A Hybrid Tag Number Estimation Scheme for Aloha Based Anti-Collision Algorithm in RFID Networks

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***Abstract*—For the aloha based anti-collision algorithm in RFID networks, the tag collisions could greatly reduce the throughput of the system. If the number of tags was gotten, the throughput could be greatly improved. Based on maximum likelihood estimation, the proposed hybrid tag number estimation scheme combined the binary search based anti-collision algorithm and aloha based anti-collision algorithm to estimate the tag number. Simulation results showed that the proposed scheme had high estimation accuracy than the existing algorithm.**

Keywords-Maximum likelihood, RFID, anti-collision algorithm, aloha

I. Introduction

Radio Frequency Identification (RFID) as a promising technology has widely application areas. Much research has been done to promote the performance of RFID. However, the tag collision problem is still confining the reading rate of RFID system, and the collision will be serious in Ultra High Frequency (UHF) RFID system. This problem is mainly solved with two kinds of algorithm: slotted aloha based anti-collision algorithm, and binary search based anti-collision algorithm.

Binary search based algorithm detecting collisions through inspecting each bit of the received tag ID. This scheme can read all the tags, but it needs many handshakes between reader and tags when the number of tags is large. Much work [1] [2] has been done to reduce the complexity of this scheme, but the reading process is till too long when there is a large number of tags. Slotted aloha based algorithm has smaller reading delay than Binary search based algorithm, so slotted aloha based algorithm is more preferred by time sensitive service. Currently, slotted aloha based algorithm has been adopted in ISO18000-3, Type A of ISO18000-6 and Class1 Gen2 of EPC Global. This paper mainly studied the slotted aloha based algorithm.

Slotted aloha based algorithm divides the time into frames which including a serial of slots, and each tag in the reading range can select a slot at random to send its tag ID to the reader after receiving the reading request. When two or more tags select the same slot, there will be collisions. The collision not only wastes the slot time but also increases the collision tag's reading delay and reduces the system's throughput. The collision probability is determined by two factors: the number of slots in a frame, the number of tags in the reading range. To effectively resolving the collisions, dynamic frame-length based slotted aloha [3][4] has been proposed. This algorithm adjusts the length of frame according to the number of tags left after a reading cycle. And the number of the left tags is estimated through the number of collision slots, idle slots and success identification slots. [5] and [6] analyzed the scheme of setting the frame length according to the number of tags to get the maximum system throughput, and these two paper further studied the solutions when there were too much tags in the reading range. [7] proposed a scheme which combines the dynamic slot allocation (DSA) and the tag estimation method (TEM) to solve the tag collision problem. This paper proposed that the number of remaining tags shall be with 2.3922 times of the collision slots. These papers show that the number of remaining tags is a very important parameter for the collision problem. [4] proposed a tag number estimation scheme based on the idle slots number, success reading slots number and the collision slots number in the slotted aloha system. This scheme is the best collision tag number estimation

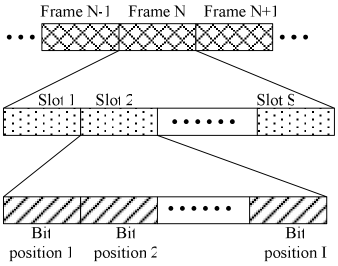

Fig.1 Frame structure of the slot aloha based algorithm

scheme at present, but its accuracy is till low. Therefore, this paper proposed a novel remaining tag number estimation scheme.

Our scheme employed the collision bits detection scheme to estimate the remaining tag number after a reading cycle in the slotted aloha based algorithm. According to the binary search based algorithm [8][9], the number of collision bits in a time slot can be gotten with proper coding schemes such as Manchester coding. Then, the number of collision slot with the same amount of collision bits can be gotten after a reading cycle. The idle slot number and the success reading slot number can also be gotten. Based on these parameters, we employed maximum likelihood estimation to estimate the number of tags left after a reading cycle. In our scheme, since binary search based algorithm was employed to estimate the number of left tags for the aloha based algorithm, our scheme is a hybrid algorithm. Therefore, our scheme is called a Hybrid Tag Number Estimation Scheme for Aloha Based Anti-Collision Algorithm in RFID Network (HTNE).

The rest of the paper is organized as follows. Section II makes a survey of the related anti-collision schemes and proposed the anti-collision scheme, section III makes theory analysis and simulation for the proposed scheme and section IV draws a conclusion.

II. THE PROPOSED SCHEME

This section firstly analyzed the problem of the aloha based anti-collision algorithm and then described our proposed scheme.

