A Novel Tag Identification Algorithm for RFID System Using UHF

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Abstract. An anti-collision algorithm is very important in the RFID system, because it decides tag identification time and tag identification accuracy. We propose improved anti-collision algorithms for RFID system using UHF. In the proposed algorithms, if the reader memorizes the Bin slot information, it can reduce the repetition of the unnecessary PingID command and the time to identify tags. If we also use ScrollAllID command in the proposed algorithm, the reader knows the sequence of collided ID bits. Using this sequence, we can reduce the repetition of PingID command and tag identification time. We analyze the performance of the proposed anti-collision algorithms and compare the performance of the proposed algorithms with that of the conventional algorithm. We also validate analytic results using simulation. According to the analysis, for the random tag ID, comparing the proposed algorithms with the conventional algorithm, the performance of the proposed algorithms is about 130% higher when the number of the tags is 200. For the sequential tag ID, the performance of the conventional algorithm decreases. On the contrary, the performance of the proposed algorithm using ScrollAllID command is about 16% higher than the case of using random tag ID.

1 Introduction

The RFID(Radio Frequency Identification) system is a simple form of ubiquitous sensor networks that are used to identify physical objects [1]. The RFID system identifies the unique tags' ID or detailed information saved in them attached to objects. Passive RFID systems generally consist of three components - a reader, passive tags, and a controller. A reader interrogates tags for their ID or detailed information through RF communication link, and contains internal storage, processing power, and so on. Tags get the processing power through RF communication link from the reader and use this energy to power any on-tag computations and to communicate to the reader. A reader in 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 receives just one response. However, if two or more tags respond, their responses will collide on the RF communication channel, and thus cannot be received by the reader. The problem is referred to as the "Tag-collision". An effective system must avoid this collision by using anti-collision algorithm be-

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cause the ability to identify many tags simultaneously is crucial for many applications [2], [3]. Anti-collision algorithms are generally classified into ALOHA-based and binary-based methods. All these methods are based upon tags that are identified by a unique ID. The ALOHA-based anti-collision algorithms, which are probabilistic, are introduced in [4]-[7], and the anti-collision algorithms using binary-based method are introduced in [8]-[11]. There are two standard organizations of anti-collision in RFID system. One is ISO-18000 and the other is EPCglobal. In the resent RFID system, UHF(Ultra High Frequency) is more important issue than HF(High Frequency) since the reader can identify the tags faster and the tag can send more information using higher data rate. Therefore, we analyze the conventional anti-collision algorithm for EPC CLASS 1 RFID Tag operating in the frequency range of 860MHz-930MHz [12], which is named as EPC CLASS 1 UHF Tag. We also propose the improved anti-collision algorithms for EPC CLASS 1 UHF Tag. We mathematically compare the performance of the proposed algorithms with that of the conventional algorithm and also validate analytic results using OPNET simulation.

2 The Conventional Anti-collision Algorithm for EPC CLASS 1 UHF Tag

The anti-collision algorithm for EPC CLASS 1 UHF Tag resolves the collision by using PingID command and Bin slots which are used to receive tags' reply. The reply period for PingID command consists of 8 Bin slots. Each slot sequentially represents from '000' to '111'. The procedure of the algorithm using PingID command is as follows. First of all the reader transmits PingID command to the tags. The tags matching [VALUE] beginning at location [PTR] reply by sending 8-bits of the tag identifier beginning with the bit at location [PTR] + [LEN], where [VALUE] is the data that the tag will attempt to match against its own identifier(From the [PTR] position towards the LSB(Least Significant Bit)), [PTR] is a pointer to a location (or bit index) in the tag identifier, and [LEN] is the length of the data being sent in the [VALUE] field. The 8-bit reply is communicated during one of eight Bin slots delineated by the reader. The communication Bin slot is chosen to be equal to the value of the first 3 MSB(Most Significant Bit)s of the 8-bit reply. So, the tags whose 3 MSBs of ID after [VALUE] field is '000' choose Bin 0 and whose 3 MSBs of ID after [VALUE] field is '111' choose Bin 7. The reader sequentially processes Bin slots from Bin 0 to Bin 7. When two or more tags choose the same Bin slot, the reader retransmits PingID command to the tags. If only one tag chooses one Bin slot, the reader sends ScrollID command to the tag. The tags matching [VALUE] beginning at location [PTR] reply by sending their all ID. In this case only one tag sends its all ID to the reader and is identified by the reader. After identifying the first tag, the reader repeats same procedure using PingID command and ScrollID command until the reader identifies all the tags. Fig. 1 shows an example of the tag identification procedure using PingID and ScrollID commands. For more details, refer to [12].

