

A Hierarchical Structure based Reader Anti-Collision Protocol for Dense RFID Reader Networks

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Abstract— Recently, RFID systems have been widely applied in many applications. And as many RFID readers are being deployed increasingly, an incorrect operation due to reader collisions deteriorates the quality of systems. Especially, as the number of channels relatively to the number of readers becomes scarce, the dense reader environment needs to be newly considered. In this paper, we present a hierarchical structure based reader anti-collision protocol for dense RFID reader networks. In this protocol, a reader should transmit pre-pulse and post-pulse to adjacent readers and make readers' hierarchy. By using the hierarchical structure, many readers efficiently can share the same channel for spectrum efficiency when the number of channels is insufficient. Moreover, the time coordination scheme among the adjacent readers and the frequency division scheme among the reader groups are used in order to avoid reader collisions. Consequently, reader collisions can be mitigated and the rate of channel occupancy is enhanced. Simulation results show that our proposed protocol has significantly better performance than the existing protocols.

Keywords— RFID, Reader collision, Anti-collision protocol, Reader hierarchy, Dense RFID reader

I. INTRODUCTION

Recently, RFID (Radio Frequency IDentification) has been widely used in many applications as an alternative technique of the existing bar code technique by using wireless frequency. Especially, RFID systems are spread far after the standardization in EPCglobal Class 1 Gen. 2 [1].

With increasing interests of RFID systems, there have been many challenging issues not yet solved. Especially, collisions among signals such as reader collisions and the tag collision are the typical trouble for development of the RFID systems. By resolving the collision problems, the read rate and throughput can be improved.

The tag collision problem arises when two or more tags transmit their data to the same reader simultaneously. There are two basic approaches to solve the tag collision problem: ALOHA-based protocols [1] and Tree-based protocols [2]. ALOHA-based tag anti-collision scheme is standardized by EPCglobal [1]. In this paper, the tag collision is not focused on.

Reader collisions are split into the reader-to-tag collision and the reader-to-reader collision [3]. The reader-to-tag collision occurs in the case that the reading range among multiple readers overlaps and the readers are trying to interro-

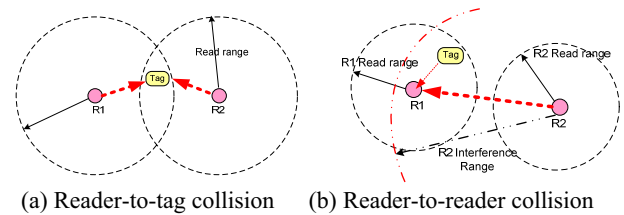


Figure 1. Reader collision problems

gate a particular tag at the same time as shown in Figure 1(a). In this case, the tag is not read by any reader though readers use different frequency bands, respectively.

The reader-to-reader collision occurs when a reader receives signals from a tag and other readers simultaneously as shown in Figure 1(b). When a signal of a reader R2 is transmitted to a reader R1 with a weak response signal of the tag which is previously issued by R1 concurrently, the R1 cannot identify the tag. Especially, this kind of collision occurs even when the reading range among readers is not overlapping.

To resolve the reader collision problems, some methods have been suggested for each collision case. For the reader-to-tag collision problem, time coordination scheme is typically used. Although adjacent readers use separate frequency channels, a passive RFID tag cannot distinguish signals from different frequency channels. Therefore, separation among readers in terms of time is required. For the reader-to-reader collision problem, EPCglobal UHF RFID standard [1] and ETSI UHF RFID standard [4],[5] use separate spectral planning. By making the readers and tags operate on different frequencies for data transmission, it prevents the tag response from colliding with signals from other readers and eventually the problem can be mitigated.

