AUTO–ID LABS

Efficient Novel Anti-collision Protocols for Passive RFID Tags

Three methods for fast tag identification: bi-slotted tree based RFID tag anti-collision protocols, query tree based reservation, and the combining method of them

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Abstract

In this paper we discuss how to reduce identification time with a given number of tags in the field of an RFID reader. This paper proposes three methods for fast tag identification: bi-slotted tree based RFID tag anti-collision protocols, query tree based reservation, and the combining method of them. Theses proposed methods can be used for enhancing the identification speed of RFID systems.

1 Introduction

Radio Frequency Identification (RFID) is one of automatic identification methods such as a barcode, a magnetic sensor, and IC card and the like; and means a technology used for wirelessly identifying data stored in a tag's microchip by using RF waves.

Ubiquitous tagging is a paradigm where everything related has a unique tag associated with it. Picture the scenario that every object in the world can be uniquely identifiable with some form of electronic tags. This would have tremendous benefits in terms of tracking and identifying an object, making ubiquitous identification possible. As ubiquitous identification systems have become commonplace in access control and security applications areas, RFID systems are increasingly being used a s the automated identification system for these applications.

Object identification problem requires the identification of multiple objects at the same time reliably and minimal user intervention. Conventional techniques like bar codes are not so efficient at solving this problem. Optical barcodes suffer from several drawbacks, but RFID can overcome the drawbacks of the barcode. RFID is regarded as a substitute technology for the barcode which is currently used in distribution and circulation fields and financial services.

However, RFID has problems with the reliability of the identified data and the delay of the technology standardization; researches on anti-collision protocols have been required to improve the characteristics of a read rate and an identification speed.

Meanwhile there are generally two types of collisions: reader collisions and tag collisions. The reader collision indicates that a plurality of readers requests inquiries to one tag concurrently, so it is confusing for the tag to identify the inquiries. On the contrary, the tag collisions indicate that a plurality of the tags responds to one reader's inquiry simultaneously and therefore the reader cannot identify any tag. Especially, in case of the tag collisions for passive RFID systems, the tags which are currently used or which will be used in the large scale distribution and circulation fields are low-cost passive tags, resulting in some restrictions such as complexity of calculating, and cost increase by the memory size and the battery installation when applying usable anti-collision protocols thereto.

RFID tag anti-collision protocols proposed up to now to solve the tag collisions can be grouped into deterministic methods and probabilistic methods. The deterministic methods, which are on the basis of tree based protocols, identify tags by constructing binary trees through the used of binary bits of tag IDs and then by circulating the nodes of the trees. Such deterministic methods can be classified into a memory based algorithm and a memoryless based algorithm. In contrast, the probabilistic methods are based on slotted aloha based protocols. They can be classified into an ID-slot algorithm and a bi-slot algorithm. According to the suggestion of EPC global, each of them is adopted in Class 0, Class 1, and Class 1 Generation 2 proposed to ISO/IEC 18000-6C of the International Standard Organization.

In this whitepaper, we focus on the anti-collision schemes to improve the readability, identification speed, of low-cost passive RFID systems. Generally, the tree based algorithms send a prefix twice except the last bit in the same tree depth. Focusing on this characteristic, both the prefix overhead and the iteration overhead are reduced by the time divided responses depending on whether the collided bit is ‘0’ or ‘1’. Thus we call the protocols taking the time-divided responses as bi-slotted query tree algorithm (BSQTA) and bi-slotted collision tracking tree algorithm (BSCTTA.)

Also, RFID systems do not have to use the whole length of tag IDs for resolving each tag in the field of a reader. Thus, the tags generate the reservation sequences, which are 16-bit random numbers (RN16s), for assigning slots to transmit their IDs, and the reader identifies tags with the query tree algorithm using the RN16s. During the identification process, the reader calls a tag with the received RN16 for collecting the tag ID when a RN16 is identified by the reader. Thus, we call the proposed protocol as 16-bit random number aided query tree algorithm (RN16QTA).

Furthermore bi-slotted query tree based reservation protocol, 16-bit random number aided bi-slotted query tree algorithm (RN16BSQTA), is presented as a substitute of the existing RFID tag anti-collision protocols. This proposed protocol takes the advantages of BSQTA and RN16QTA.

We demonstrate via simulation results that the proposed bi-slotted query tree based reservation protocol achieves considerably better performance than the existing tag anti-collision protocols implemented in EPC Class 0, Class 1, and Class 1 Gen.2. Besides, the proposed algorithm requires less time consumption for tag identification than the conventional schemes.

The content of this whitepaper is shown as follows. First we present the main components of RFID systems in Section 2. In Section 3, we analyze the RFID collision problem and then the previous works on RFID tag anti-collision protocol are reviewed by deterministic methods and probabilistic methods considered on each EPC class’ protocols in Section 4. In Section 5, we describe the proposed RFID tag anti-collision protocols and the performance evaluation is explicated in Section 6. At last, the summary and conclusions are discussed in Section 7.

2 Components of RFID Systems

RFID systems are composed of three main components as shown in Figure 1:

- One or more RFID tags, also known as transponders (transmitter/responder), are attached to the objects to count or identify. Tags could be either active or passive. Active tags are those that are partly or fully battery powered, have the capability to communicate with other tags, and can initiate a dialogue of their own with the tag reader. Passive tags, on the other hand, do not need any internal power source but are powered up by the tag reader. Tags consist mainly of a microchip and coiled antenna, with the main purpose of storing data.
- A reader or transceiver (transmitter/receiver) made up of an RFI module and control unit. Its main functions are to activate the tags, structure the communication sequence with the tag, and transfer data between the application software and a tag.
- A Data Processing Subsystem, which can be an application or database, depending on the application.

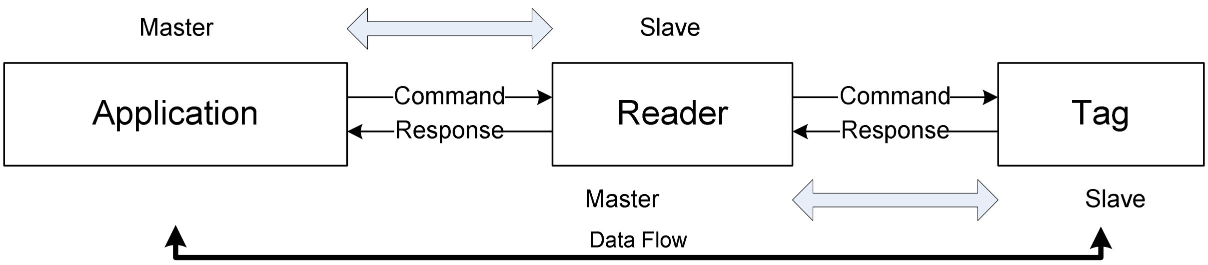

Figure 1: A Master-Slave Principle in RFID Systems

The application software initiates all readers and tags activities. RFID provides a quick, flexible, and reliable way to electronically detect, track and control a variety of items. RFID systems use radio transmissions to send energy to a RFID tag while the tag emits a unique identification code back to a data collection reader linked to an information management system. The data collected from the tag can then be sent either directly to a host computer, or stored in a portable reader and up-loaded later to a computer.

3 RFID Anti-Collision Problem

3.1 RFID Collision Problem

Simultaneous transmissions in RFID systems lead to collisions as the readers and tags typically operate on the same channel. To understand this, we will use the concepts of interrogation region and interference region of RFID readers. The interrogation region is the region around a reader where a single tag can be successfully read in the absence of any interference from another tag or reader. The interference region is a similar region where the signal from the reader reaches with sufficient intensity so that it interferes with a tag response.

Without any coordination between the reader and the tags, the responses from the tags to the reader can collide causing the IDs of the tags to become illegible to the reader. Therefore, the RFID collision problems could be summarized and classified into the tags identification problem and reader collision problem.

3.1.1 Tag identification problem

The tags identification problem is associated with how to efficiently develop an anti-collision protocol in RFID tags. It can be defined as to identify multiple objects reliably without significant delay by utilizing minimal transmission power and computation. Anti-collision protocols that address this problem cannot be directly applied to the tag identification problem due to various constraints. In multi-access protocols, the main factors for performance evaluation include throughputs, packet delay, and stability. However, in RFID arbitration, total time to identify all objects and the power consumed by tags are more relevant. Abraham claimed minimal delay, power consumption, reliability & completeness, line-of-sight independence, robustness, and scalability are all the desirable characteristics of the collision resolution protocol for communication between the tag and the associated reader. Furthermore, interference may be either frequency interference or tag interference. Frequency interference occurs when physically close readers communicate at the same time with the same frequency. Tag interference, on the other hand, occurs when neighboring readers attempt to communicate with the same tag at the same time.

