A Scheme for Guaranteeing Fair Identification Delay in Gen-2 RFID Systems

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***Abstract*—In RFID System, when multiple tags respond simultaneously, a collision can occur. A method that solves this collision is referred to anti-collision algorithm. In Gen-2 RFID system, if the slot-count size varies during a query round due to the collisions, a new query round begins with a QueryAdjust command. Anti-collision algorithm of Gen-2 RFID system is simple. But, it has the tag starvation problem that a tag may never be successfully identified because its responses always collide with others. Therefore, this paper proposes a scheme to guarantee the fair identification delay. In the proposed scheme, if the slot-count value changes due to the collisions, the reader broadcasts a CollisionRound command to begin a collision round. During the collision round, the reader identifies only tags that occurred collision during the previous query round.**

***Index Terms*—Gen-2 RFID, Anti-collision algorithm, Q-algorithm, Starvation problem**

I. INTRODUCTION

Recently, the RFID (Radio Frequency Identification) technique attracts a lot of attention due to its automatic identification capability for the identity information of an object [1]. The RFID systems provide an efficient and inexpensive mechanism for automatically collecting the identity information. An RFID system consists of a reader and one or more tags. Tags store unique identifier and are attached to objects. A reader recognizes an object by issuing RF signals to interrogate the identifier of the attached tag. In the RFID system, tags communicate with a reader over a wireless multiple-access channel. In RFID system, tag identification process is performed by the reader's query to a tag and then the tag's backscattering its identifier as its response. But if there are multiple tags within the identification range of reader, some of them might respond simultaneously and leads to collisions which decrease the performance. Therefore, the system requires a multiple-access scheme that allows the reader to read data from the individual tags. A technical scheme that handles multiple-access is called an anti-collision algorithm [2][3].

There are two types of anti-collision algorithms in RFID systems: probabilistic and deterministic algorithms [4][5]. EPCglobal Class-1 Gen-2 and ISO/IEC 18000-6 Type C use the probabilistic algorithm as the standard [6][7]. The probabilistic algorithms are based on ALOHA-like protocol that provides slots for the tags to send their data. Almost all the probabilistic algorithms use framed slot ALOHA (FSA), which has been advanced in function by adding allotting and framing on ALOHA. The tags send their identifiers at a randomly selected slot. When collisions occur, the tags that are involved in collisions retransmit their identifiers in the next query round. The probabilistic algorithms may have limitations on the completeness of tag identification because there is still a probability of failing to be identified in a limited time period. The deterministic algorithms are used in EPCglobal Class-0 and ISO/IEC 18000-6 Type B, which uses binary tree-walking scheme [8].

EPCglobal Class-1 Generation-2 standard proposed Q-algorithm to determine the slot-count for the next query round [6]. Q-algorithm determines the slot-count without conducting the tag number estimation scheme. Therefore, it wastes less computational cost and is simpler than other FSA algorithms.

In Q-algorithm, the slot-count size may be incremented or decremented according to the status of reply slot. When the result of tag's reply in a slot is idle, the reader subtracts a weight C from the slot-count. When a collision occurs, a weight C is added to the slot-count. The standard did not specify the optimal weight C values, but suggests that the reader typically uses small values of C when the slot-count is large and larger values of C when the slot-count is small. If an inappropriate weight is selected, there may be a lot of idle or collided slots.

In Gen-2 RFID system, a query round begins with a Query or QueryAdjust command. If the slot-count size varies during a query round due to the collisions, the reader broadcasts a QueryAdjust command to force a new query round. In this case, tags that are not identified randomly select a new slot-count value and start a query round. Anti-collision algorithm of Gen-2 RFID system is simple. However, it has the tag starvation problem that a tag may never be successfully identified because its responses always collide with others. It is really hard to provide a fair identification delay. Therefore, this paper proposes a scheme to guarantee the fair identification delay. In the proposed scheme, we define a collision round, which is used for identifying collided tags and is started by a CollisionRound command. If the slot-count value changes due to the collisions, the reader broadcasts a CollisionRound command to begin a collision round.

