Integrating RFID with Wireless Sensor Networks for Inhabitant, Environment and Health Monitoring

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Abstract

Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN) have been popular in industrial and academic field due to their ability in identity identification and data transmission respectively. Both RFID and Wireless Sensor Networks have undergone huge development separately. In this paper, it has been discussed how helpful and effective it will be when RFID and WSN have been combined together. It also discusses about some applications of this integrated technology in the field of precious animal and patient health monitoring where real time information is of utmost importance. A system structure of the integrated RFID and WSN has been introduced and the simulation results show that the new system outperforms traditional RFID monitory system in terms of the cost of deployment, updating delay and tag capacity requirement.

1 Introduction

Recent advancements in microelectronics and wireless technology enable the application of wireless sensors in both industry and wild environments such as inhabitant and environmental monitoring, enterpriser supply chain management and etc. The close connection with its immediate physical environment allows sensors to provide localized measurements and detailed information which is hard to obtain through traditional manual measuring approaches. Two of the most important technologies that have emerged in these years are Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN). RFID is implemented on or injected into a animal, or person for the purpose of identifications, improving the efficiency of object tracking and management, while the WSN emphasizes in physical or environmental conditions monitoring, collecting environment data such as temperature, sound, vibration, pressure, motion of each objects. Although both technologies have been playing important role in industrial and academical field based on their individual characters, at least three reasons that encourage us to integrate RFID and WSN technologies to explore higher system performance and new promising applications:

(1) New application scenarios incentive: In some special applications, only adopting one of the technologies is far enough to meet our needs. For example, in precious animal inhabitant monitoring (e.g. tiger or panda monitoring) and patient health monitoring (e.g. neuropathy or HIV patient), the real time information of individual object is most important. Such information includes physical information like body temperature, blood pressure and location information like motion tracking, rest time and etc. In addition to that, a general enterprize computer network is also in great demand for real time business process monitoring, which are related to supply or value chain management[11]. It is unfortunate that RFID network and wireless sensor network alone can not do a good job. RFID is unable to collect information about the RFID host while WSN is not efficient in identity identification and information management. Meanwhile, the deployment of sensors is expensive. However, based on the RFID, identification of each object can be easily traced which low cost and the information in the RFID tag can be effectively managed with its middleware. On the other hand, based on WSN, the information of each object can be collected in real time and transmitted to sink in a efficient way. Therefore, with the integration of RFID and WSN, their disadvantages can be overcome and their advantages can be put to some important applications. For example, the integration of RFID and wireless sensor network enable each monitored object (tiger, panda or neuropathy) to be individually taken care of.

(2) High performance incentive: In traditional RFID monitoring system, such as in supply chain management [15] or in pilot project performed by Delta Airlines for using RFID tags for baggage handling, RFID reader needs to process several tags in a very short time with differ-

ent distance. Therefore, limited communication bandwidth, background noise, multi-path fading and channel accessing contention between tags will severely deteriorate the performance of the data collection. However, based on the low-power radios and short distance transmission of tiny sensor units, wireless sensor networks transmit the collected data in a multi-hop fashion to the sinks, reducing the energy consumption and noise interference caused in the long distance direct data transmission. Therefore, inspired by the topology and transmission mode in the WSN, a group of nodes with RFID tags can also be regarded as virtual cluster. Considering different routing methods, at least two methods can be implemented in the RFID communication system to improve the data reading efficiency. That is, the information of each tag in a cluster can be gathered by a cluster head or replicated among the tags in the clusters before meeting the RFID reader. In this way, instead of reading every tag one by one within the reading range, RFID reader can get the information of a group of nodes by reading only one tag (the first meeting tag or cluster head's tag). As a result, the channel contention, noise interference during the data transmission can be significantly reduced.

(3) Economic incentive. In RFID system, a passive RFID tag is about $0.07 US dollar while a normal wireless sensor node is about $1 US dollar. However, a high quality RFID reader needs at least $500 [3]. In the environment and inhabitant monitoring, by integrating RFID with WSN, the number of RFID readers in the monitoring system can be reduced, which sequentially reduce the cost of the network deployment. The specified application structure will be discussed later.

