Transmission Probability Control Scheme in FSA-based RFID Systems

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***Abstract*—This paper proposes a transmission probability control scheme for enhancing the performances of FSA-based RFID system. In order to maximize the system performance, the number of tags attempting to transmit their identifiers in a frame should be kept at a proper level. The reader calculates the transmission probability according to the number of tags within the identification range of reader and then broadcasts it to tags. Tags, in which their slot counter values reach to zero, attempt to transmit their identifiers with the received probability. Simulation results show that the proposed scheme can offer better throughput and delay performance than the conventional one regardless of the number of tags.**

***Index Terms*—RFID system, Framed slot ALOHA, Anti-collision algorithm, Transmission probability**

I. INTRODUCTION

A reader in RFID system broadcasts a request message asking for the tag identification codes. Upon receiving this message, all tags within the identification range of reader send their response back to the reader at the same time. If only one tag answers, the reader receives just one message which is correctly decoded. If two or more tags answer, they will collide on the RF channel and cannot be correctly received by the reader. This may lead to mutual interference, which is referred to as a collision. A technical scheme that handles multiple-access without any interference is called as an anti-collision algorithm [1][2].

In RFID systems, there are two main types of anti-collision algorithms: deterministic and probabilistic algorithms [3][4]. The first ones are ALOHA-based protocols; the second ones are tree-based protocols.

In the deterministic algorithm, the reader queries all the tags within the identification range of reader for the next bit of their identifiers [5]. On detecting collision, the reader mutes subsets of tags that are involved in a collision and queries again until there is only one tag response. The main advantage of deterministic algorithm is its effectiveness, which means that all tags can be successively identified even when the number of tags is large. However, it requires a lot of query cycles to identify all tags. Also, the tags may need complex circuit and memory. The deterministic algorithms are used in EPCglobal Class-0 and ISO/IEC 18000-6 Type B, which uses binary tree-walking scheme [6].

Almost all the probabilistic algorithms use framed slot ALOHA (FSA), which has been advanced in function by adding slotting and framing on ALOHA protocol. The tags send their identifiers at a randomly selected slot. When collisions occur, tags that are involved in collisions retransmit their identifiers in the next identification 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. Almost all the 13.56 MHz RFID systems use FSA algorithms [7]. The performance of FSA algorithm is dependent on the frame size and the number of tags within the identification range of reader. If there are a lot of tags in spite of small frame size, the identification time will increase because of the frequent collisions. On the other hand, when the number of tags is small in the system with large frame size, the number of wasted slots increases. The tag identification time and system efficiency depend mainly on the frame size and the number of tags. EPCglobal Class-1 Gen-2 and ISO/IEC 18000-6 Type C use the probabilistic algorithm as the standard [8][9].

If the number of tags in the identification range of reader is larger than a frame size, the messages received by the reader may collide. If the number of tags to be identified in a frame can be remained close to a level that the system can support, it is expected to achieve the best system performance. Therefore, the number of tags attempting to transmit needs to be limited with the use of transmission control scheme. In this paper, we propose a scheme to control the transmission probability based on the number of tags.

This paper is organized as follows. Section II describes the system model for the proposed scheme. The proposed transmission control scheme is explained in Section III, and simulation results are presented in Section IV. Concluding remarks are presented in Section V.

II. SYSTEM OPERATION

The reader begins an identification round by sending a Begin Round command. After issuing a Begin Round command to initiate an identification round, the reader transmits one or more Fix Slot or Close Slot command according to the tag's reply. Fig.1 shows the operation for the proposed scheme. At first, the reader initializes the

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transmission probability into 1.0. And it transmits a Begin Round command to start an identification round. Begin Round command contains a slot-count parameter.

Upon receiving a Begin Round command, participating tags pick a random value, and load this value into their slot counter. If tags that their slot counter reaches zero are permitted in transmission, they backscatter their identifiers. When the reader receives an identifier, it acknowledges the tag with a Fix Slot command and assumes that this tag is successfully identified. After that, it reads from or writes to the identified tag. At the end of a frame, the reader checks that all tags within the identification range are identified. This is accomplished by whether all the slots are idle or not. If unidentified tags still remain in the identification range of reader, the reader calculates a new transmission probability with the scheme proposed in this paper. And it starts a new identification round at the next frame. Tags that are not permitted at their reply slots do not transmit their identifiers and waits until next frame.

