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Research on Multi-Tag Transmission Control Algorithm Based on Channel Division Dynamic Frame Slot

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Abstract. The current anti-collision algorithm in multi-tag radio frequency identification systems relies on statistical estimation of the number distribution of labels, but because the range of objects arriving and leaving the reader depends on the application scenario and is dynamically changing and therefore the number distribution of labels does not follow a particular distribution. In this paper, a transmission control mechanism CDDFSA (Channel Division Dynamic Frame Slot ALOHA Algorithm) in a multi-label environment is proposed, which combines the capture effect and the moving speed of the object, and supports the dynamic adjustment of frame length, even if there is no prior knowledge on the number of labels it can also get a higher throughput. We designed experiments to evaluate four important indicators, such as tag estimates, tag actual values, frame length, and throughput. The experimental results show that CDDFSA has been greatly improved compared with the existing methods.

Keywords: digital signal processing, e-commerce, operating systems, RFID

1 Introduction

Wireless Frequency Identification, also known as Radio Frequency Identification (RFID), is a new automatic identification technology. RFID system has been widely used in warehouse management system, automobile ETC payment, luxury security, logistics, product tracing and other fields.

The RFID system consists of a reader and an electronic tag, both of which communicate with the reflected energy of the electromagnetic wave. And electronic tags include active electronic tags and passive electronic tags. This paper introduces passive electronic tag, which uses backscatter to activate internal circuit in order to gain energy and complete data communication. However, if there are multiple tags in the scope of the reader, the data frame will collide during transmission, resulting in packet collision. At present, there are two types of anti-collision algorithms to solve this kind of collision problem: one is the non-deterministic algorithm based on ALOHA; the other is deterministic algorithm based on bit tree. [1]

In the ALOHA-based frame slot algorithm, the reader first issues a request command containing the frame length. When the tag answers, a slot is selected randomly to transmit its own ID. According to reference [2], under the condition that the number of tags is N and the data frame length is L, the maximum throughput U is

$$E(U) = \frac{N}{L}(1 - \frac{1}{L})^{N-1}. \tag{1}$$

When L = N, the maximum throughput U=1/e is achieved. However, the number of tags in the range of identification is unknown. The performance of the frame slot ALOHA depends on the estimation of the frame length, and the frame length is obtained by the distribution probability of the slot selected by the previous frame tag. There are two problems with the above method: 1. The length of the initial frame can not be determined. 2. The number of labels can not know. The second problem does not affect the

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algorithm proposed in this paper, which can be seen from the subsequent deduction process. Time slots are divided into three categories: empty slots (no slot for tag selection), successful slots (only one tag in the slot is successfully identified), collision slots (multiple labels in the slot clash). There is a capture effect in the collision slot, so that there is also a tag that is successfully recognized in the time slot of the collision. However, in the actual environment, the energy of each tag in the time slot of the collision is different, and the signal sent by the tag with large energy is likely to be recognized by the reader. The signal sent by the small tag is not enough to interfere with the reader. Therefore, the formula (1) needs to be slightly modified as follows:

$$E(U) = \alpha \bullet \frac{N}{L}(1 - \frac{1}{L})^{N-1} . \quad \textbf{(2)}$$

In the formula (1), α is the probability of capture effect.

In the actual storage system, the arrival and departure of the tag on the object to the reader range is related to the parameters of the application, such as the speed of the conveyor belt, the design of the RFID system, the deactivation of the tag, and the access to the blind area of the reader, etc. Therefore, the irregular change in the number of tags makes it difficult to model the statistical characteristics of the number distribution of tags, and the traditional multi-tag anti-collision algorithm is not ideal when the distribution characteristics can not be known in advance.

The main contribution of this paper is to propose an anti-collision algorithm based on Channel Division Dynamic Frame Slot ALOHA, which can improve throughput and signal-to-noise ratio when the number distribution of tags is unknown and the frame length is not fixed. In this paper, our experiments are more close to the real environment. At first, we clearly declare the tags randomly choose channels. It doesn't match any distribution rule. Secondly, we make the tags communicate according to CDDFSA. Finally, the scheme are compared to other classic anti-collision methods in throughput and other aspects.

