Improvements on Tags Anti-Collision Algorithm in RFID System

Wenqiang Zhu, Aijun Zhang

Abstract—**To improve the performance of the identification speed and the reliability in RFID system with large intensive tags, an improved tag anti-collision algorithm based on CSMA is proposed in this paper. The proposed model adopts the principle of the first arrival tag occupies channel and transmits packets in the next idle slot when the detected channel is idle, otherwise, adjusts the back-off time according to the collision times. Hence, the channel conflict caused by listening misjudgment is eased and propagation delay is reduced efficiently. Based on the Markov chain analysis, the simulation results show that the anti-collision algorithm proposed in this paper has higher recognition precision than the traditional algorithm.**

Index Terms—**RFID system, anti-collision, CSMA, Markov chain.**

I. Introduction

Radio Frequency Identification (RFID) is an automatic contactless identification technology, which realizes the data transmission between reader and tag by wireless communication to obtain the information of the attached tag object. With the advantage of non-contact and the ability of identifying multiple targets simultaneously, RFID technology is gaining an increasing range of applications in inventory control [1], farming [2], the real-time location tracking system to track human and assets [3]-[5].

However, in the large intensive tags environment, the integrity of RFID data transmission is still the majority of technical challenges that affect negatively on the performance of the RFID system [6]. Whereas, tag collision is the most difficult problem to settle in all factors which includes external interference, reader collision and tag collision, due to the fact that the external environment can be control and the reader has more functions than the tag [7].

Therefore, this paper dedicates to studying the problem of tag collision and achieving the goal of transmitting data between readers and tags as quickly and reliably as possible. The tag collision is referred to as follows: when the reader tries to identify all tags by firstly transmitting an inquiring command to initiate the communication, and then tags respond with their identity upon hearing the reader's command. However, as multiple tags respond to the reader simultaneously, transmitted packets will collide and be lost [8].

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To overcome this challenge, many of the tag anti-collision protocols studied have the goal of controlling the shared communication channel of multiple tags. The anti-collision protocols are mainly classified into two main approaches: tree-based (binary tree) algorithms, ones split the set of tags in disjoint smaller subsets by query command of the reader until there is only one tag in a subgroup to be identified [9] and Aloha-based (framed slotted ALOHA) algorithms, ones focus on avoiding that tags respond to the reader simultaneously by transmitting data at randomly selected time slot and known for their low complexity such as Pure Aloha (PA), Slotted Aloha (SA), Frame Slotted Aloha (FSA) and Dynamic Frame Slotted Aloha (DFSA) [10].

On the one hand, the tree-based algorithm has the characteristics of high complexity and long recognition delay caused by the continuous collision of many tags [8]. Accordingly, these schemes are not suitable for RFID system with a large number of intensive tags which need to be identified accurately and quickly simultaneously. On the other hand, Aloha-based algorithms are characterized by their minimal complexity and ease of implementation in the context of real-time location tracking system [11]. For example, DFSA-based schemes are suitable algorithms for RFID applications since they have adaptability to variable loads while maintaining an elevated level of system efficiency [12]. However, these protocols cannot guarantee high identification accuracy and low time delay in high density tags.

Therefore, this paper introduces a deterministic strategy into tag collision prevention and resolution. The proposed anti-collision protocol based on the CSMA algorithm with additional hardware device capable of detecting channel state, which is evolved from ALOHA protocol, improves the tag identification accuracy and speed by adopting the principle of the first coming tag to occupy channel with the probability P at the beginning of the free slot, otherwise deferring transmission and adjusting retreat time according to the collision times. Thereby, the channel conflict caused by listening misjudgment is eased efficiently and the speed of identifying tags is improved obviously.

The remainder of the paper is organized as follows: In section 2, the different protocols including Pure ALOHA(PA), Slot ALOHA(SA) and CSMA algorithm, are reviewed and analyzed briefly. Section 3 presents the proposed protocol based on the CSMA algorithm. Then, performance evaluation based on the analysis and simulation results is done in Section 4. Finally, Section 5 concludes and outlines possible future works.

