An Enhanced Ubiquitous Identification System Using Fast Anti-collision Algorithm

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Abstract. We analyze the tag identification procedure of conventional EPC Class 1 RFID system and propose the fast anti-collision algorithm for the performance improvement of the system. In the proposed algorithm, the reader uses information of tag collisions and reduces unnecessary procedures of the conventional algorithm. We evaluate the performance of the proposed anti-collision algorithm and the conventional algorithm using mathematical analysis and simulation. According to the results, the fast anti-collision algorithm shows greatly better performance than conventional algorithm.

1 Introduction

Object identification technology is very useful in various fields such as tracking(e.g. libraries, animals), automated inventory, stock-keeping, toll collecting, and similar tasks where physical objects are involved. The radio frequency identification (RFID) system is an important branch of the ubiquitous identification system. The RFID system identifies the unique tag ID or detailed information that saved in the tag through RF communication. Passive RFID system generally consists of three components - a reader, passive tags, and a controller. The reader interrogates tags for their ID or detailed information through RF communication link, and contains internal storage, processing power, and so on. Tags obtain processing power through RF communication link from the reader using back scattering and use this energy for on-tag computations and communication with the reader. The reader in the RFID system broadcasts the request message to the tags. Upon receiving the message, all the tags send the response back to the reader. If only one tag responds, the reader identifies the tag. However, if two or more tags respond, their responses will collide on the RF communication channel, and thus cannot be received by the reader. This problem is called "Tag-collision Problem," and the ability to resolve this collision is crucial for the performance of RFID system [1],[3].

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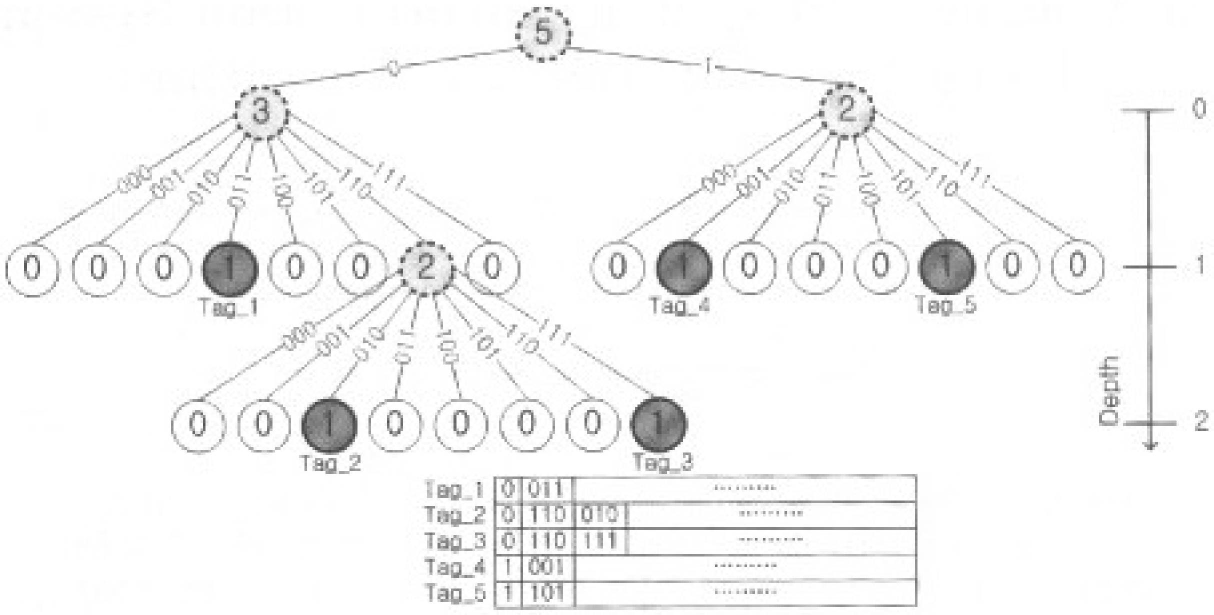

Fig. 1. An example of binary tree structure of conventional anti-collision algorithm

In this paper, we propose the fast anti-collision algorithm for EPC Class 1 systems operating in the frequency range of 860MHz-930MHz. We deduce the algorithm from experiments with conventional EPC Class 1 system since there is no detailed general anti-collision algorithm in the document [4] of the AutoID center. We observe the sending waveform on RF, convert it to the sequence of commands and then deduce the tag identification procedure of the conventional RFID system. To assess the performance of the algorithm, we derive the number of transmission, tag identification time and number of identified tags per second and validate the mathematical analysis by simulation. We also propose the fast anti-collision algorithm and compared the performance with conventional algorithm by mathematical analysis and simulation.