1，the problem of the aloha based anti-collision algorithm

Fig. 1 shows the frame structure of the slot aloha based algorithm. In this algorithm, a frame is composed of S slots,

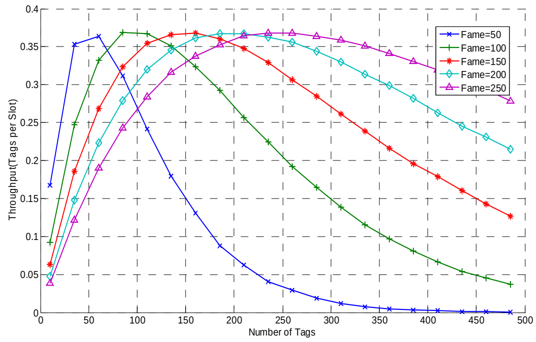

Fig.2 Throughput vs. Number of Tags

and each slot contains I bit positions for the transmission of tag ID. Therefore, the length of tag ID is I. The number of slots S within each frame and the number of tags within the reading area determined the throughput (tags being read per slot) of the system. Supposing the frame length were constant, the throughput of the system is determined by the number of tags within the reading area. Fig. 2 shows the relationship between the throughput and the number of tags. When the frame length is 50, 100, 150, 200, and 250, the maximum throughput can be gotten when the number of tags is about 50, 100, 150, 200, and 250. This shows that, if the number of tags in the reading area can be gotten, the maximum throughput can be gotten through setting the length of frame. Then, what need be done is to get the number of tags in the reading area.

After a reading cycle, the information can be employed to estimate the remaining tag number and maximize the throughput of the next reading cycle. The fast tag number estimation scheme proposed in [7] could estimate the tag number only when the system worked at the maximum throughput condition. Another tag number estimation scheme is named Efficient Object Identification with Passive RFID tags (EOIP-RFID) [4]. This scheme estimates the number of tags after a reading cycle with following formula:

$$\varepsilon(N,c_0,c_1,c_k)=\min_{n}\left\|\begin{pmatrix}a_0^{N,n}\\ a_1^{N,n}\\ a_{\geq 2}^{N,n}\end{pmatrix}-\begin{pmatrix}c_0\\ c_1\\ c_k\end{pmatrix}\right\| \qquad (1)$$

In (1), N is the length of frame, n is the number of tags, $a_0^{N,n}$, $a_1^{N,n}$, $a_{\geq 2}^{N,n}$ are the number of idle slots, success transmission slots and collision slots which are the theoretical results gotten from (2) . c_0, c_1, $c_{\geq 2}$ are the actual number of idle slots, success transmission slots and collision slots after a reading cycle. Since only a little information is used to estimate the number of tags, the accuracy of this scheme is low. Then we proposed a scheme to improve the estimation accuracy.

2, the proposed scheme

Our scheme uses not only the number of idle slots, success transmission slots but also the number of collision slots with one bit difference, two bits difference, three bits difference and so on gotten from Binary search based algorithm. To enhance the estimation accuracy, maximum likelihood estimation was employed in our scheme.

To use maximum likelihood estimation scheme for estimating the remaining tags after a reading cycle, we make following definition: let $p_{tag}(x_i)$ be the collision probability of x_i tags in a slot, let S be the number of slots of a frame, and let T be the total number of the tags. Then:

$$p_{tag}(x_i) = \binom{T}{x_i}\left(\frac{1}{S}\right)^{x_i}\left(1-\frac{1}{S}\right)^{T-x_i} \quad (2)$$

Suppose there are x_i collision tags in a slot, and $x_i \geqslant 2$. Since each bit of the tag ID is denoted with "1" or "0", the probability of all the bits at a bit position of the x_i tags being same is $1/2^{x_i}$. Let $p_{id}(x_k)$ be the probability of x_k bit position having different bits, and let I be the length of the tag ID. Then:

$$p_{id}(x_k) = \binom{I}{x_k}\left(1-\frac{1}{2^{x_i}}\right)^{x_k}\left(\frac{1}{2^{x_i}}\right)^{I-x_k} \quad (3)$$

Let $p(x_i, x_k)$ be the collision probability of x_i tags in a slot, and x_k bit positions having different bits and $x_i \geqslant 2$. Then,

$$\begin{aligned} p(x_i, x_k) &= p_{tag}(x_i)\, p_{id}(x_k) \\ &= \binom{T}{x_i}\left(\frac{1}{S}\right)^{x_i}\left(1-\frac{1}{S}\right)^{T-x_i}\binom{I}{x_k}\left(1-\frac{1}{2^{x_i}}\right)^{x_k}\left(\frac{1}{2^{x_i}}\right)^{I-x_k} \end{aligned} \quad (4)$$

When x_i=0, there is no tag response in a slot, and there is no collision. Therefore x_k=0, and:

$$p(0,0) = \binom{T}{0}\left(\frac{1}{S}\right)^{0}\left(1-\frac{1}{S}\right)^{T} \quad (5)$$