II. Conventional algorithms

A. Pure ALOHA anti-collision algorithm

Pure Aloha (PA) algorithm [13] is the most simple and basic aloha algorithm, a typical characteristic of which is that tags immediately sent data to channel without considering channel state after entering the scope effective interrogation zone of a reader. Obviously, the randomness and uncertainty of this control strategy will become higher with the increase of tags number. As shown in Fig. 1, three situations including successful identification, full collision and partial collision will occur in processing of PA.

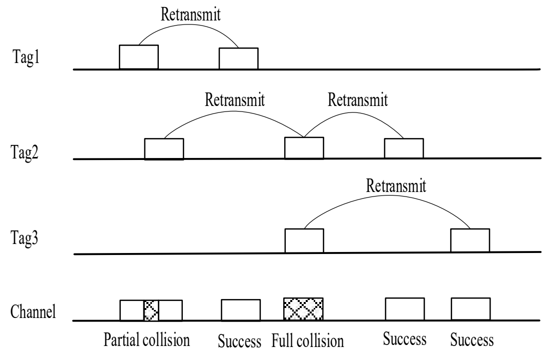

Fig. 1. Anti-collision procedure with PA

We define T_0 as the transmission time of a tag, and hence the conflict cycle of the protocol above is $2T_0$. Again, defining the system throughput rate *S*, namely the total of packets transmitted successfully, as the average number of tags completing communication successfully and the system input load *G*, namely the total account of transmitted packets, as the average number of arrival tags.

If *P* is the probability of transmitting a packet successfully, and then there will be *S*=*GP*. If the number of arrival tags in a second obeys the Passion distribution and λ is the average arrival rate of tags, the probability that there are *K* arriving tags within *t* seconds is:

$$P(K)=\frac{(\lambda t)^{K}\,e^{\lambda t}}{K!}\qquad (K\geq 0)\tag{1}$$

The condition that there is no tags collision with $2T_0$ is *K*=0.5. At this moment, the probability of transmitting packets successfully is:

$$\begin{aligned}P(K=0)&=\frac{(\lambda\times 2T_0)^{0}\,e^{\lambda\times 2T_0}}{0!}\\&=e^{-\lambda\times 2T_0}\qquad (K\geq 0)\end{aligned}\tag{2}$$

and then system throughput rate [14] is:

$$S=GP=Ge^{-2G}\tag{3}$$

Where, $G=0.5$, and maximal throughput rate of PA protocol is only 0.184.

B. Slotted ALOHA anti-collision algorithm

For the purpose of improving the channel utilization, Slotted Aloha (SA) algorithm [15], among which channel time is divided into a set of equal long slots (the slot length is equal to the packet transmission time), is proposed. As illustrated in Fig. 2, after receiving a collection command from the reader, the tag transmission is synchronized with the beginning of randomly selected slot. If two or more tags transmit their ID at the same slot, a collision will occur.

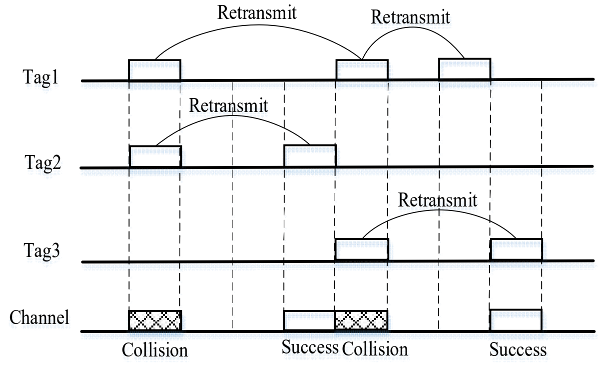

Fig. 2. Anti-collision procedure with SA

It is obvious that the conflict cycle is T_0, and the probability of transmitting a packet successfully is:

$$P(K=0)=\frac{(\lambda\times T_0)^{0}\,e^{\lambda\times T_0}}{0!}=e^{-\lambda\times T_0}\tag{4}$$

and then system throughput rate is [14]:

$$S=GP=Ge^{-G}\tag{5}$$

Equation (5) shows that collision time reduced by half and throughput doubled in SA compared with PA algorithm. Despite all this, it’s hard to satisfied the appropriate performance metric in the large density tags environment.

