Efficient Anti-Collision Algorithm Utilizing the Capture Effect for ISO 18000-6C RFID Protocol

Bo Li and Junyu Wang

Abstract—**The capture effect commonly occurs when multiple tags simultaneously transmit their signals in ISO 18000-6C RFID systems, introducing challenges and opportunities for access control method design. In this letter, a novel anti-collision algorithm utilizing the capture effect for ISO 18000-6C protocol is presented based on the design of the capture-aware backlog estimation method and the derivation of the capture-aware optimum frame length equation. The maximum achievable throughput of the proposed algorithm is analytically provided, and numerical results show that the proposed algorithm significantly outperforms other existing schemes.**

Index Terms—**RFID, anti-collision, capture, ISO 18000-6C.**

I. Introduction

ANTI-COLLISION algorithm, which allows tags to be interrogated reliably and efficiently, is important in RFID systems. In framed slotted Aloha based anti-collision algorithm, which is the case in ISO 18000-6C protocol, time is divided into frames of multiple slots [1]. The reader begins its interrogation round firstly by estimating the number of tags in the reader range based on the feedback from previous frame, and announcing the frame size (i.e., the number of slots in a frame) to all tags. Then, each tag randomly chooses a slot and transmits its unique identification number. Tags that are not identified will join the interrogation round in next frame. The throughput, defined as the ratio between successful slot number and frame size, thus depends on the accuracy of backlog estimation method and the choice of optimum frame size. Under the traditional non-capture assumption, [2-3] present several efficient backlog estimation methods, where tag number is estimated by the values of c_0 (the number of non-reply slots), c_1 (the number of single-occupied slots), c_k (the number of collided slots) in previous frame, under the condition that the reader must be able to provide accurate values of c_0, c_1, c_k. It has been well understood that the throughput of framed slotted Aloha system is maximized when the frame size is allocated to be equal to the tag number and has a limit of 1/e when the tag number goes to infinity [6]. This is different when the capture effect exists.

The capture effect refers to correct identification of a tag in the presence of collision, and it reliably exists in ISO 18000-6C RFID systems [4]. Under the capture environment, the values of c_1 and c_k provided by the reader are overestimated and underestimated respectively. Therefore, traditional backlog estimation methods [2-3] fail to work efficiently. Also, the throughput equation changes with c_1 . As a result, the traditional optimum frame size equation is improper for the capture environment. Consequently, the novel anti-collision algorithm is needed to mitigate these problems.

Two schemes considering capture effect were proposed for framed slotted Aloha RFID system [5-6]. [5] presented a ML (maximum likelihood) backlog estimation method, which is too complex to apply to RFID systems, and failed to give a closed-form optimum frame size equation. [6] proposed a capture-aware access control method by dividing tags into multiple groups depending on received signal strength and allowing only a selected pair of groups to join the contention process to activate more capture effects. This scheme achieves a good throughput performance; however, it is not compatible with ISO 18000-6C protocol. Also, the performance depends on the accuracy of the capture ratio (i.e., the threshold power ratio between expected tag and interference tags to activate the capture effect), which is difficult to obtain and varies from reader to reader.

In this work, an efficient capture-aware anti-collision algorithm is presented, which is compatible with ISO 18000-6C protocol and easy to apply. The key idea of our proposal lies in the design of a capture-aware backlog estimation method (CMEBE) and the deviation of the capture-aware optimum frame size (L_{opt}) equation. With CMEBE, the tag number and also the average capture probability can be estimated. L_{opt} is allocated to be less than the tag number to activate more capture effects. The closed-form maximum throughput limit of our proposal is also presented. Numerical results show that much higher throughput can be achieved with the use of our technique.