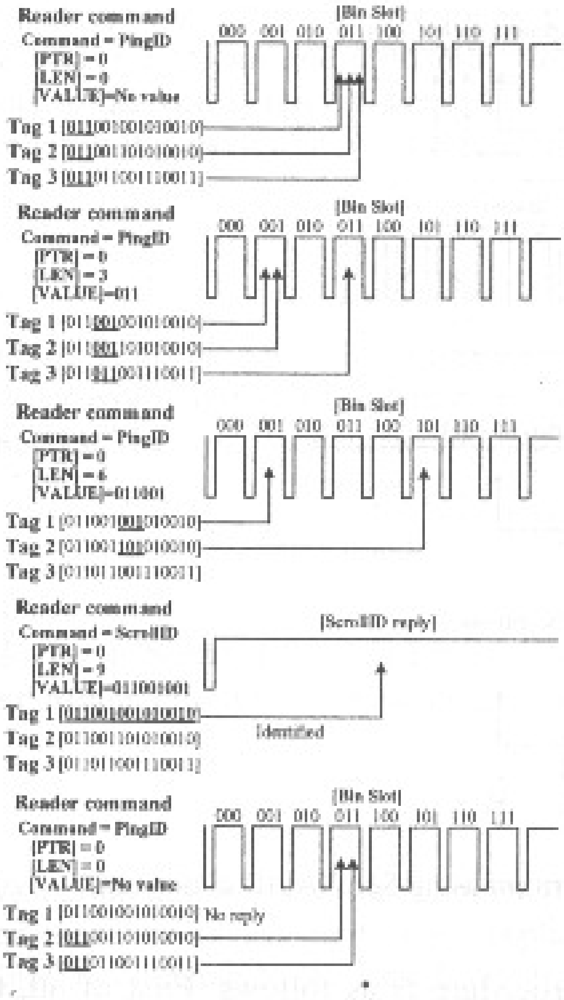

Fig. 1. An example of the conventional anti-collision algorithm

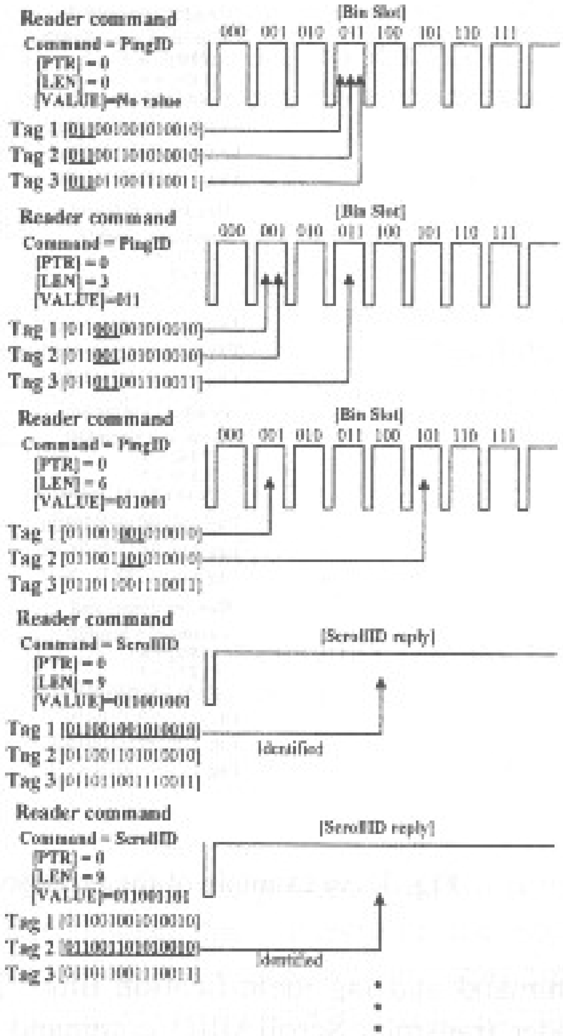

Fig. 2. An example of the proposed algorithm

3 The Proposed Anti-collision Algorithms

In the conventional anti-collision algorithm for EPC CLASS 1 UHF Tag, after the reader identifies a tag using PingID command and ScrollID command, the reader repeats all procedure to identify all the tags so that it takes much time to identify all the tags. If the reader uses the Bin slot information, it can reduce the repetition of unnecessary PingID command transmission and the time to identify tags. Fig. 2 shows an example of the tag identification procedure using the proposed anti-collision algorithm. In Fig. 1, after the reader identifies first tag, the reader goes back to the first procedure. In Fig. 2, the reader memorizes Bin slot information and using this information it can identify the second tag directly. In the conventional algorithm, the reader uses only PingID command and ScrollID command. In the case of using sequential tag ID, the conventional algorithm repeats PingID command much more times than the case of using random tag ID then it results in the longer tag identification time. If we use ScrollAllID command defined in [12] in the proposed algorithm, the reader knows the sequence of collided ID bits. Using this sequence, the reader can reduce the repetition of PingID