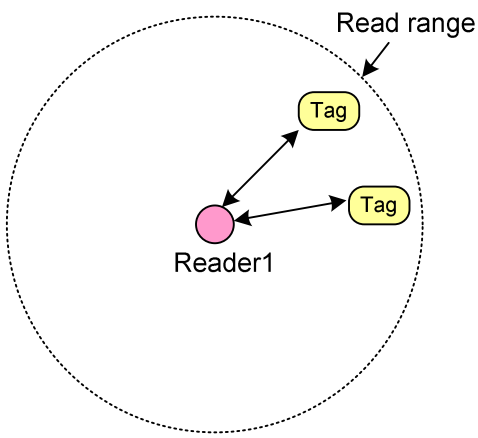

Figure 2: Tag-to-tag interference

3.1.2 Reader Collision Problem

Readers with interrogation zones intersected can interfere with one another and it will often reach to the point where neither readers will be able to communicate with any tags located within their respective interrogation zones. Readers may also interfere with another's operation even if their interrogation zones do not overlap. Such interfere is due to the use of radio frequencies for communication, and is very similar to the interference experienced in cellular phone systems. Interference detected by one reader and caused by another reader is referred to as a reader collision, and the problem to minimize reader collisions is referred to as the reader collision problem. There are two primary types of controllable interference experienced in RFID systems – reader-to-tag interference and reader-to-reader interference.

3.1.2.1 Reader-to-tag interference

Reader-to-tag interference occurs when one tag is simultaneously located in the interrogation zones of two or more readers and more than one reader attempts to communicate with that tag at the same time. In this type of interference, each reader may believe it is the only reader communicating with the tag while the tag is in fact communicating with multiple readers at the same time. The simple nature of RFID communication can cause the tag to behave and communicate in such an undesirable way to interfere with the communicating readers' capabilities to communicate with that tag and other tags in their respective interrogation zones.

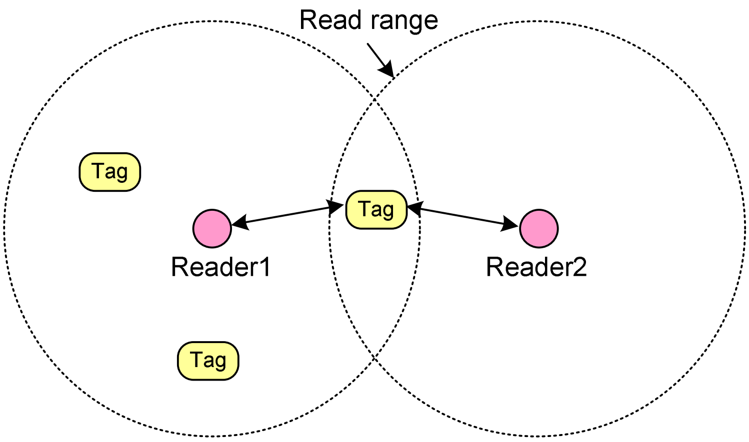

Figure 3: Reader-to-tag interference

3.1.2.2 Reader-to-reader interference

Reader-to-reader interference occurs when a reader transmits a signal that interferes with the operation of another reader, thus preventing the second reader from communicating with tags in its interrogation zone. This type of interference occurs when the signal transmitted by a reader is of sufficient strength and received at a second reader that the signal masks or jams communication from tag to the second reader. Interrogation zones will not be needed to have an overlap for reader-to-reader interference to occur.

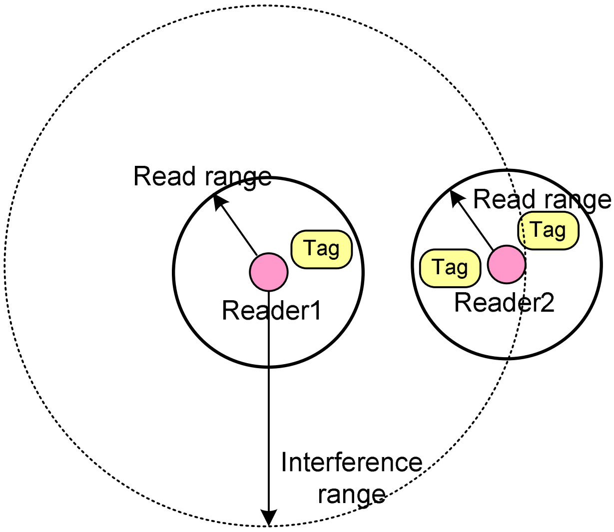

Figure 4: Reader-to-reader interference

3.2 Constraints and Desired Characteristics

The problem can be divided into the following sub problems.

- To identify multiple objects reliably without signification delay, utilizing minimal transmission power and computation (tag to tag reader communication).
- Communication between the readers and the tags.
- Communication between the readers and the centralized data base server.

The first sub problem is critical for the efficient development of the solution. It can be defined as a special case of multiple-channel-access communication problem. Anti-collision protocols that address this problem cannot be directly applied to the tag identification problem due to various constraints, which make this problem unique. The constraints are as follows:

- Lack of internal power source in the passive tags. This requires the tag reader to power-up these tags whenever it needs to communicate with them.
- Total number of tags is unknown.
- Tags cannot communicate with each other. Hence collision resolution needs to be done at the tag reader.
- Limited memory and computational capabilities at the tag. Thus the resolution protocol must be simple and incur minimum overhead from the tag's perspective.

All of the above constraints can be viewed as a requirement to keep the tags as cheap as possible. In multi-access protocols, the main factors for performance evaluation are throughput, packet delay, and stability. However, in RFID arbitration, total time to identify all objects and the power consumed by tags are more relevant. The desirable characteristics of the anti-collision protocol for communication between the tag and the tag reader are listed in Table 1.

Table 1. The desirable characteristics of the anti-collision protocol

Characteristics	Description
Minimal Delay	Time taken for identification of all the tags should be low. From a user point of view, this should not be perceptible.
Power consumption	Due to the absence of an internal power source, power consumed by the tags should be minimal. The amount of power consumed is influenced by the total number of replied sent by each of the tags. An efficient protocol will minimize the messages between the tag and tag reader.
Reliability and Completeness	All the tags in the range of the tag reader should get identified correctly
Line-of-sight Independence	The object attached with the tag can be located anywhere as long as they are in the range of the tag reading device.
Robustness	The protocol should work irrespective of environmental conditions.
Scalability	The protocol should be scalable to accommodate an increase in the number of tags.

4 Existing Protocols for RFID Tag Anti-collision

RFID tag anti-collision protocols proposed up to now to solve the tag collisions can be grouped into deterministic methods and probabilistic methods.

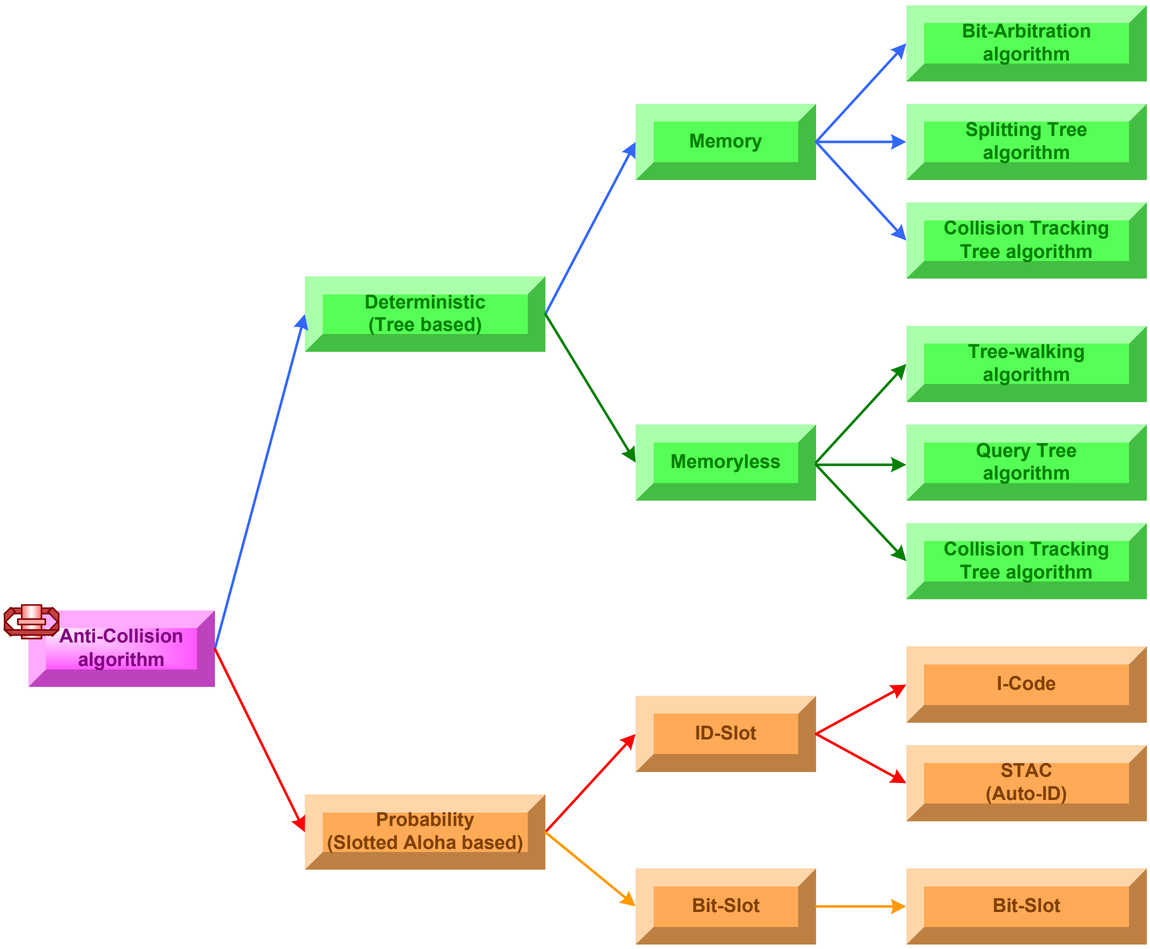

Figure 5: Taxonomy of the existing tag anti-collision protocol

The deterministic methods are on the basis of tree based protocols such as a bit-arbitration algorithm, a splitting tree algorithm (memory based protocols), a tree working algorithm, a query tree algorithm, and a collision tracking tree algorithm (memoryless based protocols). These algorithms split colliding tags into two subgroups until all tags are identified. The probabilistic methods are based on slotted ALOHA such as an I-Code algorithm, a STAC algorithm, and a bit-slot algorithm. The ALOHA based protocols are designed to reduce the probability of occurring tag collisions how tags respond at the different time.

