Optimal Frame Size Allocation Scheme for 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. Among the existing anti-collision algorithms, static framed slot allocation algorithm is very simple. But when the number of tags is variable, its performance degrades because of the fixed frame size. This paper proposes an optimal frame size allocation scheme that determines the frame size. The proposed scheme is based on the number of collision slots at every frame. According to the simulation results, the tag identification time is faster that that of SFSA.

Index Terms—RFID, Anti-collision algorithm, FSA

I. INTRODUCTION

An RFID system consists of radio frequency tags attached to objects that need to be identified and one or more electromagnetic readers [1]. Unlike the traditional bar code system, the great benefit of RFID technology is that it allows information to be stored and read without requiring either contact or line of sight between the tag and the reader. For this contact-less feature, RFID technology in the near future will become ubiquitous and an attractive alternative to bar code in many application fields.

When there is more than one tag in the identification range of a reader, all or some tags may 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, their messages 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 [2].

Two major performance measures in RFID system are the tag identification time and the energy consumption. When the reader requests the tag identification code, the identification time is fast and the energy consumption is low as the number of read-cycle is small for identifying all the tags in the reader's identification range [3]. Therefore, an anti-collision algorithm must be carefully designed for conserving low power consumption and fast identification of multiple tagged objects simultaneously.

There are two types of anti-collision algorithms: deterministic and probabilistic algorithm [4][5][6]. 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 algorithm is based on an ALOHA-like protocol that provides slots for the tags to send their data. Whenever a collision has occurred, another frame of slots is provided, and the tags that are involved in collisions will choose different slots in the next read cycle.

In almost all the 13.56 MHz RFID systems, SFSA (Static Framed Slot ALOHA) algorithm is used for anti-collision algorithm [7]. SFSA algorithm is based on the slotted ALOHA scheme with a fixed frame size. Therefore, the performance of SFSA 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 this paper, we present an optimal frame size allocation scheme. In the proposed scheme, the frame size will be determined based on the number of tags in the reader's identification range.

This paper is organized as follows. In Section II, the brief descriptions of SFSA algorithm are presented. The proposed frame size allocation scheme with the numerical analysis for SFSA algorithm is presented in Section III while in Section IV we show the results of simulation. In Section V, conclusion and future work complete the paper.

II. ANALYSIS OF SFSA ALGORITHM

In slotted ALOHA algorithm, a time frame that tags respond is composed of slots with fixed length. The tags randomly select a slot and transmit their identification code through the selected slot. The reader can identify

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the tag only if there is no collision in the slot. FSA (Framed Slot SLOHA) algorithm, which is one of the slotted ALOHA, is used in most 13.56MHz RFID system. The frame means the time duration between the reader's requests. The frame size varies depending on the number of slots because a frame consists of slots.

The frame size in SFSA algorithm, which is one of FSA algorithm, is fixed. The reader broadcasts a read request command to all the tags within the reader's identification range and waits during a frame until the tags transmit their identification code. The frame defined here consists of a fixed number of slots that the tags transmit their response. The request command from the reader to the tags also includes a dynamic parameter by which every tags generates a random number for selecting a slot. When the tag receives a read request command, it generates a random number uniformly distributed within the range from 1 to frame size. The generated random number is the slot number. The tag transmits its identification code through the selected slot. If two or more tags select the same slot, a collision occurs. If the reader detects a collision in the slot, no actions can be occurred, and the tags involved in the collision repeat the next read cycle. On the other hand, if no collision occurs, the reader sends acknowledgements to those tags whose their identification codes have been successfully received. These acknowledgements are also used to disable the tags such that they cannot respond to the request command at the next read cycle.

An example provided in Fig. 1 illustrates the process of SFSA algorithm. In this example, we assume that there are 4 tags and a frame consists of 2 slots. We denote the read cycle as the tag identification process with a frame. In the first read cycle, tag 1, 3, and 4 transmit their identification code in time slot 1. The transmissions cause a collision because they occur at the same time slot. Only tag 2 sends its identification code in time slot 2, and thus can be successfully identified by the reader because that slot is singly occupied. After successfully receiving the identification code, the reader sends an acknowledgement to tag 2, and the acknowledgement is used to disable tag 2. Since a collision occurs in time slot 1, this case implies that there exist at least two tags, which need to be read. Therefore, another read cycle is required. The second read cycle uses a new frame, and these read cycles repeat until completing the readings of all tags.

