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The Performance of Collision Arbitration for ISO/IEC 18000-6 RFID Standard

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***Abstract*—For multiple random accesses, a low throughput due to channel contention is the major limitation. The most latency occurs in the contention phase and, therefore, reducing the delay time thus becomes a relevant task. A collision occurs in real network access if two or more packets are simultaneously transmitted. Hence, the contention must be resolved when applying a protocol in the wireless data network. RFID anti-collision of ISO/IEC 18000-6 [1-2] adopts the concept of tree [3] expansion in to reduce the delay time and enhance the throughput. Analyses results indicate that the variety of the mean delay time performance is insignificant related to its probability factors. However, the impact on the throughput performance due to these probability factors is significant.**

Keywords—RFID; anti-collision; throughput; mean delay time; tree elimination algorithm

I. INTRODUCTION

Basic RFID [4-6] typically consists a reader and tags. Tag becomes activate after it receives a command which is initiated from a reader. For a passive tag, the energy to make the tag to be activated is gained from the transmitted power of reader by coupling. In a RFID system, RFID reader is required to identify multiple tags in a given period of time simultaneously. If a transmission channel is simultaneously accessed by multiple tags within the range of a reader, mutual interferences incurred and this phenomenon is known as tag collision. To resolve the collision problems is a crucial issue to a RFID reader network system.

When considering the sharing of bandwidth in random access network communication, throughput performance and mean delay time are two critical factors. Therefore, the collision resolution algorithm must be used to obtain the system performance of the multiple access schemes. In this paper, we will analyze the system performance of RFID anti-collision of ISO/IEC 18000-6 that adopts the concept of tree expansion in to reduce the delay time and enhance the throughput.

The rest of this paper is organized as follows. Section 2 describes the operation of RFID anti-collision of ISO/IEC 18000-6. Section 3 illustrates the relationship among the delay-throughput characteristics for RFID anti-collision of ISO/IEC 18000-6. Numerical results are presented in Section 4. Concluding remarks are finally made in Section 5.

II. ANTI-COLLISION PROCEDURE

A means of enhancing the system performance is to resolve the probability of contending packets. According to information theory, the more pertinent information which is available to describe the observed event allows us to more accurately estimate the event. In real network access, a collision may occur if two or more packets are simultaneously transmitted at the same slot. Hence, how to resolve the contention collision is a relevant issue when applying a protocol in the wireless data network.

In the ISO/IEC 18000-6 international standard, the collision arbitration be briefly summarized as follows.

Step 1: When the interrogator initiates a tag census to these selected tags, these tags with counter at 0 will transmit their ID.

Step 2a: If more than one tag transmits simultaneously, the interrogator may detect the collisions and receives the erroneous contention from multiple transmissions. Then, the interrogator will respond a FAIL command to these tags. Go to Step 3a.

Step 2b: If only one tag transmits its ID and the transmitted ID is correctly received by the interrogator, the interrogator sends a DATA_READ command with the received ID to the corresponding tag. Then go to Step 3b. Otherwise, if only one tag transmits its ID and the transmitted ID is erroneously received by the interrogator, the interrogator sends a RESEND command with the received ID to the corresponding tag. If the number to a RESEND command with the same received ID excesses the level of error handling for the system, the interrogator assumes that more than one tag transmit simultaneously, and go to Step 2a.

Step 2c: If no reply is received by the interrogator, it means that no tag with counter at zero exists. The interrogator sends a SUCCESS command to all tags which enter the energizing field of the interrogator. Go to Step 3c.

Step 3a: Tag will randomly generate a number (just 0 or 1 can be generated) from its random generator when it detects its contention is failed. When a tag rolls 1 with probability $1-p_c$ from its random generator, the content of counter increases one. The counter will keep its counter at zero if the tag rolls 0 with probability p_c.

Step 3b: If the transmitted DATA_READ command is correctly received by the corresponding tag, the tag will transient to DATA_EXCHANGE state and then transmit its data.

Step 3c: When tags receive the SUCCESS command from the interrogator, the value of counters decreases one.

Step 4: Step 1 repeats.

The detailed flow chart is given as Fig. 1. To analyze the protocol, we assume that these tags have to randomly generate a number from its random generator before the interrogator initiating a tag census.