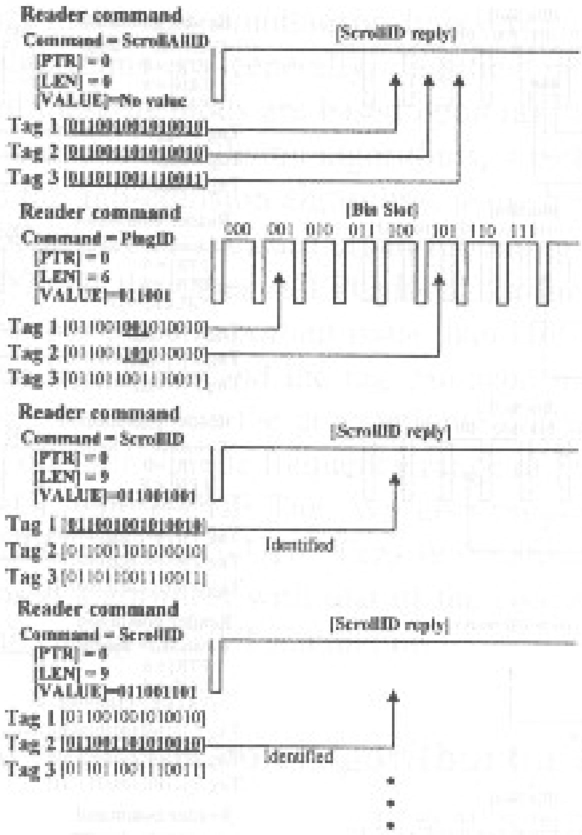

Fig. 3. An example of the proposed algorithm using ScrollAllID command

command and tag identification time. The procedure is as follows. First of all, the reader transmits ScrollAllID command to the tags. All the tags which are in active state send all of their ID bits to the reader. The reader knows the sequence of collided ID bits. So, the reader sets the [PTR] field to the position of second collided bit - 1 and transmits PingID command to the tags. Then, the tags whose first collided bit is '0' reply reader's PingID command, and the reader repeats transmission of PingID command until only one tag reply in one Bin slot. The reader transmits ScrollID command and identifies that tag. After the reader identifies the tag, the reader performs the next procedure using Bin slot information until all the tags are identified. The reader can reduce unnecessary repetition of PingID command. Fig. 3 shows an example of the tag identification procedure of the proposed anti-collision algorithm using ScrollAllID command.

4 Performance Analysis

In this section, we compare the performance of the conventional anti-collision algorithm with that of the proposed anti-collision algorithm for EPC CLASS 1 UHF Tag. For performance matrix, we consider the number of repetition of PingID command and the time to identify the tags.