2 Related Work

Wieselthier proposed a frame slotted ALOHA anti-collision algorithm based on the capture effect. The algorithm assumes that the number of slots of the frame length L is fixed, adjusts the probability of the D tag access to channel by the number of tags in the previous frame. The drawback of this algorithm is that the frame length is fixed. Schoute assumes that the number of tags per slot is subjected to a Poisson distribution with a mean value of 1, and the frame length is estimated based on the number of backlog tags. The result is below.

$$B_t = 2.39c . \quad \textbf{(3)}$$

In the formula (3), C refers to the collision slot in the current frame. Because the distribution of the number of tags is not known, this assumption leads to a discrepancy between the estimated and the true values. The above assumption is not an effective way to solve the anti-collision under multiple tags. The method in this paper does not make this assumption, but there are computational and storage costs. In this paper, we will use iterative joint method to solve the problem of probability distribution. Zhen [3] improved the estimation algorithm proposed by Schoute. The anti-collision algorithm proposed by Vogt [4] obtains the optimal frame length, under the circumstance of the minimum error between the estimated value and the true value of the empty slot, the successful slot, and the collision slot. But the algorithm does not consider the diversity of collision, only considers the current frame, and does not refer to the collision of the previous frame. Vogt finally gets the lower bound of the estimated frame length:

$$B_t = 2c . \quad \textbf{(4)}$$

The idea of the Q algorithm proposed in [5] is that when the collision occurs, the current frame length is multiplied by a constant β, and when the empty slot is found, the current frame length is divided by a constant β. Although the computational complexity of the Q algorithm is small, the method of calculating β value is not proposed, but only the range of β value is presented. L. Liu [6] proposed an estimated method based on frame length of intra-frame. The approach of Rivest [7] is based on the assumption that the number distribution of tags is subject to Poisson distribution, whereas the arrival and departure of tags in the actual RFID system leads to the assumption of the Poisson distribution is not accurate enough.

3 Multi-Tag Transmission Control Algorithm Based on Channel Division Dynamic Frame Slot

This paper proposes a transmission control mechanism in a multi-tag environment—Channel Division Dynamic Frame Slot ALOHA Algorithm (CDDFSA). The algorithm solves the shortcomings of the algorithms mentioned in the previous sections. First, the communication channel is grouped by frequency, and then the group, according to the feedback obtained by the reader, calculates the probability of each tag in the time slot, and then estimates the optimal frame length. The algorithm does not make any restrictive assumptions on the distribution probability of the number of tags, and considers all the transmission states of past frames instead of just considering the transmission state of the past one frame.

3.1 Multi-Tag Transmission Control Algorithm for Channel Grouping

In the real world, the tag has a variety of channels, we can distribute tags to several channels to transmit data packets, greatly improving the recognition rate and recognition time. The maximum number of known tags is n, and the slot N that each frame can hold can be calculated. Grouping can be completed at the time of system design. Each group has its own channel, and groups can be obtained by the following formula [8]:

$$G = n / N \,. \tag{5}$$

3.2 Multi-Tag Transmission Control Algorithm for Intra -Group Dynamic Frame Slot

Steps of the estimation of optimum frame length. Send a frame With L length and wait for the response of the tag. The probability distribution of the current number of tags N is updated by combining the probability distribution of the empty time slot, the successful slot and the collision slot of the historical frame. The probability distribution of the number N of tags is adjusted according to the arrival and departure of the tags. The learning factor is determined based on the probability distribution of the current number N of labels, and the frame length L' is calculated. The throughput U is calculated according to the optimum frame length L'.

The calculation process of probability distribution of the tag number. E, S and C represent empty slots, successful slots, collision slots respectively, L refers to frame length, and N refers to tag number. E, S, and C are known when the reader receives a tag response. According to the Bayesian law, from the beginning to the t-1 moment of transmission, we can get the distribution probability of the N tags at the t moment, as follows:

$$\begin{aligned} P_r\left(N \mid z_{1:t}\right) &= \alpha P_r\left(N \mid z_{1:t-1}\right) \bullet Pr\left(z_t \mid N\right) \\ &= \alpha P_r\left(N \mid z_{1:t-1}\right) \bullet P_r\left(E,S,C \mid N\right) \end{aligned} . \tag{6}$$

In the formula (6), α is a normalized constant. The probability of $P_r\left(E,S,C \mid N\right)$ can be calculated by the following formula:

$$\begin{aligned} P_r\left(E,S,C \mid N\right) &= P_r\left(S,C \mid N\right) \\ &= P_r\left(S \mid C,N\right) \bullet P_r\left(C \mid N\right) \end{aligned} . \tag{7}$$