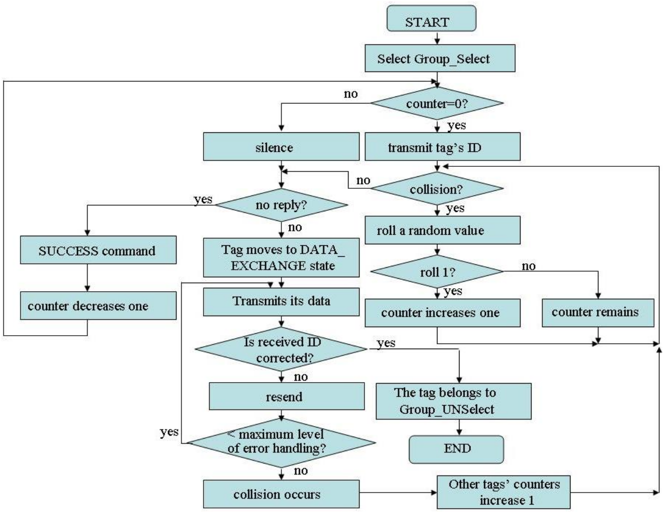

Fig. 1. The detailed flow chart of ISO/IEC 18000-6 Collision Arbitration

III. SYSTEM PERFORMANCE

In this section, we establish a system model to obtain the performance of system. All tags are assumed to be independent and identical sources, in which each tag has exactly a packet with a fixed packet length to be transmitted at any time. Herein, the packet of a tag is immediately generated after receiving the polling command from the interrogator which covers the tag. In this manner, a perfect physical transmission to generate the polling request from the interrogator is assumed. However, an imperfect physical transmission to receive the generated packet from a tag is assumed.

A. *ISO/IEC 18000-6 standard*

In general, throughput and average delay time largely justify a system's robustness. Denote t_s to be the ID packet's transmission time of a tag, t_c to be the packet's collision period. Let t_{poll} be the time, including the propagation time, to poll the tags with counter at zero. Denote t_{max} is the time to justify that no tags with counter at zero exist. τ is the maximum propagation delay and t_f is the time to justify the transmitted ID packet is erroneously received the transmitted ID from the tag and to process it. In addition to include the propagation time and processing interrogator and tags, the times t_s and t_c include the time of transmitted DATA_READ command, and transmitted RESEND command or transmitted FAIL command, respectively. Time t_f includes the propagation time, processing interrogator and tags and the time to send a SUCCESS command.

B. *Throughput performance*

We define the throughput as the ratio of expected successful transmission duration to the total time, denoted as a round cycle, for completely serving all tags in which are located within the coverage of a specified interrogator. Now, let us consider the case that there are n tags being selected by the interrogator at the beginning of performed collision arbitration. Assume that there are n_d tags with counter 0. Among these n_d tags, assume that there are n_f tags receiving RESEND command from the interrogator with probability p, and n_d - n_f tags receiving a DATA_READ command from the interrogator with probability 1-p. While considering n tags within the coverage of a RFID reader and neglecting the situation of n_f = 0, the following cases should be considered independently.

Case 1: $n_d = 0$

In this case, it means that no tags with counter at zero exist. Therefore, the time to completely serve these n tags for a round cycle under the condition that there are n_d non-collision tags is given as

$$T(n \mid n_d = 0) = (1 - p_c)^n \left[t_{poll} + t_{\max} + \tau + T(n) \right] \tag{1}$$

Case 2: $n_d = 1$

In this case, it means that just one tag with counter at zero exists. Therefore, the time to completely serve these n tags for a round cycle under the condition that there are n_d tags with counter 0 is given as

$$T(n \mid n_d = 1) = n p_c (1 - p_c)^{n-1} \left[t_{poll} + t_s + \tau + T(n-1) \right] \tag{2}$$

Case 3: $n_d \geq 2$

In this case, it means that there is more than one tag with counter at zero exists. These tags will randomly generate a random number (just 0 or 1 can be generated) from its random generator when it detects its contention to be failed. The probability that a tag rolls 1 is 1-p_c from its random generator, the content of counter increases one. The counter will keep its counter at zero if the tag rolls a zero with probability p_c. Since the counters at one among these tags which roll 1 will rejoin the contention with other n - n_d tags, the time to completely serve these n tags for a round cycle under the condition that there are n_d tags with counter 0 is given as [7-9].