Since this whitepaper is focused on anti-collision protocols for low-cost passive RFID tag, we do not consider the memory based tag anti-collision protocol after now.

4.1 Tree based Tag Anti-Collision Protocols

4.1.1 Binary Tree Working Algorithm

A reader chooses '0' or '1' for the initiative. If the reader makes a choice, the identification process should keep the way of choice order when the tree splits at a node. Then the binary tree working algorithm (BTWA) is operated as follows:

Step 1. The reader transmits k-length prefix.

Step 2. Tags send (k+1)th bit if the first k bits of tag IDs are the same as the prefix.

Step 3. If the received bits collide, the extended prefix attached '0' or '1' to the prefix is retransmitted by the reader. If they do not collide, the received bit is attached to the prefix for the next prefix. If there is no response, the branch is ignored. Also, a collision occurs at the last bit of the tag IDs, the reader assumes there are two tags because of the uniqueness of the tag IDs.

Step 4. The reader repeats the procedure until all branches are searched.

4.1.2 Query Tree Algorithm

The query tree algorithm (QTA) is based on BTWA. The difference between QTA and BTWA is as follows:

Step 2. Tags send from (k+1)th bit to the end bit of tag IDs if the first k bits of tag IDs are the same as the prefix.

Step 3. If there is a collision, the extended prefix attached '0' or '1' to the prefix is retransmitted. Furthermore, if there is no collision, the reader identifies a tag corresponding to the detected ID, which is the connection of the prefix and the response.

4.1.3 Collision Tracking Tree Algorithm

The collision tracking tree algorithm (CTTA) is based on QTA except that this scheme uses collision tracking. The difference between CTTA and QTA is as follows:

Step 2. ***Tag***: the tags send their IDs from (k+1)th bit to the end bit if the prefix is the same as the first k bits of tag IDs. However, the tags stop sending their IDs when an ACK signal is received.

Reader: the reader checks whether a collision occurs or not in each bit on the received sequences, and transmits an ACK signal to stop being sent the tag IDs by the tags if there is a collision.

Step 3. If there is a collision at nth bit in the received sequences, the two new prefixes, 'the former prefix k bits + the received n-1 bits + 0 or 1', are retransmitted sequentially to the tags in the field of the reader. Furthermore, if there is no collision, the reader identifies a tag corresponding to the detected ID, which is the connection of the prefix and the response.

4.2 Slotted ALOHA based Tag Anti-collision Protocols

4.2.1 I-Code

I-Code is similar to the frame slotted ALOHA (FS-ALOHA). In FS-ALOHA, a reader gives the information, which includes read range, clock, and frame size, to tags. Then the tags choose a slot with random backoff time in a frame to send their IDs. If a tag is identified by the reader, the tag changes its state as `inactivated'. Do this procedure during the number of cycles determined by target accuracy in Markov process. How to choose a frame size with the unknown number of tags can be a good research subject.

4.2.2 STAC

STAC is based on FS-ALOHA. The only difference is that STAC reduces the waste of time caused by empty slots in a frame. In the FS-ALOHA algorithm, there is no consideration for empty slots which makes the algorithm inefficient. In the STAC algorithm, a reader sends the 'close slot sequence' to tags when an empty slot occurs. Thus, the empty slot interval is reduced.

4.2.3 Bit-Slot

The bit-slot algorithm is a kind of reservation based algorithm, which assigns the order of transmitting tag IDs by using the reservation sequences. With the reservation sequences, the overhead for assigning slots to transmit the tag IDs is reduced. In the bit-slot algorithm, tags send reservation sequences randomly generated by only one `1' and several `0's, and a reader checks the reservation sequences whether the positions of `1' in the sequences are collided or not. Then, the reader saves the list of the identical reservation sequences to call each tag, and communicates with each tag sequentially.

4.3 PS-ALOHA in EPC Class 1 Gen.2 Protocol

The performance of ALOHA based systems is usually measured by the throughput indicating the efficiency of a system, which can be expressed as the number of success slots over the total number of attempt slots. Typical ALOHA systems with a fixed frame size show good throughput only for the specific number of tags in the field of a reader, but the throughput decreases dramatically as the number of tags increases. To solve this problem, a dynamic frame slotted (DFS)- ALOHA algorithm is devised to maintain the good throughput for any number of tags, where its frame size is flexibly changed according to the number of tags.

EPC Class 1 Gen.2 protocol adopts the probabilistic slotted (PS)-ALOHA algorithm as its anti-collision scheme. Most parts of the PS-ALOHA in EPC Class 1 Gen.2 protocol are similar to the conventional DFS-ALOHA, but the algorithm has its own characteristics as follows:

1. **SLOTS CONTROLLED BY READERS**: Each slot is controlled not by the synchronized clock but by the commands of a reader. Thus, the reader makes a slot finish its duration when the slot is empty, and makes the next slot start for reducing the waste of time caused by the empty slot occurring in the middle of a frame.

2. **TEMPORARY IDs**: Instead of the tag IDs with dozens or hundreds of bits in a slot, the temporary IDs, which consist of 16-bit random numbers (RN16s), are used for the collision detection in a slot, and also used when the reader queries identified tags. The temporary IDs reduce the duration of the slots, and enhance the security of reader-tag communications because the randomly generated temporary ID is used as the key of taking the tag ID.

3. **STATES OF TAGS**: The identified tags change their states from ‘arbitrary’ to ‘acknowledged ’, and do not participate in the next inventory rounds (frames). Thus, the number of tags, which attends the next inventory rounds, decreases.

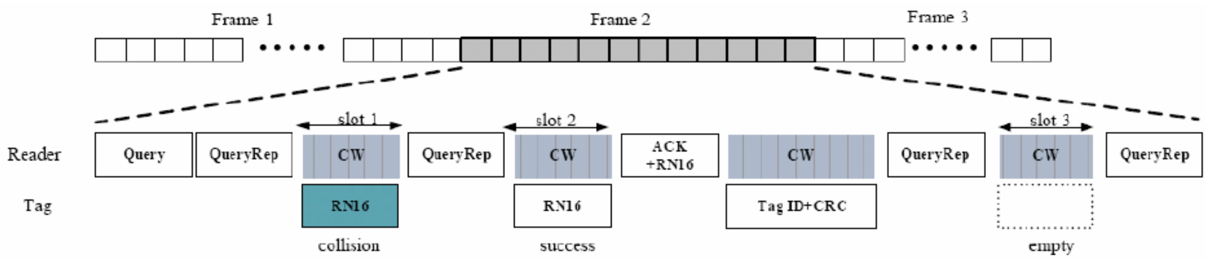

Figure 6: Multi-tag reply in EPC Class1 Gen.2 Protocol

Figure 6 briefly indicates the EPC Class 1 Gen.2 protocol. At first, a reader broadcasts the frame size and notifies the beginning of a frame to all tags with a Query command. After the frame is started, each tag generates a 16-bit random number (RN16) as a temporary ID, and selects a slot in the frame. Next, the reader proceeds to transmit a QueryRep command to the tags for being counted the slot index by the tags. The tags count the slot indexes, and backscatter their RN16s in their own slot time. If a collision occurs, the reader queries the next slot by sending another QueryRep command. If only one tag responds to the slot, the reader transmits an ACK command with the received RN16. Then, the tag replies its tag ID with 16-bit CRC redundancy bits to detect errors. After receiving the tag ID, finally, the reader checks errors, and transmits the QueryRep command if the tag ID is valid. Otherwise, the reader transmits a NAK command.

5 Proposed RFID Tag Anti-collision Protocols

Since the slotted ALOHA based algorithms cannot guarantee the 100% read rate, and experience significant performance degradation in the large amount of tags; this whitepaper considers the performance enhancement of the tree based algorithm. In this whitepaper, we propose two new efficient RFID tag anti-collision protocols, the bi-slotted tree based anti-collision protocols and the query tree based reservation protocol, and the protocol combining the two proposed protocols. With the proposed protocols, the RFID systems can achieve faster tag identification than the existing RFID tag anti-collision protocols.