The conditional probability of Pr(S|C,N) and Pr(C|N) is calculated below:

As represents an event that has no or only one tag response in slot s. The probability of an event with no or only one tag response in slot 1, 2, ..., k is:

$$\mathrm{P}_r(As) = L^{-N}\binom{L}{k}\binom{N}{k}k!(L-1)^{N-k} \,. \tag{8}$$

From the Inclusion - Exclusion Principle, we can see that the probability of choosing the exact m slots is:

$$P_r(M = m \mid N) = \underset{k=m}{P_r}(As). \tag{9}$$

L time slots, N tags, the probability of C collisions is as follows:

$$\begin{aligned} &P_r\left(C = c \mid N\right) = P_r\left(M = c \mid N\right) \\ &= L^{-N} \binom{L}{c}\binom{N}{c} c!(L-1)^c \end{aligned}. \tag{10}$$

2c+i tags, permutations and combinations after a total of C collisions are:

$$D(C = c, I = i) = \binom{N}{L-c}\binom{N-(L-c)}{2c}\binom{N-(L-c)-2c}{i} c^i. \tag{11}$$

So, conditional probability:

$$P_r(S = s \mid C = c, N) = \frac{D(C = c, I = N - 2c - s)}{\sum_{k=0}^{N-2c} D(C = c, I = k)}. \tag{12}$$

The model of arrival and departure of tags. Once the tag is successfully recognized, it will be set in silence state, which will result in a decrease in the number of tags transferred next time. At this point we need to remove the successfully identified tag.

$$P_r\left(N_{t+1} = n \mid z_{1:t}\right) = P_r\left(N_t = \left(n + s\right) \mid z_{1:t}\right). \tag{13}$$

Because of the arrival of new labels, some of the lack and inactivation of energy leads to a change in the number of labels. The arrival and departure probabilities PA(n), PD(n) of tags depend on the applied scenes and parameters. The probability N 't+1 that we can compute is as follows:

$$\begin{aligned} &P_r = (N'_{t+1} = n) \\ &= \sum_{j=0}^{n} P_r(N_{t+1} = j) P_A(n-j) + \sum_{j=n+1}^{n_{\max}} P_r(N_{t+1} = j) P_D(n-j) \end{aligned}. \tag{14}$$

In this formula, the condition z1:t is omitted to write out.

4 Evaluation

In this paper, we compare the estimated value of tag number corresponding to three algorithms — CDDFSA, 3, Voge and Schoute according to the five different frame lengths set (16, 32, 64, 128, 256). The results are shown in Fig. 1. The data transfer rate in the figure is the ratio of the number of tags to the frame length, and the number of tags is 64. It can be seen from the figure, in different scenarios, the adjustment of CDDFSA algorithm is the fastest, and its performance is significantly beyond the other algorithms. Because CDDFSA dynamically adjusts the learning factor, and Schoute, Vogt's learning factor is fixed, respectively 2.39 and 2. Of course, the closer the estimated value of tag number is to the true value, the higher the throughput is. The estimated value of Schoute algorithm and Vogt algorithm is reasonable, but the strain capacity is poor. It is also worth mentioning that the CDDFSA algorithm will converge better and better because it takes into account all historical distributions, while Schoute and Vogt only consider the nearest one distribution, and the convergence is relatively poor. Fig. 2 and Fig. 3 show the simulation results that do not take into account the "arrival and departure" of the tag. Among them, the initial tag value is 500. As can be seen from the figure, the throughput can not always be increased throughout the recognition process, and there is a lot of fluctuation, which is caused by the dramatic change in the number of tags in the application scenario. Fig. 4 shows the simulation results without the capture effect. A comparison between Fig. 3 and Fig. 4 shows that the capture effect has an impact on the estimation of labels, thereby reducing throughput without compromising throughput trends. The horizontal axis represents the frame, and the vertical axis gives the label estimated value, the true value, the throughput, and the frame length. From the simulation results, CDDFSA throughput becomes very high from the second frame, because it has little bias in the estimation of the number of tags. The throughput exceeds the theoretical value e-1 in that there exists capture effect.