2 The Conventional Anti-collision Algorithm

In the EPC CLASS 1 system, the reader identifies tags in their interrogation zone with a binary tree structure which is composed of 8 branches for each node. Fig. 1 shows an example of a tag identification procedure when there are 5 tags in the RFID reader's interrogation zone. The labels on the lines between nodes represent a tag ID. And, the numbers in the nodes indicate the number of tags with same prefix. If the number is more than one, there are two or more tags in that node (with same prefix) so that the reader is not able to identify tags.

The reader requests the tags in its interrogation zone to reply by transmitting command and prefix bits. If the reader transmits request bits, the tags with matched prefix will reply. *PingID* and *ScrollID* are the most important commands in the EPC CLASS 1 system. The reader transmits *PingID* command when it concludes that there are more than one tags (collision). Then

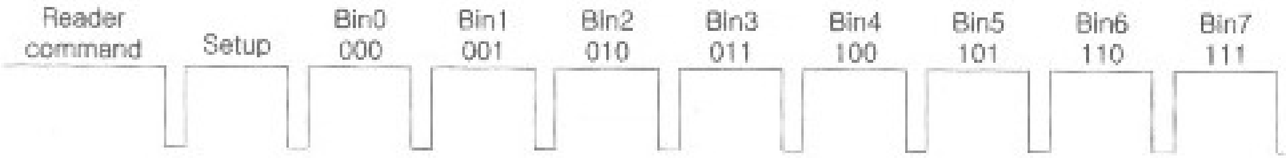

Fig. 2. *PingID* reply response period

the tags with matched prefix reply by transmitting their next 8 bits of identifier tag memory (ITM). Each replying tag transmits 8 bits in the bin slot (time slot) matched with most significant 3 bits out of 8 bits. Fig. 2 shows *PingID* reply response period [4]. Because there are 8 bin slots, the tree structure in fig. 1 has 8 branches. Another important command, *ScrollID* is transmitted when the reader requests tag's full ITM. In the conventional anti-collision algorithm, there are two confirmation procedures by transmitting *PingID* and *ScrollID* after successful identification.

We choose the ALR-9780 system of the Alien Technology Corporation as the conventional EPC CLASS 1 system. The Alien Technology Corporation system is one of leading companies in the field of RFID. We find out three main characteristics of conventional anti-collision algorithm by experiments and analysis. First, if there is a response in a bin slot, the reader request tags with the same prefix to transmit their full ITM. Second, there are two confirmation procedures after each successful identification. Third, in a tag identification procedure, ITMs have a remarkable characteristic caused by its structure. ITMs of the tags are always distributed randomly because the CRC is located in front of the tag ID, even though the IDs of tags are sequentially distributed. These three observations motivate us to propose the fast anti-collision algorithm.

3 The Fast Anti-collision Algorithm

In this paper, we assume that the reader use the collision information in bin slots of *PingID* replies. Fig. 3 shows the flow chart of the fast anti-collision algorithm. LEN and $VALUE$ are the bit length and exact value of prefix. The main ideas of the fast anti-collision algorithm is following two ideas.

1. The reader operates each bin slots with two different ways according to the collision information in bin slots.
   (a) If there is a collision in the bin slot, the reader sends *PingID* while the conventional reader sends *ScrollID*.
   (b) If there is no collision in the bin slot, the reader requests tags ITM as the same way as the conventional algorithm.
2. We reduce the additional confirmation procedures (*ScrollID* and *PingID* transmissions) after successful identification because there is not considerable performance decrease in the RFID system. Even though there are remaining or missed tags, those will be identified next identification procedure.

