

An Anticollision Protocol for Large-Scale Single-Reader RFID Systems

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Abstract: There are two challenges for the frame-slotted ALOHA algorithms in radio-frequency identification (RFID). The first challenge is estimating unknown tag-set size accurately; the second challenge is improving the efficiency of the arbitration process so that it uses less time slots to read all tags. A novel anti-collision technique is proposed to maximize identification performance in slotted ALOHA based RFID systems. The performances of these protocols are evaluated and it is verified that this protocols outperforms the traditional frame slotted ALOHA protocols.

Key words: Anticollision, framed ALOHA, radio-frequency identification, tag estimate.

INTRODUCTION

Radio Frequency identification (RFID) is considered a key technology for item identification and efficient object tracking (Want, 2006) which is fast pervading in many application fields, like inventory management and supply-chain management, due to its ability to identify objects wirelessly without line-of-sight and high efficiency.

An RFID system consists of radio frequency tags attached to objects that to be identified and a reading device called a reader. The reader is typically a powerful device with ample memory and computational resources. Tags can be active or passive. Active tags have storage capability and are provided with power sources for computing and transmitting data. Passive tags instead rely only on RF energy induced by the electromagnetic waves emitted by reader and can have limited storage functionality.

As an alternative of bar codes, typical applications require cheap and unobtrusive identification tags to be attached to various different items. Thus tags should be small, light, low cost and can be operate independently of external source of energy. Passive tags fulfill these purposes. While a very important issue in RFID systems with passive tags, is complexity and computing and transmitting capacity of tags in the identification.

In a typical communication sequence, the reader queries the tags for their ID by broadcasting a request message. When tags receive this message, they respond to the reader with their ID messages. When a single reply is received, the reader will identify a tag successfully. If two or more tags answer, their messages will collide on

the RF communication channel and cannot be correctly received by the reader. This is so called a tags collision problem which will results in wastages of bandwidth, energy and increase identification delays. So in order to improve the RFID system efficiency, the reader must adopt an anti-collision protocol.

Several technologies available on tag collision had been proposed. These anti-collision protocols are often categorized into ALOHA-based protocol and Tree-based protocol.

ALOHA-based protocols consider the channel to be slotted into intervals of time. ALOHA-based protocols such as ALOHA, slotted ALOHA (Lam and Kleinrock, 1975; Anatharam, 1991) and frame slotted ALOHA (Schoute, 1983), reduce the occurrence probability of tag collisions since tags transmit at distinct times.

The start of each slot is signaled by the reader with a short message. Slots are issued in groups, or frames (from which the name Framed Slotted ALOHA), whose size is set and communicated by the reader at the beginning of each frame. Each tag randomly and uniformly selects one slot and transmits its ID during that slot time. At the end of the frame, tags that are successfully identified become silent, while tags that generated collisions keep trying in the following frames. The performance of ALOHA-based protocols is highly affected by the frame size. Because the cardinality of tag population to be identified is not known, frame sizing is a big issue for ALOHA-based protocols.

The second group of anti-collision protocols builds on serial tree algorithms. Such as the binary tree protocol (Hush and Wood, 1998) and the query tree protocol (Law *et al.*, 2000), Tree-based protocols proceed more

deterministically: They iteratively query a subset of tags which match a given property until all tags are identified. These protocols are called tree-based, because the identification process can be represented as a tree where the root is the set of tags to be identified; intermediate nodes represent groups of colliding tags answering the same reader request and the leaves correspond to single-tag responses. Tree based protocols differ in the way tags are queried (e.g., based on a counter stored in the tags, or on the binary structure of tag IDs).

Tree-based tag anti-collision protocols can have a longer identification delay than slotted ALOHA based ones but they are able to avoid the so called tag starvation, in which a tag may not be identified.

OVERVIEW OF THE FRAME-SLOTTED ALOHA ALGORITHMS

In Slotted ALOHA (SA) based RFID systems, tags transmit their ID in synchronous time slots. If there is a collision, tags retransmit after a random delay. The collision occurs at slots boundary only, hence there are no partial collisions. In SA based systems, a tag with a high response rate will frequently collide with potentially valid responses from other tags. Therefore, FSA protocols mandates that each tag responds only once per frame. FSA protocols with variable frame sizes are called dynamic framed slotted ALOHA (DFSA). In DFSA, frame size is automatically adjusted after each frame. It is important for the frame size N value not be so far from tag's population value n . This requires making tag's population estimate operation that can be done by exploiting the outcomes of the previous frame information for the next frame sizing.