This paper proposes a specific inhabitant and health monitoring application which represents the incentives explained above. A new architecture was proposed to meet the performance need called Hybrid RFID and WSN system (HRW) which systematically integrates the traditional RFID system and WSN system. In this system, a new node called Hybrid Smart Node (HSN) which combines the function of the wireless sensors, RFID tag and reduced function RFID reader is used for host information collection and transmission. More specifically, in the HSN, a sensor is used to be responsible for information collection with no transmission function. While the RFID tag serves as traditional packet buffer for the information storage. In addition, a reduced function RFID reader implemented onto HSN for the data transmission. The most significant difference to the traditional wireless sensor network is that in HRW, packet receiver will actively ask for the packets rather than passive receive data, which will significantly reduce transmission overhead. Moreover, since the date is stored in RFID tag, the transmission can still happen even if one of the transmission participation is in sleep mode which can greatly increase transmission efficiency. After the data of certain host is collected by the sensor, instead of only being stored in the host node, the data is replicated among the nodes in a virtual cluster. If one of the nodes with the replicas move into the transmission range of any Gateway RFID reader (GRFID), the transmission for this packet is completed. GRFID readers further send this raw information to the middleware, in which the data are filtered and delivered to applications according to the application logic. Since the transmission links between hosts in some inhabitant monitoring environment (such as animal monitoring) are usually intermittently connected, several routing protocols in Delay Tolerant Networks (DTN) are discussed in the paper in order to find a good message routing way for the application. Several tag management methods are also proposed to increase the information replicate efficiency. The simulation results show that taking advantage of the integration of the RFID and WSN system, the number of RFID readers, the transmission power of each node, and the demand of a large capacity of the tag can be reduced, compared to the traditional RFID monitoring system.

The rest of this paper is organized as follows. Section 2 we list related work. Section 3 provides the brief overview of RFID and WSN. and Section 4 propose a new architecture for the environment and inhabitant monitory. The simulation results will be presented and discussed in section 5, and finally section 6 concludes this paper.

2 Related Work

In the past few years, Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN) have been separately studied. The industry focuses on the use of RFID to keep track of their products [20, 1]. Some of the major companies such as CISCO [30], Intel [12], and Microsoft [13] are currently researching RFID to make use of its potential capabilities in keeping taps over their products, and help them when dealing with the inventory dilemma. Health monitoring systems [22] is one of the promising application for the RFID technology, RFID can be used to keep track of medicine especially the ones that cannot be given unless monitored by a doctor [16]. In general the main application the RFID is to keep track of things. Regarding the research and development of the WSNs the academic circles focus on developing a better WSNs in terms of energy efficiency [27, 24, 9], localization [17], routing [27, 7], and so on. Little work had been done to bridge the gap between WSN and RFID [23], though the benefits from integrating both technologies can outweigh the benefit gained from individual technologies. To briefly describe both technologies components, RFID system is composed of tags, readers (antennas), and middleware [4], while in WSN the system is composed of wireless sensors (to sense the occurring events) and sinks (to collect the data that had been sensed by the deferent deployed sensors) [18]. By intelligently integrating the tags with the sensors, and the readers with the sinks our design can significantly enhance the performance of the RFID in tracks the test subjects (by giving it a better communication range) and it also can enhance the performance of WSNs (by giving it the ability to track certain objects instead of just monitor the reg ion). Our work in this paper shares similarities with the work in [23] to integrate the WSN and RFID. The difference between the two works is that in addition to proposed a new structure of monitoring system, we also propose a dynamic clustering scheme to deliver the gathered data to the sink, while their work only propose a systematic approach to effectively integrate the RFID and wireless network to create what its known as smart environment [19]

3 Overview of the RFID and WSN

3.1 Radio Frequency Identification

The first appearance of the RFID technique was during the time of the World War II [2], in that time the armies were using the radar to discover the incoming airplanes, the problem was that the radar system at that time didn't have the ability to distinguish between friendly and hostile Planes. The German scientist found that if the airplanes rotates while they were returning to their bases their radar signature will be different, and that is the first appearance of RFID in the world. The main objective of the RFID system is to keep track of a set of objects, each equipped with an electronic circuit called the TAG. Tag gives a unique ID to the object that the tag is on. By using this ID the sink (also known as the tag reader or RFID reader) will have a way to collect information about all of the desired objects (the ones that have tags on) and attach these information with the unique object ID, this attachment will give the organization (the end user) a better understanding of the object behavior, which will lead to a better decision making. Each RFID system consists of 3 main parts as figure 1 shows : (1) the tag, which will be attached to the object to be tracked, and it will give it a unique ID, (2)the middleware, which is responsible to interpret the data from the tags and rewrite them in a format that will be understandable to the organization that deployed the system, and (3) the Reader, which is responsible for communicating with the tags and collect the information from the tags, the following graph shows the different parts of RFID system and how do they work together. RFID have a great deal of importance these days, its being used in a lot of industrial system such that it's being used in assembly lines to keep track of the machines, it's also being used to make easy and accurate inventory results. RFID also being used in hospitals to keep a 24 hours a day patient monitoring so if anything wrong happened to them the doctors will be immediately notified.