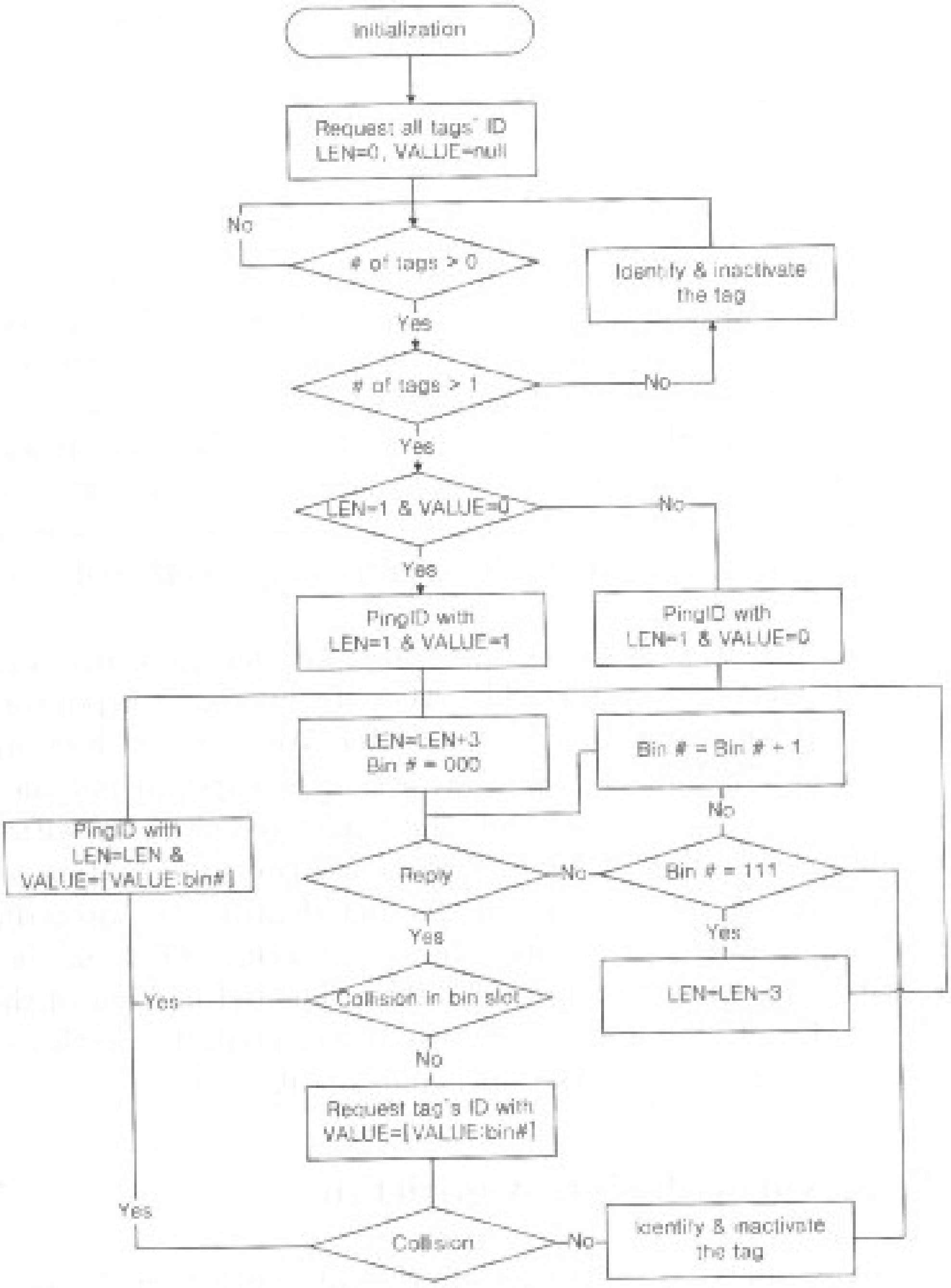

Fig. 3. *PingID* The flow chart of the fast anti-collision algorithm

4 Performance Analysis

In this section, we analyze the performance of the conventional and the proposed fast anti-collision algorithm. For the performance metrics, we consider the time to identify tags and the number of command transmission. First, we derive the time to identify tags ($T_{identification}$).