II. System Model under Capture Environment

The average capture probability in a collision slot, denoted as α, is defined in (1), where $p_{cap}(i)$ is the capture probability when i tags collide, $p_{col}(i)$ is the probability that i tags collide in one slot, and n is the tag number. In general, α approximately equals $p_{cap}(2)$, since $p_{cap}(i)$ and $p_{col}(i)$ are very small when i>2.

$$\alpha = \sum_{i=2}^{n} p_{cap}(i) p_{col}(i) \tag{1}$$

In the framed slotted Aloha system, the values of c_0, c_1, c_k are given by [2]

$$c_0 = L(1-\frac{1}{L})^n, c_1 = n(1-\frac{1}{L})^{n-1}, c_k = L - c_0 - c_1 \tag{2}$$

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where L is the current frame size. In realistic RFID systems, the values of c_0, c_1, c_k are provided by the reader by estimating c_e (the number of empty slots), c_s (the number of successful reception slots), and c_f (the number of failure slots). Under the non-capture environment, the reader can provide accurate values for c_0, c_1, c_k, that is: $c_0{=}c_e, c_1{=}c_s, c_k{=}c_f$. However, when the capture effect exists, the values of c_s and c_f provided by the reader deviate from c_1 and c_k:

$$c_e = c_0, c_s = c_1 + \alpha c_k, c_f = c_k - \alpha c_k \tag{3}$$

Based on (2) and (3), the system throughput under the capture environment can be written as

$$\eta = \frac{n(1-\frac{1}{L})^{n-1} + \alpha[L - L(1-\frac{1}{L})^n - n(1-\frac{1}{L})^{n-1}]}{L} \tag{4}$$

III. Capture-Aware Anti-collision Algorithm for ISO 18000-6C Protocol

The results from (3) and (4) indicate how the capture-aware anti-collision algorithm needs to be designed. The algorithm proposed in this work contains the following features:

1) It is fully compatible with ISO 18000-6C protocol.

2) The backlog estimation method is capable of estimating not only the unidentified tag number under the capture environment, but also the average capture probability.

3) The optimum frame size is allocated to be less than the tag number, aimed at activating more capture effects in collided slots and maximizing the throughput.

We first design the capture-aware backlog estimation method. The key idea is to estimate *n* and α using the values of c_e, c_s, c_f provided by the reader. Rewrite (3) as (5),

$$\begin{aligned} c_e &= L(1-\frac{1}{L})^n \\ c_s &= n(1-\frac{1}{L})^{n-1} + \alpha[L - L(1-\frac{1}{L})^n - n(1-\frac{1}{L})^{n-1}] \\ c_f &= (1-\alpha)[L - L(1-\frac{1}{L})^n - n(1-\frac{1}{L})^{n-1}] \end{aligned} \tag{5}$$

where L is the previous frame size. Referring to Chebyshev's inequality, which states that the outcome of a random experiment involving a random variable X is most likely somewhere near the expected value of X [2], we propose a *capture-aware minimum error backlog estimation method* (CMEBE). CMEBE selects the tag number n ($n \geq 1$) and average capture probability α ($0 < \alpha < 1$) that minimize the error

$$\varepsilon = \left| \begin{pmatrix} c_{e\_m} \\ c_{s\_m} \\ c_{f\_m} \end{pmatrix} - \begin{pmatrix} c_{e\_c} \\ c_{s\_c} \\ c_{f\_c} \end{pmatrix} \right| \tag{6}$$

where ε is the distance between measurement results $(c_{e\_m}, c_{s\_m}, c_{f\_m})$ provided by RFID reader and calculation results $(c_{e\_c}, c_{s\_c}, c_{f\_c})$ provided by equation (5). Compared with the original Vogt method [2], CMEBE has a y-fold complexity increase due to the additional task of estimating α. Typically, y is slightly larger than 2, given that, once α is estimated after the first frame (denoted as $\alpha 1$), in the following frames, α estimates only have to be chosen from these 3 values: $\alpha 1 - step$, $\alpha 1$, $\alpha 1 + step$, where $step$ is a searching step length of α. For example, given n tags in the reader range, after the first frame, the CMEBE will traverse the value of n and α from a predefined searching range $\mathbf{N}$ (eg., from $2c_k$ to $3c_k$) and $\mathbf{A}$ (eg., from 0.1 to 0.6), then $y+1$ equals to the number of elements in $\mathbf{A}$; And in the following frames, y is 2.

