A Mechanism for Dynamic Allocation of Frame Size in RFID System

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Abstract—The FSA algorithm for identifying multiple tags in RFID systems is based on the slotted ALOHA scheme with a fixed frame size. The performance of FSA algorithm is dependent on the frame size and the number of tags in the reader's identification range. Therefore, this paper proposes a new ODFSA. The proposed ODFSA algorithm dynamically allocates the optimal frame size at every frame based on the number of tags in the reader's identification range. According to the simulation results, the system efficiency of the proposed algorithm should be maintained optimally. Also, the proposed algorithm always obtained the minimum tag identification delay.

Index Terms—RFID, Anti-collision algorithm, FSA

I. INTRODUCTION

A reader in RFID system broadcasts a request message to tags asking for the tag identification codes. Upon receiving this message, all tags in the reader's identification range 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 communication 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].

There are two types of anti-collision algorithms: deterministic and probabilistic algorithm [3][4]. 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, FSA (Framed Slot ALOHA) algorithm is used for anti-collision algorithm [5]. The FSA algorithm is based on the slotted ALOHA scheme with a fixed frame size. The performance of FSA algorithm is dependent on the frame size and the number of 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 propose an optimal frame size allocation scheme, named as ODFSA (Optimal Dynamic FSA) algorithm. In the proposed scheme, the frame size at every frame 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 performance of the traditional FSA algorithm is analyzed numerically, and the problems of FSA algorithm are presented with the numerical analysis results. The proposed ODFSA algorithm is presented in Section III. In Section IV, we show the simulation results. In Section V, conclusion and future work complete the paper.

II. PERFORMANCE ANALYSIS OF FSA

A. System Efficiency

For analyzing the performance of FSA 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.

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

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

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$$a_{n,N}(r) = N \cdot B_{n,N}(r) = N\binom{n}{r}\left(\frac{1}{N}\right)^r\left(1-\frac{1}{N}\right)^{n-r} \quad (2)$$

Similarly, the expected number of slots $a_{n,N}(0)$ that no tag answers, $a_{n,N}(1)$ that only one tag answers, and $a_{n,N}(\geq 2)$ that two or more tags answer are defined as follows, respectively.

$$a_{n,N}(0) = N \cdot B_{n,N}(0) = N\left(1-\frac{1}{N}\right)^n \quad (3)$$

$$a_{n,N}(1) = N \cdot B_{n,N}(1) = n\left(1-\frac{1}{N}\right)^{n-1} \quad (4)$$

$$a_{n,N}(\geq 2) = \sum_{r=2}^{n} a_{n,N}(r) = \sum_{r=2}^{n} N\binom{n}{r}\left(\frac{1}{N}\right)^r\left(1-\frac{1}{N}\right)^{n-r} \quad (5)$$

In the above equations, $a_{n,N}(0)$ and $a_{n,N}(1)$ mean the average number of empty slots and successful slots, respectively. And $a_{n,N}(\geq 2)$ means the average number of collision slots.

If the system efficiency E is defined as the average number of singly occupied slots in a frame, it is given by

$$E = \frac{a_{n,N}(1)}{N} = \frac{n}{N}\left(1-\frac{1}{N}\right)^{n-1} \quad (6)$$

B. Identification Delay

If we define the tag identification delay 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.

$$S_{n,N} = \frac{B_{n,N}(1)}{n} \cdot N = \left(1-\frac{1}{N}\right)^{n-1} \quad (7)$$

$$F_{n,N} = 1 - S_{n,N} = 1-\left(1-\frac{1}{N}\right)^{n-1} \quad (8)$$

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 $E[S_{n,N}(k)]$ can be given by

$$S_{n,N}(k) = F_{n,N}^{k-1} \cdot \left(1-F_{n,N}\right) \quad (9)$$

$$E\left[S_{n,N}(k)\right] = \sum_{k=1}^{\infty} k \cdot S_{n,N}(k) = \left(1-F_{n,N}\right)\sum_{k=1}^{\infty} k \cdot F_{n,N}^{k-1} = \frac{1}{\left(1-\frac{1}{N}\right)^{n-1}} \quad (10)$$

