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ALGORITHM BASED PRIORITY (ABP) MECHANISM FOR DECREASING TAG LOSS IN MOBILE RFID SYSTEMS

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In the mobile Radio Frequency Identification system (RFID), the speed of tag recognition and the quantity of lost tags are the problems to be considered in all applications. In this paper, we proposed a novel tag loss control mechanism called Algorithm Based Priority (ABP) to reduce the label loss rate in the mobile environment. There are two kinds of priorities. To reduce the contention of new and old labels on the channel, the ABP assigns a higher-priority to old tags and assigns the other lower-priority to the new tags. The lower-priority tags cannot be identified until all the tags with higher-priority have been identified. The simulation results show that when the speed of uniform tag arrival is greater than 900 tags per second, the system using ABP starts to lose labels, it is obviously better than the Schoute method. When the speed of tag arrival rate varies from low to high, then to low, the ABP also shows its advantage of low tag loss rate. From the simulation results, ABP has good performance in controlling tag loss.

Keywords: mobile RFID, DFSA, tag loss, tags priority

1. Introduction

In the sensing layer of the Internet of Things (IOT), there are many technologies to implement data acquisition such as sensor and Radio Frequency Identification (RFID). Due to its advantages of non-contact, penetration, and multi-recognition, more and more IOT applications use RFID technology to achieve data collection. In RFID systems, the reader is responsible for identifying tags within its coverage area. Many researchers are concerned about how to quickly identify a certain number of tags, under the condition that no new tags enter or leave the covered area. However, in many practical applications, the identification of tags is more carried out in the mobile environment, and the RFID system in this situation is called the mobile RFID system (known as mRFID). The interval of tag identification from entering the reader recognition area to being

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recognized affects system stability and availability. If the tag is not identified during the time it stays in the recognition area, and such a tag is called a lost tag. The higher the tag loss rate is, the lower the stability and availability of the system is. Based on the classical Dynamic Frame Slotted Aloha (DFSA) algorithm, this paper proposes a tag loss control mechanism by setting priority to tags, which decreases the probability of collision and reduces the tag loss rate.

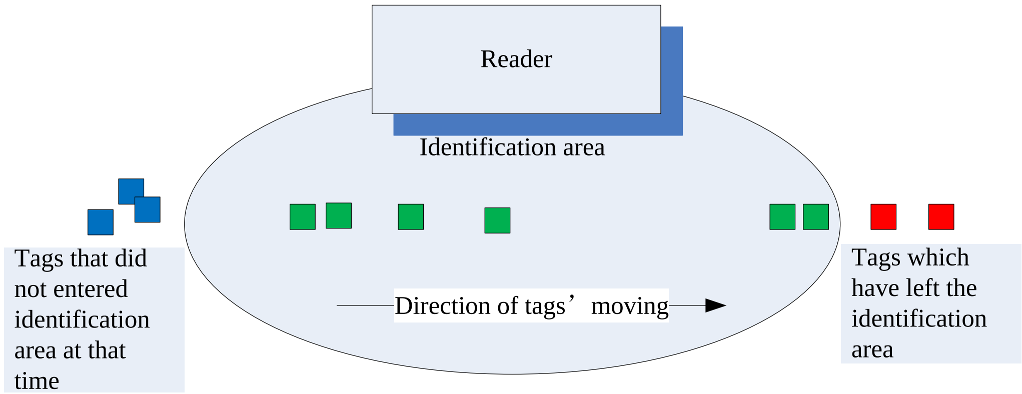

Fig. 1. model of the mobile RFID system

In the mRFID system shown in Fig. 1, there is only one reader to complete the tag identification in its coverage areas. The object attached tag is usually placed on the conveyor belt and is identified and recorded by the reader after entering the identification area. The reader periodically broadcasts a challenge command, and the unrecognized tags in the reader recognition area respond to the challenge and send back the tag information. Next, the reader sends a 'silence' signal to the tags which have been identified, and those tags will not participate in the next challenge-response process. In the process of recognition, if two or more tags respond to challenge signals at the same timeslot, the signals from different tags will overlay, and confliction occurs. The reader will receive mixed signals, so it cannot identify any correct independent signal. At this time, the conflicting tags will not be correctly identified and can only be identified in the follow-up challenge. Because of tags conflict, the identification efficiency and speed of RFID system decrease. Many researchers have proposed solutions to avoid this tag confliction, and the most widely used are Tree protocol and ALOHA protocol [1]. Tree protocol is a deterministic protocol that uses the Tree splitting technology to gradually split RFID tag IDs and finally determine a tag for identification [2,3]. This protocol overcomes the tag starving phenomenon. The tag starving phenomenon means that multiple tags compete for the channel, resulting in no one being recognized. However, due to the long identification delay, Tree methods are not suitable for the time-demanding environment of mRFID system. ALOHA protocol is an anti-collision algorithm based on random mechanisms, including Pure Aloha [4] (PA), Slotted Aloha [5] (SA), Frame Slotted Aloha [6] (FSA) and Dynamic Frame Slotted Aloha [7-10] (DFSA). DFSA is called the milestone of ALOHA algorithm. The researchers found that in DFSA algorithm, the recognition efficiency is optimal if the number of tags is equal to the length of frame length (the number of time slots within a frame). Since the total number of tags is unknown, the efficiency optimization problem is transformed into the problem of accurately estimating the number of tags. This is a focus of DFSA algorithm research.

