# Fair Identification Scheme for STAC Protocol in 13.56MHz 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 13.56MHz RFID system, STAC protocol is defined as an anti-collision algorithm for multiple tag reading. In STAC protocol, there is no differentiation between the collided tags and others in the identification process. Therefore, tags may never be successfully identified because its responses may always collide with others. This situation may cause the tag starvation problem. This paper proposes a fair identification scheme for STAC protocol. In the proposed scheme, if the number of collided slots is large during a query round, the reader broadcasts a CollisionRound command to begin a collision round. During the collision round, the reader identifies only tags that are experienced collision during the previous query round.**

*Index Terms*—**13.56MHz RFID, Anti-collision algorithm, STAC protocol, Starvation problem**

## I. INTRODUCTION

**UNLIKE** conventional barcode systems, radio frequency identification (RFID) is a wireless technology that uses electromagnetic or magnetic response exchange to identify objects at a distance without direct line of sight [1]. 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 [2]. The RFID systems provide an efficient and inexpensive mechanism for automatically collecting the identity information. RFID is an automatic identification system that consists of reader and tags [3]. A tag has an identification (ID) stored in its memory that is represented by a bit string. A reader is able to read the IDs of tags within its identification range by a simple anti-collision algorithm over the wireless channel. RFID systems have many advantages over barcode systems. RFID networks use radio frequency as a method of data transmission. Thus, unlike a barcode label, a tag does not need to be placed in a line of sight position from the reader in order to be successfully identified.

Tags may either be actively or passively powered [3][4]. Active tags are provided with their own power sources for computing and transmitting data. Due to the

complexity and cost of mounting a power source onto a tag, active tags are not practical for the consumer products. On the other hand, passive tags do not need their own power source. They instead rely on RF energy induced by the electromagnetic waves emitted by the reader. When a passive tag enters into the RF field of the reader, it receives energy from the field. Due to more advanced technology for the protocol and circuit design, the reliability and the read range of passive RFID networks continue to improve, and the cost continues to decrease, which lead to an increase of passive tag applications.

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 [5].

There are two types of anti-collision algorithms: deterministic and probabilistic algorithm [6][7][8]. The deterministic algorithm resolves collisions by muting subsets of tags that are involved in a collision. By successively muting larger subsets, only one tag will be left and finally led to successful transmission. Binary tree and query tree algorithms are the two main methods of the deterministic algorithm. 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.

In almost all the 13.56 MHz RFID systems, slotted terminating adaptive collection (STAC) protocol is used for anti-collision algorithm for multiple tag reading [9]. The basic operations of STAC protocol are similar with the framed slot ALOHA (FSA) algorithm. FSA algorithm

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is based on the slotted ALOHA scheme with a fixed frame size. Therefore, the performance of FSA algorithm is dependent on the frame size and the number tags in the reader's identification range. In case of small frame size, when the number of tags in the reader's identification range is large, the identification time will increase because of the frequent collisions. On the other hand, when the number of tags is large, the number of wasted slots increases if the frame size is large. The tag identification time and system efficiency depend mainly on the frame size and the number of tags.

In STAC protocol, a query round begins with a BeginRound command that contains the number of slots in the forthcoming round. Tags that are not identified randomly select a new slot-count value after receiving the BeginRound command and involve in the identification process. STAC algorithm 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 number of collided slots is large, 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.

This paper is organized as follows. In Section II, we describe STAC protocol. In Section III, we describe the problems of STAC protocol and present the proposed scheme. Section IV shows the simulation results, and Section V concludes the paper.

## II. STAC PROTOCOL

In STAC protocol, tags respond at randomly selected slots whose beginning and end are controlled by the reader [9][10]. A reader command signals both the end of the current and the beginning of the next slot. Fig.1 illustrates a reply round. A number of slots form a reply round.

| Slot F | Slot 0 | Slot 1 | Slot 2 | ..... | Slot n−1 |
|--------|--------|--------|--------|-------|----------|

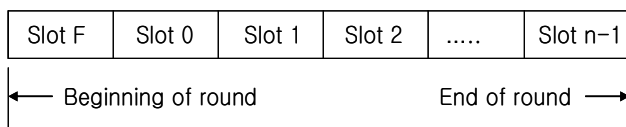← Beginning of round                     End of round →

Fig. 1. Reply round.