We defined the tag identification delay D as the product of the number of retransmissions given in Eq.(10) and the frame size N. Therefore, the tag identification delay D is given by

$$D = E\left[S_{n,N}(k)\right] \cdot N = \frac{N}{\left(1-\frac{1}{N}\right)^{n-1}} \quad (11)$$

C. Analysis Results

Fig. 1 and Fig. 2show the system efficiency and tag identification delay as a function of the number of tags, respectively. These results are obtained using Eq.(6) and (11). 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 system efficiency decreases and the identification delay 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 system efficiency decreases and the identification delay increases compared with the small frame size as the number of tags decreases.

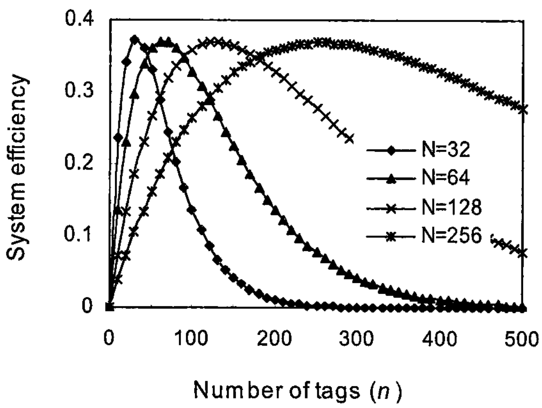

Fig. 1. System efficiency for FSA algorithm.

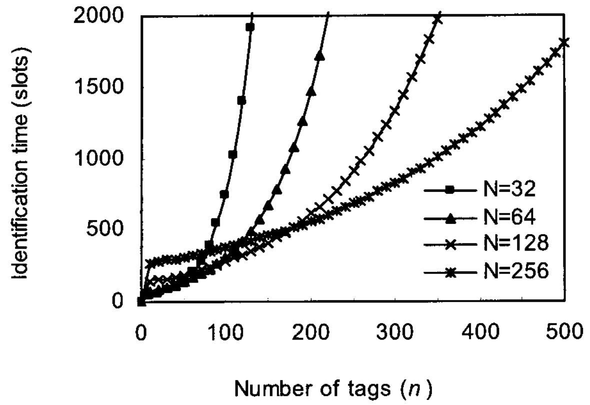

Fig. 2. Identification delay for FSA algorithm.

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, for achieving the maximum performances, it is necessary to allocate the frame size dynamically based on the number of tags in the reader's identification range.

III. ODFSA ALGORITHM

In this paper, we propose ODFSA algorithm for obtaining the maximum system efficiency and the minimum tag identification delay. In the proposed ODFSA algorithm, the frame size is dynamically allocated at every read cycle based on the number of tags within the reader's identification range. The frame size at the initial read cycle and the minimum frame size are assumed to be *minN*. The basic operation of ODFSA algorithm is same as the conventional FSA algorithm except the dynamic allocation of frame size at every read cycle.

At first, the frame size for the maximum system efficiency is considered. In order to maximize the system efficiency, we take the first derivative of system efficiency E given in Eq.(6) with respect to the frame size N. The first derivative of system efficiency is given as follows.

$$\frac{dE}{dN} = \frac{n(n-N)(N-1)^{n-2}}{N^{n+1}} \tag{12}$$

The optimal frame size for maximizing the system efficiency can be taken when we let Eq.(12) equal to zero. Therefore, the maximum system efficiency occurs at $N=n$ or $N=1$. Generally, because the frame size is greater than 1 in order for the reader to identify multiple tags, the maximum system efficiency can be achieved at $N=n$. Hence, the optimal frame size is equal to the number of tags within the reader's identification range.