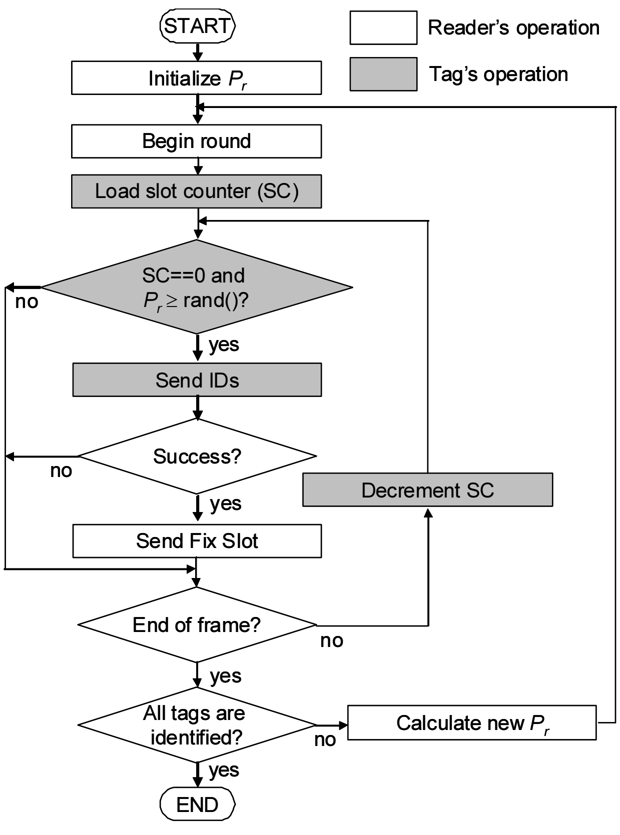

Fig.1. Flow descriptions.

Fig.2 shows the simplified state transition diagram of tag. Tags which enter the energizing or signaling field, when they have sufficient power for operation, wait before replying in a Ready state for the reception of one of several commands. Upon entering an energizing RF field, a tag that is not killed enters Ready state and remains in Ready state until it receives a Begin Round command. When tags receive a Begin Round command, they draw a number from their random number generator, load this number into their slot counter. Tags in the Ready state transition to the Arbitrate or Reply state according to their slot counter value and transmission probability. If the slot counter is zero and transmission is permitted, it transitions to the Reply state. Otherwise, it enters into the Arbitrate state.

A tag in the Arbitrate state decrements a slot counter every time it receives a Fix Slot or Close Slot command. It transitions to the Reply state and backscatters an identifier when its slot counter reaches zero and transmission is permitted. Upon entering Reply state, a tag backscatters an identifier. If the tag receives a valid acknowledgement, i.e. Fix Slot command, it enters the Acknowledged state. If the tag fails to receive a Fix Slot command within the specified time, or receives a Close Slot command, it returns to the Arbitrate state. After acknowledging a tag, a reader can choose to access it.

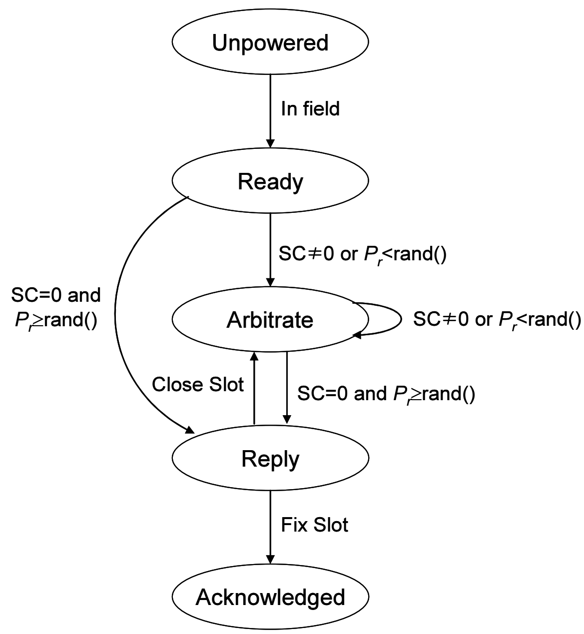

Fig.2. Simplified tag state diagram.

III. TRANSMISSION CONTROL SCHEME

As shown in Fig.1, tags that their slot counter reaches zero transmit identifiers with the transmission probability P_r. The reader calculates a transmission probability based on the estimated number of tags at every frame. The tag number estimation is performed as followings.

The reader estimates the number of tags by combining the information obtained after a read cycle with the result of probabilistic analysis. Let N_e and N_s be the number of idle and successful slots observed after the identification round, respectively. If we assume that the number of idle slots and successful slots observed after an identification round is equal to their expected values, respectively, then

N_e and N_s can be given as follows [10].

$$N_e = N\left(1-\frac{1}{N}\right)^n \tag{1}$$

$$N_s = n\left(1-\frac{1}{N}\right)^{n-1} \tag{2}$$

where N and n are the number of slots in a frame and number of tags, respectively.