The operations of STAC protocol is depicted in Fig.2. Tags which enter the energizing field, when they have sufficient power for operation, wait before replying in a READY state for the reception of one of several commands. The reader sends a BeginRound command with the number of slots in the round. The issuing by the reader of a BeginRound command causes the definition, within each of the selected tags, of a round size parameter, a selected or not selected flag, a proposed reply slot position, and sets to zero a counter of reply slot positions. Tags that are energized by the reader select a random slot number as the proposed reply slot and set their states to the SLOTTED READ state and slot counters to zero. In this state, tags calculate a proposed reply slot and wait until their slot counter reaches the proposed reply slot position, whereupon the tag will reply during the slot. This counter advances each time the reader sends the end of a slot.

A tag sends its response to the reader when its counter reaches the proposed reply slot position. The reply conditions within that slot can be separated into three categories: no tag reply present; one tag reply present; and two or more tag replies present. If the reader detects that no tag reply is present, the reader send a CloseSlot command, which signals to all tags in the SLOTTED READ state to increment their slot counter. If the reader receives a response correctly, it closes the slot by issuing a FixSlot command, which makes all tags to increment their counters and prompts the tag that was correctly heard to go into the FIXED SLOT state. In the FIXED SLOT state, the tag continues to reply in each round. If however, the reader detects a collision, it sends a CloseSlot command forcing all tags to increment their counters, while those tags that had responded in this slot, realize that there was a collision since they did not receive the FixSlot command, and thus they select another slot for transmission.
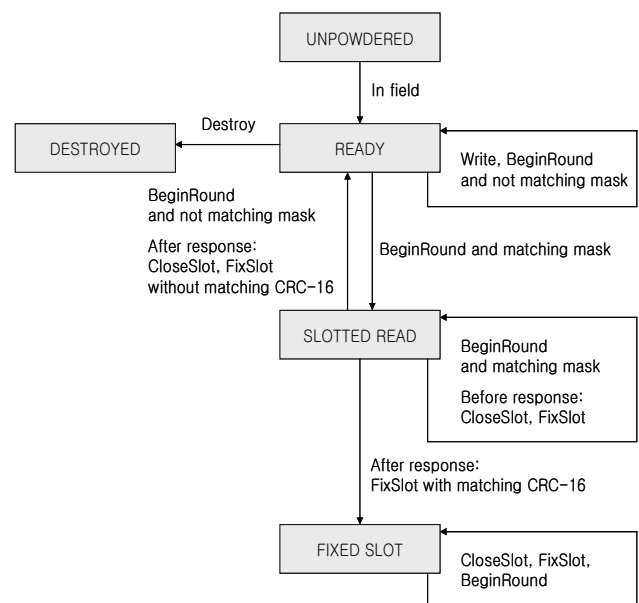


Fig. 2. Operations of STAC protocol.

## III. PROPOSED SCHEME

### A. Research motivations

In STAC protocol, the identification process will be continued by the reader until the end of query round even though a lot of slots in a round collide. A new query round begins after identifying a frame. In the new query round, tags that come into a collision in the previous round contend with other tags in selecting a slot counter value. This may cause a series of collision. Thus, it is anticipated that the identification delay for each tag will be various and it is hard to guarantee tags the fair identification delay.

