A CAPTURE-AWARE ANTI-COLLISION ALGORITHM FOR ISO 18000-6C RFID PROTOCOL

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Abstract:

RFID tag identification is one of challenging issues since the simultaneous transmissions in the shared wireless medium cause collision between the replies. In this paper, a novel anti-collision algorithm to increase the throughput of RFID systems is presented, which considers the capture effect in the context of framed ALOHA protocol. Under the capture model, the probabilistic method for estimating the backlog and the derivation of the capture-aware optimum frame length equation are provided. The numerical results show that the proposed algorithm significantly outperforms other existing schemes.

Keywords:

RFID; anti-collision; capture effect; tag estimation

1. Introduction

Anti-collision algorithm is important in RFID systems, which allows tags to be interrogated reliably and efficiently. Frame ALOHA is a discrimination of version of the ALOHA protocols, which is the case in ISO 18000-6C protocol, time is divided into frames of multiple slots [1]. Every tag in reader range randomly selects one of the time slots of a frame and transmits its unique identification number. The unidentified tags will join the interrogation round in next frame. The throughput of a framed ALOHA system, typically defined as the successful slot number divided by the frame size, which depends on the accuracy of estimating the unknown number of tags based on feedback from the reader and choosing the corresponding frame size. Many researchers present several efficient backlog estimation methods [2], [3], where tag number is estimated by the values of C_0 (the number of empty slots), C_1 (the number of successful slots), C_k (the number of collision slots) in previous frame. These schemes gave good results under non-capture or perfect capture environments.

The capture effect refers to the packet can be received successfully in the presence of other overlapping packets if its power is larger than the interfering power by a certain margin. Some realistic experiments demonstrated that the capture effect actually appears in RFID systems and the probability of occurrences depends on the relative attenuation between the tags [4], [5]. Due to the capture effect, the values of S and C provided by the reader will become inaccurate. This results in improper frame size, which deteriorates the performance of the identification procedure. Also, the throughput equation changes with S. As a result, the novel anti-collision algorithm is needed to mitigate these problems.

A great deal of research has dealt with the capture effect were proposed for framed slotted ALOHA RFID system [6], [7], [8]. [6] Presented a MLE (maximum likelihood estimation) method, which is failed to give a closed-form optimum frame size equation. A capture-aware access control method [7] is proposed by which the tags is divided into multiple groups depending on received signal strength and only a selected pair of groups are allowed to join the contention process to activate more capture effects. Although this scheme achieves a good throughput performance, it is not compatible with IS0 18000-6C protocol. [8] Presented a capture-aware backlog estimation method (CMEBE), in which the tag number and also the average capture probability, can be estimated. The closed-form maximum throughput limit is derived. The scheme achieves a good throughput performance, however, its performance will be degraded away from α=0.5 (α defined as the average capture probability).

In this paper, an efficient capture-aware anti-collision algorithm is proposed, by which the tag estimate error is reduced. The L_{opt} (optimum frame size) is allocated to be more accurate. The closed-form theoretical maximum throughput limit of our proposed scheme is also presented. Simulation results indicate that the tag estimate error of the proposed method is less than CMEBE. Use of our proposed tag estimate method with optimal frame length can achieve a better throughput performance compared with CMEBE.

2. System Model

The average capture probability in a collision slot, denoted as α, is illustrated in formula (1), where $P_{cap}(i)$ is the capture probability when i tags collide in one slot which is derived in formula (2), where Z_0 is the capture ratio. $P_{col}(i)$ is the probability that i tags allocated in one slot.

$$\alpha = \sum_{j=1}^{L_{cap}} \frac{1}{L_{cap}} P_{cap}^{j} \tag{1}$$

$$P_{cap}(i) = \Pr(\frac{P_s}{P_q} > Z_0) P_{col}(i) \tag{2}$$

In a dynamic framed slotted aloha system with n tags and a frame length of L time slots. The probability of empty, successful and collision slot is given by [2], [8], [9].