Downlink	Request	①	②	Request	①	②
Uplink		collision	0010		0001	collision
Tag 1		0001			0001	
Tag 2			0010			
Tag 3		1010				1010
Tag 4		1011				1011

Fig.1. Example of SFSA algorithm.

III. FRAME SIZE ALLOCATION SCHEME

A. Numerical Analysis of SFSA algorithm

In this paper, we present the problems of FSA algorithm when the frame size is fixed, and propose a new scheme for solving these problems. For this purpose, this section presents the numerical analysis results of SFSA algorithm.

For analyzing the performance of SFSA algorithm, it is assumed that a frame consists of N slots and there are n tags in the reader's identification range. Also, we assume that the tag selects one of N slots with the equal probability because it generates a random number uniformly distributed within the range from 1 to frame size. For a given time slot, the number of tags allocated into the slot is a binomial distribution with n Bernoulli experiments and $1/N$ occupied probability. Therefore, the probability $B_{n,N}(r)$ that r tags out of n respond in a given slot defined as follows.

$$B_{n,N}(r)=\binom{n}{r}\left(\frac{1}{N}\right)^{r}\left(1-\frac{1}{N}\right)^{n-r} \tag{1}$$

Because a frame is N slots, the expected number of slots $a_{n,N}(r)$ that r tags respond is given by

$$\begin{aligned} a_{n,N}(r) &= N\times B_{n,N}(r) \\ &= N\binom{n}{r}\left(\frac{1}{N}\right)^{r}\left(1-\frac{1}{N}\right)^{n-r} \end{aligned} \tag{2}$$

Similarly, the expected number of slots $a_{n,N}(0)$ that is empty and $a_{n,N}(1)$ that is singly occupied are defined as follows, respectively.

$$\begin{aligned} a_{n,N}(0) &= N\times B_{n,N}(0) \\ &= N\left(1-\frac{1}{N}\right)^{n} \end{aligned} \tag{3}$$

$$\begin{aligned} a_{n,N}(1) &= N\times B_{n,N}(1) \\ &= n\left(1-\frac{1}{N}\right)^{n-1} \end{aligned} \tag{4}$$

If the efficiency E is defined as the expected number of singly occupied slots divided by the frame size, it is given by

$$\begin{aligned} E &= \frac{a_{n,N}(1)}{N} \\ &= \frac{n}{N}\left(1-\frac{1}{N}\right)^{n-1} \end{aligned} \tag{5}$$

If we define the tag identification time as the delay until all the tags are completely identified, it can be represented with the product of the number of retransmissions due to the collision and the frame size.

Let $S_{n,N}$ denote the probability that a tag is successfully identified within a frame and $F_{n,N}$ the probability that a tag is not identified within a frame. These two probabilities are given as follows, respectively.

$$S_{n,N} = \frac{B_{n,N}(1)}{n} \times N = \left(1 - \frac{1}{N}\right)^{n-1} \tag{6}$$

$$F_{n,N} = 1 - S_{n,N} = 1 - \left(1 - \frac{1}{N}\right)^{n-1} \tag{7}$$

Let $S_{n,N}(k)$ be the probability that a tag is successfully identified at the k-th frame. It can be defined as the probability that (k-1) consecutive collisions occur and the identification is done at the k-th frame. The probability $S_{n,N}(k)$ and the average number of retransmissions $E[S_{n,N}(k)]$ are given by

$$S_{n,N}(k) = F_{n,N}^{k-1} \times \left(1 - F_{n,N}\right) \tag{8}$$

$$E\left[S_{n,N}(k)\right] = \frac{1}{\left(1 - \frac{1}{N}\right)^{n-1}} \tag{9}$$

We defined the tag identification time D as the product of the number of retransmissions given in Eq.(9) and the frame size N. Therefore, the tag identification time D is given by

$$D = E\left[S_{n,N}(k)\right] \times N = \frac{N}{\left(1 - \frac{1}{N}\right)^{n-1}} \tag{10}$$

Fig. 2 and 3 show the efficiency and tag identification time as a function of the number of tags, respectively. These results are obtained using Eq.(5) and (10). The slot duration for calculating the identification time is assumed to be equal to that of 13.56MHz RFID system proposed by Auto-ID Center [7]. If the frame size is small, a lot of collisions will occur. Therefore, as depicted in the figures, in the case of small frame size, the efficiency decreases and the identification time increases rapidly as the number of tags increases. On the other hand, if the number of tags is small and the frame size is large, a lot of time slots will be wasted. So, the efficiency decreases and the identification time increases compared with the small frame size as the number of tags decreases.