In this section, for the purpose of analyzing the fairness of STAC protocol, we analyze the distribution of identification delay for each tag. The performance analysis was done by the computer simulations. It is assumed that the frame structure and sot length for simulation are same with the 13.56MHz RFID system proposed by Auto-ID center [9]. Also, the initial frame size and the minimum frame size are set to 16 slots. Fig.3 and Table 1 show the frame structure and the read cycle timing of 13.56MHz RFID system, respectively. The EPC code length assumes to be 64 bits for the timing values in the Table 1.
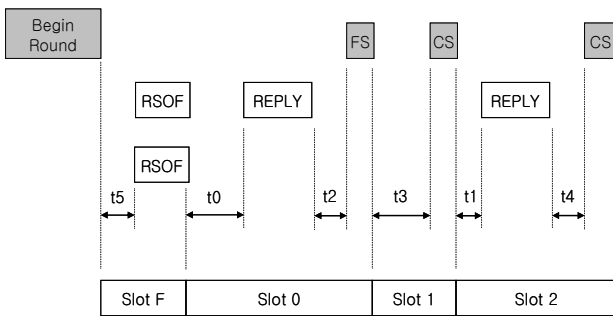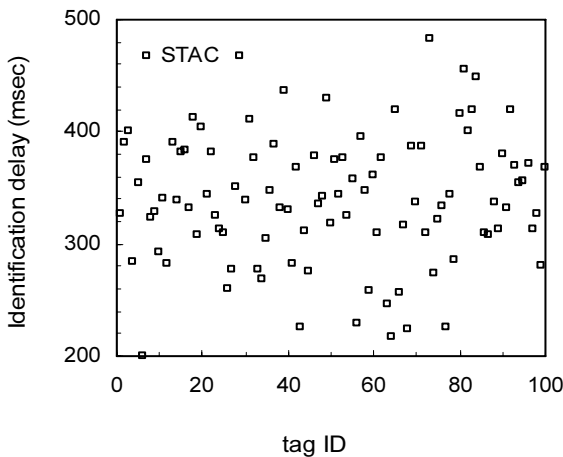


Fig. 3. Frame structure.



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

Fig.4 and Fig.5 illustrate the identification delay of each tag where the number of tags is 100 and 500, respectively. When the number of tags is 100, the average identification delay for each tag is 340msec and the standard deviation is 57.7msec. 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 1,857msec and 367.4msec, respectively. 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 guarantee a fair identification delay.

TABLE I
READ CYCLE TIMING

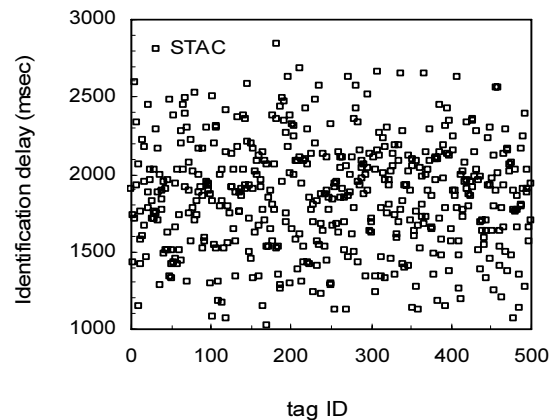| Items | | Value (μsec) |
|---|---|---|
| Begin Round | | 1,623.68 |
| Slot F | | 188.79 |
| Slot 0 | Success | 2,756.48 |
| | Collision | 2,114.56 |
| | Empty | 226.54 |
| Slot i (i≠0) | Success | 2,945.27 |
| | Collision | 2,303.35 |
| | Empty | 490.85 |



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

### B. Proposed scheme

In this paper, we propose a scheme to guarantee tags the fair identification delay. Fig.6 shows the operation for the scheme that applied in the STAC protocol. The basic operations are same as the STAC protocol, but the differences are presented by italic letters. In the proposed scheme, we added a COLLISION READ state and CollisionRound command.

At first, the reader sends a BeginRound command to initiate a query round. The issuing of a BeginRound command causes a subset of tags which are waiting in the READY state to enter the SLOTTED READ state and to

select a random slot number as the proposed reply slot. In this state, tags send a reply when their slot counters reach the proposed reply slot position. The reader issues a FixSlot or CloseSlot command according to the reply slot conditions. When there is one tag reply in the reply slot, the reader sends a FixSlot command. On the other hand, when the reply slot is empty or collision, the reader sends a CloseSlot command. Tags which are in the SLOTTED READ state increment their slot counter each time the reader issues the end of a slot.