In a frame, if mi, ms, and mc respectively represent the observed numbers of idle time slots, successful time slots, and conflict time slots, the estimated value of tags number *n* by the Schoute method is as follow:

$$n = 2.39 * \mathrm{mc} + \mathrm{ms}. \qquad (1)$$

If Li, Ls, and Lc are the theoretical values of idle time slots, successful time slots and conflict time slots, the Vogt [11] method uses the following formula to estimate the quantity of tags *n*.

$$n = argmin\left|\begin{pmatrix} Li \\ Ls \\ Lc \end{pmatrix} - \begin{pmatrix} mi \\ ms \\ mc \end{pmatrix}\right|. \qquad (2)$$

Wen-tzu Chen [12] obtained the tag estimation algorithm based on polynomial distribution and optimal probability method as follows.

$$n = argmax\{P(n|mi, ms, mc)\} \qquad (3)$$

and $P(n|mi, ms, mc) = \frac{L!}{mi!\ ms!\ mc!}\left[\left(1-\frac{1}{L}\right)^n\right]^{mi}\left[\frac{n}{L}\left(1-\frac{1}{L}\right)^{n-1}\right]^{ms}\left[1-\left(1-\frac{1}{L}\right)^n-\frac{n}{L}\left(1-\frac{1}{L}\right)^{n-1}\right]^{mc}.$

Among the above estimation methods, Wen-Tzu Chen's estimation method has the least estimation error. However, all the tag number estimation methods above do not consider the tag movement.

In the mRFID system, the tags that enter the identification area first will leave the identification area first, and the tags that enter the identification area later compete for time slots with the tags that were entered before. The former incoming tags may move out of the identification area due to conflicts, and cannot be identified, which will cause tag loss. This is an intolerable problem in any mRFID system. Many researchers proposed different methods to estimate the unidentified tags in mRFID system [13-18]. WGMSW(1,1) method [19] combines grey model with sliding window mechanism to estimate tags' arrival rate. The RPA [20] uses adaptive tag arrival rate estimation method and round-based algorithm to achieve lower tag loss rate.

Based on studying the working process of the mobile RFID system and combining it with the DFSA algorithm, this paper studies and proposes a tag loss control mechanism using priority policy, which can greatly reduce the tag loss rate and provide a reliable solution for intelligent logistics applications.

2. Related work

In this part, we first propose the working process of the DFSA algorithm, and then propose the key problems of the mobile RFID system. One of DFSA main advantages is that mobile tags need very limited capabilities to communicate with the reader. The second advantage is that the reader can automatically set the frame length after estimating the tags' quantity. An example is shown in Fig. 2.