Fig. 3 depicts the system efficiency for the frame size according to the different number of tags. As depicted in the figure, the maximum system efficiency can be obtained when the frame size is equal to the number of tags.

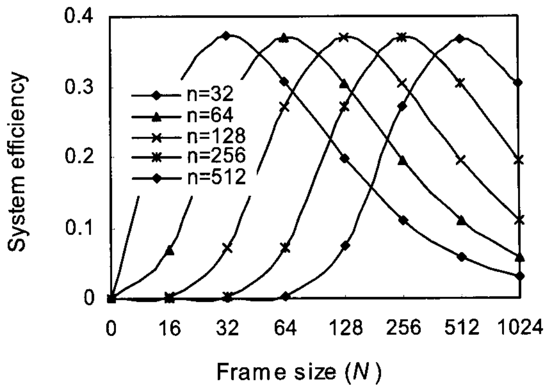

Fig. 3. System efficiency according to frame size.

Secondly, the frame size for the minimum identification delay is considered. In order to minimize the identification delay, we take the first derivative of Identification delay D given in Eq.(11) with respect to the frame size N. The optimal frame size for minimizing the tag identification delay can be taken when we let the first derivative equal to zero. The first derivative of identification delay is given as follows.

$$\frac{dD}{dN} = \frac{N^{n-2}(N-n)}{(N-1)^{n-1}} \tag{13}$$

Therefore, the minimum identification delay occurs at $N=n$ or $N=0$. In general, because the reader should allocate the frame size for identifying the tags, the minimal identification delay can be achieved at $N=n$. Hence, the optimal frame size is equal to the number of tags within the reader's identification range.

Fig. 4 shows the identification delay for the frame size according to the different number of tags. As shown in the figure, the minimum identification delay can be taken when the frame size is equal to the number of tags.

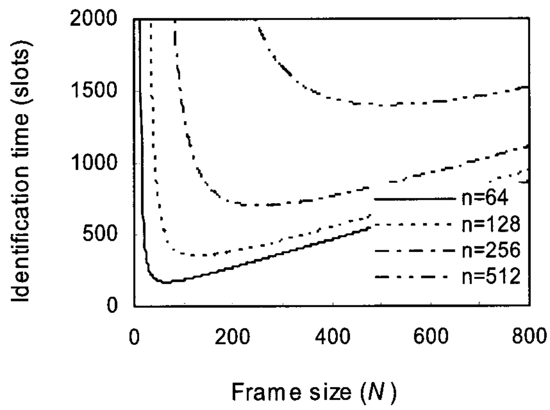

Fig. 4. Identification delay according to frame size.

From Fig. 3 and Fig. 4, we can figure out that the optimal frame size for maintaining the maximum system efficiency and the minimum identification delay is equal to the number of tags. Therefore, in ODFSA algorithm, the reader allocates the frame size equal to the number of tags in its identification range at every read cycle.

IV. SIMULATION RESULTS

In this paper, the computer simulations are performed to compare the performance of ODFSA algorithm with the conventional FSA algorithm with respect to the system efficiency and identification delay. 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 [6]. Also, the initial frame size and the minimum frame size are set to 8 slots.

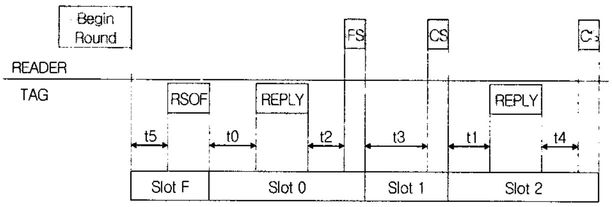

Fig. 5. Frame structure.

Table 1. 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 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. 6 shows the system efficiency of ODFSA algorithm compared with FSA algorithm as a function of the number of tags. ODFSA algorithm maintains the frame size optimally according to the number of tags. Therefore, as shown in the figure, the system efficiency of ODFSA algorithm is almost always same regardless of the number of tags.