4.1 The Conventional Anti-collision Algorithm for EPC CLASS 1 UHF Tag

We assume that tag ID is random, the number of total tags is m, and the number of Bin slot is r. Let q_n be the probability that there is no tag reply from Bin 0 to Bin n-1.

q_n is then $[(r-n)/r)]^m$. The probability that there is no reply in Bin n out of r-n slots is $[(r-1-n)/(r-n)]^m$, and the probability that there is only one reply in Bin n out of r-n slots is $[m/(r-n)]\times[(r-1-n)/(r-n)]^{m-1}$. The probability that there are two or more tag replies in Bin n out of r-n slots, q_m, can be derived in

$$q_m = \left[1-\left(\frac{r-1-n}{r-n}\right)^m - m\left(\frac{r-1-n}{r-n}\right)^{m-1}\cdot\frac{1}{r-n}\right]. \tag{1}$$

Let p_{1n} be the probability that there is no tag reply from Bin 0 to Bin n-1 and there are two or more tag replies in Bin n when the reader transmits first PingID command to the tags. Then, p_{1n} is calculated by

$$p_{1n} = \left(\frac{r-n}{r}\right)^m\left[1-\left(\frac{r-1-n}{r-n}\right)^m - m\left(\frac{r-1-n}{r-n}\right)^{m-1}\cdot\frac{1}{r-n}\right] \tag{2}$$

where r is 8 and $0\le n\le 7$ (n is an integer). Let p_1 be the probability that the reader retransmits PingID command in the first state. p_1 is then derived in

$$p_1 = \sum_{n=0}^{7} p_{1n}. \tag{3}$$

We define that p_{2n} is the probability that there is no tag reply from Bin 0 to Bin n-1 and there are two or more tags' replies in Bin n when the reader transmits second PingID command to the tags. Since the number of Bin slot is r, we can approximate the number of tags in the second state by m/r. Then, m can be substituted by m/r in the second state. p_{2n} is expressed as

$$p_{2n} = \left(\frac{r-n}{r}\right)^{\frac{m}{r}}\left[1-\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r}} - \frac{m}{r}\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r}-1}\cdot\frac{1}{r-n}\right]. \tag{4}$$

The probability p_2 that the reader re-transmits PingID command in the second state is derived in

$$p_2 = \sum_{n=0}^{7} p_{2n}. \tag{5}$$

Using same method, we can also approximate the number of tags in the k-th state by m/r^{k-1}. The probability p_k that the reader re-transmits PingID command in the k-th state is

$$p_k = \sum_{n=0}^{7} p_{kn} = \sum_{n=0}^{7}\left(\frac{r-n}{r}\right)^{\frac{m}{r^{k-1}}}\left[1-\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r^{k-1}}} - \frac{m}{r^{k-1}}\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r^{k-1}}-1}\cdot\frac{1}{r-n}\right]. \tag{6}$$

Therefore, for the first identified tag, the number of repetition of PingID command, I_1, can be calculated by

$$I_1 = 1 + \sum_{k=0}^{\infty}\sum_{n=0}^{7}\left(\frac{r-n}{r}\right)^{\frac{m}{r^k}}\left[1-\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r^k}} - \frac{m}{r^k}\left(\frac{r-1-n}{r-n}\right)^{\frac{m}{r^k}-1}\cdot\frac{1}{r-n}\right], \quad \frac{m}{r^k} > 1. \tag{7}$$

After the reader identifies a tag, the number of remaining tags is m-1. The reader repeats the same procedure to identify second tag. Using (7), the number of repetition of total PingID command until the reader identifies all the tags, I_{total}, is given by

$$I_{total} = m + \sum_{L=2}^{m}\sum_{k=0}^{\infty}\sum_{n=0}^{7}\left(\frac{r-n}{r}\right)^{\frac{L}{r^k}}\left[1-\left(\frac{r-1-n}{r-n}\right)^{\frac{L}{r^k}} - \frac{L}{r^k}\left(\frac{r-1-n}{r-n}\right)^{\frac{L}{r^k}-1}\cdot\frac{1}{r-n}\right], \quad \frac{m}{r^k} > 1. \tag{8}$$