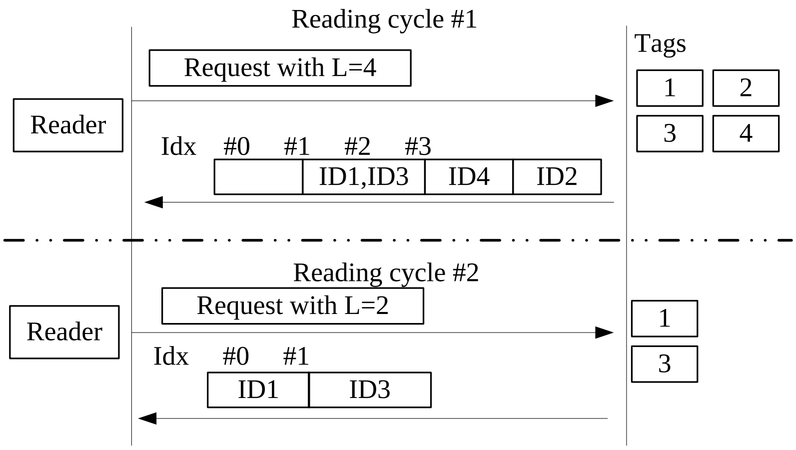

Fig.. 2 an instance of DFSA working process

In Fig. 2, the initial frame length of the reader is 4, and it is assumed that there are four tags in the recognition area, whose ids are ID1, ID2, ID3, and ID4. In a reading cycle, the reader broadcasts challenge signal carrying parameter frame length 4. After receiving the challenge, 4 tags randomly select a timeslot. When the reader receives the message and finds that slot 0 has no tag response, it is an emtpy slot. Slot 1 has two tag responses, which is a conflict time slot, and neither tag can be recognized. Both slot 2 and slot 3 have only one tag response, they are successful time slots. Therefore, after a challenge, the reader successfully identifies tag 2 and tag 4. After this reading cycle, the reader sets the frame length of the second reading cycle to 2 according to the statistical results and sends a challenging message again. Assume there is no conflict this time and tags 1 and 3 are identified. Up to now, all four tags have been identified.

From the analysis above, we find several questions. The first question is what the initial frame length is. If the frame length is small, many time slots conflicts will occur. That will lead to a decrease of the system efficiency. Too long frame length will lead to too many idle time slots, which will also reduce the efficiency of system. Therefore, the initial frame length is a factor affecting the recognition efficiency. The second question is how to predict the number of unidentified tags. This problem has been mentioned in previous part . We can use the Schoute method, Vogt method and Chen method to estimate the tags' quantity. The third question is how to set the frame length using estimated tags number. According to the results of the researchers' study, the recognition efficiency of the system is optimal when the frame length is equal to the number of tags, but in practice, it is set as a power of 2. In this paper, we will discuss these three questions and propose a novel mechanism which can apply to the mRFID system.

3. Tag identification model and analysis of mobile RFID system

In this study, we adopt the mobile RFID model as shown in Fig. 3. In this model, there is only one reader in the recognition area, and the tag to be identified enters and leaves the recognition area at a certain speed on the conveyor belt, forming a continuous recognition process.

In Fig. 3, n tags are in the recognition area at the beginning of the reading process, and all the tags are set the same priority of 0. The reader begins to identify tags according to the DFSA algorithm. After frame #1 in the 1st reading cycle, x tags are identified. The (n-x) tags will be identified in frame #2, until all n tags are totally identified. We suppose that the frame number in reading cycle #1 is t. As the conveyor moves during the reading cycle #1, some tags have entered the identification area, and these are called new tags. These new tags are assigned priority of 1. These new tags with priority of 1 should be identified in reading cycle #2 rather than in reading cycle #1. In reading cycle #2, the identification process is same to the reading cycle #1. At the end of reading cycle #2, all p tags are identified. During this process, new incoming tags are assigned to the priority of 0. At this time, the new accumulated number of tags is q, and the q tags begin to be identified in reading cycle #3. If the tags are continuously incoming, the process always goes on. In this system, two priorities (0 and 1) are enough. In the whole identification process, new tags are not identified until old ones are totally identified. So, the contention between the old and new ones can be eliminated, the efficiency of the system will be improved.