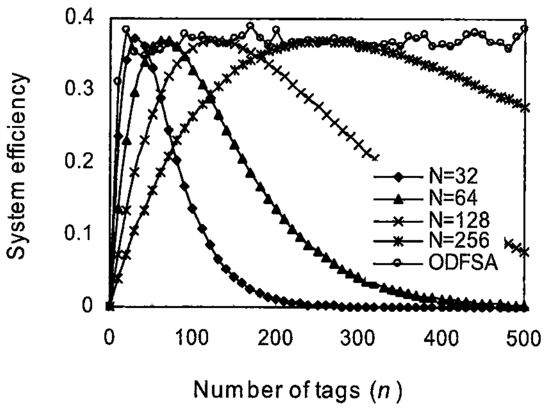

Fig. 6. System efficiency vs. number of tags.

The identification delay compared with the FSA algorithm is depicted in Fig. 7. If the number of tags within the reader's identification range is 50, ODFSA algorithm can identify 2.5 times and 3.4 times faster than *N*=128 and *N*=256 FSA algorithm, respectively. Also, as shown in the figure, is the number of tags is 1,000, the proposed algorithm can identify 18.9 times and 2.1 times faster than *N*=128 and *N*=256 FSA algorithm, respectively. In FSA algorithm with small frame size, the identification delay increases rapidly in proportion to the number of tags because a lot of collisions occur. On the other hand, ODFSA algorithm dynamically allocates an optimal frame size in proportion to the number of tags. Therefore, it can achieve shorter identification delay than FSA algorithm.

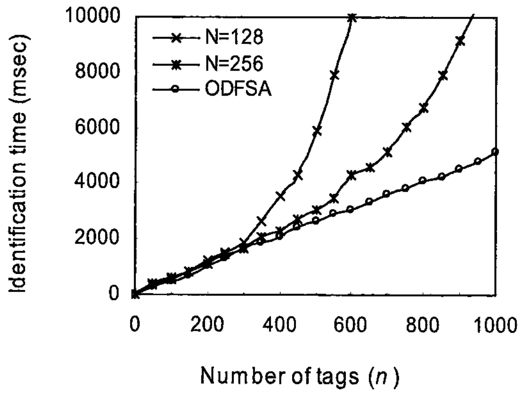

Fig. 7. Identification delay vs. number of tags.

It is anticipated that the performance of ODFSA algorithm will be affected by the minimum frame size. If the number of tags in the reader's identification range is less than the minimum frame size, the reader allocates a frame with *minN*. Fig. 8 and Fig. 9 show the system efficiency and tag identification delay according to the minimum frame size, respectively. As shown in Fig. 8, the system efficiency degrades when the minimum frame size increases. This is because a lot of slots will be idle though the number of remaining tags is small after several read cycles. But as shown in Fig. 9, the tag identification delay is not affected by the minimum frame size.

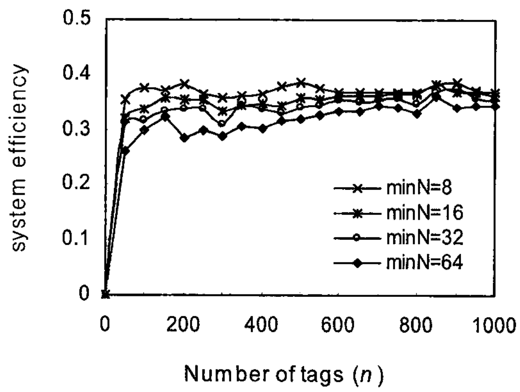

Fig. 8. System efficiency according to *minN*.