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During the collision round, the reader identifies only tags that occurred collision during the previous query round.

This paper is organized as follows. In Section II, we briefly describe Gen-2 anti-collision algorithm and Q-algorithm. In Section III, we describe the problems of Q-algorithm and present the proposed scheme. Section IV shows the simulation results, and Section V concludes the paper.

II. GEN-2 RFID SYSTEM

A. Gen-2 anti-collision algorithm

The reader begins a query round by transmitting a Query command. After issuing a Query command to initiate a query round, the reader transmits one or more QueryRep commands to detect each slot during a query round [9].

If there is only one tag reply for a Query or QueryRep command, it is a successful query round. However, if there is no tags reply or multiple tags reply, we consider it as a failure. Fig.1 and Fig.2 illustrate the timing diagrams for the case of single tag reply and collision or no tags reply, respectively. As shown in the figures, if only one tag transmits its RN16 for a Query or QueryRep command, the reader successfully receives without collisions, and then transmits an ACK command. If the tag receives the ACK command with a correct RN16, it backscatters it PC, EPC, and CRC-16.

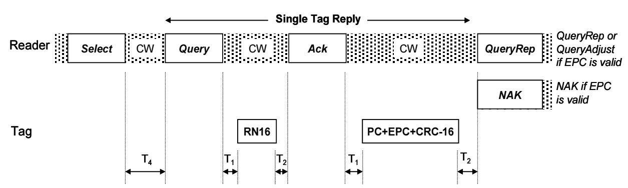

Fig.1. In the case of single tag reply.

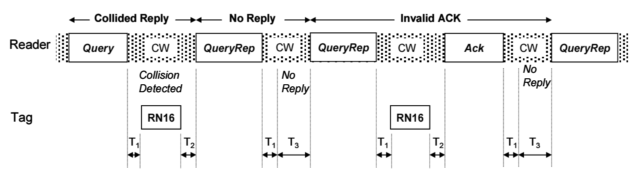

Fig.2. In the case of collision or no reply.

B. Gen-2 Q-algorithm

In EPCglobal Class-1 Gen-2 RFID system, Q-algorithm has been proposed to determine the slot-count in the next query round. Q-algorithm basically calculates the slot-count parameter Q based on the result of tag's reply in a slot [9]. The slot status is classified into three categories: success, collision, and empty slot.

Fig.3 shows an algorithm that the reader might use for setting the slot-count parameter Q in a query round. In the figure, Q_{fp} is a floating-point representation of Q. As shown in the figure, the reader updates Q_{fp} in accordance with the slot status at every slot. When a collision occurs, it adds the weight C value to the previous Q_{fp}, because it means the slot-count is smaller than the number of tags. If the result of tag's reply in a slot is idle, which means that there are no tag responses in the slot, the reader subtracts the weight C value from the previous Q_{fp}, because the slot-count is larger than the ideal one. When a new query round begins, the reader rounds Q_{fp} to an integer value Q in the Query command. Typical values for the weight C are $0.1<C<0.5$. EPCglobal Class-1 Gen-2 standard suggests that the reader typically uses small values of C when Q is large and large values of C when Q is small.

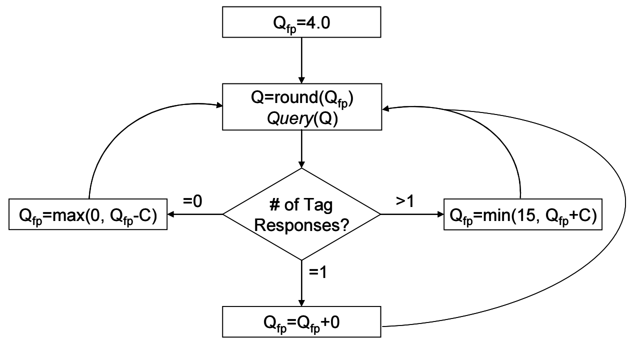

Fig.3. Gen-2 Q-algorithm.