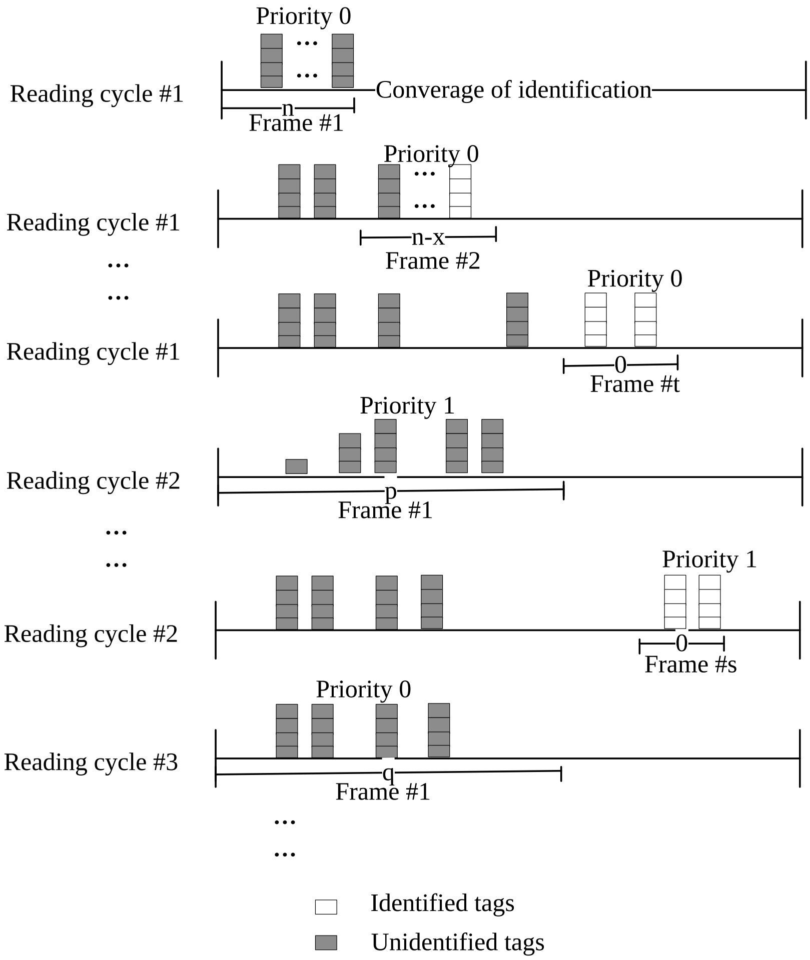

Fig. 3. Simulation of mobile RFID system identification process

PART A. Initial frame length setting

According to the identification process in Fig. 3, the reader sends the challenge information with a parameter L in cycle #1, and L represents the frame length. Using the quantity of tags n and L, the expected values of three kinds of time slots are respectively:

$$E(I) = L\left(1 - \frac{1}{L}\right)^{n} \tag{3}$$

$$E(S) = n\left(1 - \frac{1}{L}\right)^{n-1} \tag{4}$$

$$E(C) = L(1 - \left(1 - \frac{1}{L}\right)^{n} - \frac{n}{L}\left(1 - \frac{1}{L}\right)^{n-1}) \tag{5}$$

We define the recognition efficiency of the system as follows:

$$\eta = \frac{E(S)}{L} = \frac{n}{L}\left(1 - \frac{1}{L}\right)^{n-1} \tag{6}$$

When n is equal to L, the system can obtain optimal efficiency. The frame length is determined by the unidentified tags. Tags are in a cumulative state and are not recognized until the first reading cycle begins. In this case, we can control the number of tags to a certain value, and then start to identify. For example, the system starts to recognize tags when the tags accumulate to 256. We examine the efficiency of system when L is set to be 64, 128, 256, 512, and 1024 respectively and get the results shown in Fig. 4.

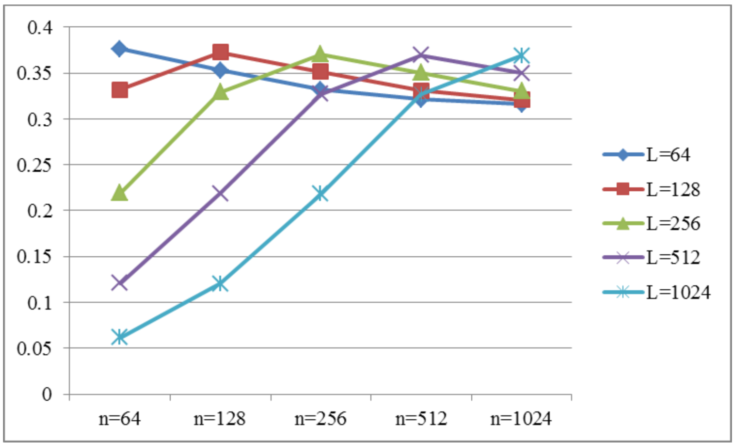

Fig. 4. The recognition efficiency of the system under different L and n

The results show that when n is 64, and L is 64, too, the system can obtain the optimal efficiency. So as to the other conditions. So, in the mRFID system, the initial L depends on the number of tags to be identified, and the optimal system efficiency can be obtained by controlling the cumulative number of tags n at reading cycle #1.

PART B. tag quantity prediction

After identifying the higher priority tags, the reader should estimate n and set the sequence L based on estimation results. The setting strategy of L is just like the Schoute method, Cha method, Vogt method and Wen-Tzu Chen method mentioned above. In our research, the Schoute method is adopted to estimate n. In practice, the frame length is the power of 2.