However, in addition to reader collisions, there is another serious problem being raised recently in RFID systems. As the number of readers increases, the available channels are relatively scarce due to the fixed number of channels. Like this, the case that the number of active readers is more than the number of available channels is called dense reader networks. In ETSI standards, only 4 channels with high power transmissions by readers are used [4],[5]. Therefore, there is lack of channel resources for readers when the readers are densely deployed, and an effective scheme to solve the problem in the dense reader environment is needed.

To overcome the limitation of frequency resources in the dense reader environment, ETSI TS 102 568 utilizes synchronization among the readers [5]. This enables multiple readers to transmit on the same channel using a hierarchical structure with the master and the slave mode.

Although resolving methods for the reader collisions and the dense reader environment problem are suggested respectively, there are little methods to be able to solve all the problems. In this paper, we propose a hierarchical structure based protocol which is solving not only the reader collisions, but also the problem of the dense-reader environment. This scheme solves reader collisions while conforming to the pre-pulse synchronization technique of ETSI TS 102 568 for the dense RFID reader environment. A reader transmits a pre-pulse to the adjacent readers and makes the hierarchical structure among readers. The reader which transmits the pre-pulse becomes a master reader of the occupied channel, and then the others which receive higher power than threshold power of the pre-pulse become slave readers of the channel. By using the hierarchical structure, many readers efficiently share one channel even when the number of channels is insufficient. Moreover, master and slave readers use the time coordination method through the slave reader contention in order to avoid reader collisions. Therefore, the throughput can be enhanced and reader collision can be avoided.

The outline of this paper is organized as follows. In Section II, we review the related work. Section III presents our proposed protocol. Section IV describes the simulation model and discusses the result of our simulation, and the conclusion is provided in Section V.

II. RELATED WORK

In this section, we present collision avoidance protocols in ETSI standard and the reason why this protocol cannot be directly applied to reader collision problems.

A. ETSI EN 302 208

ETSI EN 302 208[4] is an evolving standard being developed for RFID reader. It is CSMA based protocol called "Listen before talk" (LBT). Prior to communicate with tags, the reader listens on the data channel in order to confirm the particular channel condition. If the channel is idle for that time, a reader chooses the selected channel and starts reading tags in read range. If the channel is occupied by other readers, the reader waits a random back-off time or chooses another channel which could be used. It is that a reader should have a listen time during 5ms, a transmit window up to the 4s time limit, and a 100ms off period after channel occupied.

Although multiple readers occupy each own separated channel using the ETSI EN 302 208 protocol, the reader collisions are still an inescapable. For example, multiple readers which are located closely attempt to communicate with the tags in the overlapping range at the same time. Then the received signals from the readers collide at a tag though the readers occupy the different channels. Therefore, every reader located closely can't interrogate the tags in overlapping range because of collision problems.

B. ETSI TS 102 562

ETSI TS 102 562[5] was proposed to support ETSI EN 302 208. It has been written in response to a market requirement to operate many interrogators simultaneously in close proximity with each other. ETSI EN 302 208 protocol cannot satisfy a market requirement at the dense-reader environment. An alternative method of an operation has been devised in which multiple readers can share the same channels. This technique is spectrum efficient and relies on a process called synchronization. A reader which occupies an idle channel at the first is to be a master reader of the channel. The master reader broadcasts pre-pulse and optional data to adjacent readers which scan the channel and readers which receive pre-pulse and optional data from the master reader to be slave readers of the channel. Provided that the channel remains occupied by the master reader, the slave reader may transmit at any time within the 4 s transmit window. Also, the slave reader can be a master reader of other channels if they are possible to occupy.

However, it has problems to apply to the current RFID industry because slave readers can interrogate the tags anytime within a transmit window of a master. Therefore, they would make reader collision problems as an increase of the number of readers. Nevertheless, if a slave reader opportunistically interrogates the tags when a master reader does not works, overall throughput will be improved at the dense RFID reader environment with high data traffic situation.

III. THE PROPOSED PROTOCOL

Using a basic form of conventional LBT and existing methods of the pre-pulse synchronization technique of ETSI TS 102 562, we will propose other additional techniques in order to avoid reader collisions and increase the spectrum efficiency.