The reader counts the number of collision slots during the identification process in a query round. If the number of collision slots is larger than a certain threshold value, the reader cancels the current query round and begins a collision round by sending a CollisionRound command. The CollisionRound command contains the number of slots in the collision round. The effect of this command is to move the tag that experienced a collision in the current query round from the SLOTTED READ state to the COLLISION READ state.

During the collision round, the reader identifies only tags that experienced a collision in the current query round. The number of slots in the collision round has to be defined in the CollisionRound command. In FSA algorithm, the number of tags that are involved in collisions is $2.4N_c$ when the number of collision slots is $N_c$ [11]. Therefore, we define a new frame size for a collision round as follows:

$$n = \lceil \log_2(2.4N_c) \rceil \qquad (1)$$

At the end of a collision round, the reader issues a CollisionRound command again to initiate another collision round if if unidentified tags still remain in the COLLISION READ state.
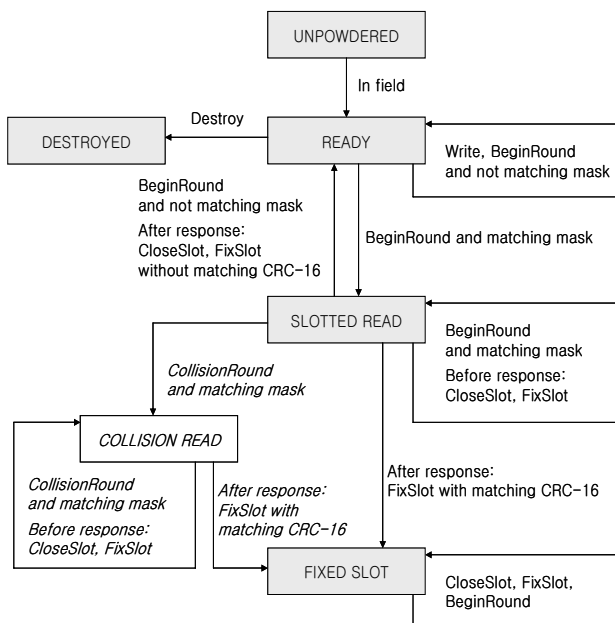


Fig. 6. Operations for the proposed scheme.

## IV. SIMULATION RESULTS

In this paper, we evaluate the performance for the proposed scheme through the computer simulations. The simulation system was developed with SMPL libraries [12] and MS Visual C++ 6.0. The system parameters for simulations are same as Table 1 in Section III. We compare the proposed scheme with STAC protocol. 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 [13]:

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

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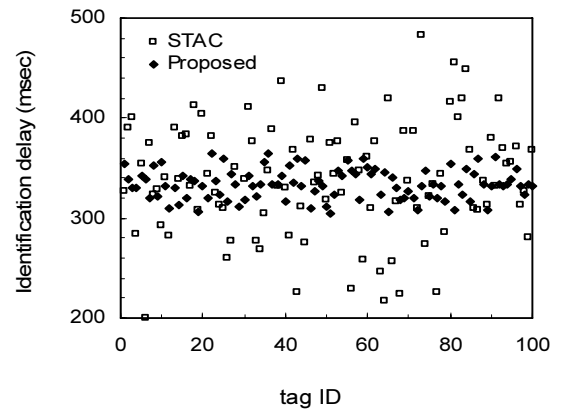


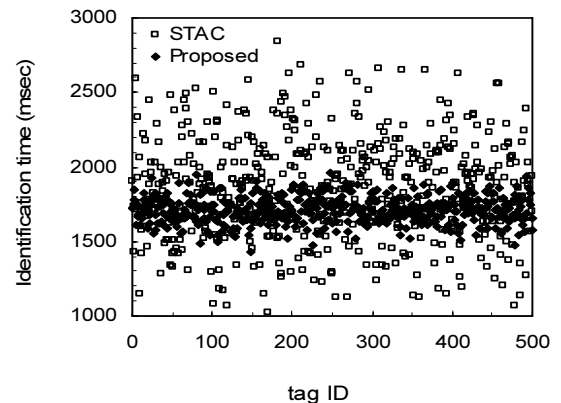Fig. 7. Delay for each tag when the number of tags is 100.