$$T(n \mid n_d \geq 2) = \binom{n}{n_d} p_c^{n_d} (1 - p_c)^{n-n_d} \left\{ \begin{array}{l} (t_{poll} + t_c + \tau) + \sum_{n_{d_1}=0}^{n_d} \binom{n_d}{n_{d_1}} p_c^{n_{d1}} (1 - p_c)^{n_d - n_{d_1}} \cdot \\ \left[\mathrm{T}(n_d \mid n_{d_1} = 0) + \mathrm{T}(n_d \mid n_{d_1} = 1) + T(n_d \mid n_{d_1} \geq 2 \right] \end{array} \right\} \tag{3}$$

Combining cases 1, 2, and 3, the time to completely serve these n tags for a round cycle is given as

$$T(n) = \mathrm{T}(n \mid n_d = 0) + \mathrm{T}(n \mid n_d = 1) + \sum_{n_d=2}^{n} \mathrm{T}(n \mid n_d \geq 0) \tag{4}$$

Consider the condition that there are n students in a classroom and $n_f \neq 0$. Assume that all tags' counters are at zero at the beginning of the initiation polling cycle. Denote the probability p is the probability that only one tag transmits its ID and the transmitted ID is erroneously received by the interrogator. Then, the probability 1-p is the probability that the interrogator can successfully access a tag. In this situation, we only modify the case 1 of $n_f = 0$. Therefore, the time to completely serve these n tags for a round cycle is given as

$$\begin{aligned} T(n \mid n_d = 1) &= np_c(1-p_c)^{n\text{-}1}\left\{(1-p)\left(\tau_s + T(n-1)\right) + p(\tau_f + T(1) + T(n-1))\right\} \\ &= (1-p)\tau_s + p\tau_f + pT(1) + T(n-1) \end{aligned} \tag{5}$$

where

$$\tau_s = t_{poll} + t_s + \tau \tag{6}$$

$$\tau_f = t_{poll} + t_f + \tau \tag{7}$$

$$\tau_{\max} = t_{poll} + t_{\max} + \tau \tag{8}$$

Let

$$H(n) \equiv \mathrm{H}(n)\,|_{m=0} \tag{9}$$

$$\begin{aligned} H(n)\,|_m =&\ (1-p_c)^n \tau_{\max} + T(n \mid n_d = 1) + \\ &\sum_{n_{d\,m}=0}^{n} \binom{n}{n_{d_m}} p_c^{n_{d\,m}} (1-p_c)^{n-n_{d\,m}} \left[\tau_c + H(n_{d\,m})\,|_{m=m+1}\right] \end{aligned} \tag{10}$$

and

$$Y(n) = (1-p_c)^n + \sum_{n_d=2}^{n} \binom{n}{n_d} p_c^{n_d} (1-p_c)^{n-n_d} \begin{bmatrix} (1-p_c)^{n_d} + \\ \displaystyle\sum_{n_{d_1}=2}^{n} \binom{n_d}{n_{d_1}} p_c^{n_{d_1}} (1-p_c)^{n_d - n_{d_1}} \left[(1-p_c)^{n_{d_1}} + \cdots\cdots\right] \end{bmatrix} \tag{11}$$

We have

$$T(n) = \frac{H(n)}{1\text{-}Y(n)} \tag{12}$$

Under a steady state, the average time ratio of non-collision packet periods in a mean round cycle is called the throughput. According to the definition of throughput, we have [9]

$$throughput\,(n) = \frac{nt_s}{T(n)} \tag{13}$$

C. Delay performance

Allow $X(n)$ to be the delay time to serve these n tags. While considering n tags within the coverage of a RFID reader and neglecting the situation of $n_f = 0$, the following cases should be considered independently.

Case 1: $n_d = 0$

In this case, it means that no tag with counter at zero exists. Therefore, the mean delay time to serve these n tags under $n_d = 0$ is given as

$$X(n \mid n_d = 0) = (1\text{-}\,p_c)^n \left[n\tau_{\max} + X(n)\right] \tag{14}$$

Case 2: $n_d = 1$

In this case, it means that just one tag with counter at zero exists. Therefore, the delay time to serve these n tags under $n_d = 1$ is given as

$$X(n \mid n_d = 1) = np_c(1\text{-}\,p_c)^{n\text{-}1}\left[(n-1)\tau_s + X(n-1)\right] \tag{15}$$