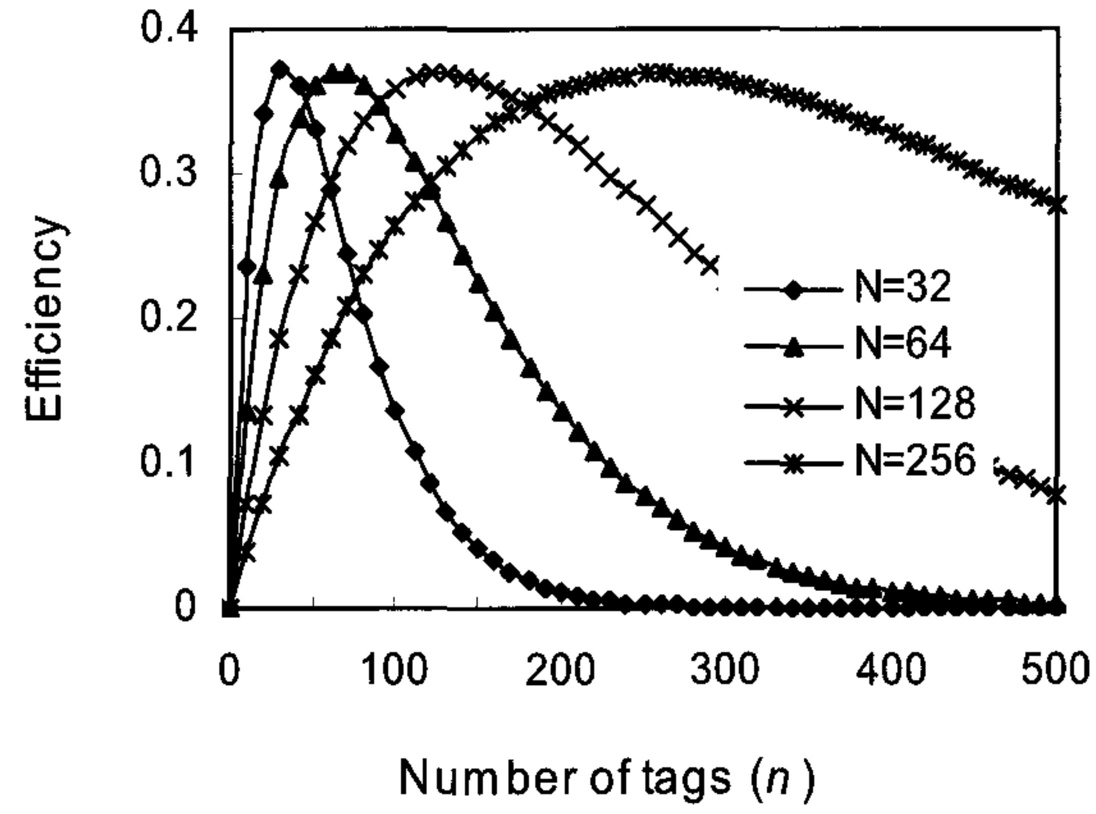

Fig. 1. Efficiency for SFSA algorithm.