$$T_{identification} = CW \times n_{total} + \frac{b_{reader}}{DR_{reader}} + \frac{b_{tag}}{DR_{tag}}, \quad (1)$$

where CW is the time to send continuous wave, n_{tatal} is the number of total command transmissions, b_{reader} is total number of bits from a reader, DR_{reader}

is reader-to-tag data rate, b_{tag} is total number of bits from tags and DR_{tag} is tag-to-reader data rate. To derive b_{reader} and b_{tag}, we derive the number of command transmission in the following sections. The mathematical approach is similar to [5],[6].

4.1 The Conventional Anti-collision Algorithm

Let the number of transmission of *ScrollID* and *PingID* commands with k depth are IS_k and IP_k respectively (k =1,2,3,). To derive IS_k and IP_k, we calculate the probabilities of replies for each case. If there is a response in a bin slot of *PingID* reply, the reader transmits *ScrollID*. The probability that one or more tags reply in a bin slot ($P_{response}$) is

$$P_{response} = 1 - \left(\frac{r-1}{r}\right)^{n}, \tag{2}$$

where r is the number of bin slot and n is the number of tags to be identified. If only one tag replies in a bin slot, there is no collision in *ScrollID* reply. The reader identifies the tag and transmits additional *ScrollID*. The probability that there is only one tags reply in a bin slot(P_{no_coll}) is

$$P_{no\_coll} = n\left(\frac{r-1}{r}\right)^{n-1} \cdot \frac{1}{r}, \tag{3}$$

Let m be the total number of tags to be identified and n_{bin} be the number of leafs with k depth, the expected number of transmission of *ScrollID* with k depth (IS_k) is given by

$$\begin{aligned} p_{ij} &= n_{bin} \times P_{response} + n_{bin} \times P_{no\_coll} \\ &= 2r^k \times \left[1 - \left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}} + \frac{m}{2r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}-1} \cdot \frac{1}{r}\right]. \end{aligned} \tag{4}$$

If two or moer tags replies in a bin slot, the reader transmits *PingID*. The probability that there are two or more tags replies in the bin slot (P_{coll}) is

$$P_{coll} = P_{response} - P_{no\_coll} = 1 - \left(\frac{r-1}{r}\right)^{n} - n\left(\frac{r-1}{r}\right)^{n-1} \cdot \frac{1}{r} \tag{5}$$

If there is no more reply in other bin slots, the reader sends additional *PingID* to search remaining tags which have same prefix with last identified tag. The number of transmissions of *PingID* commands (IP_k) is given by

$$\begin{aligned} IP_k &= [n_{bin} \times P_{coll}]_{k=k} + [n_{bin} \times P_{no\_coll}]_{k=k-1} \\ &= 2r^k \times \left[1 - \left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}} - \frac{m}{2r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}-1} \cdot \frac{1}{r}\right] \\ &+ 2r^{k-1} \times \left[\frac{m}{2r^{k-2}}\left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-2}}-1} \cdot \frac{1}{r}\right]. \end{aligned} \tag{6}$$

In Eq. 6, the first part($k = k$) is with k depth and the second part($k = k + 1$) is with $k + 1$ depth. We assumed that the remaining tags are identified in the branch if the expected number of tags in the bin slot is less than 1.

4.2 The Fast Anti-collision Algorithm

In the proposed fast anti-collision algorithm, the reader sends *ScrollID* if there is a response and no collision in a bin slot. No collision means one of two cases. First case occurs when only one tag responses. Second case occurs when two or more tags transmitted *PingID* replies with the same 8 bits. The probability that there is only one tags reply in the bin slot (P_{tag_1}) is

$$P_{tag\_1} = n\left(\frac{r-1}{r}\right)^{n-1} \cdot \frac{1}{r}. \tag{7}$$

And, the probability that there are two or more tags replies in the bin slot ($P_{tag\geq 2}$) is given by

$$P_{tag\geq 2} = 1 - \left(\frac{r-1}{r}\right)^{n} - n\left(\frac{r-1}{r}\right)^{n-1} \cdot \frac{1}{r}. \tag{8}$$