5.1 Bi-Slotted Tree based Protocols

The aspect of bi-slotted tree based RFID tag anti-collision protocols, the bi-slotted query tree algorithm (BSQTA) as shown in Figure 7 and the bi-slotted collision tracking tree algorithm (BSCTTA) as shown in Figure 8, is that the existing tree based algorithms generally send two ‘n length inquiring bits’, which have the same first n-1 bits and the different last bit. Focusing on this characteristic, both the prefix overhead and the iteration overhead are reduced by the timedivided responses depending on whether the collided bit is ‘0’ or ‘1’.

The RFID systems can reduce the identification time with the procedure as follows:

Step 1. **REQUEST**: A reader sends n-1 length inquiring bits (prefix) to tags.

Step 2. **GROUPING**: Tags in the field of the reader respond their tag IDs to the reader if the inquiring bits are matched to the first n-1 bits of tag IDs.

- When the tags respond their IDs to the reader, they choose one of two time slots depending on whether nth bit is ‘0’ (first slot) or ‘1’ (second slot). Thus, the time slot indicates the value of nth bit.
- BSQTA: tags send their IDs from (n+1)th bit to the end bit.
- BSCTTA: tags send their IDs from (n+1)th bit to the time that ACK signal, which is sent from the reader when a collision occurs, is received.

Step 3. DECISION: Depending on whether collisions have occurred or not, the reader decides on proceeding procedure with the following conditions.

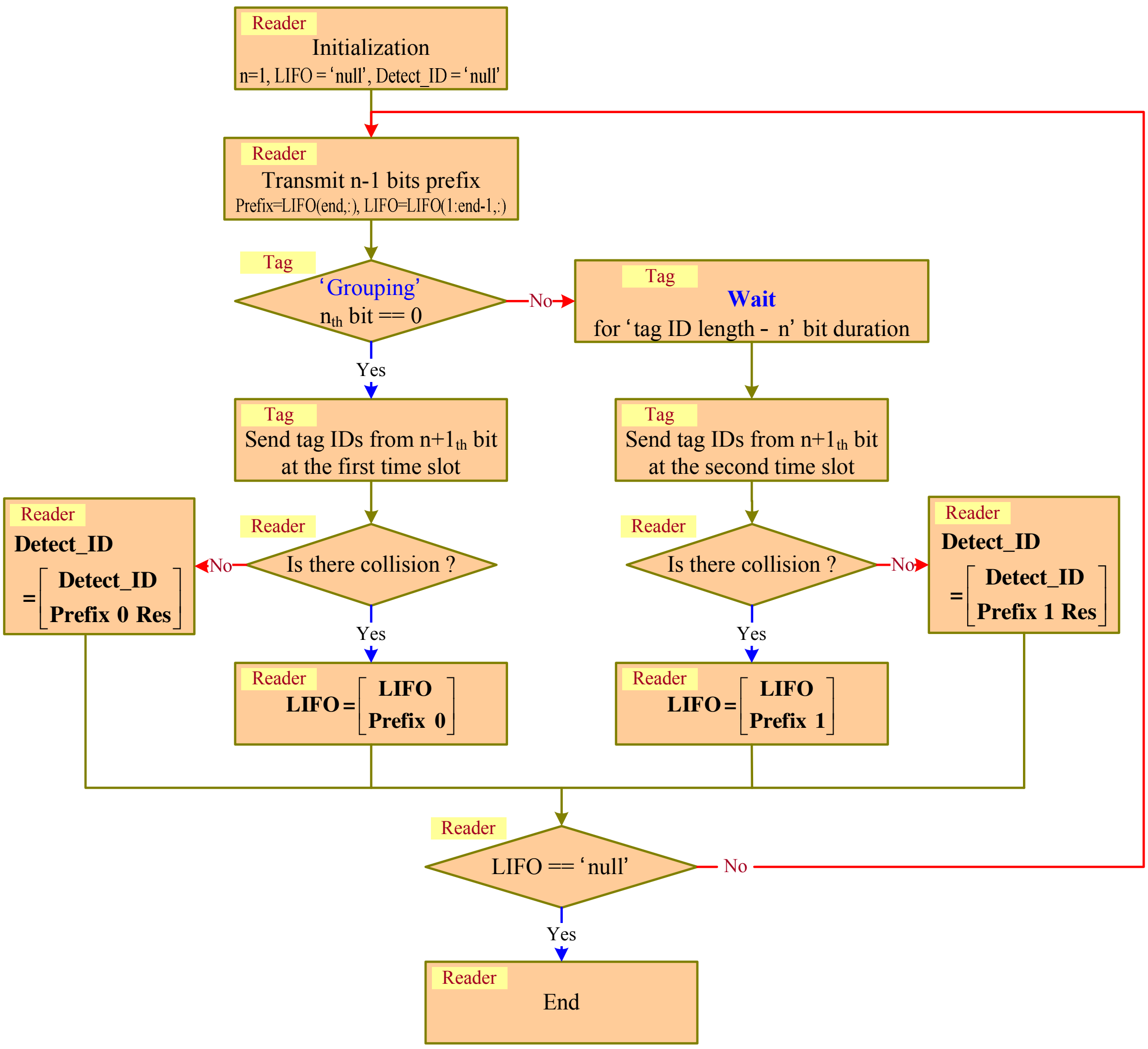

Figure 7: Flow Chart of BSQTA

- If there is a collision, the reader saves a new prefix at the last input first output (LIFO).

- BSQTA: the connection of n-1 length inquiring bits and the indication of the chosen slot
- BSCTTA: the connection of n-1 length inquiring bits, the indication of the chosen slot, and the bits received before collisions occur

 If a collision occurs at the last bit in tag IDs, the reader assumes there are two tags because of the uniqueness of the tag IDs.

 If there is no collision, the reader identifies a tag in the multi tags.

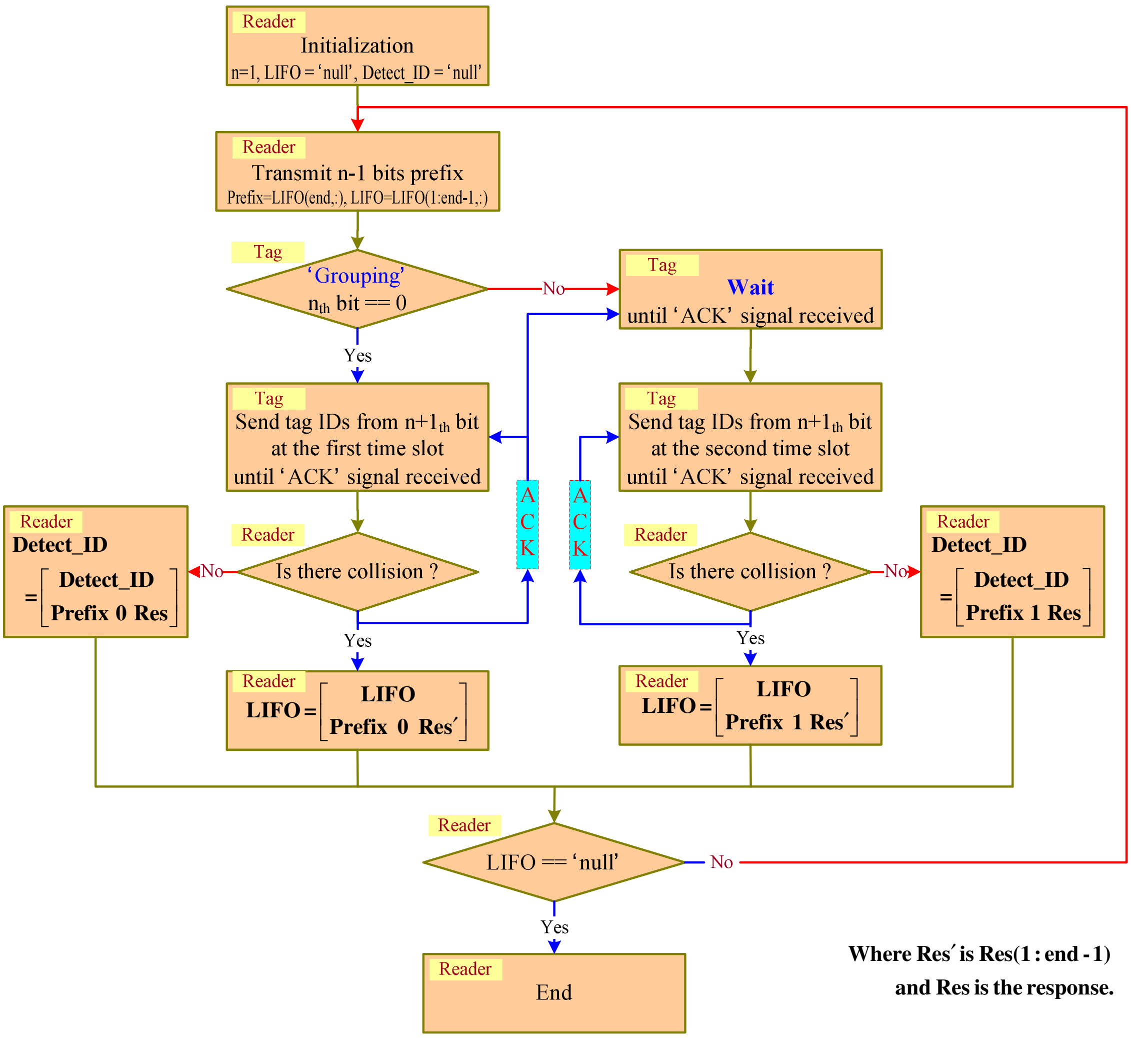

Figure 8: Flow Chart of BSCTTA

Step 4. Do these steps until the LIFO is 'null'.