Case 3: $n_d \geq 2$

In this case, it means that there is more than one tag with counter at zero exists. These tags will randomly generate a random number (just 0 or 1 can be generated) from its random generator when it detects its contention is failed. The probability that a tag rolls 1 is *1-p* from its random generator, the content of counter increases one. The counter will keep its counter at zero if the tag rolls a zero with probability p. Since the counters at one among these tags which roll 1 will rejoin the contention with other n - n_d tags, the delay time to serve these n tags under $n_d \geq 2$ is given as

$$X(n \mid n_d \geq 2) = \binom{n}{n_d} p_c^{n_d} (1-p_c)^{n-n_d} \left\{ \begin{aligned} &\tau_c + \sum_{n_{d_1}=0}^{n_d} \binom{n_d}{n_{d_1}} p_c^{n_{d1}} (1-p_c)^{n_d - n_{d_1}} \cdot \\ &\left[X(n_d \mid n_{d_1} = 0) + X(n_d \mid n_{d_1} = 1) + X(n_d \mid n_{d_1} \geq 2\right] \end{aligned} \right\} \tag{16}$$

Combining cases 1, 2, and 3, we obtain the time to completely serve these n tags for a round cycle is given as

$$X(n) = X(n \mid n_d = 0) + X(n \mid n_d = 1) + \sum_{n_d=2}^{n} X(n \mid n_d \geq 0) \tag{17}$$

Consider the condition that there are n tags within the coverage of a reader and $n_f \neq 0$. Assume that all tags' counters are at zero at the beginning of the initiation polling cycle. Denote the probability p is the probability that only one tag transmits its ID and the transmitted ID is erroneously received by the interrogator. Then, the probability *1-p* is the probability that the interrogator can successfully access a tag. In this situation, we only modify the case 1 of $n_f = 0$. Therefore, the time to completely serve these n tags for a round cycle is given as (17), excepting

$$\begin{aligned} X(n \mid n_d = 1) &= np_c(1\text{-}\,p_c)^{n\text{-}1}\left\{(1-p)\left((n-1)\tau_s + X(n-1)\right) + p(n\tau_f + X(1) + X(n-1))\right\} \\ &= (1-p)(n-1)\tau_s + pn\tau_f + pX(1) + X(n-1) \end{aligned} \tag{18}$$

Let

$$\begin{aligned} H_1(n)\,|_m =&\ (1-p_c)^n \tau_{\max} + X(n \mid n_d = 1) + \\ &\sum_{n_{d\,m}=0}^{n} \binom{n}{n_{d_m}} p_c^{n_{d\,m}} (1-p_c)^{n-n_{d\,m}} \left[\tau_c + H_1(n_{d\,m})\,|_{m=m+1}\right] \end{aligned} \tag{19}$$

then

$$H_1(n) \equiv \mathrm{H}_1(n)\,|_{m=0} \tag{20}$$

Therefore,

$$X(n) = \frac{H_1(n)}{1\text{-}Y(n)} \tag{21}$$

Moreover, one of these tags may have one packet to be transmitted during round cycle. Based on this condition, the renewal process is appropriate for calculating a packet's mean waiting time. Assume that our system is a closed system, therefore, $W(n) = 0$, and the mean delay time of a tag can be expressed as

$$D(n) = \frac{X(n)}{n} \tag{22}$$

IV. NUMERICAL RESULTS

This section evaluates the performance of anti-collision protocols with ISO/IEC 18000-6 standard. Subsequent impacts on the performance of anti-collision protocols with ISO/IEC 18000-6 standard among a variety of the number of polled tags and the system are examined by considering different response probabilities. According to our results, we change only one parameter and maintain the others unchanged to clarify the effect of the changed parameter as much as possible for each comparison.

The first comparison is made by varying the value of p_c. The relationships between throughput and the number of tags are shown in Fig. 2 and Fig. 4. The relationships between the mean delay time and the number of tags are shown in Fig. 3 and Fig. 5. These results demonstrate that the throughput decreases when the number of tags increases. From Fig. 2 to Fig. 5, if there are a few tags are polled by the RFID integrator at the beginning of anti-collision procedure, the more the probability p_c is, the better the throughput performance is. Otherwise, the performance will increase according to the decrease of p_c. It is intuitive that if the probability of p_c is, the larger the number of tags with counter zero is. This phenomenon reflects a situation in which the probability of colliding packets decreases. From this result, we also knew that the tradeoff is between p_c versus the number of tags.