C. Carrier Sense Multiple Algorithm

In order to further improve the throughput of the system, it is necessary to reduce the chance of collision. One way is to reduce the contention window, and the other way is to reduce the blindness of transmitting packets.

In the Carrier Sense Multiple Algorithm (CSMA), additional hardware devices are able to detect channel states, which evolved from ALOHA, firstly nodes listen to the channel and subsequently determine whether to send packets or not according to the detected channel state. By this way, CSMA reduces the collision between tags efficiently and improve the utilization rate of channel.

As illustrated in Fig. 3, with mechanism that tags withdraw for a period of time when the channel is busy and send the packet with the probability p when the channel is free, the p-persistent CSMA combines the advantages of both 1-persistent CSMA [16] ones efficiently reduce the identification delay in small quantity tags environment because of insistence on listening to the channel every moment and non-persistent CSMA [17] ones decrease the conflict under the circumstance of numerous intensive tags due to the randomness of back-off time.

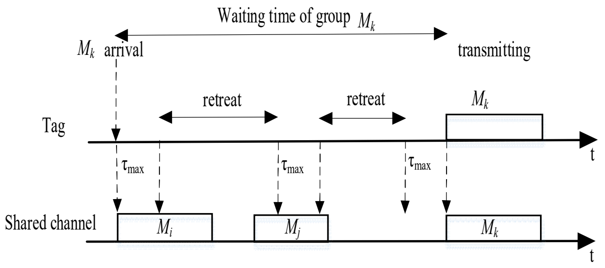

Fig. 3. Anti-collision procedure with CSMA

In reference [18], a dynamic p-persistent CSMA protocol, which improves system throughput by dynamically adjusting the data transmission probability p within the frame slot according to the number of tags to be sent, is proposed. Moreover, the reference [19] puts forward a p-persistent CSMA-based algorithm which adjust probability according to the retransmission times. However, there are a few complicated problems need to be study further in this dynamic p-persistent CSMA algorithm, such as the probability calculation in the process of tags estimation, slot adjust method and so on.

III. THE PROPOSED ANTI-COLLISION PROTOCOL BASED ON CSMA

In CSMA algorithm, the factors affecting accuracy of control strategy are as follows: on the one hand, tags may misjudge the state of channel because time delay in process of signal propagation while the appear and disappear moment of the same signal is various for the different tags; on the other hand, if there were two or more tags with the same or similar distance depart from the data source have detected idle channel at the same time, they will transmit packets simultaneously and then conflict may occur.

In order to alleviate the influence caused by the above factors on the performance of the system, time-line is divided into several time slots (this time slot is the normalization of carrier listening time) with the same width and the first tags take up idle channel until the next idle slot to transmit data in the improved CSMA algorithm as shown in Fig. 4. If the channel is busy, the tag will withdraw and occupy the channel with the probability p in the next free time slot. Fig. 5 shows the state transition of the proposed algorithm.

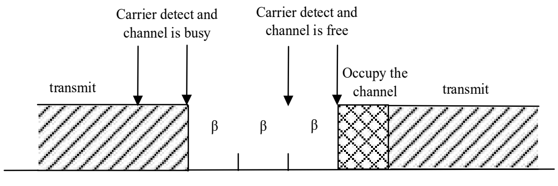

Fig. 4. Anti-collision procedure with the proposed protocol

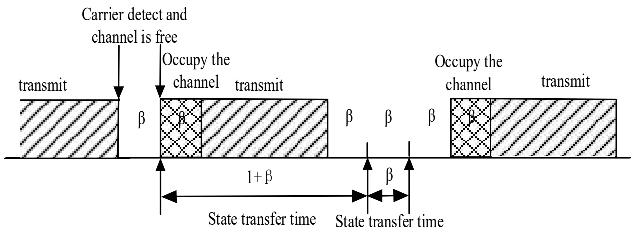

Fig. 5. State transition with the proposed protocol

A. Performance analysis of throughput

Assumptions on the performance analysis of improved CSMA algorithm are made as follows using Markov chain:

1) Generation procedure of the tag packet obeys the Poisson distribution;

2) Length of every tag packet is same and fixed, as a unit;

3) Each tag only sends a data packet whenever and detects carrier signals

4) Instantaneously without transmit-receive switch time delay;

5) There is no error in channel itself;

6) Defining the state of system as the number of tags which are waiting for retransmission and maximum of channel state feedback delay is β, therefore the time interval between two successive state is β or $1+2\beta$.

Moreover, making definitions as follows:

n: the number of tags which is wait for retransmission;

m: the total tag number in system;

q_r: the tag retransmission probability in free time slot after collision;

q_a: the arrival probability of a new tag packet in each time slot;

λ: the arrival rate of total tags, namely the arrival rate of each tag is λ/m;

$Q_r(i,n)$: the probability of there are i transmitting tags in total number n in current slot;

$Q_a(i,n)$: the probability of there are i tags detecting the free slot in total number $m-n$;

Therefore, the arrival probability of tag packet in each slot is $q_a = 1-e^{-\lambda/m}$ and under the given condition that the number of retransmission tag is n, we will obtain:

$$Q_r(i,n) = C_n^i(1-q_r)^{n-i}q_r^i \tag{6}$$

$$Q_a(i,n) = C_{m-n}^i(1-q_a)^{m-n-i}q_a^i \tag{7}$$

We define $P_{n,n+i}$ as the transmission probability that number of retransmission tags at the beginning of current slot is n and then there are $n+i$ retransmission tags at the beginning of next slot, so the state transition probability is :

$$P_{n,n+i} = \begin{cases} Q_a(i,n) & 2\le i\le m-n \\ Q_a(1,n)\left[1-Q_r(0,n)\right] & i=1 \\ Q_a(1,n)Q_r(0,n)+Q_a(0,n) & \\ \cdot\left[1-Q_r(1,n)\right] & i=0 \\ Q_a(0,n)Q_r(1,n) & i=-1 \end{cases} \tag{8}$$

Equation (8) above shows that there will be a large number of tags collisions if the retransmission probability $q_r \approx 1$. In order to explore the influence made by the retransmission probability on the performance of the system, the system state offset is defined as:

$$D_n = E\begin{Bmatrix} \text{the number of clusters within} \\ \text{the state transition interval} \end{Bmatrix} \text{-}1\times P_{succ} \tag{9}$$
$$= \lambda \cdot E\{\text{state transition interval}\} \text{-}1\times P_{succ}$$

where,

$$E\{\text{state transition interval}\}$$
$$= \beta \cdot P(\text{free slot}) + (1+2\beta)(1\text{-}P(\text{free slot})) \tag{10}$$
$$= 1+2\beta\text{-}(1+\beta)P(\text{free slot})$$

The value of $P(\text{free slot})$ is that the probability which there are no new arrival tag group in before slot and no retransmission tags in current slot, thus:

$$P(\text{slot is free}) = Q_r(0,n)Q_a(0,n)$$
$$= (1-q_r)^n (1-q_a)^{m-n} \tag{11}$$
$$= (1-q_r)^n e^{-\frac{m-n}{m}\lambda\beta}$$

In addition, the value of P_{succ} is that the probability which there is only one new tag group arriving at an idle slot without retransmission tags sending data in current or there is only one retransmission tag sending data in current slot without any new tags group arriving in before slot, therefore:

$$P_{succ} = [1\text{-}Q_a(0,n)]Q_r(0,n) + Q_a(0,n)Q(1,n)$$
$$= \left[1-(1-q_a)^{m-n}\right](1-q_r)^n + (1-q_a)^{m-n} C_n^1 (1-q_r)^{n-1} q_r \tag{12}$$
$$= (1-q_r)^n + \left(\frac{nq_r}{1-q_r} - 1\right) e^{-\frac{m-n}{m}\lambda\beta} (1-q_r)^n$$