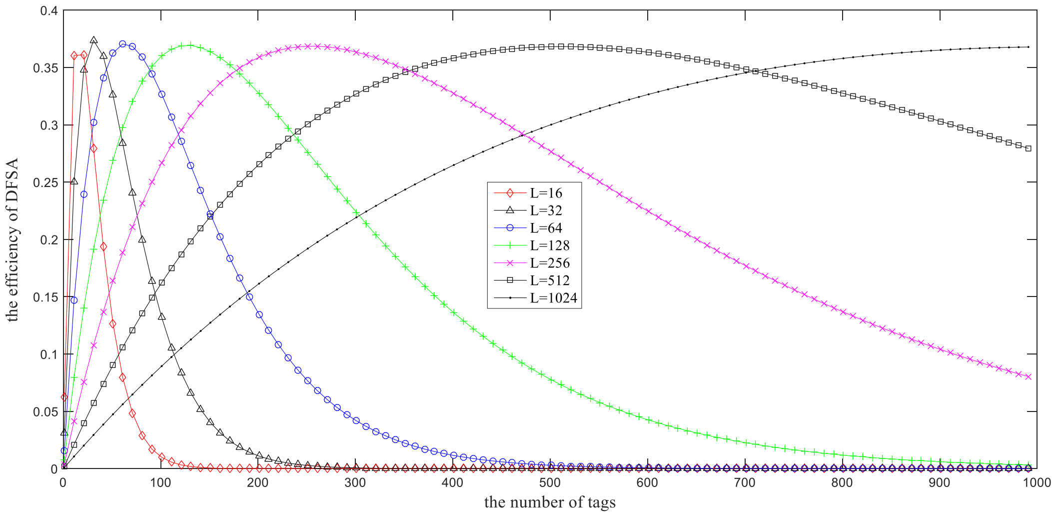

Fig. 5. The efficiency of the system under different n

From Fig. 5, it can be seen that the intersection of the two curves is the cut-off point for the change of frame length setting. When n changes, L can be set to a specific value to achieve optimal efficiency. Assuming that n ranges from 1 to 1024, the relationship between the range of n and L is shown in Table 1.

Table 1.

Corresponding of tag quantity and frame length

The range of n	L
1-22	16
23-43	32
44-88	64
89-179	128
180-354	256
355-711	512
712-1024	1024

The reader sets L by looking up n in the Table 1.

PART C. Algorithm Based Priority(ABP)

In the mRFID system shown in Fig. 3, to eliminate the time slot contention between the old and new tags, a priority control strategy is added to the protocol. If the tags with a priority are not identified yet, the tags with the other priority are not identified. The data exchange procedure between the reader and the tags is shown in Fig. 6. This mechanism is called Algorithm Based Priority (ABP).

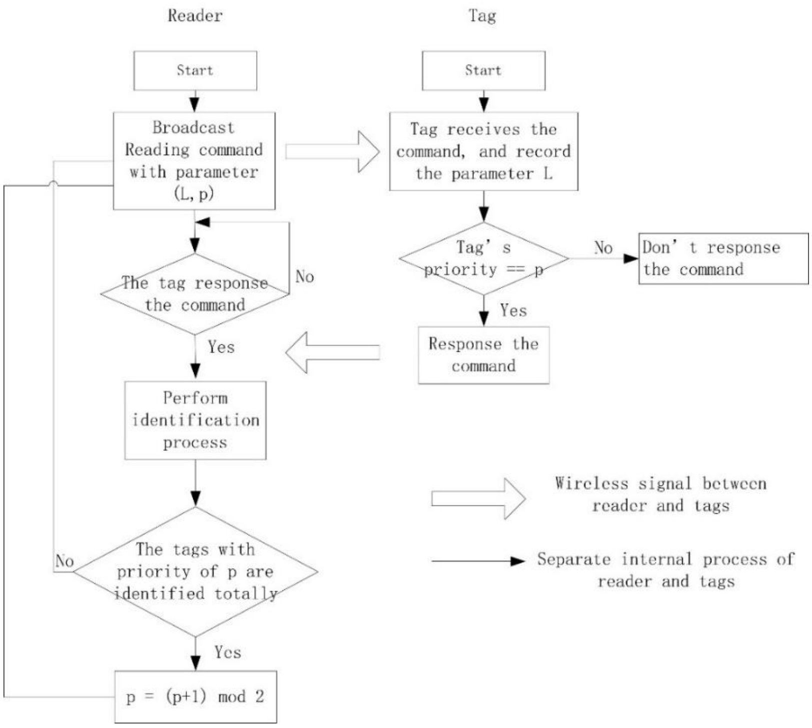

Fig. 6. Reader and tags interaction process

In Fig. 6, the priority p should be 0 or 1, it is assigned by the reader at the beginning of every reading cycle. The tags with a certain priority can be identified by readers. A

4. Results analysis

PART A. Simulation parameters

It is assumed that there is only one reader in mRFID system, the tags move along the conveyor belt at a speed of v, and the conveyor belt length in the identification area is d. When the reader starts working, n is 512, and the initial frame length of the reader is set to be 512. The results of simulation are averaged over 1000 independent experiments. The proposed method ABP is compared with the original Schoute method under the same initial conditions.