$$P_e = (1 - 1/L)^n \tag{3}$$

$$P_s = (n/L)(1 - 1/L)^{n-1} \tag{4}$$

$$P_c = 1 - P_e - P_s \tag{5}$$

In realistic RFID systems, the value of E, S, C are provided by the reader by computing C0, C1, Ck. Under the environment without capture, the reader can provide accurate values for E, S, C, that is: E= C_0, S=C_1, C=C_k. However, when the capture effect occurs, the values of E, S and C provided by the reader derived from E, S, C:

$$E=C_0,\quad S=C_0+\alpha C_k,\quad C=(1-\alpha)C_k \tag{6}$$

Based on (3)-(6), the probability of empty, successful and collision slot under the capture environment can be written as

$$P_e = (1 - 1/L)^n \tag{7}$$

$$P_s = (n/L)(1-1/L)^{n-1} + \alpha[1-(1-1/L)^n - (n/L)(1-1/L)^{n-1}] \tag{8}$$

$$P_c = (1-\alpha)[1-(1-1/L)^n - (n/L)(1-/L)^{n-1}] \tag{9}$$

3. Capture-aware anti-collision algorithm

In this section, we use the combination of Bayesian and minimum error method to achieve the capture-aware anti-collision algorithm. Firstly, we need to derive the probability that there are E empty slots, S successful slots and C collision slots in a frame of length L. The problem can be modeled as a multinomial distribution with L repeated independent trials. The probability that in L trials, empty outcome occurs E times, successful outcome occurs S times, and collision outcome occurs C times is

$$P(E,S,C) = \frac{L!}{E!S!C!}(P_e^E P_s^S P_c^C) \tag{10}$$

Therefore, for a read cycle with frame length L, the Bayesian posterior-probability estimate expression can be derived as

$$\begin{aligned} P(n/E,S,C) = {} & \frac{L!}{E!S!C!}[(1-1/L)^n]^E \\ & *[(n/L)(1-1/L)^{n-1} + \alpha(1-(1-1/L)^n - (n/L)(1-1/L)^{n-1})]^S \\ & *[(1-\alpha)(1-(1-1/L)^n - (n/L)(1-1/L)^{n-1})]^C \end{aligned} \tag{11}$$

Where L is the previous frame size. Meanwhile, the estimation function by CMEBE method is as follows [8]

$$\xi = \min_n \left\{ \left\| \begin{pmatrix} E_{e\_m} \\ S_{s\_m} \\ C_{s\_m} \end{pmatrix} - \begin{pmatrix} E_{e\_c} \\ S_{s\_c} \\ C_{c\_c} \end{pmatrix} \right\| \right\} \tag{12}$$

Where ξ is the minimum distance between measurement results (E_{e_m}, S_{s_m}, C_{c_m}) provided by RFID reader and calculation results (E_{e_c}, S_{s_c}, C_{c_c}) provided by equation (6).

Set the tag estimate n_{est}^1 =n, if P(n/E, S, C) is maximum, n_{est}^2 =n, if ξ is minimum. We can get the final tag estimate result as follows

$$n_{est} = (1.5-\alpha)n_{est}^2 + (\alpha - 0.5)n_{est}^1 \tag{13}$$

To measure the performance of the proposed tag estimate method, we define the estimate error as

$$error = \left| \frac{n - n_{est}}{n} \right| \tag{14}$$

After obtaining the estimate of actual tag, the reader can then forecast the number of unidentified tags by subtracting the number of successful slots from the above estimate. The next process is the derivation of the optimum frame size L_{opt} under the capture environment. The system throughput is defined as the expected value of successful slots divided by frame length

$$U = \frac{S}{L} = (n/L)(1-1/L)^{n-1} + \alpha[1-(1-1/L)^n - (n/L)(1-1/L)^{n-1}] \tag{15}$$

In order to maximize system throughput, we let the differentiation of (3-6) to be zero

$$\frac{dU}{dL} = \frac{n(1-1/L)^{n-2}}{L^3}[\alpha + (1-\alpha)n - L] = 0 \tag{16}$$

We derive that the optimum frame size is

$$L_{opt} = \alpha + (1-\alpha)n \tag{17}$$

Furthermore, substituting formula (17) to (15), we obtain the closed-form maximum theoretical throughput of proposed scheme as follows

$$U_{\max} = \alpha + (1-\alpha)(1 - \frac{1}{(1-\alpha)n + \alpha})^{n-1} \tag{18}$$