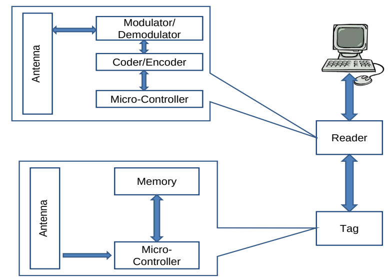

Figure 1. The components of RFID

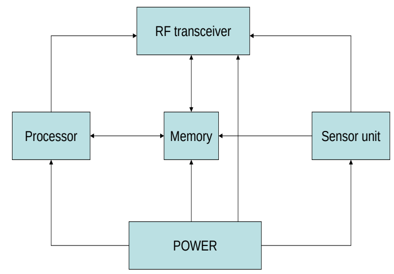

Figure 2. The components of wireless sensor

3.2 Wireless Sensor Monitoring Networks

Wireless sensor network is a collection of nodes organized into a cooperative, self-configuring and self-organized network deployed in an ad hoc fashion. As figure 2 shows, normally, each wireless node consists of processing capability (e.g. micro-controllers, CPUs or DSP chips), memory (e.g. flash memories), a radio frequency (RF) transceiver and a sensor units (e.g. thermostat). These wireless sensors are great for deployment in hostile environments or over large geographical areas for environmental observation, military monitoring, building monitoring, motions monitoring, medical diagnostics, disaster management and etc. The envisaged size of a single sensor node can vary from brick-size device down to the dust size device. The cost of sensor nodes is varies over a large spectrum, ranging from hundreds of dollars to a few cents, depending on the size of the sensor network and the complexity required of individual sensor nodes [26].

Normally, wireless sensor network for environment monitoring consists of hundreds of low cost nodes with either a fixed location or mobile location to monitor the environment [6]. A WSN consists of base stations (also called sinks) and a number of wireless sensors. Flows of data are usually gathered at the base stations, by which the WSNs can be connected to other networks such as Internet. Base stations have higher capabilities over simple sensor nodes since they can do complex data processing. The communication between base stations is over high bandwidth links.

Because of its self-organized, low power transmission nature, wireless sensor network has such characters: (1)

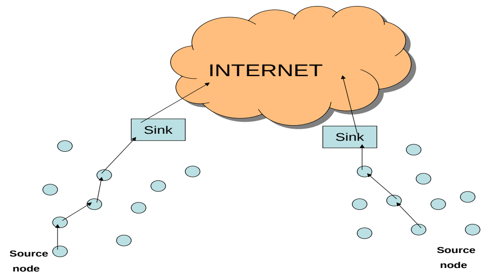

Figure 3. Typical Multi-hop Wireless sensor network architecture for environment monitoring

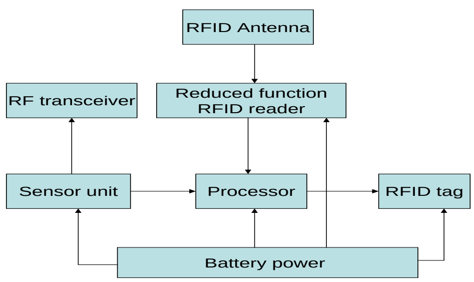

Figure 4. The components of HSN

person inaccessible since it normally deployed in harsh environments.(2) limited resource-power, memory, CPU. (3) Topology changes and link frequently breaks and noise interference. However, enormous efforts have been putting into the WSN researches which lead to a comparably stable and efficiently data routing in WSN [10, 21, 8]