When x_i=1, there is one tag response in a slot, and there is no collision. Therefore x_k=0, and:

$$p(1,0) = \binom{T}{1}\left(\frac{1}{S}\right)\left(1-\frac{1}{S}\right)^{T-1} \quad (6)$$

When $x_i \geqslant 2$, there is more than one tag response in a slot, and there is collision. Therefore, x_k shall be 1, 2, $\cdots$, I. The probability of have x_k bit position having different bits is:

$$p(x_i \geq 2, x_k) = \sum_{x_i=2}^{T} p(x_i, x_k) \quad (7)$$

Let $n_{0,0}$ be the number of slots with no response, and no collision bits. Then the probability of having $n_{0,0}$ slots within a frame is:

$$p_m(0,0;T) = p(0,0)^{n_{0,0}} \quad (8)$$

Let $n_{1,0}$ be the number of slot with one tag response, and no collision bits, that is, the number of success reading slot. Then, the probability of having $n_{1,0}$ slots within a frame is:

$$p_m(1,0;T) = p(1,0)^{n_{1,0}} \quad (9)$$

Let $n_{Xi\geqslant 2,Xk}$ be the number of slot with more than one tag response and x_k bit position having different bits. Then, the probability of having $n_{Xi\geqslant 2,Xk}$ slots within a frame is:

$$p_m(x_i \geq 2, x_k) = p(x_i \geq 2, x_k)^{n_{x_i \geq 2, x_k}} \quad (10)$$

Then, the likelihood function for the number of the tags T in the reading area can be constructed as follows:

$$\begin{aligned} &L(n_{0,0}, n_{1,0}, n_{x_i \geq 2,1}, n_{x_i \geq 2,2}, \cdots, n_{x_i \geq 2,I}; T) \\ &= p_m(0,0)\, p_m(1,0) \prod_{x_k=1}^{I} p_m(x_i \geq 2, x_k) \end{aligned} \quad (11)$$

Then, the estimated tag number $\hat{T}$ is:

$$\begin{aligned} &L(n_{0,0}, n_{1,0}, n_{x_i \geq 2,1}, n_{x_i \geq 2,2}, \cdots, n_{x_i \geq 2,I}; \hat{T}) \\ &= \max_{T \in N} L(n_{0,0}, n_{1,0}, n_{x_i \geq 2,1}, n_{x_i \geq 2,2}, \cdots, n_{x_i \geq 2,I}; T) \end{aligned} \quad (12)$$

In (12), N is the set of nature numbers. Then, the number of left tags after a reading cycle is:

$$\hat{T}_{left} = \hat{T} - n_{1,0} \tag{13}$$

III. Simulation and Analysis

The simulation was made for our proposed scheme and the EOIP-RFID scheme proposed in [4]. To further evaluate the performance of the maximum likelihood estimation employed in our scheme, moment estimation was introduced into our scheme.

The simulation was done in two scenarios. In each scenarios, 10^6 times of estimation were done and the mean estimation error and the covariance of the mean estimation error of the estimation were studied. In the first scenarios, the system performance was evaluated when the frame length was changing. The parameters set in this scenario are as follows:

- The actual tag number: 20
- The length of tag ID: 30 bits
- The frame length: 10slots~115slots

The mean estimation error in our simulation was denoted with percentage error which was the mean of the ratio of estimation error and the actual tag number. Fig.3 showed the percentage error for different length of frame. This figure showed that The percentage error of EOIP-RFID varied from -100% to 150%, while the percentage error of our scheme HTNE based on moment estimation and maximum likelihood estimation were only varying between -1% and 0 when the length of frame was more than 40 slots. Fig. 3 showed that the tag number estimation error was large and EOIP-RFID couldn't estimate the tag number accurately.

Fig. 4 studied the covariance of percentage error. The covariance of percentage error was the covariance of the ratio of estimation error and the actual tag number. Fig. 4 showed that the covariance of percentage error of EOIP-RFID varied from 1% to 150%, and the covariance of percentage error of HTNE based on moment estimation varied from 1% to 370%, while the percentage error of HTNE based on maximum likelihood estimation were lower than 1%. This figure showed that the estimation variance of EOIP-RFID and HTNE based on moment estimation were large, and these schemes couldn't estimate the tag number accurately. Fig.3 and Fig.4 showed that the estimation error of HTNE based on maximum likelihood estimation was low when the actual tag number was 20 and the frame length was from 10 slots to 115 slots.