Each tag transmits 8 bit reply in the bin slot matched with most significant 3 bits out of 8 bits when it replies to *PingID* command. Therefore the probability that there is no collision between tags which replied in a bin slot depends on least significant 5 bits. $P_{bin\_no\_coll}$ is derived by

$$P_{bin\_no\_coll} = \left(\frac{1}{2^5}\right)^{n} \quad , n \geq 2. \tag{9}$$

If more than two tags reply in the bin slot, the reader sends *PingID* with the probability of $P_{bin\_no\_coll}$. Here, we assume that $P_{bin\_no\_coll}$ is zero in numerical analysis since it is negligible. Therefore, the expected number of transmissions of *ScrollID* with k depth (IS_k) is

$$\begin{aligned} IS_k &= n_{bin} \times (P_{tag\_1} + P_{tag\geq 2} \times P_{bin\_no\_coll}) \\ &\approx n_{bin} \times P_{tag\_1} = 2r^k \times \left[\frac{m}{2r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}-1} \cdot \frac{1}{r}\right]. \end{aligned} \tag{10}$$

And, the number of transmission of *PingID* with k depth (IP_k) is

$$\begin{aligned} IP_k &= n_{bin} \times P_{tag\geq 2} \times (1 - P_{bin\_no\_coll}) \approx n_{bin} \times P_{tag\geq 2} \\ &= 2r^k \times \left[1 - \left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}} - \frac{m}{2r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{2r^{k-1}}-1} \cdot \frac{1}{r}\right]. \end{aligned} \tag{11}$$

Table 1. Simulation parameters

Parameter	**Value**
CW	0.064 msec
master clock interval (T_0)	0.025 msec
DR_{reader} ($1/T_0$)	40 kbps
DR_{tag} ($2/T_0$)	80 kbps
Transaction gap($1.25T_0$)	0.3125 msec
Tag setup period ($8T_0$)	0.2 msec
Tag response period ($64T_0$)	1.6 msec