In addition, From Fig.2 to Fig. 5, the impact on the throughput performance due to probability p is also significant. The less the probability p is, the better the throughput performance is. Therefore, the value of p is a prerequisite for reducing the delay and obtaining the maximum throughput. Figures also reveal that the variety of the mean delay time performance is insignificant when the numbers of the tags within the coverage of the interrogator is less than a level. These figures also depict that the variety of the mean delay time performance is insignificant related to parameters p and p_c.

The second comparison is performed by varying the value of t_c. From Fig. 4 to Fig. 7, the smaller time factor t_c implies a better performance of the protocol. This is attributed to that the probability of generating the collision packet is more than the probability of generating the transmitted successful packet periods. Therefore, the performance increases by reducing the time of collision detection.These figures also reveal that the time factor t_c is most important factor to the performance of the protocol than that of p_c.

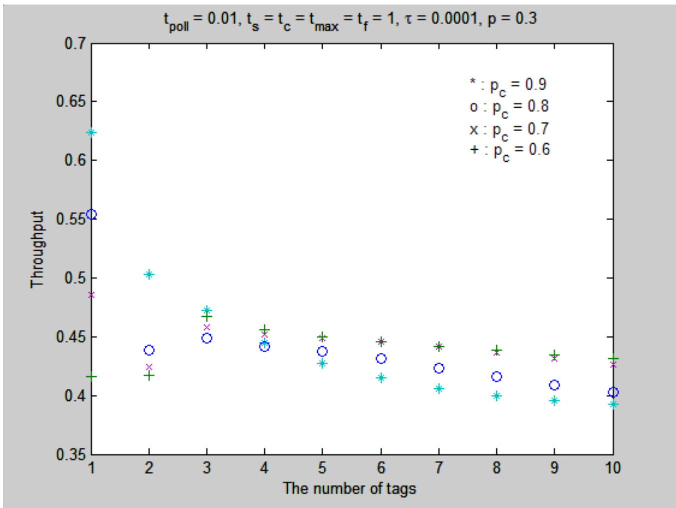