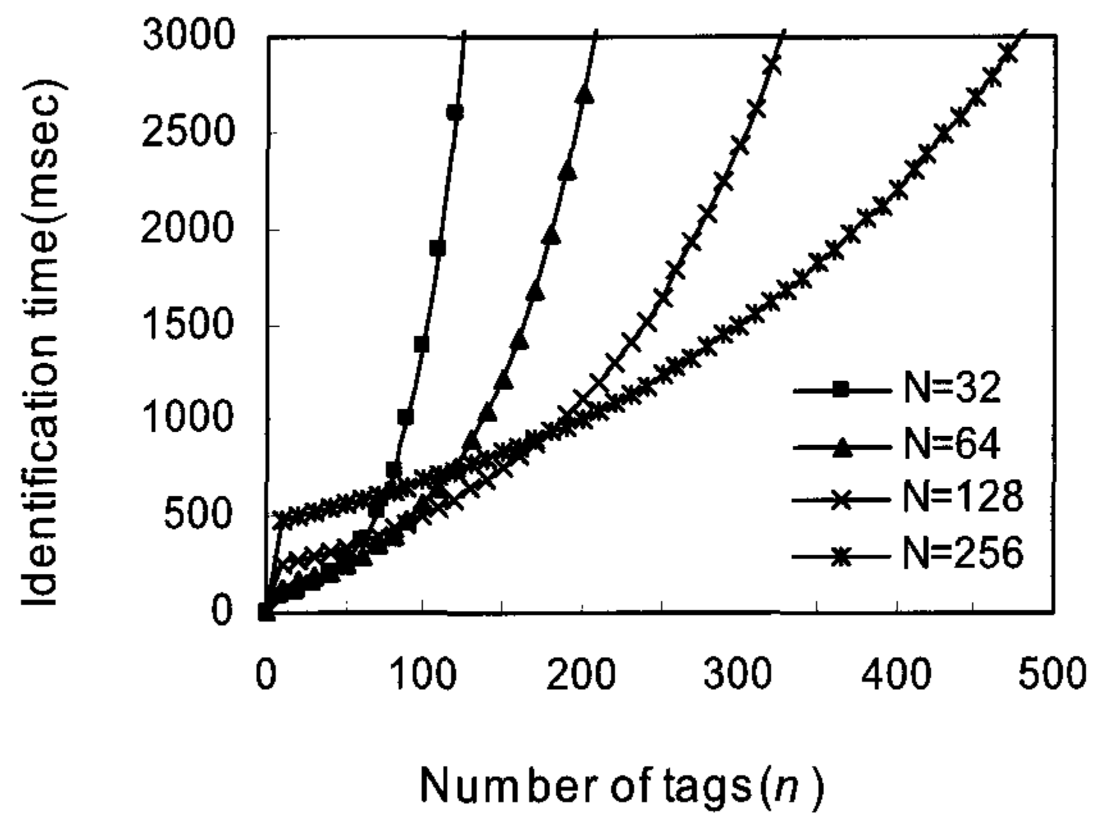

Fig. 2. Identification time for SFSA algorithm.

As shown in the figures, the performances of framed slot ALOHA algorithm in RFID system are dependent on the frame size and the number of tags in the reader's identification range. Therefore, it is necessary to allocate a frame size dynamically for achieving the maximum performances.

B. Optimal Frame Size Allocation

The basic tag identification process for the proposed scheme is same as that of SFSA algorithm, except that the reader dynamically allocates the frame size for the next read cycle. The proposed frame size allocation scheme is based on the number of collision slots in the previous frame.

As an example, suppose that there exists a single slot and a collision occurs at the given time slot. Since the reader can only infer that at least two tags are involved in the collision, it allocates two time slots as the frame size for the next read cycle. At the next read cycle, if collisions occur at the two time slots, it can be estimated in the same way that at least four tags are present in its identification range. The reader then increases the frame size to four. At the following read cycle, if there exist two successful slots, one collision slot and one idle slot out of four slots, the reader decreases the frame size to two because at least two tags still exist in the reader's identification range.

As explained in the above example, the reader can keep track of the minimum number of collision tags. For a given time slot, there are only three possible outcomes: idle, success, and collision. The time slot is idle if no tag transmits its identification code in the time slot. The time slot is successful if exactly one tag sends its identification code to the time slot. If two or more tags transmit in the same time slot, the slot suffers from the collision and the reader cannot identify any tag. After finishing a read cycle with frame size N, the reader can observe the number of idle slots (N_i), the number of successful slots (N_s), and the number of collision slots (N_c), where $N = N_i + N_s + N_c$. The number of collision tags can be estimated from the observed number of idle slots, successful slots, and collision slots at the previous frame. With the estimated number of collision tags, the reader can estimate the minimum number of time slots necessary at the next read cycle.

Let $N_c^{(k)}$, $N_s^{(k)}$ be the number of collision slots and the number of successful slots at the k-th frame, respectively. If we let $N^{(k)}$ be the size of k-th frame, the (k+1)-th frame size $N^{(k+1)}$ can be allocated with the following.

$$N^{(k+1)} = \begin{cases} N_{\min} & ,\text{if } N^{(k)} = N_s^{(k)} \\ Max\{N^{(k)} - N_s^{(k)}, 2 \times N_c^{(k)}\} & ,\text{if } N^{(k)} \neq N_s^{(k)} \end{cases} \quad (11)$$

Here, $N_{\min}$ represents the minimum frame size.

IV. SIMULATION RESULTS

In this paper, the computer simulations are performed to compare the performance of the proposed scheme with the traditional SFSA algorithm with respect to the efficiency and identification time. 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. Also, the initial frame size and the minimum frame size are set to 16 slots.