With BSQTA and BSCTTA, we can reduce the average required prefix overhead for one-tag identification to 'half – 1bit' of that in the existing tree based RFID tag anti-collision protocols, QTA and CTTA, without any increase in the tag response overhead. Also, the average required iterations for one-tag identification are decreased as 'half '.

5.2 Query Tree based Reservation Protocol

RFID systems do not have to use the whole length of tag IDs for resolving each tag in the field of a reader. According to the characteristic of QTA and CTTA, QTA requires significantly more bits for both the average inquiring bits and response bits for one-tag identification than CTTA. However, since CTTA is not applicable to the low-cost passive RFID systems as we already mentioned, this performance can be the function of an arbitrary upper bound.

For enhancing the performance of the tree based algorithm, we apply the characteristics of EPC Class 1 Gen. 2 protocol to the query tree algorithm. In other words, the tags generate the reservation sequences, which are 16-bit random numbers (RN16s), for assigning slots to transmit their IDs, and the reader identifies tags with QTA using the RN16s. During the identification process, the reader calls a tag with the received RN16 for collecting the tag ID when a RN16 is identified by the reader.

The RFID systems can reduce the identification time with the procedure as follows:

Step 1. **RN16 Generation**: All tags in the field of a reader generate temporary IDs, 16-bit random numbers (RN16s), for giving the uniqueness to them. This step is performed exactly like in standard EPC Class 1 Gen. 2.

- Probability of a single RN16

  : 0.8/216 < P(RN16 = j) < 1.25/216, where j is any possible number generated by the random number generator.

- Probability of simultaneously identical sequences

  : For a tag population up to 1,000 tags, the probability of existing tags having the same RN16 is less than 0.1%.

- Probability of predicting a RN16

  : A RN16 shall not be predictable with a probability greater than 0.025%.

Step 2. **Applying RN16s to QTA**

- Request: The reader sends n length inquiring bits (prefix) to tags.
- Response: Tags send their RN16s from (n+1)th bit to the end when the first n bits of the tag IDs are the same as the prefix.
- Decision: Depending on whether collisions have occurred or not, the reader decides on proceeding procedure with the following conditions.
  - If collisions occur, the reader saves two new prefixes at the last input first output (LIFO).

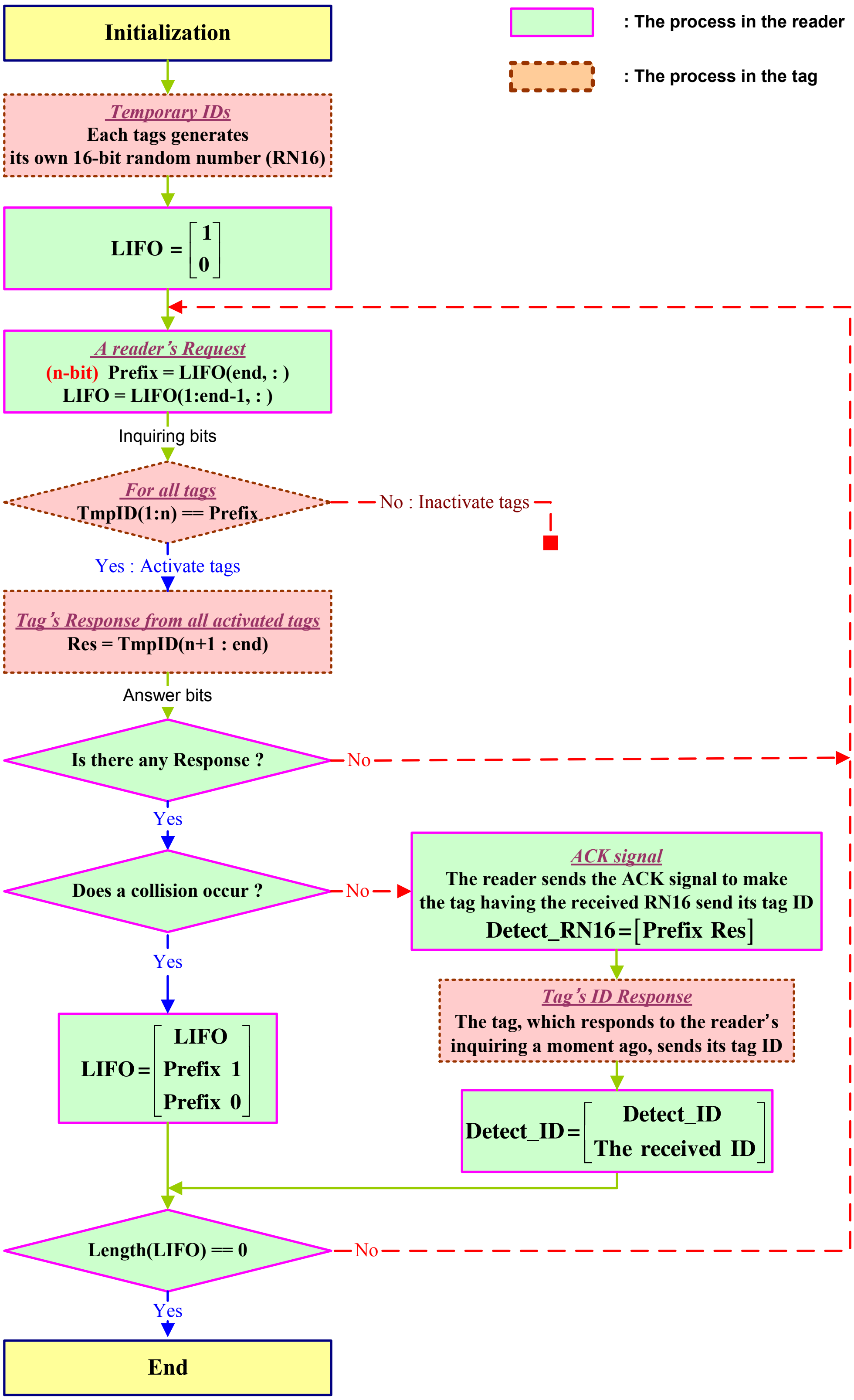

Figure 9: Flow Chart of RN16QTA

- Two new prefixes : the connection of the prefix and either ‘0’ or ‘1’
- If a collision occurs when the tags respond with only the last bits in the RN16s to the reader's inquiring, the reader assumes that there are two tags because of the uniqueness of RN16s.
- If there is no collision, the reader identifies a RN16 from the tags.

- Do these steps until a RN16 is identified.

Step 3. **Sending an ACK command when a RN16 is identified**

- If the reader identifies a RN16, the reader calls the tag having the RN16 with an ACK command. There are two types of the ACK command.
  - The reader sends `a two-bit ACK code' only for indicating that the signal is an ACK command.
  - The reader sends `the ACK code + the received RN16' for improving the security of the RFID systems.
- Only the tag sending the whole RN16 is activated by the ACK command of the reader, and responds with its tag ID to the ACK command.

Step 4. Do (2) and (3) until the LIFO is ‘null’.

The performance of the RFID tag anti-collision protocols means how fast the identification process in the field of a reader is. In the tree based algorithms, the performance depends on the tree depth, which is equal to the length of the tag IDs. Here, we propose the query tree based reservation protocol, which is called the 16-bit random number aided query tree algorithm (RN16QTA), for efficient RFID tag anti-collision as shown in Figure 14. RN16QTA does the identification process with temporary IDs shortening the tree depth. After identifying a temporary ID, the reader calls a tag with the temporary ID for collecting the tag ID. With RN16QTA, consequently, we can reduce the identification time by the shortened tree depth.

5.3 Bi-Slotted Query Tree based Reservation Protocol

The bi-slotted query tree based reservation protocol is presented as a substitute of the existing RFID tag anti-collision protocols. This proposed protocol takes the advantages of both the time-divided responses and the distributed reservation based protocol. In other words, the bi-slotted query tree based reservation protocol applies BSQTA to RN16QTA, so we call this proposed protocol as the 16-bit random number aided bi-slotted query tree algorithm (RN16BSQTA).

The procedure of RN16BSQTA is the same as the procedure of RN16QTA except the step 2. In step 2, RN16BSQTA applies RN16s to BSQTA instead of QTA.