If $m \to \infty$ and q_r is small, and there will be:

$$D_n \approx \lambda\left[(1+2\beta) - (1+\beta)e^{-\left(q_r n + \frac{m-n}{m}\lambda\beta\right)}\right] - \left[e^{-q_r n} + (nq_r - 1)e^{-\left(q_r n + \frac{m-n}{m}\lambda\beta\right)}\right]$$
$$\approx \lambda\left[(1+2\beta) - (1+\beta)e^{-(q_r n + \lambda\beta)}\right] - \left[e^{-q_r n} + (nq_r - 1)e^{-(q_r n + \lambda\beta)}\right] \tag{13}$$
$$\approx \lambda\left[(1+2\beta) - (1+\beta)e^{-g(n)}\right] - \left(g(n) - \lambda\beta + e^{\lambda\beta} - 1\right)e^{-g(n)}$$

Where, $g(n) = q_r n + \lambda\beta$, presents the number of clusters which are trying to sending data including the new groups and retransmission packets.

Making $D_n < 0$, namely the condition that success of tag groups transmission is:

$$\lambda < \frac{\left(g(n) - \lambda\beta + e^{\lambda\beta} - 1\right)e^{-g(n)}}{(1+2\beta) - (1+\beta)e^{-g(n)}} \tag{14}$$

As shown in the right side of (14), the molecular expresses that the successful transmission number of tag clusters in each state transfer interval and the denominator represents the average length of state transition interval, so the division means the throughput in per unit time.

B. Performance analysis of time delay

Time delay characteristic is another important indication of system performance evaluation because conflict decomposition and data retransmission are needed after collision. Defining normalized average transmission delay (D) as average time interval from the beginning time of data transmission to the arrival time, including normalized waiting time, sending time and transmission delay. Besides, a tag packet transmission time includes not only the first transfer time, but also the retransmission time. So, the tag packet transmission interval, which obeys the general distribution, equals the time from the first transmission to the end.

In addition, a tag packet transmission interval includes not only the first transfer time but also the packet retransmission time, so it obeys the general distribution.

In transmission process, as shown in Fig. 6, the maximum retransmission interval is $m-1$, which is consist of occupy channel time and transmission delay. Therefore, any packet will be retransmitted after $m-1$ packets if error occurs.

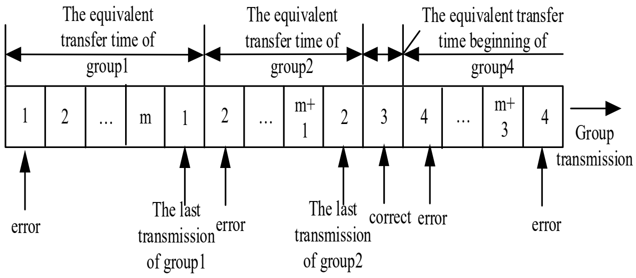

Fig. 6. A schematic diagram of a vibration separator

Supposing p as the probability that it fails to transmit packet, and then $p = 1 - P_{succ}$. Moreover, if we define k as the retransmission times, the probability distribution of equivalent transmission time will be:

$$P(X_k = 1 + km) = p^k (1-p) \tag{15}$$

It's first order matrix and second order matrix are:

$$\overline{X} = \sum_{k=0}^{\infty}(1+km)(1-p)p^k = 1 + \frac{mp}{1-p} \tag{16}$$

$$\overline{X^2} = \sum_{k=0}^{\infty}(1+km)^2(1-p)p^k = 1 + \frac{2mp}{1-p} + \frac{m^2(p+p^2)}{(1-p)^2} \tag{17}$$