Fig.2. The throughput performance of the protocol for various p_c for $p=0.3$

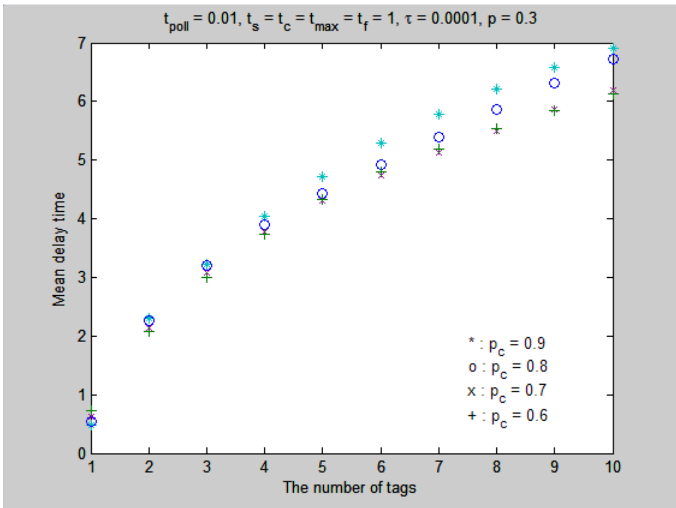

Fig. 3. The man delay performance of the protocol for various p_c for $p=0.3$

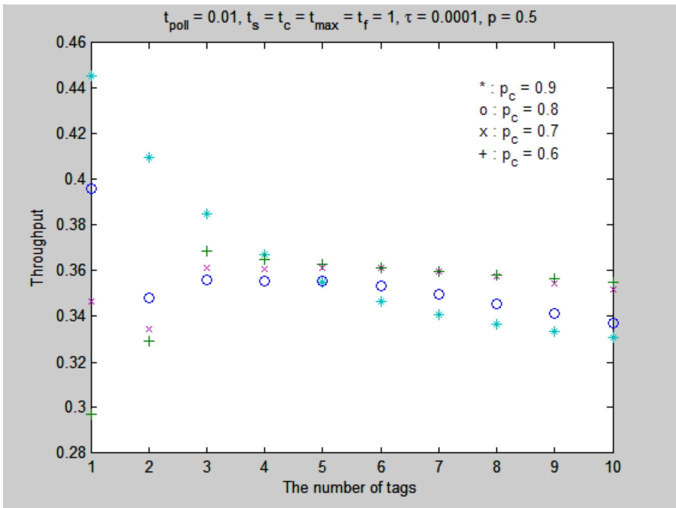

Fig. 4. The throughput performance of the protocol for various p_c for $p=0.5$

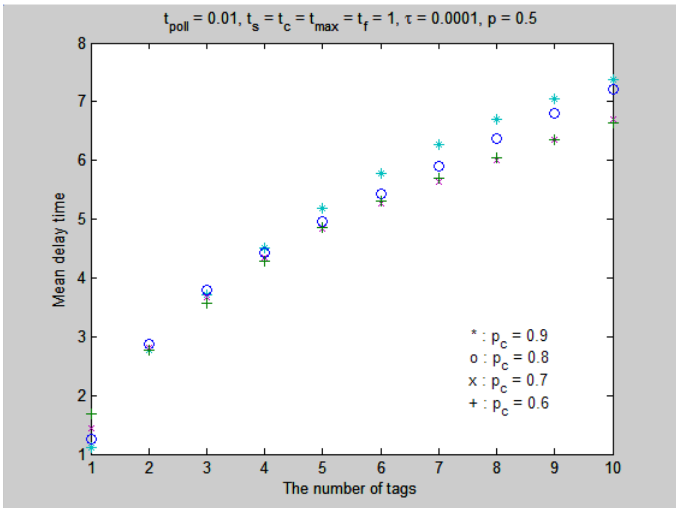

Fig. 5. The man delay performance of the protocol for various p_c for $p=0.5$

To see the impact on the performance of anti-collision protocols with ISO/IEC 18000-6 standard, the third comparison is made by varying the value of t_f based on the condition of $p\neq0$. It is intuitive that if the number of tags do not surpass the “pre-defined” level of tags in the system, then the performance is largely enhanced when p_c becomes larger. Otherwise, the performance decays rapidly when p_c becomes larger. This phenomenon is found to be the same as that of $p=0$. However, reducing the value of t_f can strongly enhance the system performance. We also believe that if the time factor t_f exceeds the packet length t_s, then the performance decays rapidly (not shown in this paper).