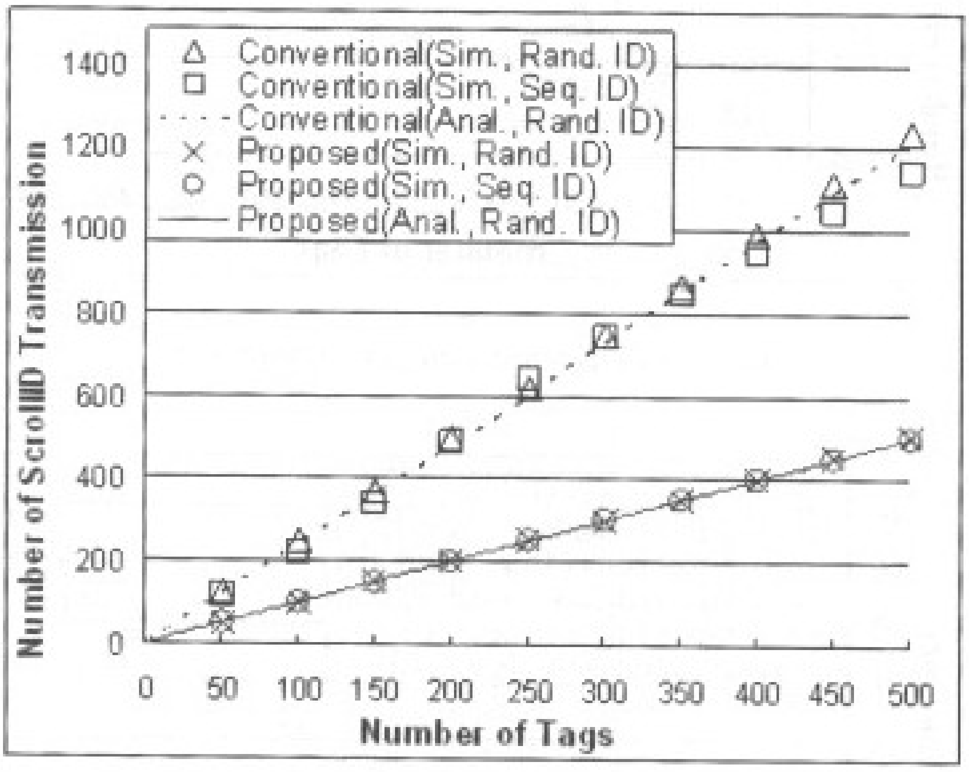

Fig. 4. Number of *ScrollID* transmission

5 Numerical and Simulation Results

We compare the performance of the proposed algorithm with that of the conventional algorithm and validate analytic results using simulation. Table 1 shows parameters used in mathematical analysis and simulation [4], [7]. The range of considered number of tags is from 50 to 500. In the mathematical analysis, we assume that ID of tags distributes randomly. However, we perform the simulation with both randomly distributed tags ID and sequentially distributed tags ID.

The results of mathematical analysis and simulations are illustrated from Fig. 4 to Fig. 7, and curves mean the mathematical results and symbols mean the simulation ones. The results of mathematical analysis are very close to the simulation ones. And, the results of simulations with randomly distributed tag IDs and sequentially distributed tag IDs are much similar. The reason is that ITMs