6 Performance Analysis of Anti-Collision Schemes

This simulation is intended for the performance comparison between the existing tree based RFID tag anti-collision protocols and RN16BSQTA in the algorithm point, and the performance comparison between RN16BSQTA and PS-ALOHA in EPC Class 1 Gen.2 protocol in the implementation point.

One important point of the observation is whether the simulated protocol is implementable to the low-cost passive RFID systems or not. QTA is already applied to the RFID systems with EPC Class 1 protocol. On the other hand, CTTA is not applied to any RFID systems yet because tags cannot support CTTA with transmitting and receiving simultaneously. Since RN16BSQTA is the protocol applying the characteristics of PS-ALOHA in EPC Class 1 Gen.2 protocol to RN16QTA, the algorithm is easily implementable for the low-cost passive RFID systems.

The simulation condition is as follows. There is only one reader. In the field of the reader, the number of tags increases from 2 to 512. The length of the tag IDs is 96 bits. Both tag-to-reader data rate and reader-to-tag data rate are chosen as 80 kbps. The reason is that the middle speed in EPC Class 1 Gen.2 proposed by EPCglobal to ISO/IEC 18000-6 C is equal to the chosen data rate. There is some iteration overhead because of propagation delay from the channel and latency from the signal processing. For the comparison of the algorithm point, the iteration overhead is not considered.

For the comparison of the implementation point, we set a simple EPC Class 1 Gen.2 architecture without considering both the multisession commands for the multi-reader environment and the probability of receiving an invalid tag ID. There are three important commands: Query, QueryRep, and ACK; the Query (22 bits) is for starting a frame, the QueryRep (4 bits) is for beginning each slot, and the ACK (18 bits) is for informing the identification of a tag ID to a tag. To calculate the average number of identified tags per second, the RFID systems choose 8 bits for request and 3 bits for detecting collision, no collision, or no response for substituting the iteration overhead. For solving error detecting problem, moreover, 16-bit CRC coding is required.

6.1 Results: BSQTA and BSCTTA

We start with the comparison between BSQTA and QTA. Figure 10 shows the average required inquiring and response bits for one-tag identification. According to the figure, BSQTA reduces the average required inquiring overhead to ‘half - 1bit’ of the inquiring overhead in QTA without any increase in the average required response bits for one-tag identification. Thus, BSQTA requires less average required bits for one-tag identification than QTA. The performance gap between BSQTA and QTA in the average required bits for one-tag identification increases with the number of tags because the average required inquiring overhead linearly increases with the number of tags as shown in Figure 10. In other words, the average required inquiring overhead for one-tag identification depends on the number of collisions, which are similar to the number of tags. The average required iterations for one-tag identification are another important factor in evaluating the RFID system performance because iteration overhead affected by the processor in both the reader and the tags gives time delay to the tag identification. Figure 11 indicates that BSQTA needs 'half' of the average required iterations for one-tag identification in QTA. Accordingly, BSQTA achieves somewhat better performance than QTA in both the average required bits and the average required iterations for one-tag identification.

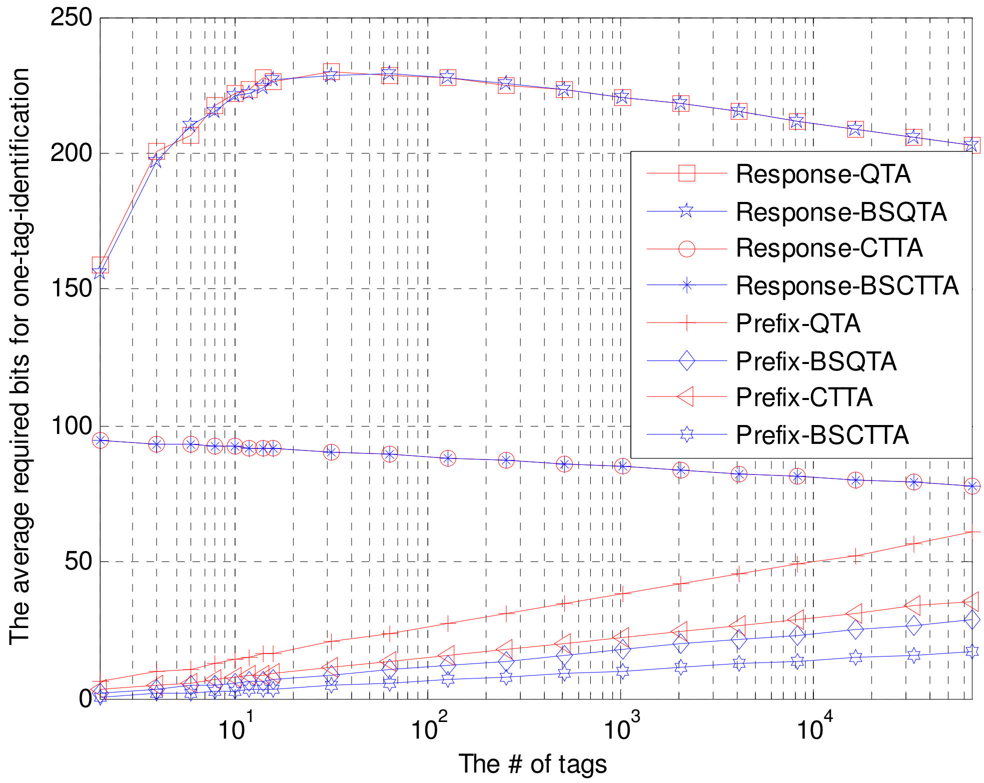

Figure 10: Search Cost (Bits): BSQTA and BSCTTA

Next, we compare BSCTTA with CTTA. Similarly, BSCTTA gets better performance than CTTA in the average required bits for one-tag identification. Also, the average required inquiring overhead for one tag identification in BSCTTA is 'half - 1bit' of that in CTTA without any performance degradation on the average required response bits for one-tag identification as shown in Figure 10. Thus, BSCTTA requires less average required bits for one-tag identification because of the reduced inquiring overhead. Furthermore, the average required iterations for one-tag identification in BSCTTA are half of those in CTTA as shown in Figure 11.

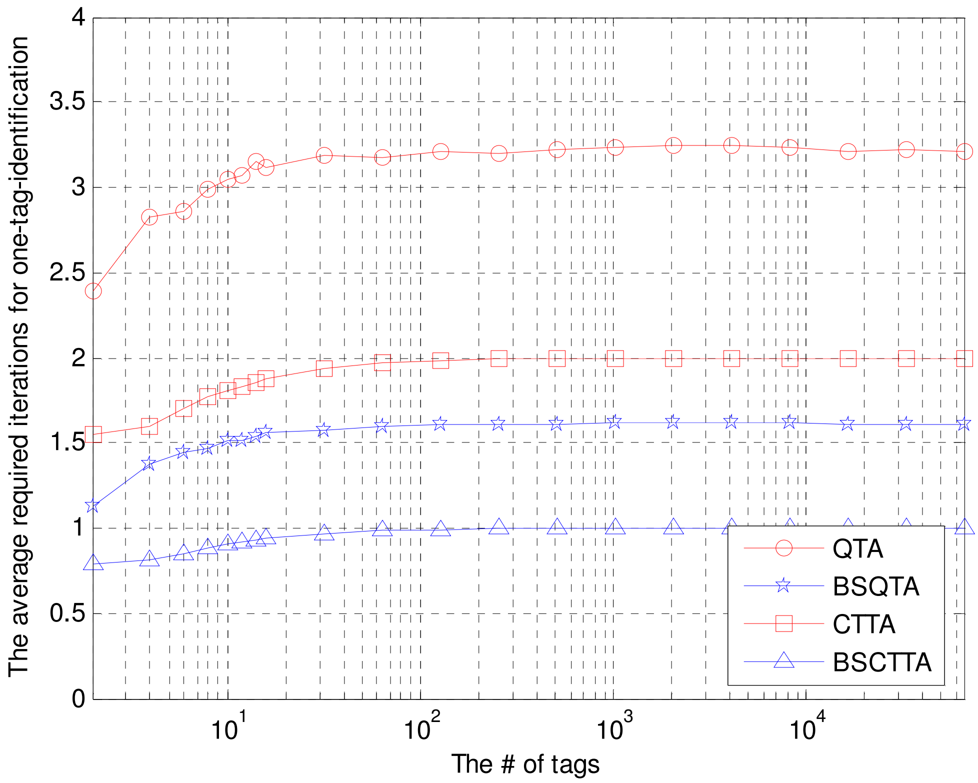

Figure 11: Search Cost (Iteration): BSQTA and BSCTTA

Finally, Figure 12 shows the average number of identified tags per second in each algorithm. In conformity with the simulations, BSQTA achieves faster identification than QTA, and BSCTTA also achieves faster identification than CTTA. Consequently, the proposed protocols, BSQTA and BSCTTA, accomplish faster tag identification than the existing tree based tag anti-collision protocols, QTA and CTTA.