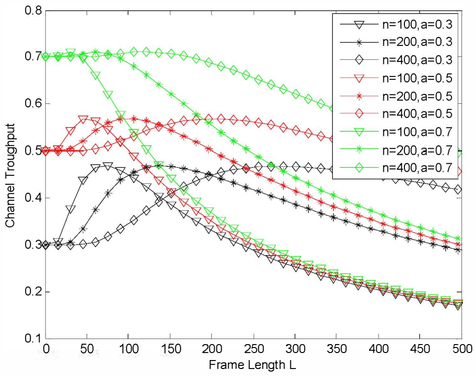

Fig. 1 Channel throughput as function of frame length

Fig. 1 shows channel throughput as a function of the frame lengths for different average capture probabilities. Each curve has a maximum value when the frame length equals to L_{opt} rather than tags number. For example, the maximum channel throughput equals to approximately 0.46 when frame lengths equal to L_{opt} and average capture probabilities α=0.3. Meanwhile, as α increases, the channel throughput increases simultaneously. From Fig.1, we can know the channel throughput of α=0.7 higher than α=0.3 or α =0.5 when the tag number is the same. It demonstrates that the capture effect is more evident the throughput is higher.

Our RFID anti-collision procedure is summarized as follows:

```
Dynamic ALOHA ()
{     cycle_counter=0;
     // frame counter
     L=Lini;
     // initial frame length
     do {
          cycle_counter++;
         [E, S, C]=performReadCycle(L);
          // slots number of previous frame
         [nest, α]=performTagEstimate(L, E, S, C);
          // estimate tag quantity nest and average
              probability α
          Lopt=α+(1-α)(nest-S);
          // set a new frame length
          } while (C!=0)
            // repeat read process if collision occur
 }
```

4. Numerical and analytical result

The proposed tag estimate method's performance is simulated.

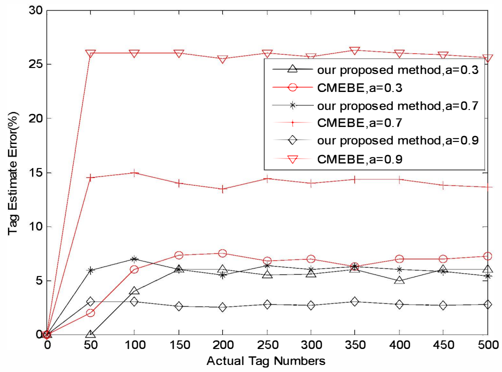

Fig. 2 Tag number estimation under capture environment (α=0.3, 0.7 and 0.9)

Fig. 2 shows the tag number estimation accuracy under a capture environment where α=0.3, 0.7 and 0.9, compared with CMEBE [8], which is also compatible with ISO 18000-6C protocol. Results indicate the proposed method provides much more accurate and reliable estimates of tag number than the CMEBE. The CMEBE causes higher error especially when the value of α is very large. For example, the CMEBE estimate error reaches 15% if α=0.7. Our method can achieve estimate error lower than 6%. Moreover, we compare the read performance of our anti-collision algorithm with the CMEBE and perfect estimation. Initial frame length is set to the same slots in this case.

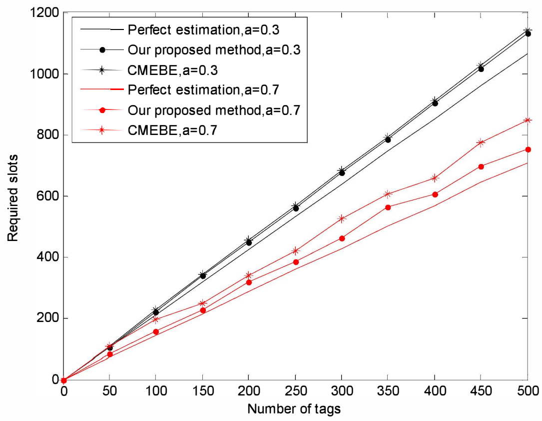

Fig. 3 Simulation results for time slots required to read all tags

We find from Fig. 3 that of three estimate method, our method requires lower time slots to read a set of tags than the CMEBE, which almost close to the curve of perfect estimation.

5. Conclusion

A more accurate tag estimate method for solving the anti-collision problem in RFID systems using capture effect has been proposed which is compatible with ISO 18000-6C protocol. Our method includes backlog estimation method and optimum frame size equation. Analytical and simulation results show that the proposed algorithm can achieve a better performance.

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