4 Integration of RFID and WSN

Recall that RFID is sophisticated in identity identification and data management such that currently US government put the RFID tag in the passport for the people identification tracking. While WSN is much more mature in source information collection and data transmission routing. For example, sensor is implemented in the human body to monitor medical problems like cancer and help patients maintain their health. It is very predicable that the integration of the RFID technology with the WSN technology can lead to some novel applications to meet our daily life's need, such as precious animal monitoring or patient health monitoring. In these applications, taking precious animal monitory for instance, the information about health situation (blood pressure, temperature), or location trace of each individual animals is very important to us. However, in pure wireless sensor network, it is very hard to maintain the identification of each node accurately and effectively in a high dynamical environment [14]. On the other hand, the traditional RFID system can not effectively and dynamically receive information from tags for its immobility and long distance transmission feature. Meanwhile, since the RFID reader can get the information of tags only when the tags stay in its transmission field, it may take a long time for each individual node with a tag to meet a RFID reader. Although increasing the number of RFID readers can increase their coverage in the system, the cost of establishing such systems will be very high especially in a environment with large scale size. In this section, we will investigate a specific system call Hybrid RFID and WSN System which integrate the RFID and WSN technologies.

Host ID: 3 | Time stamp: 11230145

ID	Blood pressures	Temperature	Created Time
3	100-150	27.3 C	11230345
4	90-130	26.5 C	11231237
17	60-150	27.1 C	11231467
.....	....	....	

Figure 5. Data structure in HSN tag

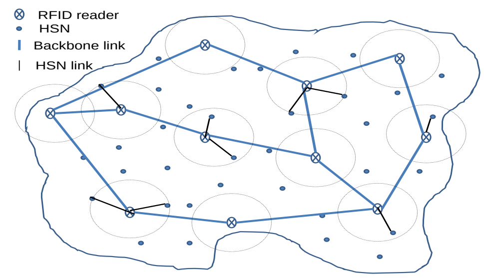

Figure 6. Traditional RFID monitory architecture

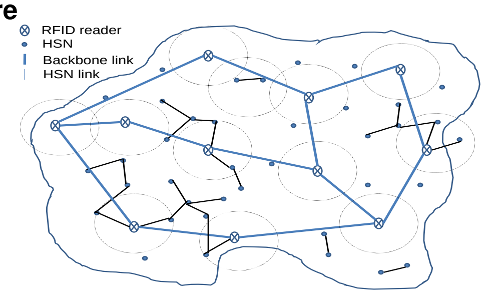

Figure 7. HRW monitory architecture

4.1 Hybrid Smart Node

In HRW, in order to systematically integrate RFID and WSN function , we combine the RFID and WSN technology in one node called Hybrid Smart Node (HSN). Both data collections from hosts and the data replicating between different hosts are conducted by these HSN in the HRW system. Figure 5 shows the typical components of HSN. The key component of HSN is the Reduced Function RFID Reader (RFRR) which is a special sensor that is able to read other nodes' tag information and write them in its own tags. By this means the tag's information can be exchange and replicated between the neighbor nodes in the proactive way. Such RFRR can just be a simple UHF reader module from traditional RFID readers.

The sensor units are responsible for collecting information about its host. Through the central processor, the sensor unit ask RFRR to write the collected host data into the tag. The central processor is a central mini-controller which also servers as a information filer. The reduplicated and outdated information from incoming tag will be prevented from writing into this own tag.

Since there are many HSNs in the system, and transmitting the collected information to RFID readers connected to middleware is delay tolerant, it is not necessary that all of the HSNs remain active at all the time which waste considerable batter power that is precious to the HSNs. Therefore, each HSN node has two modes: sleep mode, active mode. In the active mode, the sensor units in the HSN is able to collect the physical information of the HSN host and write it in its own tag. It can also read the tag information from nearby neighbors within its transmission range, no matter those node are in sleep mode or not. [11]. While in the sleep mode, HSNs will stop any activities until the next active cycle arrives, but their tags can still be read by other active nodes. However, the time configured in active mode and sleeping mode should meet the need of different applications as well as consider the balanced power consumption of each HSNs. For example, since collecting information of HSN hosts also consume a considerable energy, the patients that need intensive care can be set with a short active time with high frequency information updating rate (collecting rate), while the patients that almost recover can give low frequency information updating rate but a long active time to server in data forwarding.