A. Band scan

When the reader is turned on, the reader always senses entire usable channels in order to recognize an operation of readers in channel zone. When there is no action of adjacent readers in channel zone, a triggered reader should be a master and start to the master reader operation by occupying the selected channel. The channel zone is maximum range that a reader interfere the other reader operation by reader collisions, and the range is defined by received power level of pulse signals. At the scanning time, a reader receiving the pulse signals from the master reader should be a slave and begin to operate as the slave reader. The slave readers do not work with a master reader at same time because it is to avoid reader collisions.

B. Master reader operation

If there is no action of readers in channel zone, a triggered reader starts to interrogate tags by becoming a master. First, a reader selects a channel among candidate frequency channels. After that, the reader has to recognize the channel condition whether busy or idle. If the channel is not busy, the reader should operate using the selected channel.

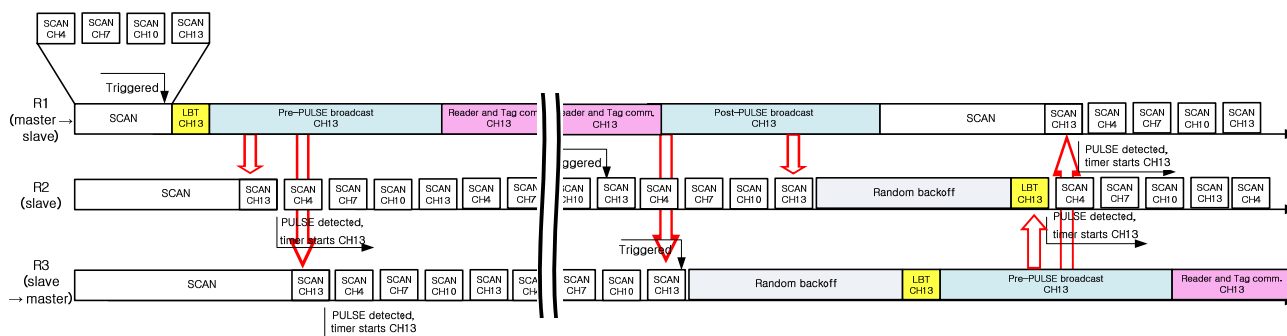


Figure 3. Example of proposed scheme

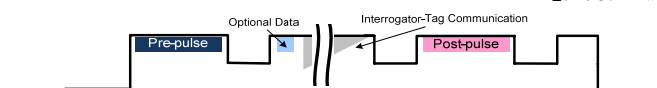


Figure 2. Signal transmitted by a master reader

The reader that occupies the channel broadcasts the pre-pulse to adjacent readers in order to report its operation and make reader hierarchy. The pulse duration is long enough to be recognized at slave readers. The pre-pulse transmitted by a master reader indicates as Figure 2. It can include optional data that is not defined and may be proprietary to individual manufacturers. Manufacturers may also interleave the transmission of the optional data with the interrogation of tags.

After the master reader sends the pre-pulse, it starts to interrogate tags in its read range. When all of tags in read range are interrogated, the reader broadcasts the post-pulse in order to inform adjacent readers the end of an operation. After the master operation, slave readers recognize the end of master's works by receiving post-pulse and occupy the channel in succession through contention of readers.

C. Slave reader operation

A reader that receives the pulse signal from the master reader should be a slave reader. The slave readers would sense not only the channel which is occupied by the master reader but also the other channels and make an operation table.

When the reader receives the pre-pulse, the reader writes information about pulse to an operation table. An operation table includes the information about power threshold of pulse and pulse type. An operation table helps a slave reader to avoid reader collisions. The table includes the result of sensing a channel status that readers remember received pulse level and pulse type from adjacent readers.