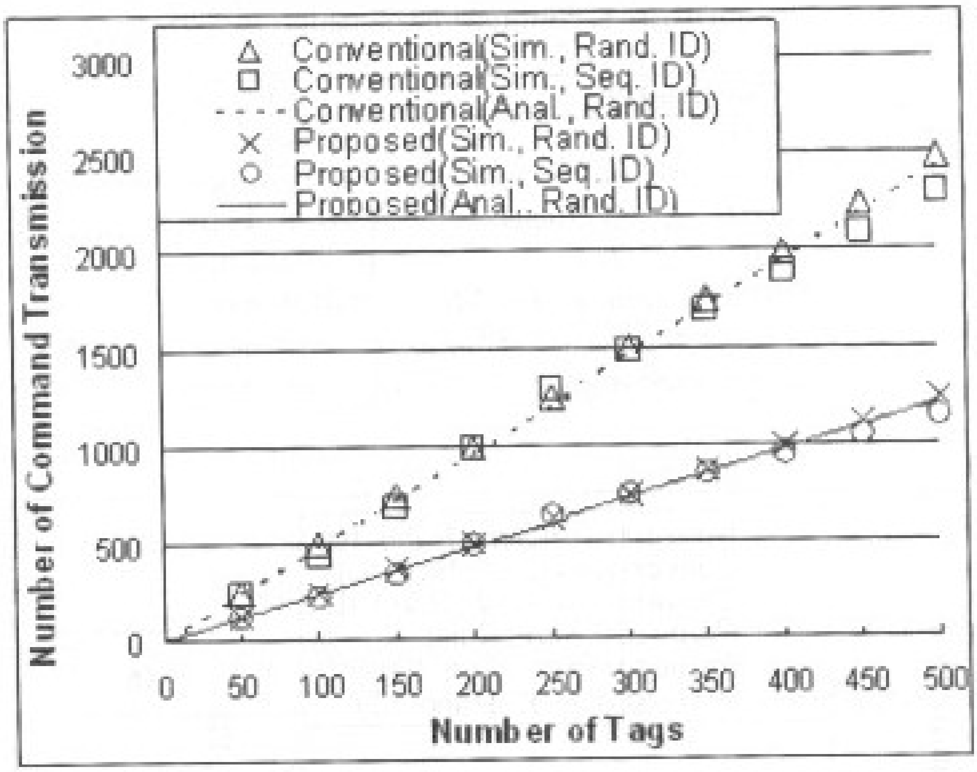

Fig. 5. Number of command transmission

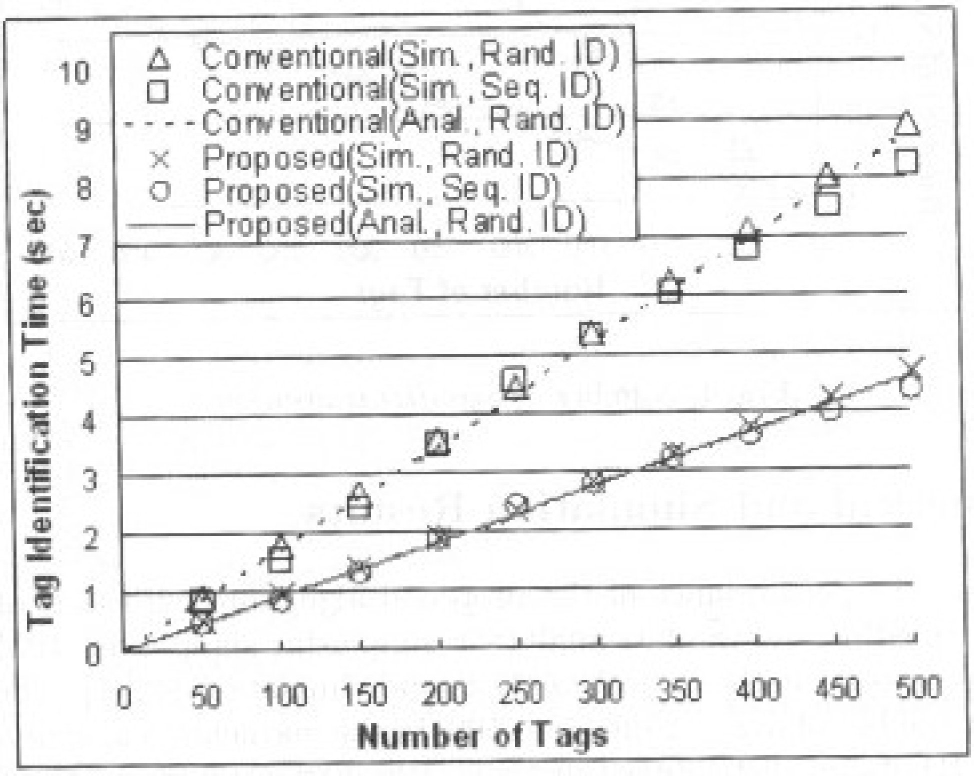

Fig. 6. Tag idnetification time

of the tags are always distributed randomly because the CRC is located in front of the tag ID, even though the IDs of tags are sequentially distributed. Fig. 4 and Fig. 5 show the number of *ScrollID* and total command transmissions for the number of tags. The transmission number of commands increases linearly as the number