The reader repeats the transmission of ScrollID command m times to identify m tags. The total time to identify m tags is composed of ScrollID command transmission time, PingID command transmission time, tag response time, transmission delay of the reader, and transmission delay of the tag. We assume that the size of the packet from reader to tag is RL_C and the data rate of the reader is DR_{reader}. Then, command packet transmission time from reader to tag to identify m tags, t_{reader}, is derived in

$$t_{reader} = \frac{RL\_C(I_{total} + m)}{DR_{reader}} \tag{9}$$

where RL_C is 147 bits and DR_{reader} is 70,180 bps [12].

Assuming that the size of the tag response packet for PingID command is TL_P, the size of the tag response packet for ScrollID command is TL_S, and the data rate of the tag is DR_{tag}. Then, the response time of the tag to identify m tags, t_{tag}, is

$$t_{tag} = \frac{TL\_P \times I_{total} + TL\_S \times m}{DR_{tag}} \tag{10}$$

where TL_P is 8 bits, TL_S is 120 bits, and DR_{tag} is 140,350 bps [12].

To find the total delay to identify m tags, t_{delay}, we define that transmission delay of the reader is DE_{reader} and transmission delay of the tag is DE_{tag}, and t_{delay} is

$$t_{delay} = (I_{total} + m)(DE_{reader} + DE_{tag}) \tag{11}$$

where DE_{reader} is 17.81μs and DE_{tag} is 57μs [12]. Finally, we find the total time to identify m tags t_{total} in

$$t_{total} = t_{reader} + t_{tag} + t_{delay}. \tag{12}$$

4.2 The Proposed Anti-collision Algorithms

Using the same assumption in the section 4.1, the number of total tags is m, and the number of Bin slot is r. Tag ID is also random. Let p_{col} be the probability that there are two or more tag's replies in one Bin slot when the reader transmits the first PingID command to the tags. Then, p_{col} can be calculated as follows

$$P_{col} = \left[1 - \left(\frac{r-1}{r}\right)^m - m\left(\frac{r-1}{r}\right)^{m-1} \cdot \frac{1}{r}\right]. \quad (13)$$

Because the number of Bin slot is r, the number of repetition of PingID command in the first state, I_1, is given by

$$I_1 = r \times \left[1 - \left(\frac{r-1}{r}\right)^m - m\left(\frac{r-1}{r}\right)^{m-1} \cdot \frac{1}{r}\right]. \quad (14)$$

In the case of the proposed algorithm, the reader can memorize Bin slot information so that the number of repetition of PingID command in the k-th state, I_k, (k=1,2,3, ...) is

$$I_k = r^k \times \left[1 - \left(\frac{r-1}{r}\right)^{\frac{m}{r^{k-1}}} - \frac{m}{r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{r^{k-1}}-1} \cdot \frac{1}{r}\right]. \quad (15)$$

Finally, the number of repetition of total PingID command until the reader identifies all the tags, I_{total}, can be represented as

$$I_{total} = \sum_{k=0}^{\infty} I_k = I_0 + \sum_{k=1}^{\infty} r^k \times \left[1 - \left(\frac{r-1}{r}\right)^{\frac{m}{r^{k-1}}} - \frac{m}{r^{k-1}}\left(\frac{r-1}{r}\right)^{\frac{m}{r^{k-1}}-1} \cdot \frac{1}{r}\right], \quad \frac{m}{r^{k-1}} > 1. \quad (16)$$

I_0 is the number of the first transmission of PingID command and the value of I_0 is 1.

In the proposed algorithms, we can calculate total time to identify m tags, t_{total}, by (12). In the case of using ScrollAllID command, we can calculate total time to identify m tags, t_{total}, as same as in (12) with substituting m by m+1.

5 Analytic and Simulation Results

In this section, we mathematically compare the performance of the proposed algorithm with that of the conventional anti-collision algorithm for EPC CLASS 1 UHF Tag and validate analytic results using simulation. Tag's ID is 96 bits and the portion of the ID to identify the tags is 36 bits. To maximize the reliability of simulation, we apply the real packet size, packet transmission delay, and date rate [12].