By solving Eq.(1) and (2) for the number of tags, we can obtain

$$n = (N-1)\frac{N_s}{N_e} \tag{3}$$

The number of tags that will be involved in the next identification round is equal to the number of colliding tags n_c. Therefore, the number of colliding tags can be estimated by subtracting Ns from Eq.(3) as follows.

$$n_c = (N - N_e - 1)\frac{N_s}{N_e} \tag{4}$$

Because the reader can obtain the number of successful slots and idle slots after an identification round, it also can estimate the number of unidentified tags from Eq.(4). But, as shown in Eq.(4), if there are neither successful slots nor idle slots, we cannot use the above equation. Therefore, we supplement the result of probabilistic analysis for the exact estimation.

If we let α be the average number of tags in each collision slot, α can be given by

$$\alpha = \frac{\sum_{r=2}^{n} rN\binom{n}{r}\left(\frac{1}{N}\right)^r\left(1-\frac{1}{N}\right)^{n-r}}{N - N\left(1-\frac{1}{N}\right)^n - n\left(1-\frac{1}{N}\right)^{n-1}} \tag{5}$$

The optimal performance for the identification delay and efficiency can be obtained when the frame size is equal to the number of tags. Therefore, from Eq.(5), the average number of tags in each collision slot is about 2.4. If we let N_c be the number of collision slots, the number of colliding tags with the probabilistic analysis is give by

$$n_c = 2.4N_c \tag{6}$$

By combining the observed result in Eq.(4) with the probabilistic result in Eq.(6), we can estimate the number of unidentified tags as following.

$$n_c = \begin{cases} (N - N_e - 1)\dfrac{N_s}{N_e} & \text{, if } N_e \neq N_s \neq 0 \\ 2.4N_c & \text{, otherwise} \end{cases} \tag{7}$$

With the estimated number of unidentified tags, the reader calculates the transmission probability as follows:

$$P_r = \begin{cases} 1, & \text{if } n_c \le N \\ \dfrac{N}{n_c}, & \text{otherwise} \end{cases} \tag{8}$$

In the proposed scheme, if the number of unidentified tags is less than the frame size, all the tags should be allowed to transmit their identifiers. If the number of unidentified tags becomes more than the number of slots in a frame, the reader sets P_r as the values at which the total number of tags becomes N, in order to minimize the collision rate.

IV. SIMULATION RESULTS

In this paper, the computer simulations were performed to compare the performance of proposed scheme with the conventional scheme with respect to the system efficiency and identification time. The identification time is defined as the time to identify all tags and the efficiency as the number of tags identified in a slot. For the purpose of performance comparison, the conventional scheme does not have any transmission control scheme. 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 [7].

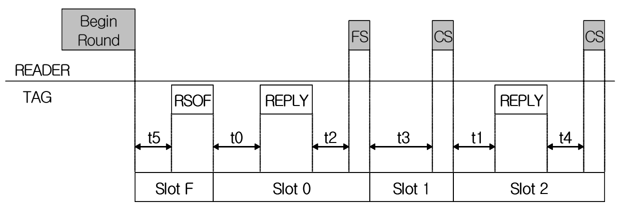

Fig.3. Frame structure.

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.3 and Table 1 show the frame structure and the read cycle timing of 13.56MHz RFID system for obtaining the tag identification delay, respectively. The EPC code length assumes to be 64 bits for the values in the Table 1.

Fig.4 shows the collision slot rate with respect to the frame size, when the number of tags in the identification range of reader is 200. The collision slot rate is defined as the ratio of collision slots to the frame size. As shown in Fig.4, the collision slot rates for the proposed scheme and conventional scheme are 43% and 61%, respectively. Moreover, when the frame size is small, the collision slot rate of proposed scheme decreases more sharply than the conventional one by decreasing the frame size. Therefore, as shown in Fig.5, the identification time of proposed scheme is almost same regardless of the frame size. But in the case of conventional scheme, the identification time increases very sharply when the frame size is small.

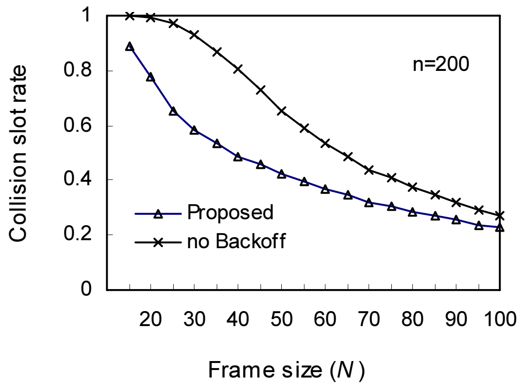

Fig.4. Collision slot rate according to frame size.