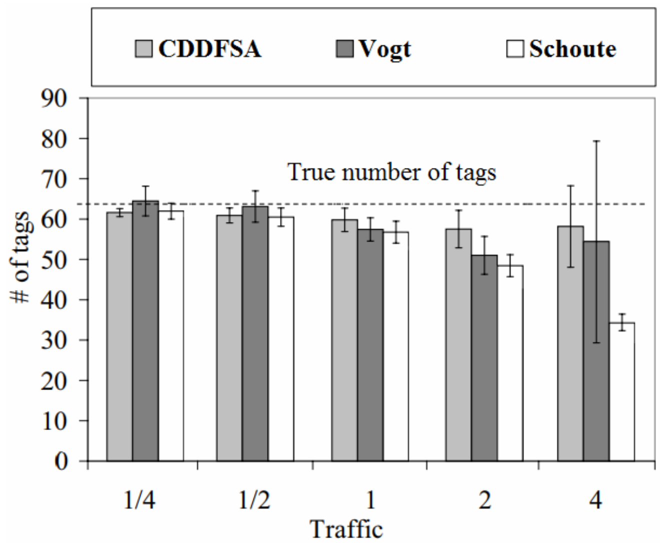

Fig. 1. Comparison of CDDFSA algorithm with SChoute algorithm, Vogt algorithm

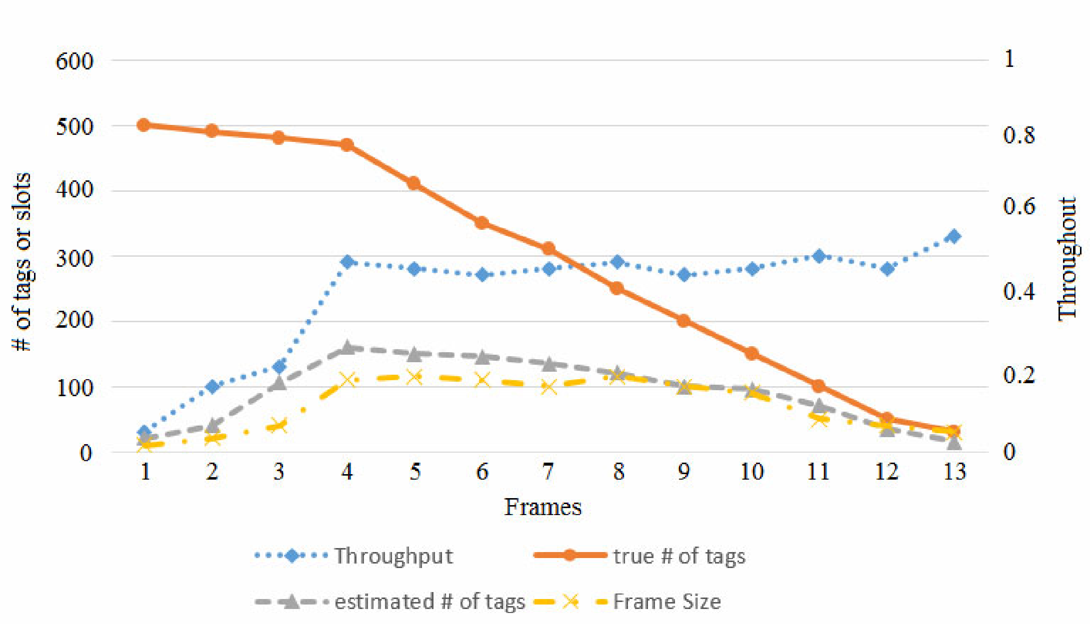

Fig. 2. Estimation algorithm based on boundary value

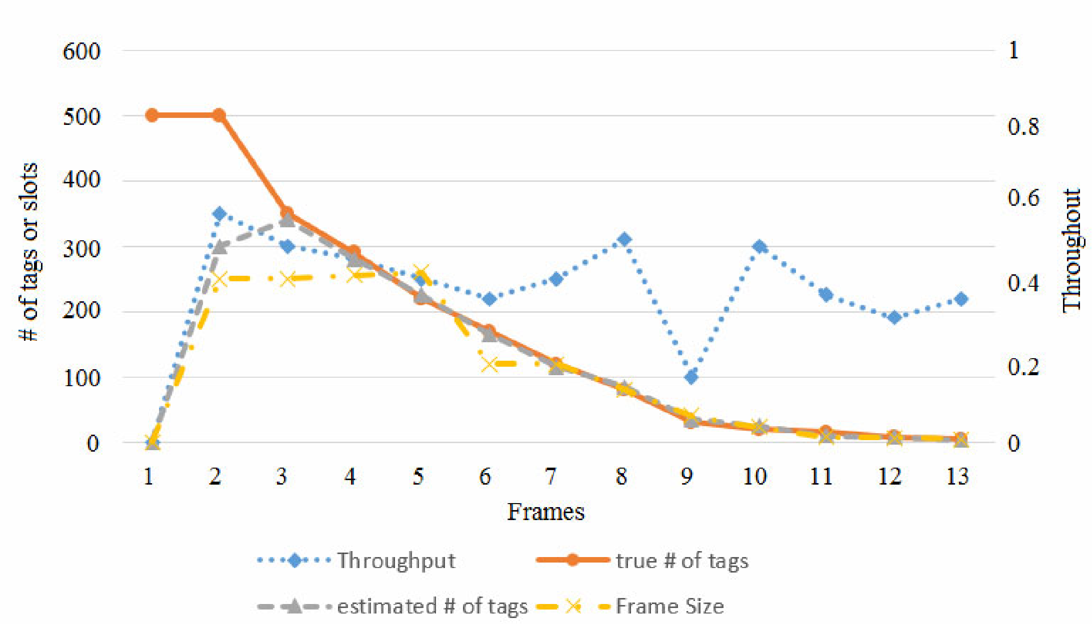

Fig. 3. CDDFS simulation results under the capture effect

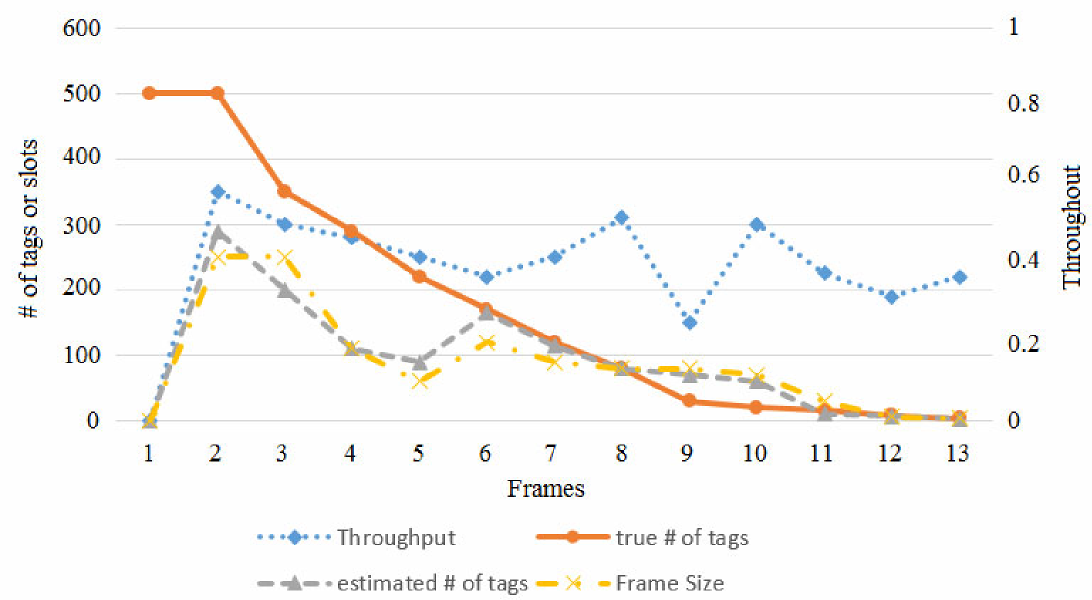

Fig. 4. CDDFS simulation results without taking the capture effect into account

5 Conclusion

In the RFID system with large number of tags, the parameters of the physical layer have a great impact on the overall recognition speed, and how to improve the tag recognition rate is a major challenge for the current RFID system. This paper proposes an anti-collision algorithm called ALOHA based on dynamic frame length CDDFSA to solve the above problems. The algorithm calculates the distribution of the current number of tags and the learning factors according to the distribution of tag number in the historical frame, and finally calculates the optimal frame length. The advantage of this algorithm is that there is no assumption that the number of tags is subject to a particular mathematical distribution, and thus can be adapted to different application scenarios. The experimental results and the comparison data show that CDDFSA can obtain high throughput and signal to noise ratio under the condition of high data transmission rate and the existence of capture effect. The future work mainly includes the research on slot-by-slot-based tag number estimation method and the interruption method research when the length of the current frame is sub-optimal.

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