And then using the P-K formula [20]:

$$W = \frac{\lambda\overline{X^2}}{2(1-\rho)} \tag{18}$$

Where, $\rho = \lambda/\mu$, presents the packet transmission rate. Therefore, under the condition that packet length is one unit length, namely $\mu = 1$, the average waiting delay W and the average delay T of tag groups are as follows:

$$W = \frac{\lambda\overline{X^2}}{2(1\text{-}\lambda)} \tag{19}$$

$$T = \overline{X} + W \tag{20}$$

IV. SIMULATION RESULTS

With the different value of normalized channel delay factor, simulation analysis and comparison are studied on the PA, SA, p-persistent CSMA and the proposed algorithm on the MATLAB platform.

According to the specification of ISO/IEC 18000-6C (EPC Gen2) standard, the empty slot and collision slot are all shorter than the slot with correct tag ID packets. However, we provide an approximation of the average identification time, that the duration of all slots is the same as the correct transmission time of tag ID packet with the length of 128. Thus, this is a conservation estimate, since empty and collision slots are actually shorter.

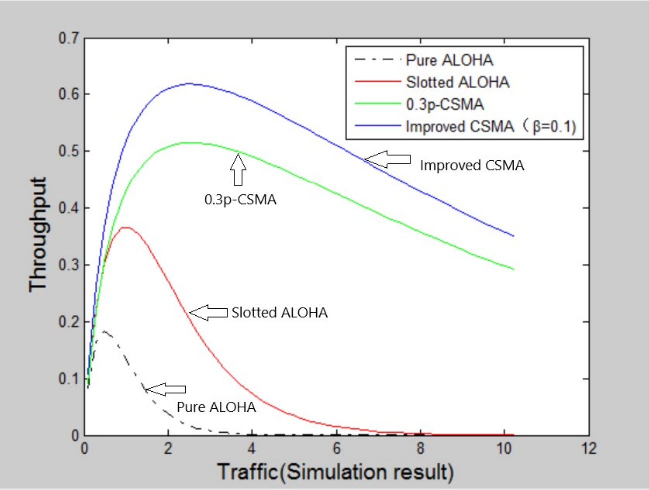

Fig. 7. Comparison of throughput when $\beta = 0.1$

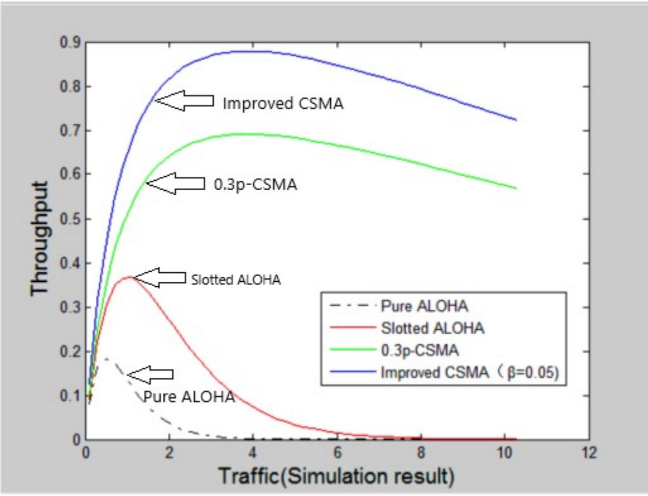

Fig. 8. Comparison of throughput when $\beta = 0.05$

In this case, we set bit rate to 512000 bit/s and symbol rate to 256000 bit/s. On the other hand, set the probability that the tag ID packet is sent. In Fig. 7, the throughput comparison results of the proposed algorithm with PA, FA and conventional CSMA are shown when the normalized propagation delay $\beta = 0.1$ and throughput of the proposed algorithm increase by 20% compared with CSMA. Moreover, in the case of $\beta = 0.05$, the throughput performance of the proposed algorithm and CSMA is even better than PA and FA as shown in Fig. 8. Furthermore, from the comparison between Fig. 7 and Fig. 8, we can see that the throughput descent speed of the proposed protocol when $\beta = 0.05$ is slower.