III. PROPOSED SCHEME

A. Research motivations

In Gen-2 anti-collision algorithm, if the slot-count size varies due to the successive collisions, a new query round begins with a QueryAdjust command. In the new query round, tags that come into a collision contend with other tags in selecting a slot counter value. This may cause a series of collision. It is anticipated that the identification delay for each tag will be various and it is hard to guarantee tags the fair identification delay. Therefore, we analyze the distribution of identification delay for each tag.

The performance analysis was done by the computer simulations. The system parameters for simulation are shown in Table I [6], which are based on the EPCglobal Gen-2 specification. Also, we assume that the Query commands will be transmitted as follows:

1) When there is a successful reply, the reader transmits QueryRep command.
2) When there is a collided reply or no reply, the reader sends QueryAdjust command if the slot-count gets changed or QueryRep command if the slot-count has no change.

Fig.4 and Fig.5 illustrate the identification delay of each tag where the number of tags is 100 and 500, respectively. It is assumed that the weight C value and initial slot-count Q_{fp} for Gen-2 Q-algorithm are 3.0 and 4.0, respectively. When the number of tags is 100, the average identification delay for each tag is 141msec and the standard deviation is 54msec. On the other hand, when there are 500 tags in the identification range of reader, the average identification delay for each tag and standard deviation are 683msec and 276msec, respectively.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
T_{ari}	12.5μs
0_{length}	12.5μs
1_{length}	18.75μs
RT_{cal}	31.25μs
TR_{cal}	64μs
LF	125KHz
T_{pri}	8μs
RT_{rate}	64Kbps
TR_{rate}	125Kbps
T_1	80μs
T_2	80μs
T_3	0μs
T_4	62.5μs
R=>T preamble	120.25μs
R=>T frame sync	56.25μs
T=>R preamble	48μs

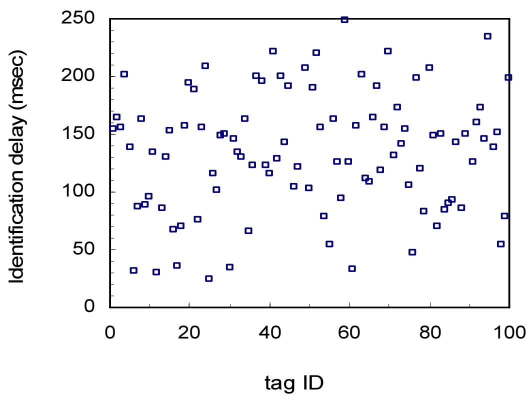

Fig.4. Identification delay for each tag (the number of tags is 100).

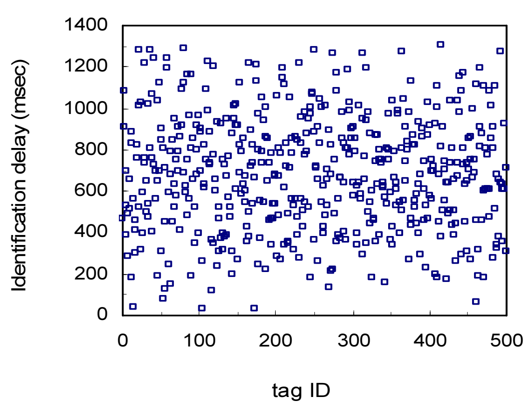

Fig.5. Identification delay for each tag (the number of tags is 500).

As shown in the figures, the more tags are in the identification range of reader, the more various the distribution of identification delay is. Therefore, it seems that a scheme needs to provide a fair identification delay.

B. Proposed scheme

In this paper, we propose a scheme to guarantee tags the fair identification delay. Fig.6 shows the operation for anti-collision algorithm that applied the proposed scheme. At first, the reader selects a tag population for a query round by transmitting a Select command. And it transmits a Query command to decide which tags participate in the query round. Query command contains a slot-count parameter Q, and the initial value of Q is 4.