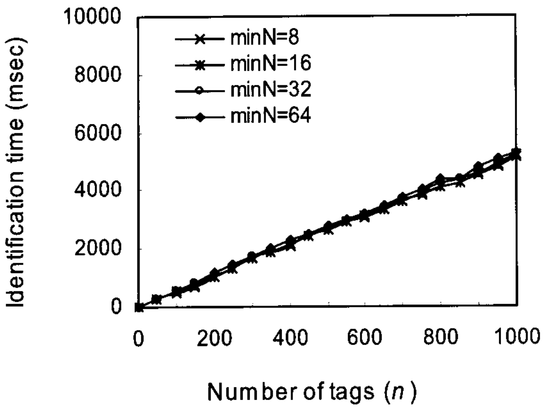

Fig. 9. Identification delay according to *minN*.

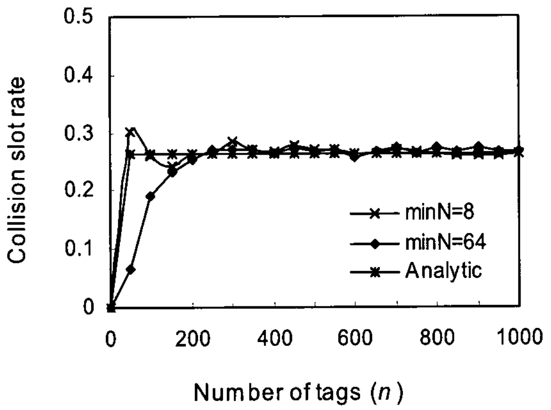

Fig. 10. Collision slot rate according to *minN*.

If we define the collision slot rate(C_{rate}) as the ratio of collision slots to the frame size and the idle slot rate(I_{rate}) as the ratio of idle slots to the frame size, these are given by

$$C_{rate} = \frac{\sum_{r=2}^{n} N \binom{n}{r} \left(\frac{1}{N}\right)^{r} \left(1-\frac{1}{N}\right)^{n-r}}{N} \quad (14)$$

$$I_{rate} = \left(1-\frac{1}{N}\right)^{n} \quad (15)$$

Fig. 10 and Fig. 11 show the collision slot rate and idle slot rate with the different minimum frame sizes. If we let the frame size be equal to the number of tags in order to obtain the maximum performance, the collision slot rate and idle slot rate are 26.4% and 36.7%, respectively. As depicted in Fig. 10, the minimum frame size does not affect the collision slot rate. But, as shown in Fig. 11, if the minimum frame size is large, the idle slot rate is large compared with the small minimum frame size. Therefore, it is unnecessary that the minimum frame size becomes large.

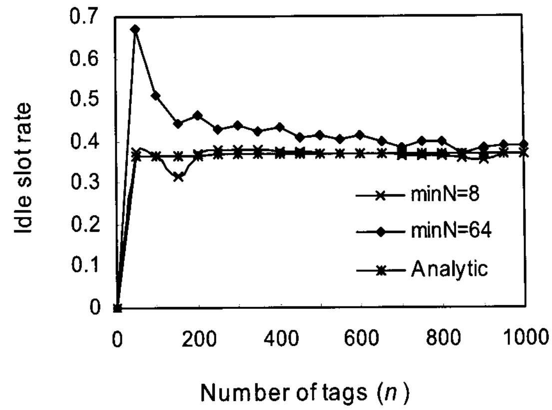

Fig. 11. Idle slot rate according to *minN*.

V. CONCLUSIONS

This paper proposed ODFSA algorithm and compared the performance with FSA algorithm. In ODFSA algorithm, the reader dynamically allocated an optimal frame size at every read cycle based on the number of tags within its identification range. In the proposed algorithm, in order to obtain the maximum system efficiency and the minimum identification delay, the reader allocated the frame size equal to the number of tags. As the results of computer simulations, the system efficiency was more stable and the identification delay was shorter than FSA algorithm.

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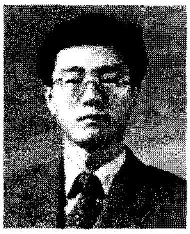

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