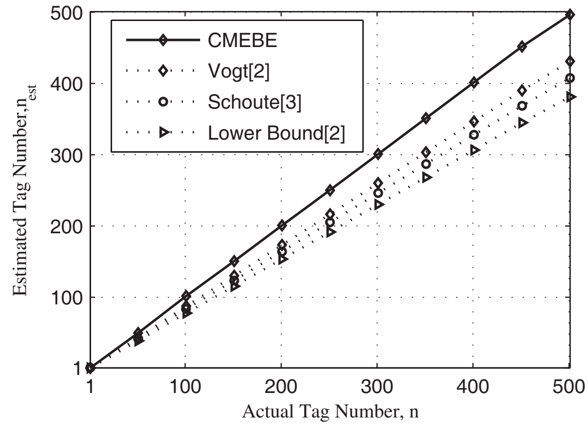

Fig. 1. Tag number estimation of CMEBE under capture environment ($\alpha = 0.5$).

The next process is the derivation of the optimum frame size (L_{opt}) under the capture environment. L_{opt} can be obtained by finding the value of L that maximizes the system throughput given in (4). Letting the differentiation of (4) to be zero

$$\frac{d\eta}{dL} = \frac{n(1-\frac{1}{L})^{n-2}}{L^3}[\alpha + (1-\alpha)n - L] = 0 \tag{7}$$

we derive that the optimum frame size is

$$L_{opt} = \alpha + (1-\alpha)n \tag{8}$$

Equation (8) indicates that the capture-aware optimum frame size is less than the tag number n, and monotonously decreases when α increases from 0 to 1.

Our capture-aware anti-collision algorithm is summarized in the following table:

For each frame{
initial parameters:
$i = 1$ // frame counter
$L_i = L_{ini}$ // initial frame length
repeat:
$i = i + 1$ // increment frame counter
observe c_e, c_s, c_f // slots number of previous frame
estimate n_i and α_i using CMEBE //
$L_i = \alpha + (1-\alpha)n_i$ // determine optimum frame length
reader-tag interrogation within L_i slots //
until $c_s = 0$ & $c_f = 0$ }

IV. Numerical and Analytical Result

The performance of the proposed backlog estimation method CMEBE is simulated. Fig.1 shows the tag number estimation accuracy under a capture environment where α is 0.5, compared with Vogt [2], Schoute [3], and Lower Bound [2], which are widely used in ISO 18000-6C RFID systems. Considering that the diagonal line of Fig.1 corresponds to perfect estimation (i.e., n_{est} always equals n), it can be seen

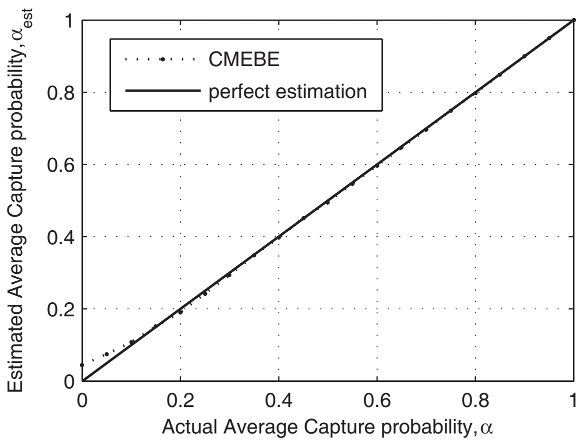

Fig. 2. Average capture probability estimation of CMEBE ($n = 200$).