4.2 The Architecture of HRW System

In the tradition RFID system, RFID reader can communicate with a node with certain information only when this node move into its transmission range. We call such transmission mode as *direct transmission*. Moreover, if a bunch of nodes move in to the reader at the same time, the tags will contend to access to channels for the information transmission. Figure 6 shows the direct transmission mode in traditional RFID system. In this system, only the nodes in the transmission range of RFID readers can send them information in the tags. On the other hand, HRW System is also composed of two kind of nodes: one is the HSN and the other is the traditional RFID reader connected with middlewares. In order to distinguish the traditional RFID reader with the reduced function RFID reader in HSN, we call the tradition RFID reader as Gateway RFID reader (GRFID) in HRW system. HSN and GRFID form the hierarchical architecture of HRW. The upper layer is composed of GRFID readers connected to the end applications (e.g. some desktop computer in doctor's office) through middle-ware with high-speed lined backbone links. The lower layer is formed by a considerable number of HSNs moving around that communication with wireless RF channels.

Traditional RFID system needs every tag move into the range of RFID readers before their data can be acquired by the RFID reader. However, such scenario requests enormous RFID readers to increase their coverage. Since the price of the high quality GRFID reader and the cost of establishing links among GRFID readers are very high, the deployment of traditional architecture for the large scale monitoring is not profitable. Furthermore, if too many RFID tags come into the range of certain RFID reader at the same time, channel access congestion will happen between tags in the limited bandwidth, resulting in a high data missing rate (normally the system efficiency in traditional RFID system is merely 34.6% to 36.8% [11]). On the contrast, in the HRW system, the tag information of each HSN can be exchanged and replicated with its neighbor node as figure 7 shows. That is, each tag of HSNs can contain the information about all its neighbor HSNs. In this case, only if one node in the virtual cluster enters the reading range of the GRFID readers, the information of nodes in this virtual cluster can be transmitted into the GRFID reader. Moreover, if several nodes enter the range of RFID reader at the same time, the GRFID reader will give the first meeting tag a higher priority to access the channel, reducing channel contention and long distance transmission interference.

4.3 Proactive packet replication

Different from traditional RFID system using direct transmission, HRW system replicate the information in some virtual clusters. Figure 8 shows an example of a replication process of two HSNs. After sensor units in a HSN collect the information about tag host, the information will be stored in its tag through the RFRR. The information stored in the tag can be read by the neighbor HSNs if they are within its transmission range.

Furthermore, compared to the packet replication in traditional delay tolerant wireless sensor network [29] where the packet receivers are passive to receive the packets, which means a source node sends packets to its neighbor nodes regardless if they want to receive it or not. In contrast, the packet replication in HRW system are proactive, which means the node that wants to get other's information initial the transmission by reading other's tag. Meanwhile, when the wireless sensors in traditional wireless sensor networks are scheduled with sleep and active mode to save energy, if one of two nodes in the system meeting together is in the sleep mode, no transmission will happen. While in HRW system, since the information are stored in the tag, other active nodes can retrieve the information at any time no matter what state the other HSN is in. Obliviously, the HRW sys-

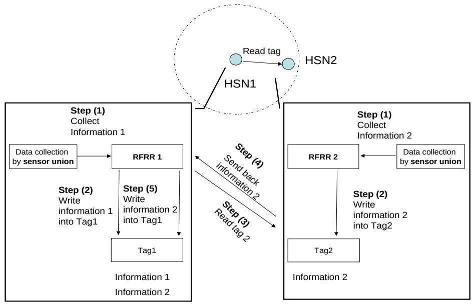

Figure 8. The replication process of two HSNs

tem can reduce the packet dropping resulted from the non-purposed transmission and sequentially reduced resources consuming. It is true that such proactive replication method will bring some security problems. Therefore, In other to increase the transmission security, some encryption techniques or authorization methods[32, 25, 5] can be applied into the HRW. The detailed discussions of security is out of the coverage of this paper.

4.4 Tag Management

With the rapid development of the hardware technology, the capacity of the RFID tag becomes increasingly large. Currently, the RFID tag with capacity as 32kb has already existed in the market which is big enough to store some simple information as figure 5 shows. However, HSN still adopts some tag information management methods to guarantee a high performance of the packet replication. Figure 5 shows the data structure of a RFID tag.

(1) Since in the tags, the information with the oldest created time has higher possibility that one of its replicas has already been received by the RFID readers, therefore, when the buffer is nearly full, the new created data will replace the oldest data.

