in the application layer protocol,

which makes the combination of the two systems simple and reliable under a unified standard and architecture.

**Large number of device.** While the applications become larger and more complex under particular scenarios, a large number of tags or even readers may be required. To link them all together we need the network standard to be capable for massive device management. The current wireless technologies are very limited for large-scale applications since the Bluetooth master device can connect with 7 active devices and the 802.11 standards allow a connection with up to 32 devices for each access point (AP). The situation will be even worse when nodes from other systems, such as the sensor nodes, are added. Zigbee has the potential to make things easier as each reader/router device will be able to interconnect with up to 255 active devices, and each of these devices can connect to a further 255 devices which can extend the system capacity to up to 65536 nodes.

**Wireless network architecture.** Zigbee provides us a network infrastructure that is completely wireless. With the support of Zigbee a cable free RFID system can be established with increased flexibility. It will be easy to install as the readers may be implemented at any place where the application needs. The cost of a system will thus be cut down, too. One may argue that the WIFI and Bluetooth technologies may also provide a similar structure and most of the features, but actually they are not doing the same thing. Current Bluetooth enabled RFID readers can communicate with the server via an IEEE 802.15.1 connection. Pairing needs to be done each time before working and a very limited RF range, up to 10m at the moment, makes it difficult to satisfy the applications in wide area. The WIFI based RFID systems are using either the 802.11 connections between server and readers, or use the WIFI tags for real-time locating (RTLS) applications. When server and readers construct a WLAN, communication is possible but the power consumption of WIFI will be a problem for battery-based devices such as a handheld reader. Meanwhile wired WIFI access points (AP) may be necessary in a reader WLAN and are essential in a WIFI RTLS system as they act as the readers; this makes the system back to a wired one and will significantly increase the difficulty and cost of the system implementation.

**Active RFID standard.** ISO 18000-7 may be the only RFID standard established particularly for active RFID, but virtually no two different 433MHz ISO tags work with each other's system. One manufacturer's active RFID tags do not necessarily work with any other manufacturer's RFID readers, even at the same frequency. With the crossbreeding caused by licensing, one manufacturer can comply with the ISO standard, yet not be interoperable with another product that conforms to that same standard [10]. So simply adherence to the ISO 18000-7 standard protocol does not ensure true interoperability, which is actually the goal to have a

standard. Zigbee is the same communications technology based on the IEEE 802.15.4 protocol in 2.4 GHz frequency to everyone. So by using those same Zigbee nodes, regardless of which manufacturer the tags are produced by, they can be expected to work together.

#### 4. Demonstration System

This demonstration is used to test the feasibility of using Zigbee technology for RFID system. One Zigbee device is set as the command device, which is used to receive messages from a remote reader. We suppose one Zigbee device integrated with temperature and humidity sensors as a RFID reader. Three Zigbee devices are set as routers deployed between the coordinator and the remote reader. Figure 3 shows the deployment of this experiment. When the Zigbee reader reads signal from tag, it will send out the tag information to the Zigbee coordinator immediately. Then the information will be displayed on the screen to the users. According to our test, the minimum interval time for sending out tag information can be 100ms.

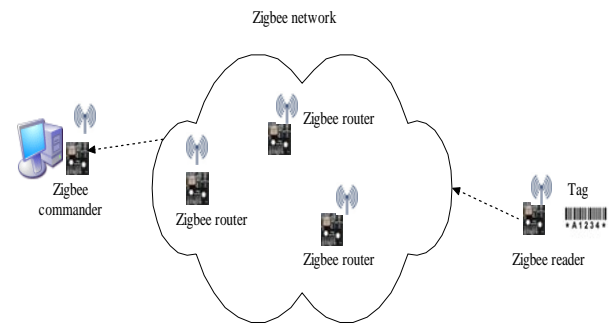


Figure 3: Deployment of the Zigbee/RFID experiment

When the system starts, the commander (coordinator) and three routers are shown on the screen. The responsibility of the coordinator is to create the Zigbee network. After those three routers joining the Zigbee network created by the coordinator, they will be ready for relaying messages from the Zigbee reader to the coordinator. Figure 4 shows the user interface of initialization.



Figure 4: Initialization. Node 1, 2, 3 express the routers.

After initialization, the Zigbee reader will join the Zigbee network through one of those routers and start to work.

When it detects some tags, it will immediately send out the tag information and the sensor readings through those routers to the coordinator. The coordinator will display the received message on the screen. Figure 5 shows the displaying interface. Node 4 is the Zigbee reader. Figure 6 gives the explanation of detail of node 4.