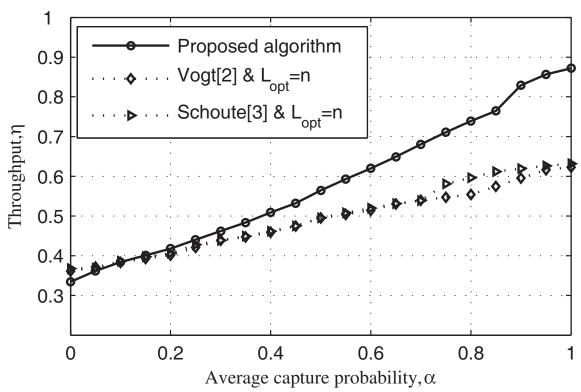

Fig. 3. Throughput improvement of proposed capture-aware anti-collision algorithm ($n = 200$).

that CMEBE provides much more accurate and reliable estimates of tag number than the other three methods. Fig.2 shows the average capture probability estimation accuracy when the tag number is 200. Still, the diagonal line corresponds to perfect estimation. Thus, we can see that CMEBE has a good estimation performance of α especially when $\alpha \geq 0.2$.

Moreover, the performance of the proposed capture-aware anti-collision algorithm under ISO 18000-6C protocol is simulated. Fig.3 shows the throughput as a function of the average capture probability when the tag number is 200. Our proposed algorithm is compared with two alternatives, namely, algorithms with backlog estimation method Vogt [2] and Schoute [3], in which all the optimum frame sizes equal tag number. We observe that when α is 0, the throughputs of these three algorithms are all around 1/e, which is the well-known performance limit of framed slotted Aloha system under the non-capture environment. As α increases, our proposed algorithm achieves much higher throughput than [2] and [3], especially when $\alpha \geq 0.2$, i.e, when the capture effect is more evident.

Furthermore, the closed-form maximum achievable throughput of proposed capture-aware anti-collision algorithm is analytically derived. Substituting L in equation (4) with L_{opt} in equation (8), we obtain

$$\eta_{max} = \alpha + (1-\alpha)\left(1 - \frac{1}{(1-\alpha)n + \alpha}\right)^{n-1} \qquad (9)$$

As $n \to \infty$, we have

$$\lim_{n \to +\infty} \eta_{max} = \alpha + (1-\alpha)e^{-\frac{1}{1-\alpha}} \qquad (10)$$

where the throughput limit is only the function of α. And when α is 100%, the throughput limit is 100%, which is reasonable given that, at that time, the frame size is set to be 1 and capture always happen.

V. Conclusion

This letter proposes a capture-aware anti-collision algorithm compatible with ISO 18000-6C protocol, which consists of a capture-aware minimum error backlog estimation method and a novel optimum frame size equation. Analytical and simulation results show that the proposed algorithm outperforms existing alternatives.

References

[1] Class 1 Generation 2 UHF Air Interface Protocol Standard Version 1.0.9, EPCglobal, 2005. Available: http://www.epcglobalinc.org.

[2] H. Vogt, F. Mattern, and M. Naghshineh, editors, "Efficient object identification with passive RFID tags," in *Proc. 1st Int. Conf., PERVASIVE 2002*, Zurich, Switzerland, Aug. 2002, LNCS, vol. 2414, pp. 98-113.

[3] F. C. Schoute, "Dynamic frame length ALOHA," *IEEE Trans. Commun.*, vol. COM-31, pp. 565-568, Apr. 1983.

[4] C. Floerkemeier and S. Sarma, "RFIDSim–a physical and logical layer simulation engine for passive RFID," *IEEE Trans. Autom. Sci. Eng.*, vol. 6, no. 1, Jan. 2009.

[5] Y. Oh, S. Jung, J. Hong, and C. Lie, "A scheme to increase throughput in framed-ALOHA-based RFID systems with capture," *ETRI Journal*, vol. 30, no. 3, June 2008.

[6] W. J. Shin and J. G. Kim, "A capture-aware access control method for enhanced RFID anti-collision performance," *IEEE Commun. Lett.*, vol. 13, no. 5, pp. 354-356, May 2009.