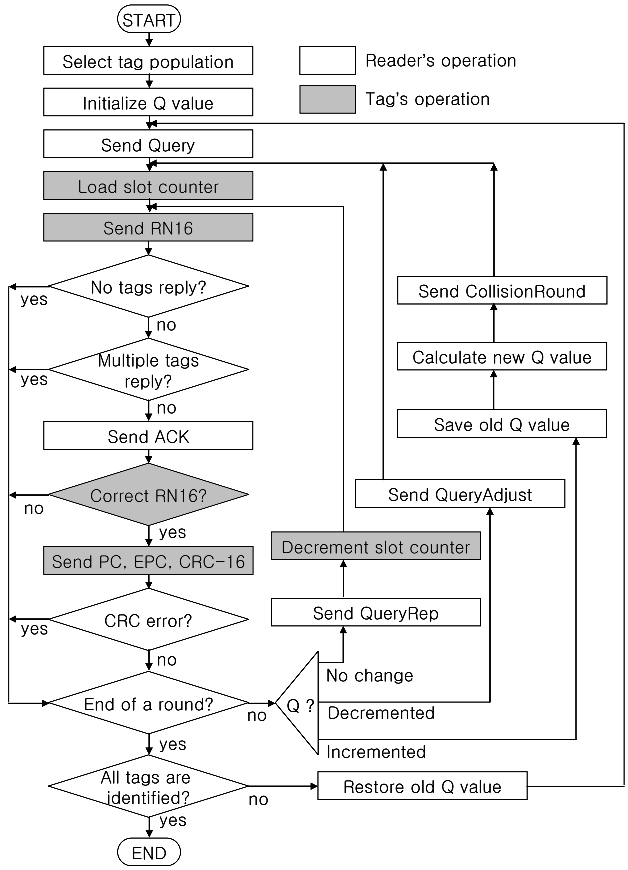

Fig.6. Flow descriptions for the proposed scheme.

Upon receiving a Query command, participating tags pick a random value in the range (0, 2^Q-1), inclusive, and load this value into their slot counter. Tags that pick a zero backscatter an RN16, which is a 16-bit random number. If the reader receivers an RN16 without collision, it acknowledges the tag with an ACK command containing this same RN16. If the tag receives the ACK command with a correct RN16, it transmits its PC, EPC, and CRC-16. The reader checks CRC errors with the received CRC-16 value. If no CRC errors are found, the reader assumes that this tag is successfully identified. After that, it reads from or writes to the identified tag.

The reader runs Q-algorithm slot by slot. At the end of each slot, a reader adjusts the Q value obtained by Q-algorithm. If the new Q value is same as the previous one, the reader continues an identification process for the next slot by transmitting a QueryRep command. If the new Q value is decremented due to the continuous idle slots, the reader broadcasts a QueryAdjust command. When the tags receive a QueryAdjust command, they load a slot counter with the adjusted Q value.

If the new Q value is incremented because of the continuous collisions, the reader cancels the current query round and begins a collision round by transmitting a CollisionRound command. During the collision round, the reader identifies only tags that experienced a collision during the current query round. The slot-count size for a collision round has to be defined. In framed slot ALOHA (FSA) algorithm, the number of tags that are involved in collisions is $2.4N_c$ when N_c slots have collisions [9]. Therefore, we define a new slot-count size for a collision round as follows:

$$Q = \lceil \log_2(2.4N_c) \rceil \quad (1)$$

At the end of query round, if unidentified tags still remain though a query round is terminated, the reader issues a new Query command to initiate another query round. The new Query command also contains a slot-count parameter Q, which is calculated during the query round.