(2) As figure 5 shows, each HSN holds a time stamp. When the HSNs move into the transmission range of GRFID reader, the GRFID reader will read the tag of the first meeting HSN and set the time value of its time stamp as the latest time value in the receiving record and then erase the tag of the communicating HSN and read the next HSN. Initially, the value of each node's time stamp is 0.

(3) During the information transmission, only the information with created time bigger than the time stamp are recorded by the HSN readers. For example, suppose the time stamp of a HSN is 11230327 which represents the information is created at 03 27 am, Nov. 23th. Therefore, the information that is created before this time will be ignorant by the HSN in the information transmission. It helps HSN avoid recording those outdated or uploaded information which increase the unnecessary overhead in the transmission. In addition, the HSN reader only records the information that has not been recorded in the tag currently, to prevent the same information from overlapping in the tap.

5 Performance Evaluation

In this section, we implement HRW system with Spray and Wait routing protocol [29] and Epidemic routing protocol [31] respectively to compare the performance of direct transmission in the traditional RFID system. "Direct" in the figure denotes the direct transmission adopted by traditional RFID system. In the "Direct", the information collected by a node will be kept in the tag until the sensor reach the range of any readers. In the Spray and Wait routing protocol, a packet is initially replicated to a certain number of nodes, which store the packet until one of these replicates reach the range of any RFID reader. In the Epidemic routing protocol, the packets of the node are replicated to other nodes a TTL (Time to live) hops. The simulation is built on a custom discrete event-driven simulator [28]. Random waypoint model is used as nodes' movement model. Each node wait for a pause time randomly chosen from $(1-5)$s, then moves to another random position with a speed chosen between 1 to 10m/s. This scenario consists of a $600m \times 700m$ area where 50 nodes are identical, independent distributed (IID) placed. These 50 nodes represent 50 precious animals living in a certain environment. The RFID readers are also IID placed. In this scenario, each node generates a new packet every 10s in active state. The active time of each node are randomly choose between 10-15s and the sleep is choose from $0-10$. All the simulations have been executed for 10 times with the simulation time 1000s. The warming time is 100s. We set the hop count of the Epidemic routing is 6 hops. the number of replicate copy of HUM and Spray and wait routing is 10.

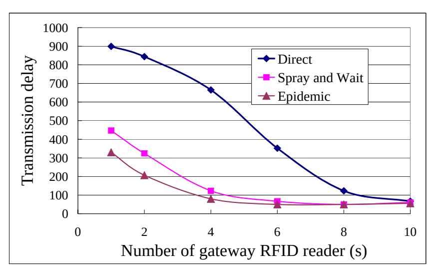

Figure 10. Transmission delay versus different number of GRFID readers

5.1 Comparison of Packet Delivery Delay

In this experiment, the number of GRFID reader is set as 5. Figure 9 presents the transmission delay with different reading ranges $R = 20m$ and $R = 40m$ of the RFID reader. It is very easy to find out that as the reading range of the node increase, the transmission delay of all these three protocols decrease. The reason is very intuitively that, a