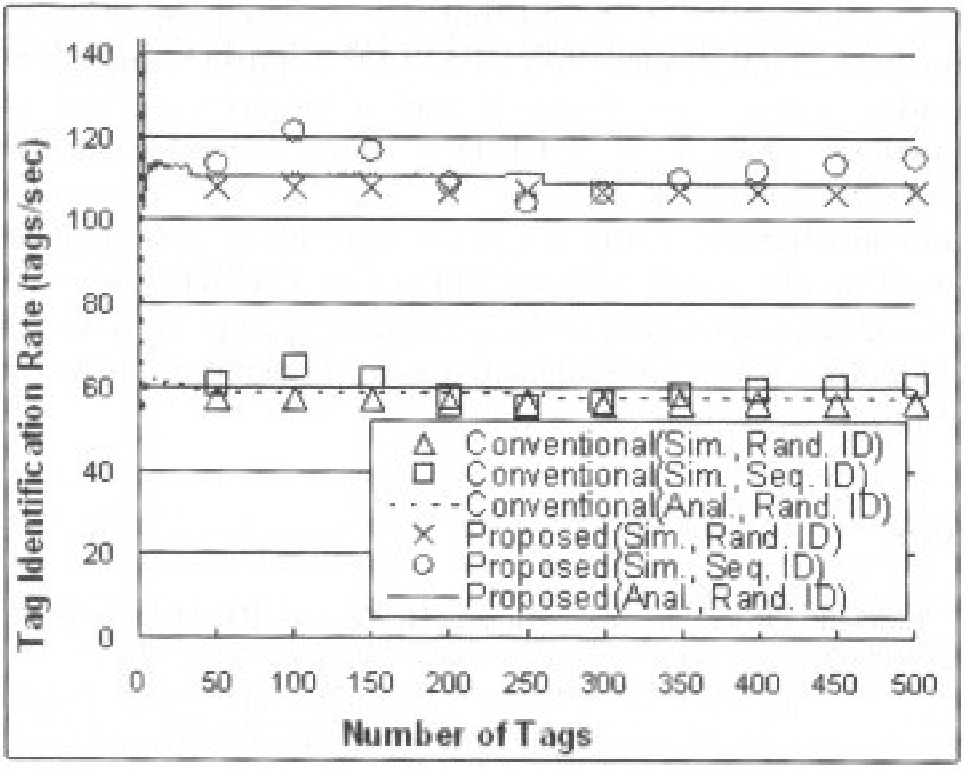

Fig. 7. Tag identification rate

of tags increases. In Fig. 4, the number of ScrollID transmission is about 1210 for the conventional algorithm and 500 for the proposed algorithm when the number of used tags is 500. It presents that using collision information in bin slots reduces number of ScrollID transmission. In Fig. 5, the number of total command transmissions is about 2400 and 1200 for the conventional algorithm and the proposed algorithm respectively. The results show 50.21% performance improvement for the proposed algorithm in terms of the total number of command transmission. Fig. 6 and Fig. 7 show the tag identification time and tag identification rate, which indicates the number of identified tags per second. In case of randomly distributed tags ID, the proposed algorithm identifies 500 tags at 4.7 second while the conventional algorithm does at 8.9 second in Fig. 6. It means that each algorithm identifies approximately 106 tags and 56 tags per second respectively as shown in Fig. 7. The proposed algorithm shows about 89.2% performance improvement compared to the conventional algorithm in the view of tag identification rate.

6 Conclusion

In this paper, we analyzed the anti-collision algorithm of the conventional EPC Class 1 RFID system and proposed the fast anti-collision algorithm. In the proposed algorithm, the number of unnecessary transmission of *ScrollID* commands is reduced by using the collision information of bin slots. Moreover, transmissions of unnecessary verification commands are eliminated. We mathematically analyzed the performance of the conventional anti-collision algorithm and the proposed anti-collision algorithm. We also validated analytic results using simulation.

According to the results, we found that the proposed algorithm shows about 89.2% performance improvement compared to the conventional algorithm in aspect of the identification rate. Consequently, if the proposed fast anti-collision algorithm applies to EPC Class 1 RFID system, the reader can identify more tags within shorter time.

The main contributions of this paper are threefold:(1) we analized tag anti-collision algorithm of the conventional EPC Class 1 RFID system, (2) proposed the fast anti-collision algorithm, and (3) evaluated the performance of both the conventional and proposed anti-collision algorithm using mathematical analysis and simulations.

References

1. Vogt, H.: Efficient Object Identification with Passive RFID tags. In: IEEE ICPC, pp. 98–113 (2002)
2. Finkenzeller, K.: Radio-Frequency Identification Fundamentals and applications. In: RFID Handbook, John Wiley & Sons Ltd, Chichester (1999)
3. Sarma, S., Brock, D., Engels, D.: Radio frequency identification and electronic product code. In: IEEE MICRO, pp. 50–54 (2001)
4. Auto-ID Center: Technical report 860MHz-930MHz Class I Radio Frequency Identification Tag Radio Frequency & Logical Communication Interface Specification Candidate Recommendation, Version 1.0.1 (2003)
5. Choi, H.S., Cha, J.R., Kim, J.H.: Fast Wireless Anti-collision Algorithm in Ubiquitous ID System. IEEE VTC 2004 26–29 (2004)
6. Choi, H.S., Kim, J.H.: A Novel Tag identification algorithm for RFID System using UHF. In: Yang, L.T., Amamiya, M., Liu, Z., Guo, M., Rammig, F.J. (eds.) EUC 2005. LNCS, vol. 3824, pp. 629–638. Springer, Heidelberg (2005)
7. EPCglobal: EPCTM Tag Data Standards Version 1.1 Rev.1.24 (2005)