IV. SIMULATION RESULTS

In this paper, we evaluate the performance for the proposed scheme through the computer simulations. The system parameters for simulations and the rules for Query command transmission are described in Section II. We compare the proposed scheme with Gen-2 Q-algorithm. All the results of simulation were averaged after iterating 100 times. The performance measures of interest are the identification delay, identification speed, slot efficiency, and fairness index. The identification delay means the elapsed time to identify the tag. The identification speed is defined as the number of tags identified in a second. The slot efficiency is defined as the average number of tags identified in a slot. The fairness index rates the fairness of a set of values where there are N tags. The delay fairness index is defined as follows [10]:

$$Fairness = \frac{\left(\sum_{i=1}^{N} Y_i\right)^2}{N\sum_{i=1}^{N} Y_i^2} \quad (2)$$

where Y_i is the measured delay for the tag i, and N is the total number of tags.

The identification delay of each tag for both schemes is compared in Fig.7 and Fig.8 when the number of tags is 100 and 500, respectively. In the proposed scheme, when the number of tags is 100, the average identification delay for each tag is 129msec and the standard deviation is 7msec. When there are 500 tags in the identification range of reader, the average identification delay for each tag and standard deviation for the proposed scheme are 640msec and 37msec, respectively. Fig.9 compares the fairness index according to the number of tags. As shown in the figure, the fairness index for the proposed scheme is 0.99 while the fairness index of Gen-2 algorithm is 0.87

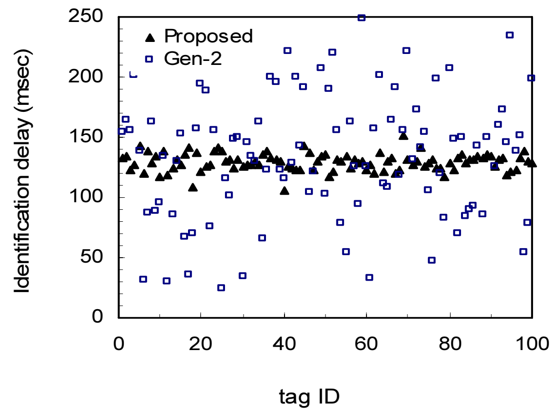

Fig.7. Delay for each tag when the number of tags is 100.

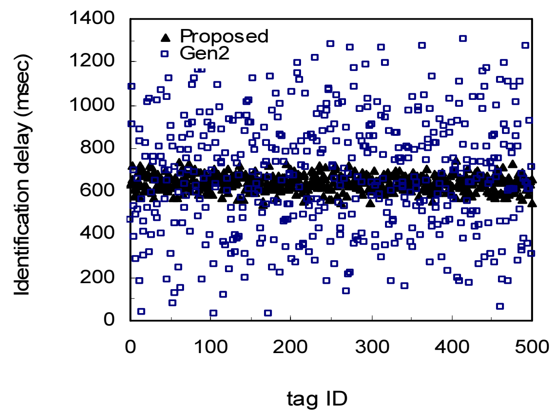

Fig.8. Delay for each tag when the number of tags is 100.

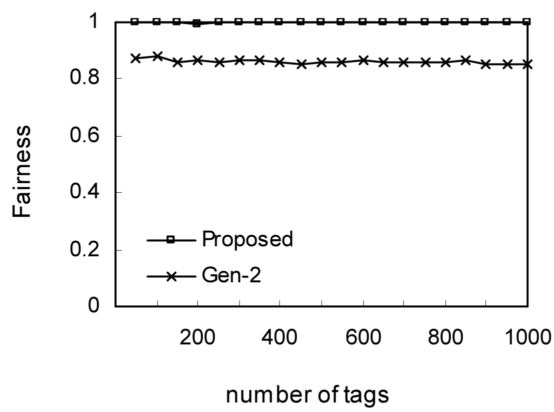

Fig.9. Fairness index.

Fig.10 and Fig.11 illustrate the identification speed and slot efficiency according to the number of tags within the identification range of reader, respectively. As shown in Fig.10, if there are a lot of tags, the reader using the proposed scheme and Gen-2 algorithm can identify 384 and 367 tags per a second, respectively. Thus, the proposed scheme is about 5% faster than Gen-2 algorithm. The average slot efficiencies for the proposed scheme and Gen-2 algorithm are 36.9% and 34.1%, respectively. Furthermore, as shown in Fig.10 and Fig.11, the proposed scheme is more stable than Gen-2 algorithm in spite of the number of tags.