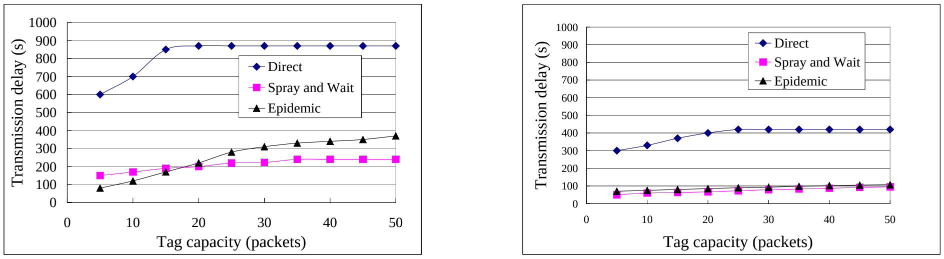

Figure 9. Transmission delay versus tag capacity

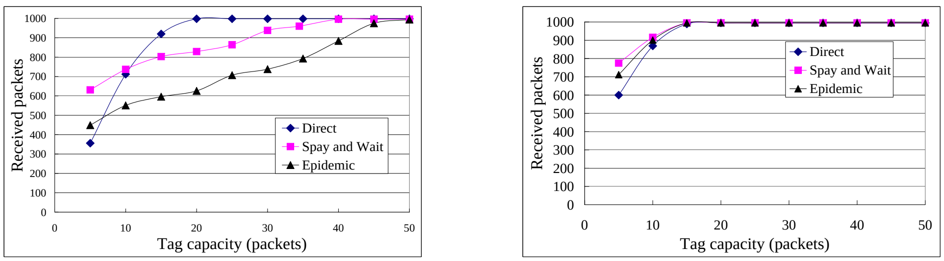

Figure 11. Delivery ability versus tag capacity

larger reading range makes it easier to find other neighbor nodes, which may either be the RFID readers or promising relay nodes which is moving to a RFID reader. Moreover, the speed of the electromagnetic wave moves much faster than the moving node, thus message delivery delay with larger transmission range will be less. It is also very interesting to find out that increasing the queue size, the delay for messages is also increased. It is not surprising, since the increased delay is resulted from those extra delivered messages which were dropped at smaller queue sizes, and there is no re-transmission function for those dropped packets in the simulator. With the increase of the buffer size, those dropped packets are able to reside in the queues long enough to be delivered to their destination.

On the other hand, the comparison of three protocols indicate that the direct transmission which used by traditional RFID system can have a comparable good performance only when it has a bigger transmission range. However, such big transmission power will consume enormous battery energy which is precious to the HSNs. Therefore, HRW significantly outperform traditional RFID system for the energy efficiency consideration.

Figure 10 shows the change of the transmission delay versus the number of GRFID readers. We fix the capacity of the HSN to 30 packets, and the reading range of the GRFID and HSN reader to 30m. It is very easy to find out that, with the increase number of GRFID readers, delay of all protocols are reduced sharply. However, even with a small number of GRFID readers, the Spray and Wait protocol and epidemic protocol are still performed much better than direct transmissions. The performance of the direct transmission can be comparable with other two protocols only when there are 10 GRFID readers in the system. Since adding a GRFID reader usually costs a lot, HRW is more profitable than the tradition RFID system for the economic consideration.

5.2 Comparison of the Delivery Ability

Figure 11 indicates that as the queue size increases, so does the number of the message delivered to their destination. In addition, as the transmission range of the mobile node increases, the received number of messages also increased. The reason is that with the increasing reading range, it is more likely for a certain node to meet the GRFID reader or to find more neighbor nodes for the information replication. On the other hand, a larger queue size means more messages can be buffered, and the risk of throwing away a message decreases. All these factors can enhance the delivery ability of HRW.

Meanwhile, Figure 11 also shows that the direct transmission suffers from more congestion than other two protocols when a tag has small capacity. It is because the transmission delay of direct transmission is much longer than the other two protocols, leading to the host has much less free buffer than the host with other two protocols. Therefore, since the capacity of the tag is normally limited and precious in HSNs, the traditional RFID system is not a wise choice for inhabitant or Health Monitoring application.

6 Conclusions

Radio Frequency Identification (RFID) system and Wireless Sensor Networks (WSN) system has been playing important role in industry and academic field based on their individual characters. RFID is good at identification management while WSN is adept in data collection and dynamic data transmission. However, very less effort is made to integrate the RFID system and WSN system to explore more novel applications such as precious animal inhabitant monitoring (e.g. tiger or panda monitoring) and patient health monitoring (e.g. neuropathy or HIV patient), in which the real time information of each individual object is most important. In this paper, we propose a specific system call Hybrid RFID and WSN System (HRW) to integrate the RFID and WSN technology, which overcomes their disadvantages and puts their advantages to a good cause. The HRW is composed of Gateway RFID readers (GRFID) and Hybrid Smart Nodes (HSN). Instead of waiting each tags being read by the RFID readers, the information in HSNs can be replicated among its neighbor nodes based on a special reduced functional RFID readers in HSNs . The packets are sent to GRFID readers when one of he replicas move into the range of GRFID reader. Some tag capacity management methods are also used to increase the transmission efficiency. Simulation results show that the HRW outperforms traditional RFID in habitat, environment and health monitoring in terms of the cost of the deployment, updating delay and tag capacity requirement. In the future, we are planing to implement it onto the test-bed, to explore further commercial usage.

Acknowledgements

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