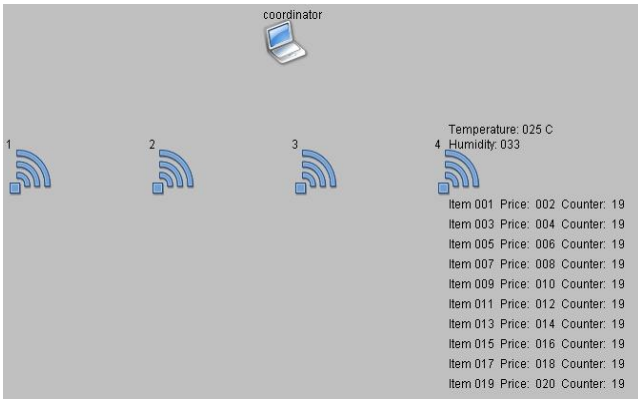


Figure 5: Displaying information received from the reader

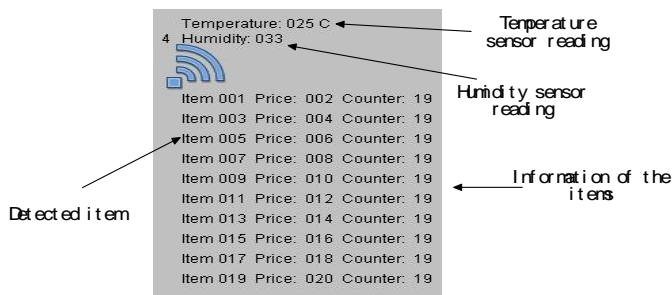


Figure 6. Explanations of the received information

If some items have been removed, the display will keep update and show the current status. Figure 7 shows the status of items when last five items have been removed.

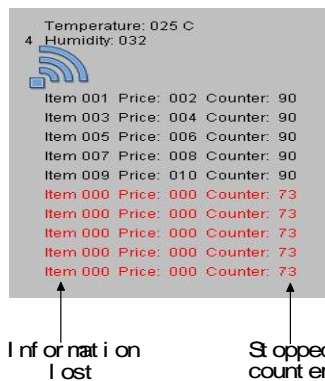


Figure 7: Reading information after removing some items

In the second experiment, we tried to make the tag as an end device associated with the temperature and humidity sensor. When this tag reaches in the range of a Zigbee reader, it will send its own information and temperature and humidity values sensed around itself to the

coordinator via the routers. Figure 8 shows the deployment of the active RFID mode based on Zigbee.

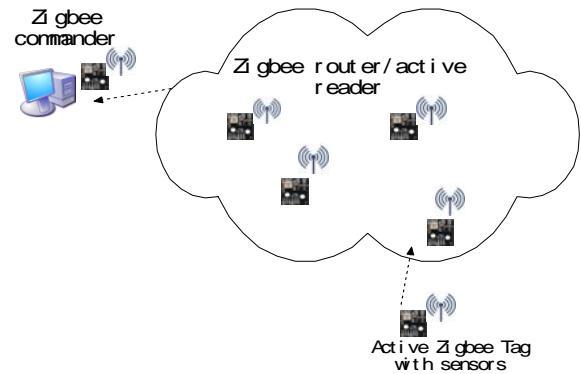


Figure 8: Active mode of RFID/Zigbee network

After the Zigbee coordinator and four Zigbee routers creating the network, the whole network is ready for receiving active Zigbee tag's information. Figure 9 shows the interface of the displaying when an active Zigbee tag is within the range of the network.

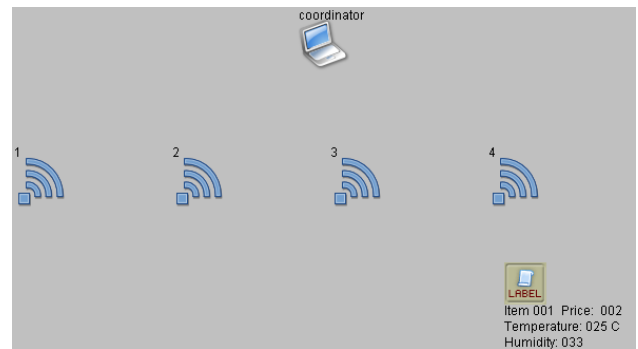


Figure 9: Interface of the demo for active Zigbee tag

The experiment illustrates the combination of the Zigbee and RFID technology. Using the network capability of Zigbee, the effective range of RFID can be extended. According to our test, the minimum interval time for the reader to send out information can be 100ms.

## 5. Conclusion

In this paper we have discussed the possible implementation of the Zigbee technology into the RFID systems. After discussing the Zigbee compatibility of the devices and communication links in the typical RFID system, we presented an integrated Zigbee enabled RFID architecture for both the passive/semi-passive systems and the active systems, followed by the benefits of having such an architecture compared to the current wireless technologies used in RFID products. A demonstration of a Zigbee enabled RFID system backbone is shown in the last part of the paper. An integrated Zigbee RFID platform, which will have real tag reading ability, is under construction in our research group.

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