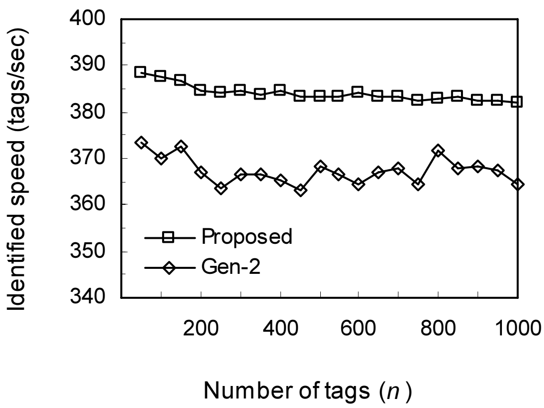

Fig.10. Identification speed.

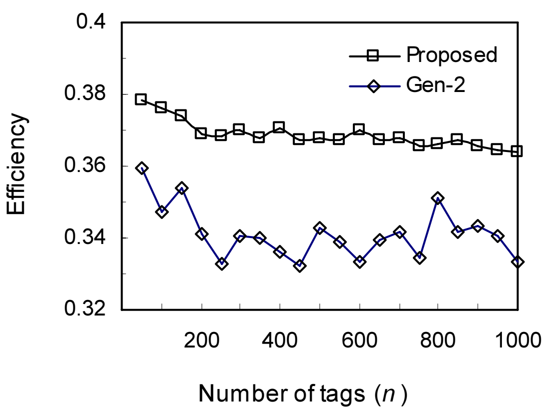

Fig.11. Slot efficiency.

The collision rate for the proposed scheme and Gen-2 algorithm is compared in Fig.12. We define the collision rate as the ratio of the number of collided slots over the total number of slots consumed for identifying all tags. In the proposed scheme, we introduced the collision round. If there is a series of collisions during a query round, the reader stop the current query round and begins a collision round. Only tags that have a collision respond during the collision round. Therefore, as shown in Fig.12, the collision rate of proposed scheme is 14.3% less than the Gen-2. In general, because the duration of collided slot is longer than no reply slot, the less the number of collisions is, the faster the reader will identify all tags. Therefore, as shown in Fig.10, the identification speed of proposed scheme is faster than Gen-2 algorithm.

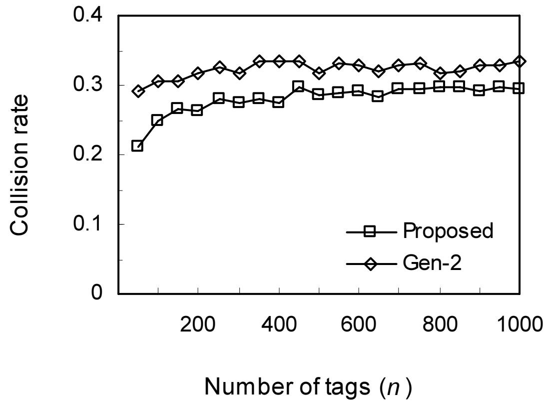

Fig.12. Collision rate.

V. CONCLUSIONS

In this paper, we proposed a scheme to guarantee tags the fair identification delay in Gen-2 RFID systems. In the proposed scheme, we defined a collision round that it is different from the query round. The collision round begins with a CollisionRound command. In a query round, the reader calculates the slot-count size with Q-algorithm. If the slot-count value changes due to a series of collisions, the reader cancels the current query round and broadcasts a CollisionRound command to begin a collision round. During the collision round, the reader identifies only tags that experienced collision during the previous query round with FSA algorithm. The simulation results showed that the proposed scheme outperforms Gen-2 algorithm, and is more stable than Gen-2 algorithm.

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