To compare the characteristics of different algorithms, we define the following performance indicators.

Identification speed s:

$$s = \frac{the\ number\ of\ identified\ tags}{total\ number\ of\ slots} \tag{7}$$

The maximum residence period of tags in the identified area is d/v seconds. If the tags are not identification in this period, the tags will be lost. Tag loss rate r is defined in equation (8):

$$r = \frac{the\ number\ of\ lost\ tags}{total\ number\ of\ tags} \tag{8}$$

We think about two scenarios. One is that the number of tag arrivals per unit time is constant m, and the other is that the number of tag arrivals increases and then decreases. At the beginning of reader recognition, n is 512, and the L is set to be 512. The RFID system identifies tags in DFSA mode. The time slots are the same length, and all of which are 400μs.

In Schoute method, the n consists of two parts: tags that are not identified due to conflicts in the previous read period (old tags) and labels that enter the identification area in the previous read period (new tags). These tags will attend the identification together. In ABP, the new tags will not content the timeslots with the newer ones.

Part B. Analysis of performance results

When tags arrive uniformly, the arrival speed affects the system efficiency. The faster the arrival speed is, the more tags are accumulated, the higher the requirement for system identification speed is, and the higher the possibility of tag loss is.

Table 2.

The simulation parameters

Number of initial Tags n	512	The tags moving speed v (m/s)	3
Tags' arrival rate λ (pieces per second)	500-610	The distance of conveyor belt(m)	5
Initial frame length f	512	Tags' estimation method	2.39*Nc+Ns

When only the Schoute method is used, the average identification speed and tag loss rate are shown in Fig. 7 when the tag arrival rate changes from 500 to 610. These data are the average values obtained from 1000 times of independent execution.

From Fig. 7, the system starts to lose tags at the arrival rate of 530. The reason is that the Schoute method does not take into account that old tags have a greater tendency to leave the identification area and need to be identified first. The old and new tags are in the same priority and the time slot contention is treated equally. When the tag arrival rate is less than 530, the system performs identification at a high speed of 904 and the tag loss rate is 0. The reason is that old and new tags can be identified at the same time, which can effectively use the time slots. When the tag arrival rate changes from 530 to 610, the system starts to lose tags, and the recognition speed decreases. In this case, there is a serious conflict between the old and new tags.

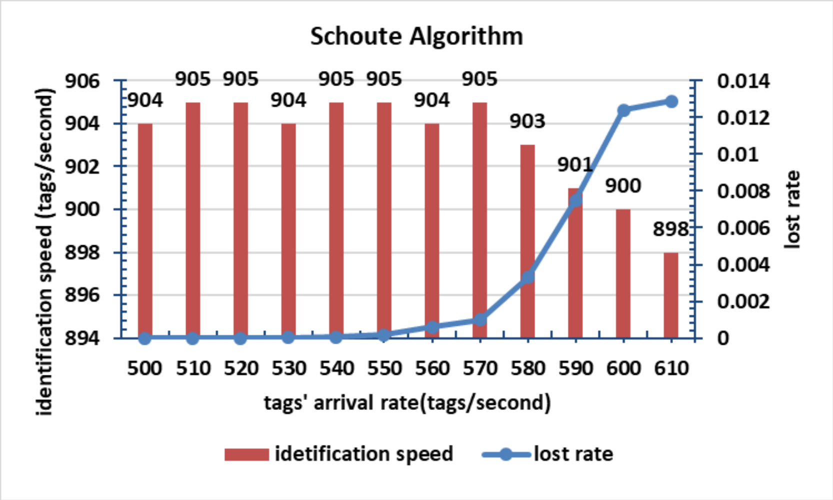

Fig. 7. mobile tag recognition results under Schoute algorithm

The ABP is used, and the parameters are set the same as those in Table 2. The average identification speed and tag loss rate are obtained when the tag arrival rate changes from 500 to 1100. From Fig. 8, when the tag arrival rate is lower than 900, there is no tag loss, but the recognition speed is not as high as that of the Schoute method. The reason is that the timeslots are not fully utilized. When the tags arrival rate is higher than 900, the recognition speed decreases, and tags begin to be lost.