Fig. 4 shows the number of PingID command for the number of used tags in the conventional anti- collision algorithm for EPC CLASS 1 UHF Tag, the proposed algorithm not using ScrollAllID command, and the proposed algorithm using ScrollAllID command for random tag ID. Lines and symbols represent analytic and simulation results, respectively. In Fig. 4, we observe the small difference between analytic and simulation results in the conventional algorithm. In the analytic result, we do not consider the addictive number of PingID command in the condition of $m / r^k \leq 1$. That is why there is a small difference between analytic and simulation results. In Fig. 4, the number of PingID command of the proposed algorithms is less than that of the conventional algorithm.

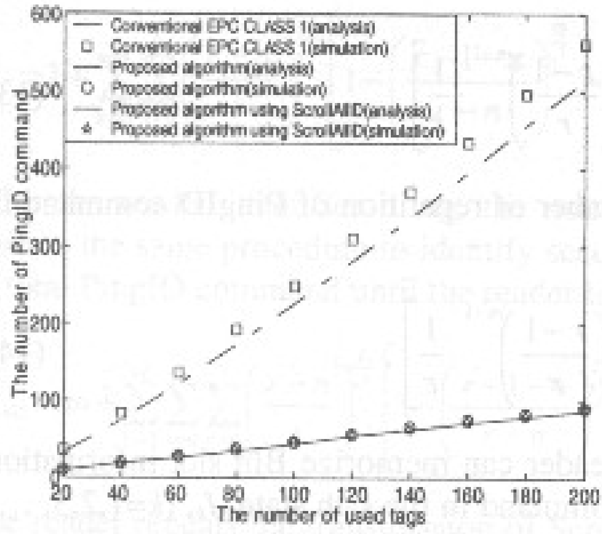

Fig. 4. The number of PingID command for the number of used tags(random tag ID)

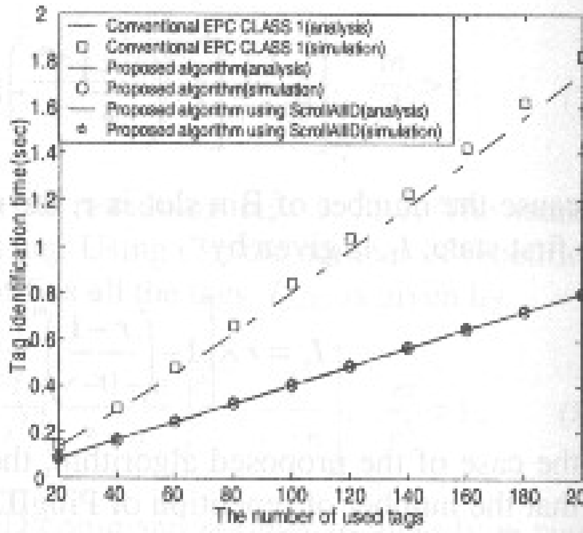

Fig. 5. Tag identification time for the number of used tags(random tag ID)

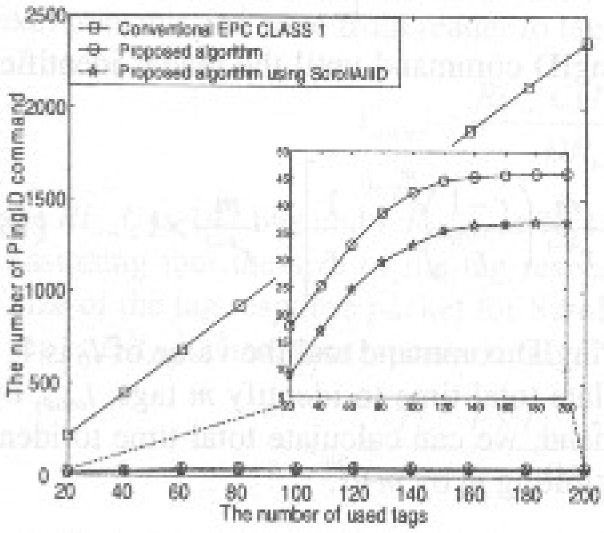

Fig. 6. The number of PingID command for the number of used tags(sequential tag ID)