At each reading cycle, we obtain a triple $\langle c_0, c_1, c_k \rangle$ quantifying the empty or idle slots, success slots and slots with collisions, respectively. According to Chebyshev's Inequality, the outcome of a random experiment involving a random variable X is most likely near the expected value of X . By using this property to compute the distance between the effective results $\langle c_0, c_1, c_k \rangle$ and the expected results $\langle a_0, a_1, a_k \rangle$ of a reading cycle, respectively and by minimizing such a distance, defined in Eq. 1, it is possible to estimate the number of tags n that are transmitted in such a cycle:

$$\varepsilon(N, c_0, c_1, c_k) = \frac{\text{Min}}{n} \left(\begin{array}{c} a_0^{N,n} \\ a_1^{N,n} \\ a_k^{N,n} \end{array} \right) \quad k \geq 2 \quad (1)$$

where, N and n denote the frame size in the reading cycle and the number of tags, respectively. When the reader

uses a frame size equal to N and the number of responding tags is n , the expected value of number of slots with r responding tags is given by:

$$a_r^{N,n} = N \times \binom{n}{r} \left(\frac{1}{N} \right)^r \left(1 - \frac{1}{N} \right)^{n-r} \quad (2)$$

The number of success slots is given by:

$$a_1^{N,n} = n \left(1 - \frac{1}{N} \right)^{n-1} \quad (3)$$

The number of expected empty is defined by:

$$a_0^{N,n} = N \left(1 - \frac{1}{N} \right)^n \quad (4)$$

Therefore the number of slots with collision is given by:

$$a_k^{N,n} = N - a_1^{N,n} - a_0^{N,n} \quad (5)$$

Most commonly the bounded values $c_1 + 2c_k$ and $2(c_1 + 2c_k)$ are adopted as possible representative values for the number of tags.

Many disadvantages are associated with using ALOHA-based algorithms such the fact that the rapidly system efficiency is degrading as the number of tags increased, due to the limitation of the upper bound of frame size. ALOHA-based algorithms, also, cannot ensure 100% of tags reading accuracy. Many researchers have proposed new algorithms derived from DFSA. They attempted to overcome its general drawbacks such as limited system efficiency and performance degrading when the number of tags increased.

THE PROPOSED ANTICOLLISION ALGORITHM

Then the system efficiency is calculated as follows:

$$\text{System efficiency} = \frac{a_1^{N,n}}{N} \quad (6)$$

When the number of tags and the frame size are approximately the same, the system efficiency becomes the maximum. Therefore, accurate tag estimation is important to improve the system efficiency for large scale RFID system.

To solve this problem, we divide the whole set tags into many small subsets from which the size of the entire tag population can be inferred.

The rationale behind this method is that higher throughput can be obtained by performing identification

for multiple smaller subsets of equal size instead of doing so for all tags at once. Then, the disadvantage of the limitation of the upper bound of frame size of DFSA is overcome.

After the optimum repartitioning is finished, the identification process is then performed sequentially for each subgroup. In particular, the estimate of the number of tags in a subgroup becomes more accurate as more subgroups have been identified. By taking the average of the tag populations been processed, we can obtain size of the next subgroup.

The system is initialized with an initial frame size of l_0 . The partition process begins by broadcasting a partition message $P<\gamma_i>$ to the tags. The role of this message is to tell the tags how many subgroups should be partitioned into. When tags receive message P , each of them generates a random number in the range of 1 to γ_i . Next, the reader broadcasts a request message $R<l_{0,s}>$ which informs tags in the s th subgroup that in the next round the frame size is 1.

Once receiving message R , each tag in the subgroup s selects its response slot by generating a random number in the range (1, l_0) and transmits its ID in such a slot.

According to the responds of tags, the reader makes a decision whether to repartition or not. Repartitioning occurs whenever the following situations are happened:

$$\frac{c_k}{l_0} - \frac{a_k^{l_0}}{l_0} \quad (7)$$

When Eq. 7 is satisfied, the tag set will be partitioned into $2\gamma_i$ subgroups.

Once a frame is completed without repartitioning, we get a rough estimate of the number of tags in the first subgroup and the size of the entire tag population can be inferred.

The number of groups is calculated as follows:

$$\gamma_{opt} = \frac{\text{The No. of tags}}{\text{The frame size}} \quad (8)$$

The identification process includes several stages. In the first reading cycle, the reader broadcasts a request message $R<l_{0,s}>$ which informs tags in the s th subgroup that in the next round the frame size is l_0 . Tags in the subgroup answer at their randomly selected time slots within l_0 . The reader observes the reading result and updates the frame length in the next cycle:

$$l_{i+1} = n^i - c_i^i \quad (9)$$

where, $n^i - c_i^i$ are the estimation according to Eq. 1 and the number of slots with collision related to reading cycle i .