Through an operation table, they should determine whether join to contention of slave table readers or not. If a reader receives pre-pulse and then receives post-pulse after some time at same channel, the reader will offset the pulse information at this channel and join to contention to occupy the channel when all of channels are clear. However, at this time if the reader already received the pre-pulse at the other channel and the pulse level was higher than threshold, the reader could not participate in contention at this time.

All of readers except the master reader should make an operation table. The table is the most important thing in order to avoid reader collisions between readers, because slaves could know on an operation status about adjacent readers.

D. Reader contention & new master reader

The slave readers that receive the post-pulse participate in the contention of slave readers. Readers should contend with triggered readers during contention window for channel access. It is the method for slave readers to occupy a channel without collisions after receiving the post-pulse. As soon as a slave reader receives the post-pulse, it waits random back-off time in order to avoid collisions. After the random back-off time, the reader scans the channel which was occupied by a master reader. If the channel is idle, the reader should be a new master and operate at this channel. Otherwise, a reader receives a pre-pulse from the new master reader, and then become a slave reader again.

Figure 3 describe the example of the proposed scheme operation by 3 readers which is located in same channel zone. First of all, R1 should be a master reader and interrogate the tags. After R1 operation, R3 should be a new master reader through contention with R2. R3 subsequently interrogates the tags and R2 should be a slave reader again.

IV. SIMULATION RESULTS

We have simulated the UHF RFID network in MATLAB at four channels, 4, 7, 10 and 13, using ETSI TS 102 562 band plan [5]. Our simulation model has the following characteristics.

- No inter channel interference between channels
- Free space propagation path loss, no fading
- A reader interrogate the tags in its read range during 1s without the tag collision
- ETSI EN 302 208 is LBT protocol with a basic form that is a minimum listen time of 5ms and maximum reading time of 4s
- ETSI TS 102 562 is also LBT protocol with a basic form of ETSI EN 302 208. It is developed from ETSI EN 302 208 and readers should make readers' hierarchy by occupied channel and transmission of pre-pulse
- The scan duration of each channel and the pulse duration are set to 5ms and 40ms respectively.
- Each reader is assumed to generate packets randomly and independently. Such packet generation is called the Poisson distribution.

RFID systems are usually used in a supermarket or a warehouse. In this case, readers are setting on the shelf side by side for interrogation of tags and they are operating periodical-

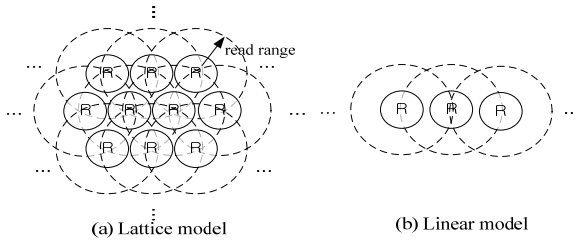


Figure 4. Configuration of readers

ly. Based on this scenario, we could design representative simulation scenarios to the worse case and the better case. The worse case is the configuration of readers to be lattice as Fig. 4(a) because readers are interfered to each other in the lattice model. The better case is the configuration of readers to be linear as Fig. 4(b) because readers are interfered only with beside readers.

In order to determine the efficiency of channel use, throughput is used for performance measurement. Throughput is the ratio of total time to time for interrogating the tags.

$$\text{Throughput} = \frac{T_{R-T \text{ comm.}}}{T_{\text{Total}}} \quad \begin{array}{l} T_{R-T \text{ comm.}} : \text{the time that readers interrogate tags} \\ T_{\text{Total}} : \text{Total simulation time} \end{array}$$

From the above equation, we can know how much overall channel use effectively at not only the proposed scheme but also the existing schemes in comparison with the offered traffic [6] that the total quantity of the packets in a time interval. For simulation, we would configure readers to two models as varying the offered traffic at the dense reader environment using 24 readers and 4 channels scenario.