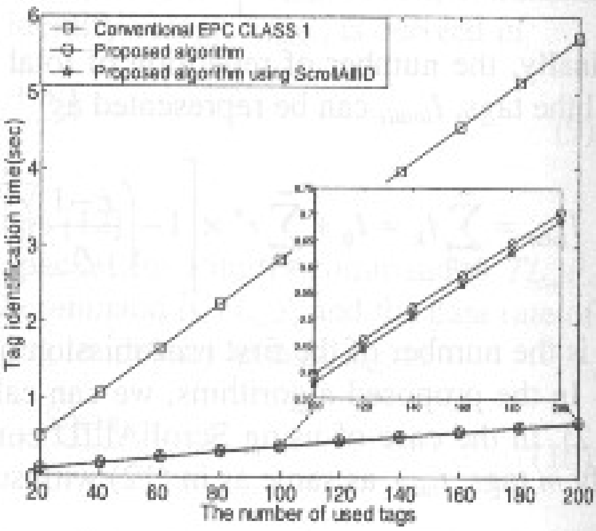

Fig. 7. Tag identification time for the number of used tags(sequential tag ID)

Fig. 5 presents the tag identification time for the number of used tags of each algorithm for random tag ID. Lines and symbols represent analytic and simulation results, respectively. In Fig. 5, the tag identification time for the same number of used tags of the proposed algorithms is much less than that of the conventional algorithm. The performance of the proposed algorithms is about 70% higher than that of the conventional algorithm for the 20 tags and about 130% higher for the 200 tags. Tag identification rate of the conventional algorithm is 117 tags/sec and that of the proposed algorithms is 252 tags/sec.

In Fig. 6, we show the number of PingID command for the number of used tags of each algorithm for the sequential tag ID. Fig. 6 represents the simulation result. In this figure, in the conventional algorithm for the sequential tag ID, the number of PingID command is very large. In the case of the conventional algorithm, when the reader transmits PingID command, many tags reply in the same Bin slot. That is why the number of PingID command is larger. On the contrary, the number of PingID command of the proposed algorithms is very smaller than the case of using random tag ID. When the reader uses ScrollAllID command, it knows the sequence of the collided bits so that unnecessary transmission of PingID command can be reduced.

Fig. 7 illustrates the tag identification time for the number of used tags of each algorithm. This result is for the sequential tag ID and represents the simulation result. In Fig. 7, the tag identification time of the conventional algorithm increases comparing with the case of using random tag ID. However, for the 200 tags, we found that the performance improvement of the proposed algorithm not using ScrollAllID command is about 13% and that of the proposed algorithm using ScrollAllID command is about 16%, respectively.

6 Conclusion

We analyzed the conventional anti-collision algorithm for EPC CLASS 1 UHF Tag and proposed the improved anti-collision algorithms. In the proposed algorithms, if the reader memorizes the Bin slot information, it can reduce the repetition of unnecessary PingID command and the time to identify tags. If we also use ScrollAllID command in the proposed algorithm, the reader knows the sequence of collided ID bits. Using this sequence, the reader can reduce the repetition of PingID command and tag identification time. We compared the performance of the proposed algorithms with that of the conventional anti-collision algorithm for the random tag ID and sequential tag ID, respectively. We also validated analytic results using simulation. In the case of using random tag ID, the performance of the proposed algorithms is about 130% higher for the 200 tags. Tag identification rate of the conventional algorithm is 117 tags/sec and that of the proposed algorithms is 252 tags/sec. For many practical RFID applications using sequential tag ID, the conventional anti-collision algorithm shows performance degradation since the reader transmits many PingID commands. However, the proposed algorithm using ScrollAllID command shows performance improvement as much as about 16%. In conclusion, the proposed algorithms will contribute to improve the performance of the RFID system because the reader can identify more tags with shorter time.

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