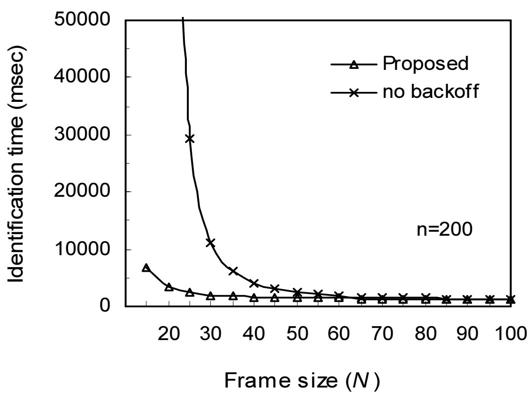

Fig.5. Identification time according to frame size.

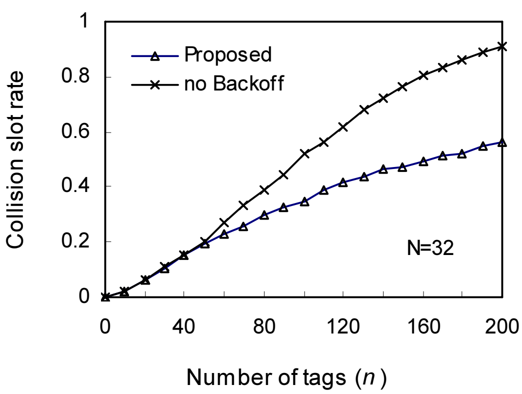

Fig.6. Collision slot rate according to the number of tags.

Fig.6 shows the collision slot rate according to the number of tags when a frame consists of 32 slots. When the number of tags is 100, the collision slot rate for the proposed scheme and conventional scheme is 35% and 52%, respectively. On the other hand, when there are 200 tags within the identification range of reader, the collision slot rate for the proposed scheme and conventional scheme is 56% and 91%, respectively. As shown in Fig.6, when the number of tags increases, the collision slot rate for the conventional scheme increases more than the proposed scheme. This will be the cause of increases for the identification time.

The identification time and efficiency according to the number of tags in the identification range of reader are depicted in Fig.7 and Fig.8, respectively. The proposed scheme and conventional scheme can identify 100 tags within 0.68 and 0.87 second. When the number of tags is small, the identification time for both schemes is almost same. On the other hand, as shown in Fig.7, when the number of tags is 200, the identification time for the proposed scheme is 4.5 times faster than the conventional scheme. Furthermore, the efficiency for the conventional scheme decreases more sharply than the proposed scheme. This is because the collision slot rate of conventional scheme increases by increasing the number of tags.

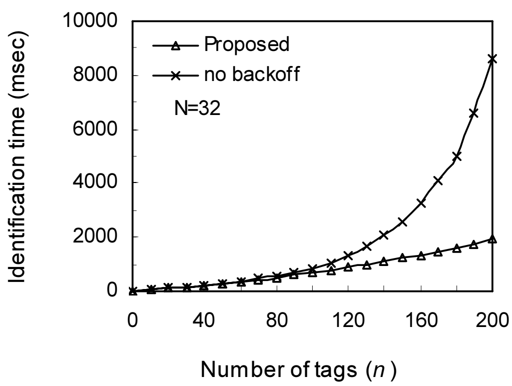

Fig.7. Identification time according to the number of tags.

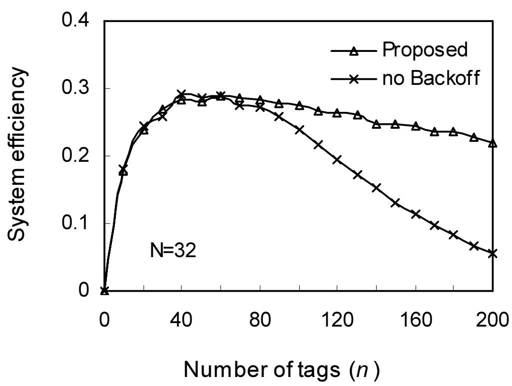

Fig.8. Efficiency according to the number of tags.

V. CONCLUSIONS

This paper has proposed a transmission probability control scheme for FSA-based RFID systems. In the conventional FSA anti-collision algorithm, tags transmit their identifiers unconditionally when the slot counter is zero. This may cause a high collision slot rate.

The design objective of proposed scheme is to improve the system efficiency and identification time. In the proposed scheme, the reader calculates a transmission probability of tags based on the frame size and estimated number of tags within the identification range of reader. And it broadcasts before an identification round begins. All the tags that the slot counter reaches zero transmit their identifier with the received transmission probability. The simulation results show that the proposed scheme achieves better performances than the convention scheme without the transmission probability control.

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