Fig. 5 shows the throughput comparison with the lattice model using 24 readers with varying offered traffic. If traffic increases, TS 102 562 protocol is better performance than EN 302 208 protocol because a slave reader opportunistically interrogates the tags when a master reader does not works within master transaction time.

The proposed protocol shows the high throughput than the other two protocols because conflicts almost do not occur even in the dense reader condition. Also channels are used more efficiently because of subsequently acts of a slave reader after the master reader operation.

Fig. 6 shows the throughput comparison with the linear model. In this model, we can get the similar results of the throughput with the lattice model. Overall, the linear model scenario shows better performance than lattice model scenario. We can find its reason in the effect of interference between readers. The linear model receives interference only the side readers but the lattice model receives interference from around maximum six readers.

V. CONCLUSIONS

In this paper, we propose a hierarchical structure based protocol to avoid reader collisions for the dense RFID reader environment. In this protocol, readers in channel zone make a reader hierarchy and operate one by one in order to avoid reader collisions. Therefore, the proposed scheme of through-

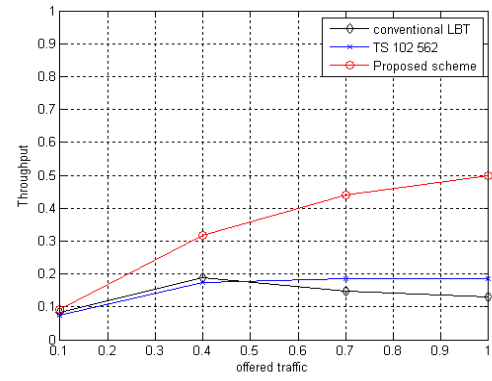


Figure 5. Simulation result with lattice model (24 readers, 4 channels)

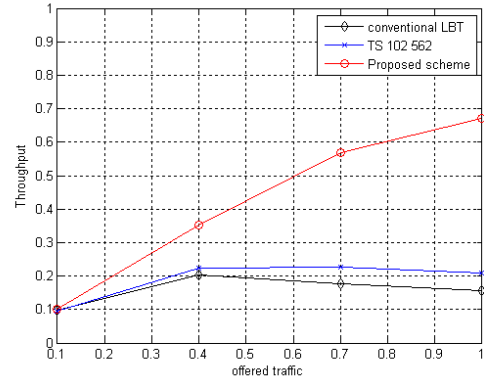


Figure 6. Simulation result with linear model (24 readers, 4 channels)

put improves than the existing protocols because conflicts almost do not occur even in the dense reader condition. Also channels are used more efficiently because of subsequently acts of slave reader after the master reader operation. At a comparison of different models, the linear model has better performance than the lattice model because readers interfere in only the side readers using the linear model.

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REFERENCES

- [1] EPCglobal, "EPCTM radio-frequency identification protocols class-1 generation-2 UHF RFID protocol for communications at 860 MHz-960 MHz Ver.1.2.0," EPCglobal Standard Specification, 2008.
- [2] J. Myung, W. Lee, and J. Srivastava, "Adaptive binary splitting for efficient RFID tag anti-collision," *IEEE Commun. Lett.*, vol. 10, no. 3, pp.144-146, Mar. 2006.
- [3] D. Engels and S. Sarma, "The reader collision problem," in *Proc. IEEE Int. Conf. Syst., Man, Cybern.*, Oct. 2002, pp. 641-646.
- [4] ETSI, "ETSI EN 302 208-1 v1.1.2: electromagnetic compatibility and radio spectrum matters (ERM); radio frequency identification equipment operating in the band 865 MHz to 868 MHz with power levels up to 2W; part 1: Technical requirements and methods of measurement," 2006.
- [5] ETSI, "ETSI TS 102 562 v1.1.1:electromagnetic compatibility and radio spectrum matters (ERM); Improved spectrum efficiency for RFID in the UHF Band," 2007
- [6] H. Harada and R. Prasad, *Simulation and software Radio for Mobile Communications*, Artech House, 2002.