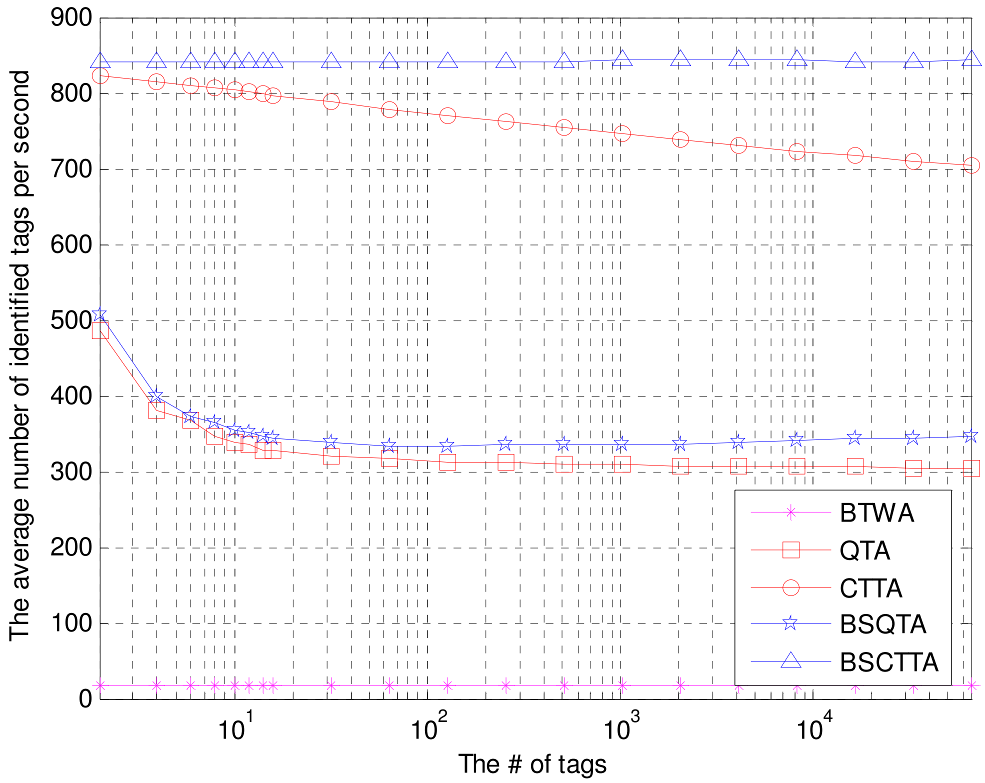

Figure 12: Identification Performance: BSQTA and BSCTTA

6.2 Results: RN16QTA and RN16BSQTA

Since BSQTA achieves better performance than QTA, RN16BSQTA allows faster tag identification than RN16QTA. In this section, we compare RN16QTA with the existing tag anti-collision protocols. As we already mentioned, RN16QTA is considered for faster tag identification than the existing tag anti-collision protocols. Thus, the simulation results will support that RN16BSQTA is the most efficient protocol among the compared protocols.

For better performance on RN16BSQTA, the last parts of tag IDs can be used for temporary ID instead of RN16s. RN16BSQTA-ID achieves better performance than RN16BSQTA because 16 bits are decreased in the overhead of collecting the real tag IDs. With RN16BSQTA-ID, however, it makes the tags require complex process to solve the problem when there exist tags which have the same pattern at the last parts of tag IDs. In that case, the tags should make the reader know whether their RN16s are the last part of the real tag IDs or the regenerated RN16s, and the reader should keep the information that the tags use randomly generated RN16s when some tags have the same pattern at the last parts of tag IDs. Thus, RN16BSQTA-ID is not suitable for the RFID tag anti-collision protocol.

6.2.1 Simulation results

Above all else, Figure 13 shows the average inquiring bits and response bits for one-tag identification. In the RN16QTA, both the average inquiring bits and response bits for one-tag identification are between the case of QTA and the case of CTTA. The reason is that RN16QTA reduces the overhead from both the average inquiring bits and response bits by using the temporary IDs, but generates the overhead caused by collecting the tag IDs. The former one affects RN16QTA to get better performance than QTA, and the latter one influences RN16QTA to get worse performance than CTTA. Since RN16BSQTA is the protocol applying the time-divided responses to RN16QTA, the average inquiring bits for one-tag identification in RN16BSQTA is 'half - 1bit' of that in RN16QTA without any increase in the average required response bits for one-tag identification.

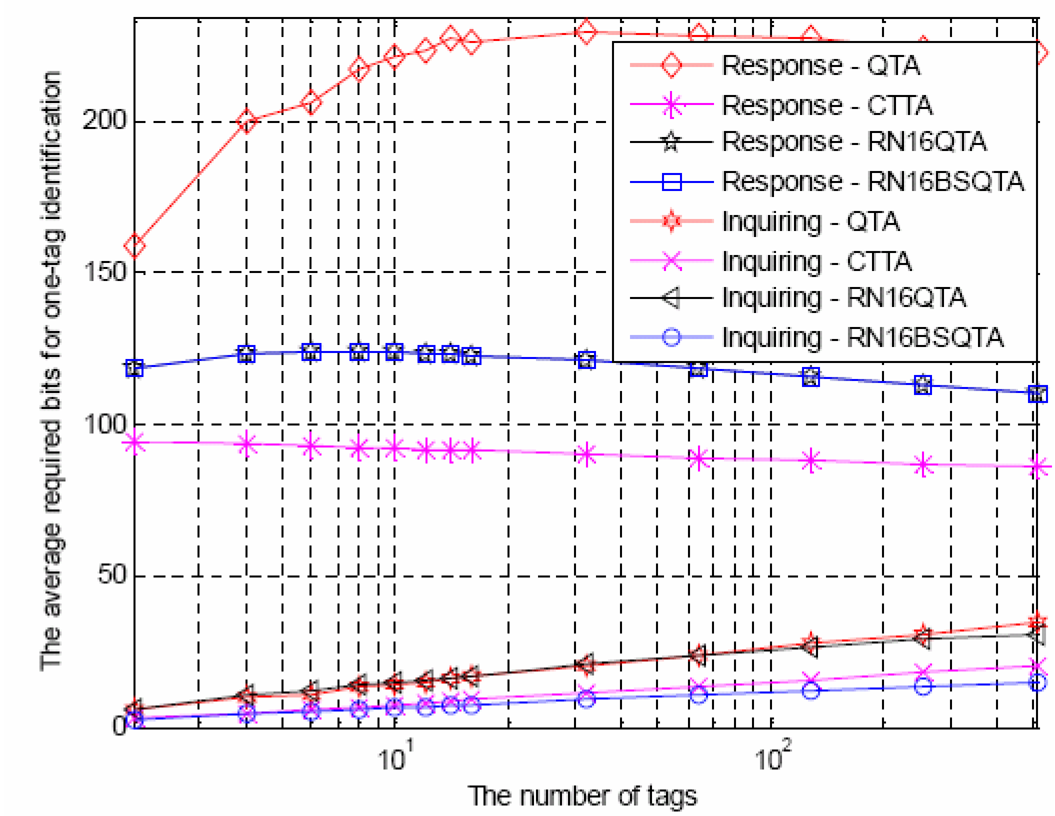

Figure 13: Search Cost (Bits): RN16QTA and RN16BSQTA

Next, Figure 14 indicates the average required iterations for one tag identification. RN16QTA requires one more iteration than QTA because of the step collecting the real tag IDs, but the overhead from each iteration is 1/6 of the others as the length of RN16s is 1/6 of the real tag IDs. Also, Figure 14 shows that RN16BSQTA needs 'half' of the average required iterations for one-tag identification in RN16QTA.