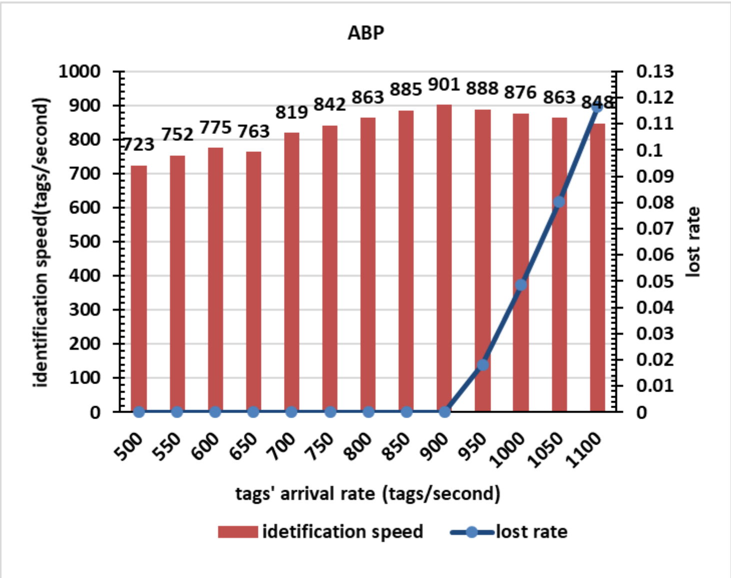

Fig. 8. mobile tag recognition speed under ABP

Comparing Fig. 7 and 8, although the recognition speed under ABP is not as high as that of the Schoute method, it can still work well without losing tags in the case of faster arrival rate.

The case discussed above is the uniform arrival of tags. In practical applications, the arrival of tags will have peak and trough periods in many cases. So, we'll talk about the tag arrival rate going from low to high, then to low again. The arrival speed of tags increases linearly first and then decreases linearly, and the initial arrival rate of tags is 100 as shown in Fig. 9. Under different growth rates, the system performance of Schoute algorithm is studied.

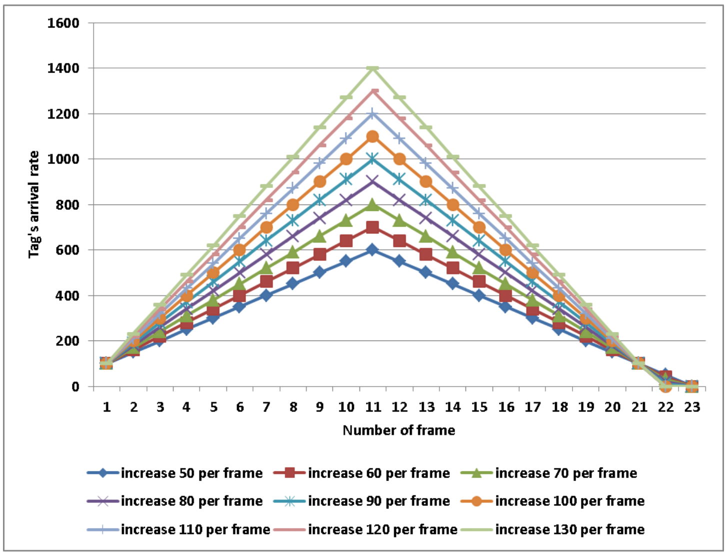

Fig. 9. Tag arrival rate change diagram

The recognition speed and tag loss rate of Schoute method under different tag rates are shown in Table 3.

Table 3.

Identification speed and tag loss rate under different tags rate

	Schoute method		ABP	
Increase tags per frame	Identification speed	Tag loss rate	Identification speed	Tag loss rate
80	902	0	831	0
90	901	0	839	0
100	904	0	845	0
110	905	7.88e-5	853	0
120	902	0.0102	864	0
130	877	0.0723	873	0
140	848	0.1389	882	0
150	811	0.2222	888	0.0032
160	796	0.2892	864	0.0653

From Table 3, we can find that when the number of tags added in each frame is greater than 100, the system using Schoute method will lose tags, whereas the ABP will not. In terms of tag loss, the ABP also outperforms the Schoute algorithm. So the ABP method has higher identification speed and lower tag loss rate.