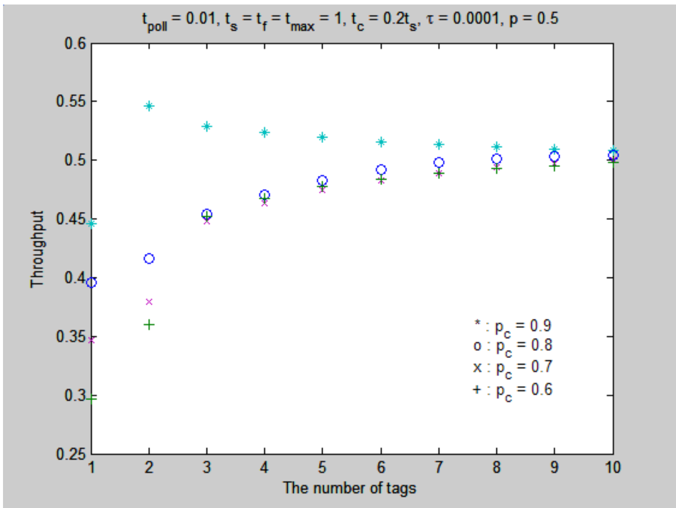

Fig. 6. The throughput performance of the protocol for $t_c=0.2t_s$ and $p=0.5$

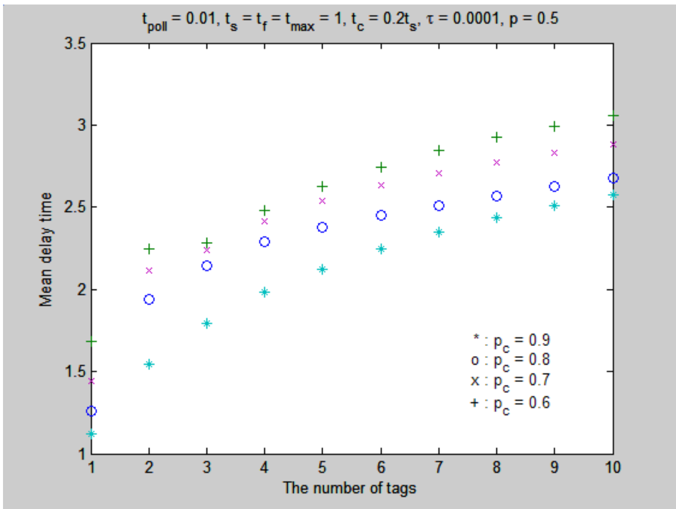

Fig. 7. The man delay performance of the protocol for $t_c=0.2t_s$ and $p=0.5$

The final comparison is made to compare the impacts on the system performances between time factor t_f and time factor t_c. Based on the same conditions, from Fig. 6 to Fig. 9, these figures illustrate that the system performance decays related to the increment of p_c. Instead of the result of t_f, the system performance is enhanced according to the increment of p_c. We also see that the time factor t_f more profoundly influences the system performance time factor t_c.

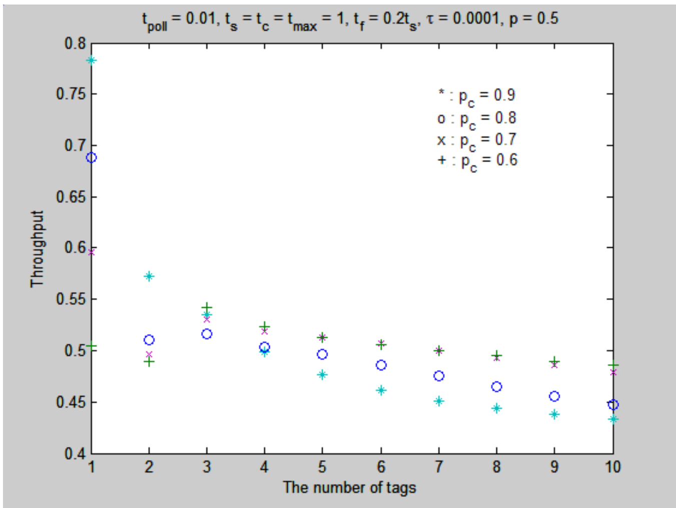

Fig. 8. The throughput performance of the protocol for $t_f=0.2t_s$ and $p=0.5$

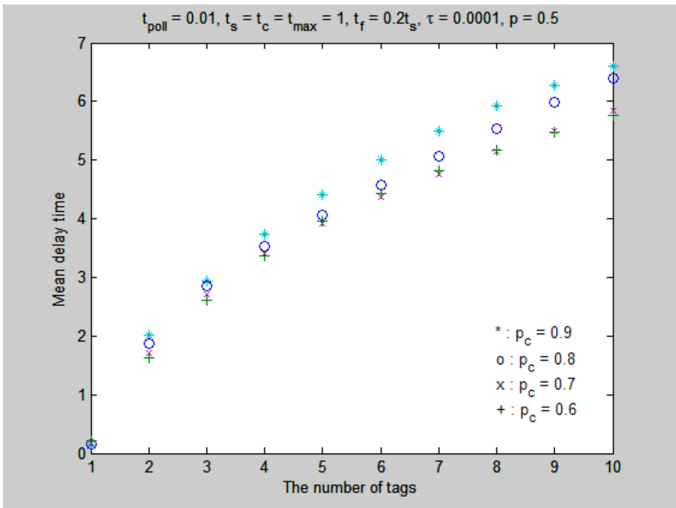

Fig. 9. The man delay performance of the protocol for $t_f=0.2t_s$ and $p=0.5$

V. CONCLUSIONS

This paper presents the impact on the system performance among time factor t_c, time factor t_f, the probability p, the probability p_c and the number of tags at the beginning of anti-collision procedure which is initiated by the RFID integrator. A preferred choice is studied to examine the influence of this protocol. For ISO/IEC 180006-6, the fact that we adopt tree algorithm to resolve the colliding packets in the contention phase institutively accounts for why the contention time can be largely reduced. It is intuitive that the lesser amount of contention time implies a higher throughput performance. In addition, in order to enhance system performance, the collision resolution strategy should be used to reduce the contention time, t_c, and reduce the time, t_f, to justify the transmitted ID packet is erroneously received the transmitted ID from the tag and to process it. If not, collision time seriously degrades the system performance. In addition, these important factors are available to enhance the system performance.

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