When we begin the identification of the following subgroup, the initial frame size is set according to the rough estimate, thereby yielding a throughput close to its possible maximum. In particular, these estimates become more accurate as the remaining subgroups are identified. Before identifying the s th subgroup, we already know the tag population of previous subgroups. By taking the average of those, we can produce a more accurate estimate \hat{n}_i of number of tags in the i th subgroup:

$$\hat{n}_i = \frac{\sum_{j=1}^{i-1} n_j}{i-1} \quad (10)$$

where, n_j is the number of tags in j th subgroup.

PERFORMANCE ANALYSIS OF THE PROPOSED ALGORITHM

To evaluate the performance of the proposed algorithm, we have performed extensive simulations. Two primary performance metrics in our experiments are the average throughput and average identification time. The average throughput is defined as a ratio of the number of tags to the number of slots used to read the tags. The average identification time is the number of slots used to identify all the tags.

In the first experiment, we examine the effects of different initial frame size to the read performance as we vary the number of tags from 100 to 1000.

Figure 1 shows the simulation results of the algorithm with different sizes of initial frame. Meanwhile, we compare the read performance of the proposed algorithm with that of other algorithms. In the second experiment, the proposed algorithm was

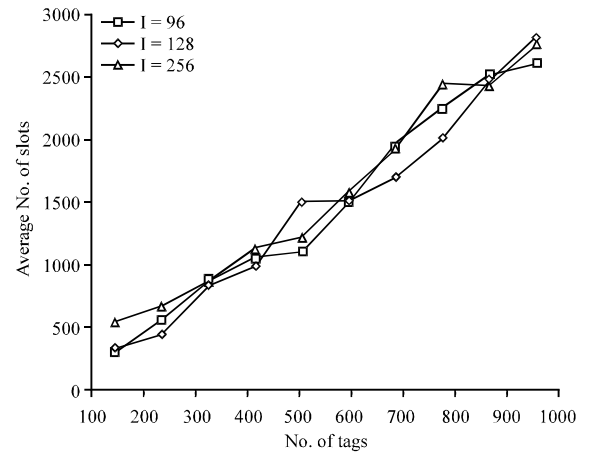


Fig. 1: The simulation results with different initial frame length

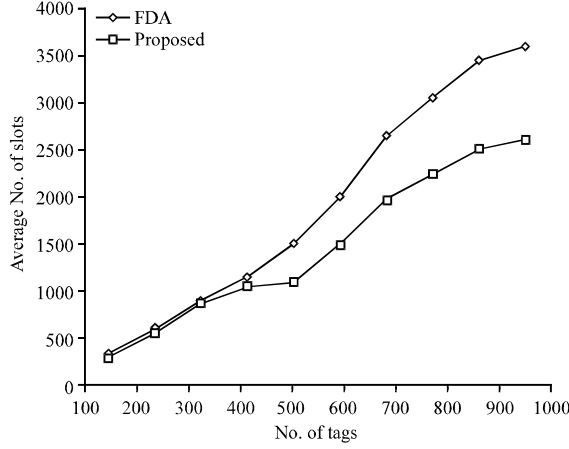


Fig. 2: Comparison of the simulation results for DFA and proposed algorithm, initial frame size $l = 96$

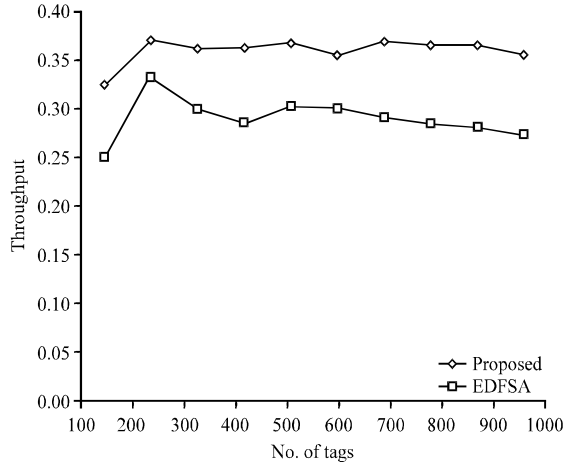


Fig. 3: Comparison of the simulation results for EDFSA and proposed algorithm, initial frame size $l = 128$

compared with DFA (Chen, 2009) in the performance of the average identification time, as shown in Fig. 2.

In the third experiment, the proposed algorithm was compared with EDFSA (Lee *et al.*, 2005) in the performance of throughput with initial frame size $l = 128$. As shown in Fig. 3, the proposed algorithm can produce higher throughput.

CONCLUSION

In this work, we proposed a novel anti-collision algorithm that utilizes the partitioning technique. The proposed estimation algorithm has low average estimation errors in a high tag density environment. Our proposed

anticollision algorithm can effectively solve and use less time slots to read all tags. The simulation results show that proposed algorithms outperform others.

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