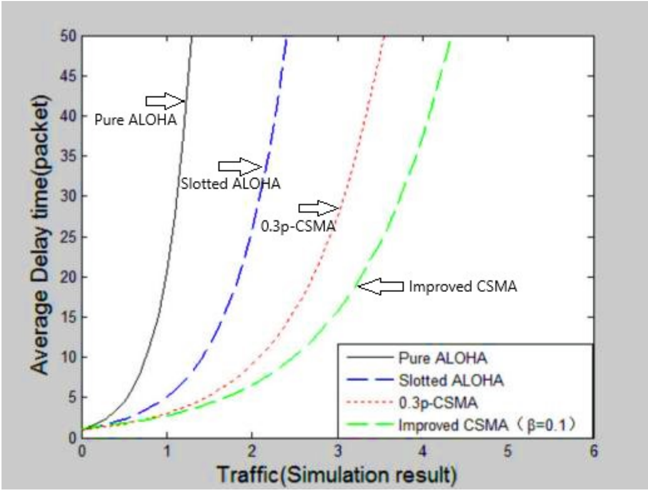

Fig. 9. Comparison of average identification delay when $\beta = 0.1$

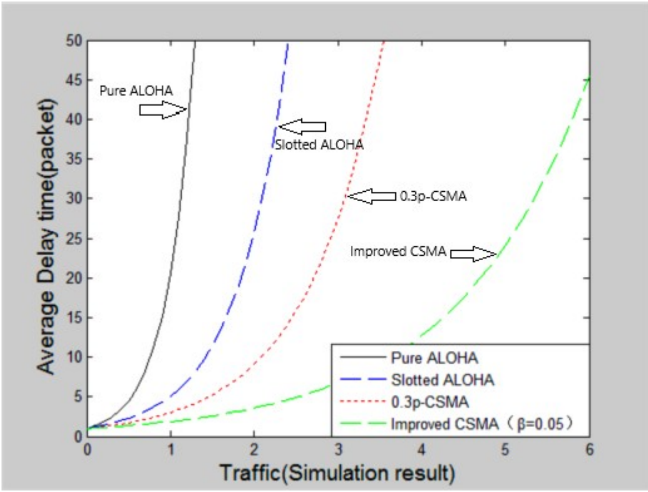

Fig.10. Comparison of average identification delay when $\beta = 0.05$

In addition, we once again assume that the identification period is the time from the first transmission to the end of the correct recognition of the proposed algorithm. Although, the identification time is increased to a certain extent because of the channel occupation without transmitting tag packets, the method of preemption effectively avoids tags collision resulting from misjudgment and dynamic adjustment of back-off time according to collision times improves the channel utilization. As illustrated in Fig. 9, the proposed algorithm allows for a quicker identification when $\beta = 0.1$ although the effect is not obvious. Compared with Fig. 9, average identification delay of the proposed protocol is smaller in Fig. 10 when $\beta = 0.05$.

V. CONCLUSIONS

In this paper, we propose an anti-collision algorithm based on CSMA protocol, which is used to solve the problem of low recognition accuracy in high-density tags environment. Current recommendations make it difficult to ensure tag recognition accuracy and low transmission latency for highly dense RFID tags.

In addition, we have evaluated the throughput and average latency required to identify using this mechanism and compared it with PA, FA and CSMA protocols. With the ISO/IEC 18000-6C (EPC Gen2) standard, the comparison simulation results show that that the transmission delay of the proposed algorithm also decreases under high load when the throughput is significantly increased.

Even the propagation delay factor has a great impact on the throughput of the system. In future work, research on delay factors and ways to reduce the impact is under way.

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REFERENCES

[1] W. Zhou, S. Piramuthu, Identification shrinkage in inventory management: an RFID-based solution[J]. Annals of Operations Research, 2017, 258(2):285-300.