5. Conclusion

In this research, a tag loss control mechanism ABP is proposed in the mRFID systems. Compared with the existing approach Schoute, the ABP produces a lower tag loss rate. Although the identification speed of ABP is not always superior to Schoute method, it is much more stable than Schoute. Therefore, the proposed ABP is suitable for mRFID systems. To implement the ABP, the tag should have enough memory to record the priority and reply to the reader according to the current reading priority. Moreover, the reader should be able to activate others priority tags after these priority tags have been identified. All of this increases the complexity of tags and readers. But with the development of hardware processors, these functions can be easily implemented.

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R E F E R E N C E S

1. Dheeraj K. Klair, Kwan-Wu Chin, and Raad Raad, A Survey and Tutorial of RFID Anti-Collision Protocols. IEEE Communications survey and tutorials, 2010, 12(3):400-421.
2. Hush Don, Wood Cliff. Analysis of Tree Algorithms for RFID Arbitration. IEEE International symposium on Information Theory, Mexico City, USA, 1998.
3. Lai, Y. C, Hsiao, L. Y, Chen, H. J, etc. A Novel Query Tree Protocol with Bit Tracking in RFID Tag Identification. IEEE Transactions on Mobile Computing, 2013, 12(10):2063-2075
4. B, A I, Venkatesh T G. Order Statistics Based Analysis of Pure ALOHA in Channels with Multipacket Reception. IEEE Communications Letters, 2013, 17(10):2012-2015.
5. Lee M, Kim Y, Lee T J. A spatial slotted-Aloha protocol in wireless networks for group communications. EURASIP Journal on Wireless Communications and Networking, 2017, 2017(1):1-16
6. Li Xiaowu, Wang Zhenjiang, Ren Xin, Liu Yuyan, Zhao Qing. An Improved Frame Slotted Aloha Protocol with Early End in Mobile RFID Systems. Sensors & Transducers, 2013, 154(7):2-86
7. F. C. Schoute, Dynamic frame length ALOHA. IEEE Transactions on Communications, 1983,

31(4):565-568.
8. Jiang, Z., Li, B., Yang, M., & Yan, Z.. (2020). Lc-dfsa: low complexity dynamic frame slotted aloha anti-collision algorithm for rfid system. Sensors (Basel, Switzerland), 20(1).
9. Gan, L., & Beaulieu, N.C.. A Simple Novel Idle Slot Prediction and Avoidance Scheme Using Prediction Bits for DFSA in RFID. 2020 IEEE Wireless Communications and Networking Conference (WCNC). IEEE(2020).
10. Alcaraz, J., J., Vales-Alonso, J., Egea-Lopez, & E., et al.. A stochastic shortest path model to minimize the reading time in dfsa-based rfid systems. Communications Letters, IEEE (2013).
11. Harald Vogt. Efficient Object Identification with Passive RFID Tags. International Conference on Pervasive Computing. 2002, 2414(1):98-113.
12. Chen W T. An Accurate Tag Estimate Method for Improving the Performance of an RFID Anticollision Algorithm Based on Dynamic Frame Length ALOHA.IEEE Transactions on Automation Science and Engineering, 2009, 6(1):9-15.
13. Chen YH and Feng QY. A collision avoidance identification algorithm for mobile RFID device. IEEE Trans Consum Electr 2019; 65(4): 493–501.
14. Zhu W, Cao J, Chan HCB, et al. Mobile RFID with a high identification rate. IEEE T Comput 2014; 63(7): 1778–1792.
15. Ojha, A., Pandey, A., Rahman, A., Sharma, B., Nethravathi, B., & Dayananda, P.. (2020). Anti-collision for mobile rfid - a review. IJERT-International Journal of Engineering Research & Technology(15).
16. Liu, T. P., Chen, Y. Y., & Yu, J.Y.. (2021). Implementation and evaluation of mobile shopping services based on rfid sensing technology. Sensors and Materials, 33(5), 1501.
17. Yi, J., Zhang, R., Wei, C., Li, B., & Wei, S.. (2016). An Adaptive Ternary Query Splitting Based Tag Anti-Collision Protocol for Mobile RFID Systems. 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall). IEEE.
18. Chen, Y., & Feng, Q.. (2019). A collision avoidance identification algorithm for mobile rfid device. IEEE Transactions on Consumer Electronics, 65(4), 493-501.
19. Zhang L, Fu X, Li H. A tags' arrival rate estimation method using weighted grey model(1,1) and sliding window in mobile radio frequency identification systems. International Journal of Distributed Sensor Networks, 2020(10).
20. Zhang L, Fu X, Li H. Round-priority-based anti-collision tag identification method in a mobile radio-frequency identification system. International Journal of Distributed Sensor Networks, 2019, 15(5):155014771984604.