In the second scenarios, the system performance was evaluated when the actual tag number was changing. The parameters set in this scenario are as follows:

- The actual tag number: 10~45
- The length of tag ID: 30 bits
- The frame length: 30slots

Fig.5 showed the percentage error for different length of frame. This figure showed that the percentage error of EOIP-RFID varied from -80% to 110%, while the percentage error of our scheme HTNE based on moment estimation and maximum likelihood estimation were only varying between -5% and 0. Fig. 5 showed that the estimation error of EOIP-RFID was large, and this scheme couldn't estimate the tag number accurately.

Fig. 6 studied the covariance of percentage error. This figure showed that the covariance of percentage error of EOIP-RFID varied from 1% to 150%, and the covariance of percentage error of HTNE based on moment estimation varied from 30% to 160%, while the percentage error of HTNE based on maximum likelihood estimation were lower than 5%. This figure showed that the estimation variance of EOIP-RFID and HTNE based on moment estimation were large and these schemes couldn't estimate the tag number accurately. Fig.5 and Fig.6 showed that the estimation error of HTNE based on maximum likelihood estimation was low when the frame length was 30 slots and the actual tag number was from 10 to 45.

The simulation results showed that HTNE based on maximum likelihood estimation could much more accurately estimate the tag number than the other two estimation schemes.

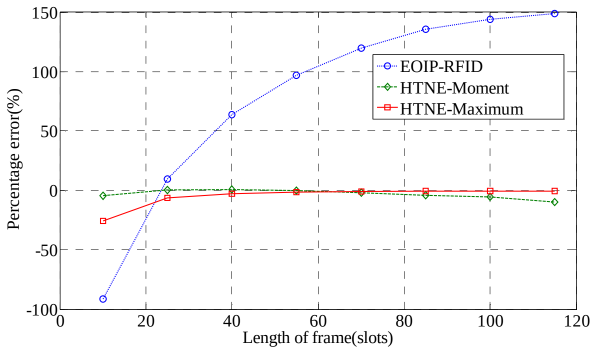

Fig. 3 Percentage error vs. the Length of the frame

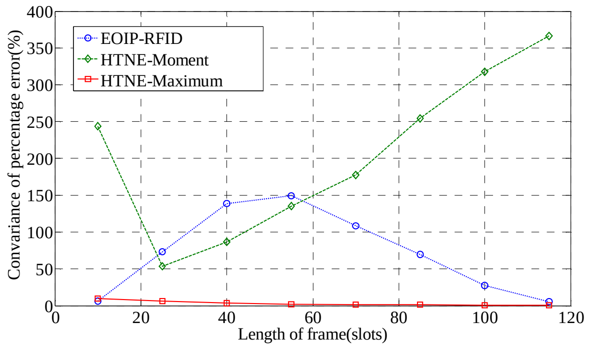

Fig. 4 Covariance of percentage error vs. the Length of the frame

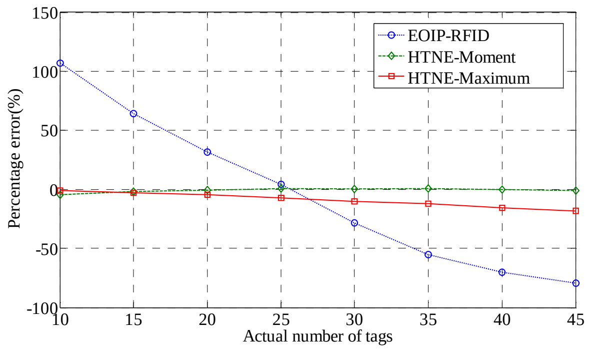

Fig. 5 Percentage error vs. the actual number of Tags

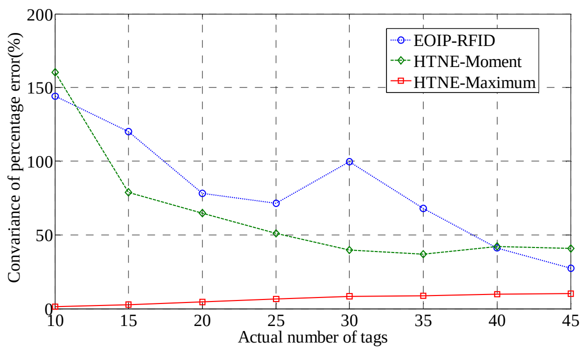

Fig. 6 Covariance of percentage error vs. the actual number of tags

IV. CONCLUSION

The hybrid tag number estimation scheme could effectively make use of the information gotten after a reading cycle of aloha based anti-collision algorithm. Through maximum likelihood estimation, the tag number information was extracted from the information gotten after a reading cycle as much as possible. The mean and covariance of the estimation error were studied, which could indicate the estimation accuracy of the tag number estimation schemes. Simulation results showed that our scheme based on maximum liklihood had much higher accuracy than the existing tag number estimation algorithm EOIP-RFID.

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