[2] M. Hossain, M. Quaddus, Does Mandatory Pressure Increase RFID Adoption? A Case Study of Western Australian Livestock Industry[M]// Grand Successes and Failures in IT. Public and Private Sectors. Springer Berlin Heidelberg, 2013.

[3] Jannati H, Ardeshir-Larijani E, Detecting relay attacks on RFID communication systems using quantum bits[J]. Quantum Information Processing, 2016, 15(11):4759-4771.

[4] G. Alfian, J. Lee, H. Ahn, J. Rhee, Application of RFID and Computer Vision for the Inventory Management System[C]// International Conference on Computer Science & Its Applications. Springer Singapore, 2016.

[5] Marcello F, Roberto M, Fabio F, Alfredo L, Salvatore M, Application of a business process model (BPM) method for a warehouse RFID system implementation[J]. international Journal of RF Technologies: Research and Applications,2017,8(1-2):57-77.

[6] S. Ullah, W. Alsalih, A. Alsehaim, N. Alsadhan, A Review of Tags Anti-collision and Localization Protocols in RFID Networks[J]. Journal of Medical Systems, 2012, 36(6):4037-4050.

[7] J. Li, M. Jin, J. Liu, An enhanced slotted ALOHA algorithm for anti-collision in RFID system[M]// Advances in Future Computer and Control Systems. Springer Berlin Heidelberg, 2012.

[8] C. T. Nguyen, K. Hayashi, Megumi Kaneko, Probabilistic Dynamic Framed Slotted ALOHA for RFID Tag Identification[J]. Wireless Personal Communications, 2013, 71(4):2947-2963.

[9] B. I. Jang, C. S. Kim, H. K. Jung, Y. T. Kim, G. C. Park, Performance Analysis of Tag Identification Method Based on Multi-Reader Using Anti-Collision Algorithm[M]// Future Information Communication Technology and Applications. Springer Netherlands, 2013.

[10] S. Liu, X. Peng, Improved Dynamic Frame Slotted ALOHA Algorithm for Anti-collision in RFID Systems[M]// Knowledge Discovery and Data Mining. Springer Berlin Heidelberg, 2012.

[11] C. Salgado, L. Cardoso, P. Gonçalves, A. Abelha, J. Machado, Tracking people and equipment simulation inside healthcare units[M]// Ambient Intelligence - Software and Applications. Springer International Publishing, 2013.

[12] Y. I. Joo, D. H. Seo, J. W. Kim, an efficient anti-collision protocol for fast identification of rfid tags[M]. Kluwer Academic Publishers, 2014.

[13] F. Zheng, T. Kaiser, Adaptive Aloha anti-collision algorithms for RFID systems[J]. Eurasip Journal on Embedded Systems, 2016, 2016(1):7.

[14] Q. Wu, H. S. Li, Y. Yang, Z. X. Jiang, "Research on UHF Multi-tag Identification and Anti-collision Algorithm," Ph.D Dissertation, Inner Mongolia university of science and technology (2014).

[15] H. Wang, S. Xiao, F. Lin, T. C. Yang, L. T. Yang, Group improved enhanced dynamic frame slotted ALOHA anti-collision algorithm[J]. The Journal of Supercomputing, 2014, 69(3):1235-1253.

[16] Z. Zhang, "Simulation and Improvement of Back-off Algorithhm in CSMA," Ph.D Dissertation, Hunan University (2011).

[17] P. Zhu, Z. L. Zhang, "RFID Anti-collision Algorithm Based on p-Persistent CSMA," Telecommunications Information: Network & Communication 2 (2013) 33.

[18] B. S. Li, C. Qiao, Improved Algorithm Based on p-Persistent CSMA to Increase Throughput of RFID System[J]. Computer Measurement & Control, 2013.

[19] W. He, J. C. Nan, F. Pan, Improved Dynamic p-Persistent CSMA Protocol[J]. Computer Engineering, 2010, 36(21):118-120.

[20] J. Li, "Communication Network Foundation," Higher Education Press (2011).