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

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 of each tag is 334msec and the standard deviation is 15msec. On the other hand, the identification delay of each tag and standard deviation for the STAC protocol are 340msec and 58msec, respectively. When there are 500 tags in the identification range of reader, the average identification delay of each tag and standard deviation for the proposed scheme are 1,711msec and 88msec, respectively. And those for STAC protocol are 1,857msec and 367msec, 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 STAC protocol is 0.96.
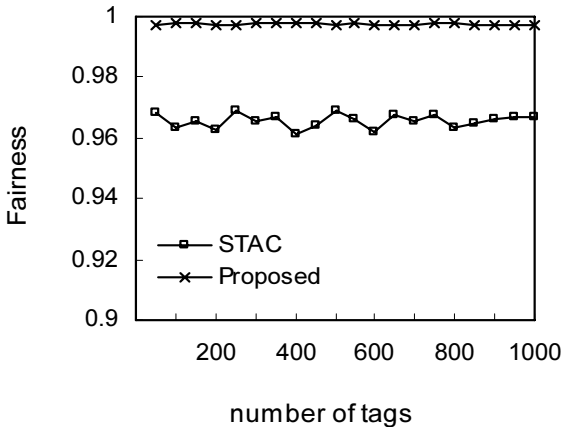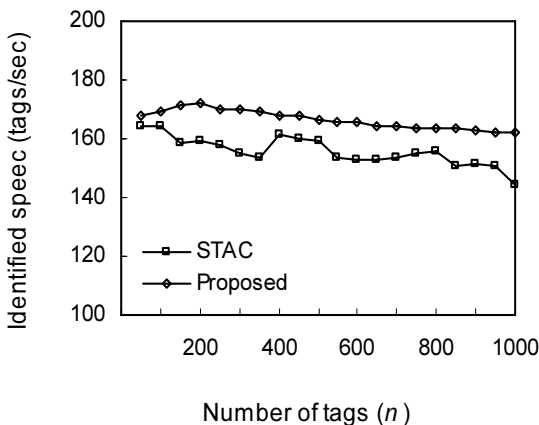


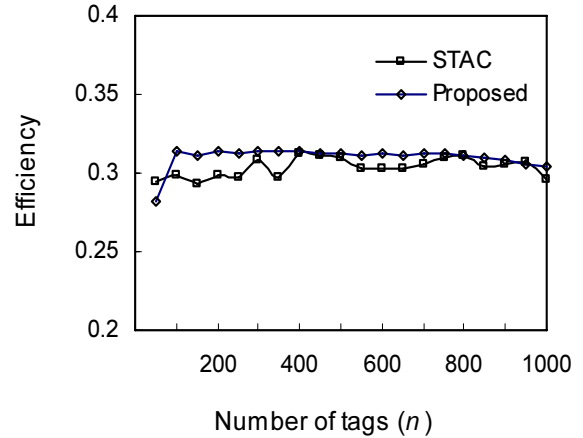Fig. 9. Fairness index.



Fig. 10. Identification speed.



Fig. 11. Slot efficiency.

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, the reader using the proposed scheme and STAC protocol can identify 166 and 155 tags per a second, respectively. Thus, the proposed scheme is about 7% faster than STAC protocol. The average slot efficiencies for the proposed scheme and STAC protocol are 31% and 30%, respectively. Furthermore, as shown in Fig.10 and Fig.11, the proposed scheme is more stable than STAC protocol when the number of tags is large.

## V. CONCLUSIONS

This paper proposed a scheme for tags to be identified fairly in STAC protocol of 13.56MHz RFID systems. In the STAC protocol, the reader continues an identification process until the end of query round. But, 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 counts the number of collision slots. If the number of collision slots is above a certain threshold, the reader cancels the current query round and broadcasts a CollisionRound command to begin a collision round. When tags detect a CollisionRound command, only tags that experienced a collision in the previous query round select a random slot and reply their IDs. The simulation results showed that the proposed scheme outperforms and is more stable than STAC protocol. For the further researches, we are planning to evaluate the number of collision slots for the reader to decide whether it starts the collision round or not.

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