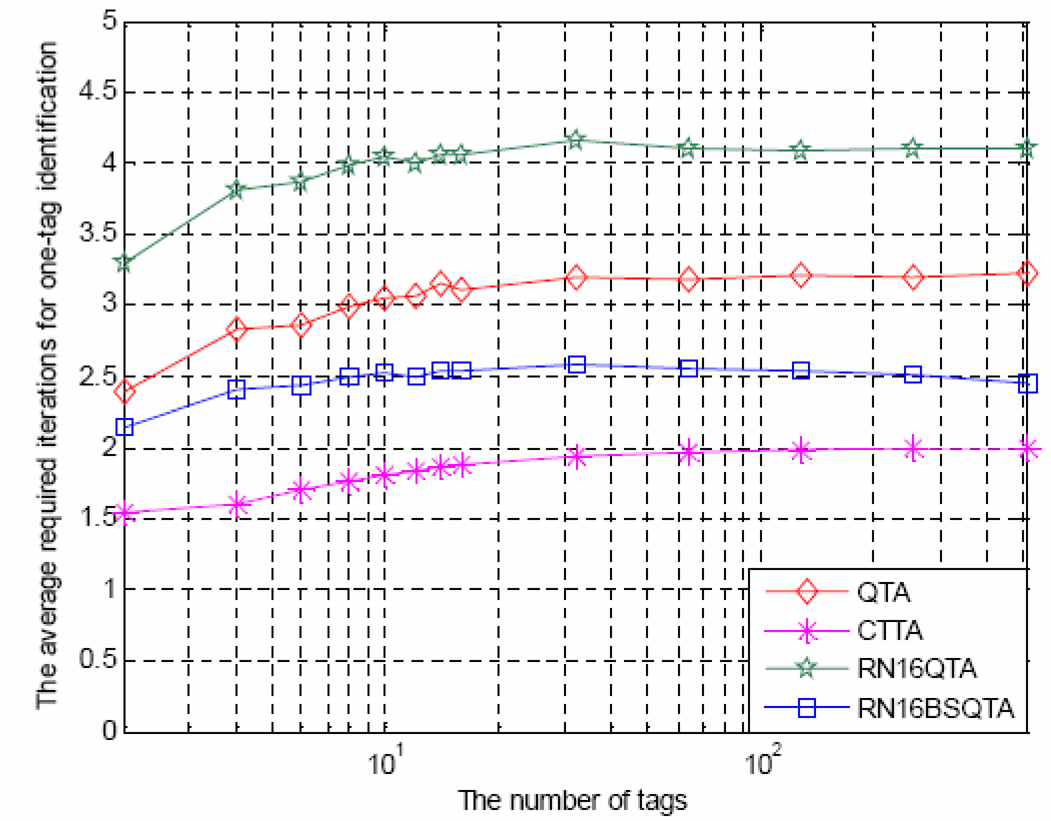

Figure 14: Search Cost (Iteration): RN16QTA and RN16BSQTA

Finally, Figure 15 shows the average number of identified tags per second in each algorithm. In conformity with the simulations, RN16QTA achieves faster identification than QTA, and approaches to the performance of CTTA. Also, RN16BSQTA allows lower time consumption than RN16QTA.

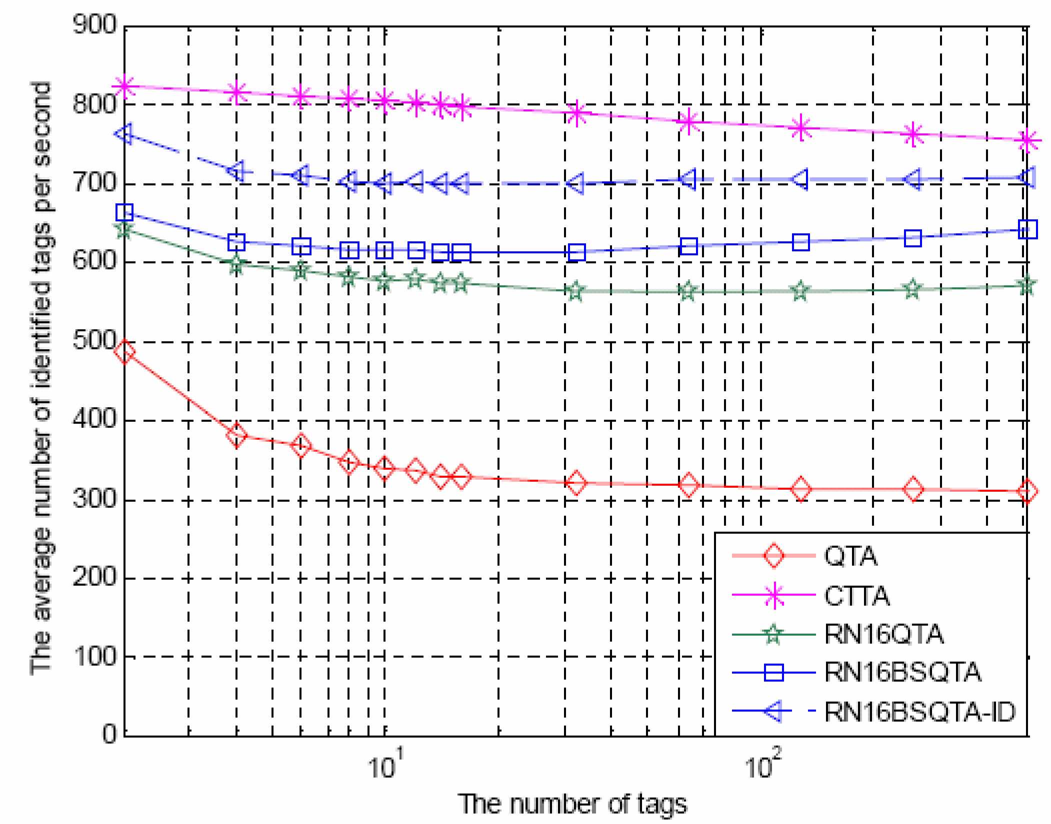

Figure 15: Identification Performance: RN16QTA and RN16BSQTA

6.2.2 Implementation Results

Figure 16 indicates the average number of identified tags per second in each protocol. Depending on the default frame size (16 slots or 64 slots) in EPC Class 1 Gen. 2 protocol, the tendency of the performance is different in the small amount of tags. However, the performance of PS-ALOHA in EPC Class 1 Gen. 2 protocol is always less than that of the proposed RN16QTA as shown in Figure 16. Consequently, the proposed protocol, RN16QTA, accomplishes faster tag identification than the implemented protocols, QTA in EPC Class 1 protocol and PS-ALOHA in EPC Class 1 Gen. 2 protocol.

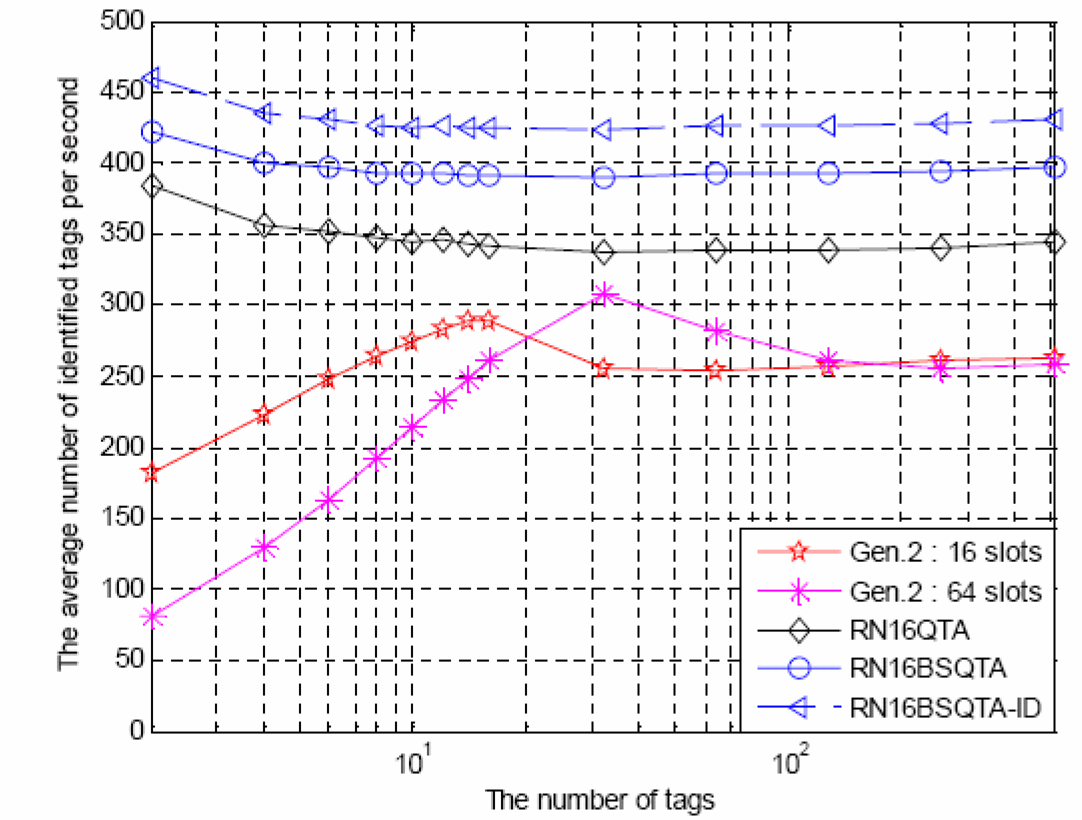

Figure 16: Identification Performance: RN16QTA and RN16BSQTA in Simple EPC Class 1 Gen.2 Protocol

7 Conclusion

In this whitepaper, we propose three methods for fast tag identification: bi-slotted tree based RFID tag anti-collision protocols, query tree based reservation, and the combining method of them. First of all, bi-slotted tree based RFID tag anti-collision protocols, bi-slotted query tree algorithm (BSQTA) and bi-slotted collision tracking tree algorithm (BSCTTA), decrease in both prefix overhead and iteration overhead by the time-divided responses depending on whether the collided bit is ‘0’ or ‘1’. Next, query tree based reservation (RN16QTA: the 16-bit random number aided query tree algorithm) diminishes in the tree depth on the identification process for decreasing the identification time. The query tree based reservation applies the characteristics of temporary IDs in EPC Class 1 Gen. 2 protocol to the query tree algorithm, which is for assigning slots to transmit tag IDs, instead of the real tag IDs. Finally, bi-slotted query tree algorithm takes the advantages of both BSQTA and RN16QTA. Consequently, these proposed methods can be used for enhancing the identification speed of RFID systems.

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