Fig. 4 shows the efficiency compared with the SFSA algorithm as a function of the number of tags. Since the proposed scheme allocates the frame size according to the number of tags, it can maintain almost the same efficiency regardless of the number of tags. As depicted in the figure, the efficiency of the proposed scheme is 0.36, which is the maximum achievable efficiency of slotted ALOHA.

The identification time compared with the SFSA algorithm is depicted in Fig. 5. And Fig. 6 shows the identification compared with the frame size allocation scheme proposed for Phillips I-code system [6]. Suppose that there are 500 tags in the reader's identification range. If the frame size of SFSA algorithm is fixed with 128 slots, the proposed scheme can identify all the tags 4.4 times faster than SFSA algorithm. Also, the proposed frame size allocation scheme is 1.2 times faster than SFSA algorithm with 256 slots.

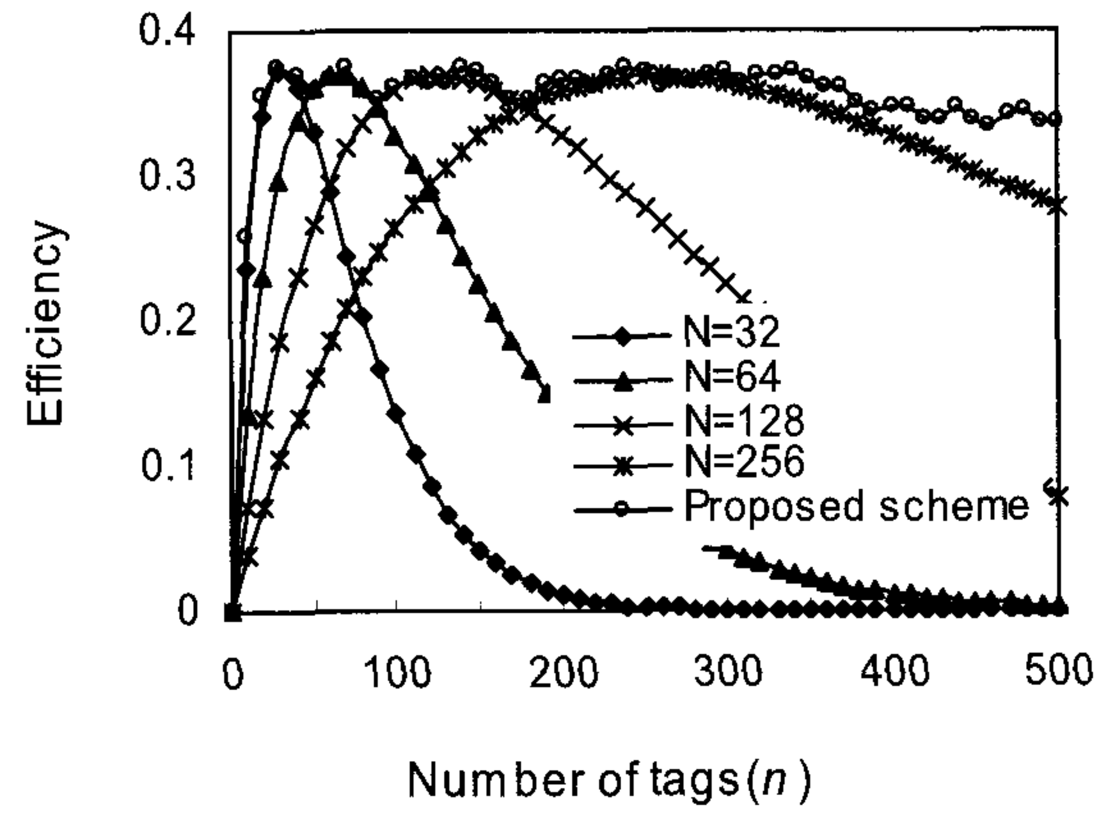

Fig. 4. Efficiency comparison.

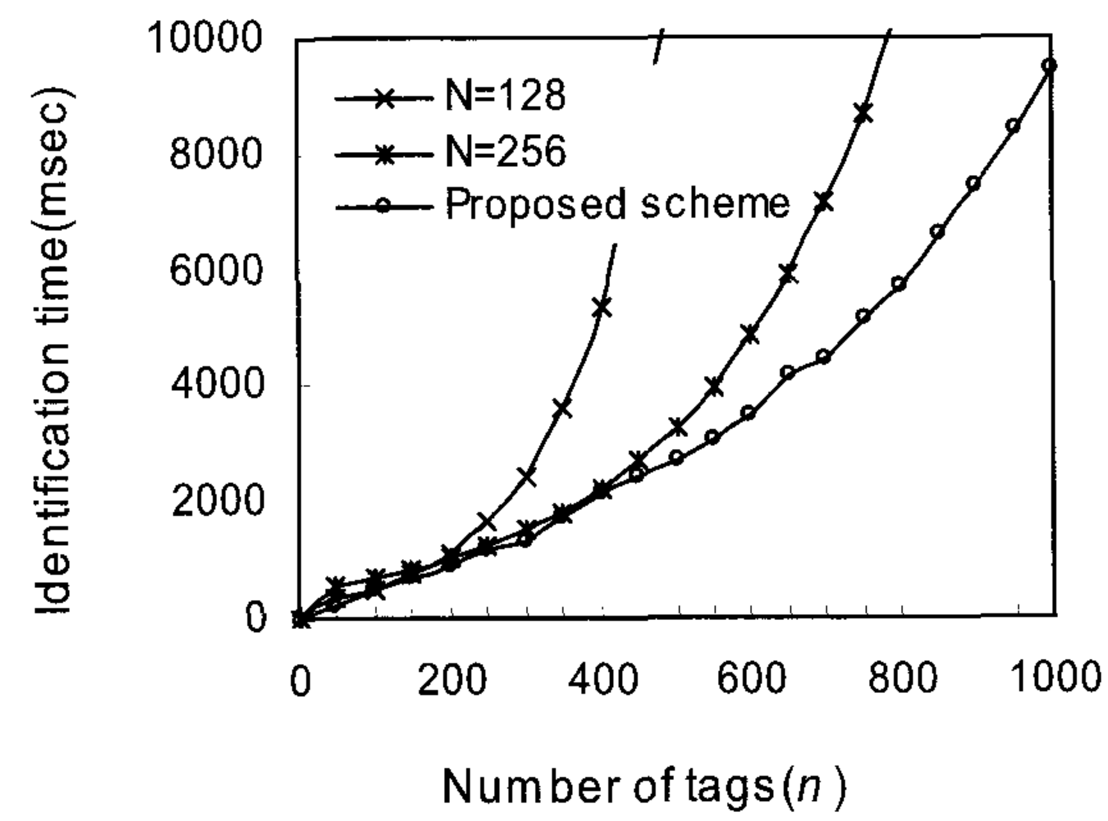

Fig. 5. Identification time comparison.

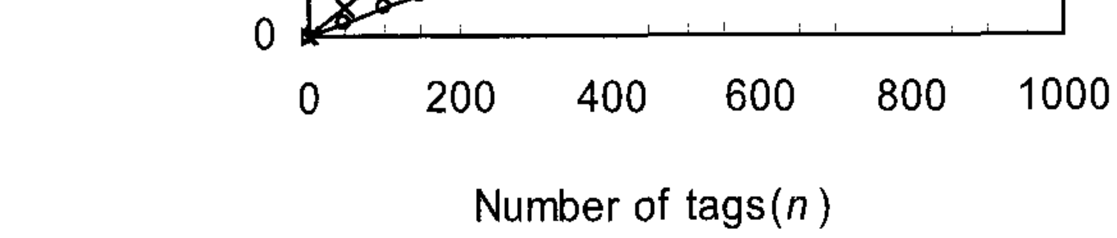

Fig. 6. Comparison with I-code.

V. CONCLUSIONS

This paper proposed an optimal frame size allocation scheme for RFID system, and compared the performance with SFSA algorithm. The frame size of the proposed scheme was based on the number of tags in the reader's identification range. In this scheme, the frame size for the next read cycle could be allocated according to the number of successful slots and collision slots at the current read cycle. As results of simulations, the efficiency was more stable and the identification time was faster than SFSA algorithm.

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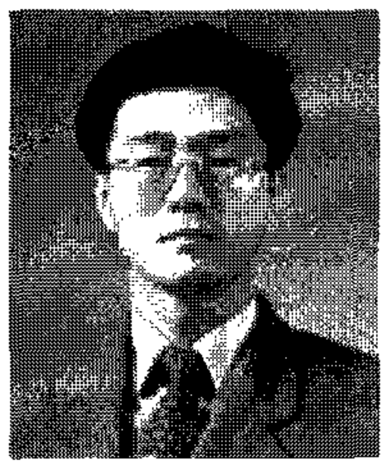

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