

# Novel Anti-collision Algorithms for Fast Object Identification in RFID System

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## Abstract

*We propose two ALOHA-based Dynamic Framed Slotted ALOHA algorithms (DFSA) using Tag Estimation Method (TEM), which estimates the number of tags around the reader, and Dynamic Slot Allocation (DSA), which dynamically allocates the frame size for the number of tags. We compare the performance of the proposed DFSA with the conventional Framed Slotted ALOHA algorithm (FSA) using simulation. According to the analysis, two proposed DFSA algorithms show better performance than FSA algorithm regardless of the number of tags.*

## 1. Introduction

Reliable identification of multiple objects is especially challenging if many objects are present at the same time. Several technologies are available, but they all have limitations. For example, bar code is the most pervasive technology used today, but reading them requires a line of sight between the reader device and the tag, manual, and close-ranging scanning. But Radio Frequency Identification (RFID) system which is a simple form of ubiquitous sensor networks that are used to identify physical objects permits remote, non-line-of-sight, and automatic reading. Instead of sensing environmental conditions, RFID system identifies the unique tags' ID or detailed information saved in them attached to objects. Passive RFID system generally consists of a reader and many tags. A reader interrogates tags for their ID or detailed information through an RF communication link, and contains internal storage, processing power, and so on. Tags get processing power through RF communication link from the reader and use this energy to power any on-tag computations. A reader in RFID

system broadcasts the request message to the tags. Upon receiving the message, all tags send the response back to the reader. If only one tag responds, the reader receives just one response. But if there is more than one tag response, their responses will collide on the RF communication channel, and thus cannot be received by the reader. The problem is referred to as the "Tag-collision". An effective system must avoid this collision by using anti-collision algorithm because the ability to identify many tags simultaneously is crucial for many applications[1]-[4]. Anti-collision algorithm using ALOHA-based method described in [5] did not consider the inactivation state in which tags do not respond next reader's request temporarily. In Dynamic Slot Allocation (DSA) introduced in [6], there are no detailed methods how to dynamically allocate the frame size. Therefore there is the limitation to apply for those methods in RFID system. In this paper, to improve the performance of conventional ALOHA-based anti-collision algorithms we propose the Dynamic Framed Slotted ALOHA algorithms (DFSA) using Dynamic Slot Allocation (DSA) and Tag Estimation Method (TEM). We compare the performance of DFSA algorithms with that of the conventional Framed Slotted ALOHA (FSA) algorithms using OPNET simulation.

## 2. Anti-collision algorithms in standards

Moving into the UHF frequencies to exploit range benefits through use of unlicensed industrial, scientific, and medical (ISM) bands have led to the creation of several first-generation protocol standards. One of these traces is EPCglobal, an organization that recognized the potential of RFID early. Other standards originated with the International Standards Organization (ISO) as part of the ISO 18000 family, with 6 groups of documents dedicated to UHF operation. Table 1 compares the major attributes of the significant UHF standards. For anti-collision algorithms, EPCglobal proposed bit-based Binary Tree algorithm (deterministic) and ALOHA-based algorithm (probabilistic). On the other hand, ISO proposed the Adaptive Protocol

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|                            | Anti-collision Algorithm               | Tag Read Speed                         |
|----------------------------|--|--|
| EPCglobal CLASS 0 (UHF)    | Bit-based Binary tree (Deterministic)  | Avg. : 200 tags/s<br>Max. : 800 tags/s |
| EPCglobal CLASS 1 (UHF)    | Binary tree (Bin slot) (Probabilistic) | Not specified                          |
| ISO 18000-6 TYPE - A (UHF) | Dynamic Framed ALOHA (Probabilistic)   | Avg. : 100 tags/s                      |
| ISO 18000-6 TYPE - B (UHF) | Binary Tree (Probabilistic)            | Avg. : 100 tags/s                      |

**Table 1. First-generation UHF standards for RFID tag**

which is similar to the ALOHA-based algorithm proposed by EPCglobal, and binary tree search algorithm[6].

### 3. Framed Slotted ALOHA algorithms

We now give the procedure identifying a set of tags, named as the collision arbitration sequence in FSA algorithm, which is for optimizing the relatively low throughput of the ALOHA-based anti-collision algorithm. The purpose of the collision arbitration sequence is to perform a census of the tags present in the reader field and to receive information on tag ID. The collision arbitration sequence uses a mechanism that allocates tag transmissions into rounds and slots (time frame). Each slot has duration, long enough for the reader to receive a tag response. This time frame is divided into a number of slots that can be occupied by tags and used for sending their replies. The reader determines the actual duration of a slot. After the reader has sent its request to the tags, it waits for a certain amount of time for their answers. When multiple tags use the same slot, a collision occurs and data get lost. Fig. 1 shows briefly the procedure of FSA algorithm to identify four tags in Table 2. Tags receiving REQ (Request command sent by the reader) randomly select a slot in which to respond. The number of slots in a round referred to as frame size is determined by the reader[5],[7]-[9].

In Fig. 1, TAG1, TAG2, TAG3, and TAG4 selected Slot1, Slot3, Slot3, and Slot4 respectively. Slot2 in which no tags select is an idle slot. Slot1 and Slot4 which TAG1 and TAG4 select respectively will accomplish successful transmission. And the collision will be occurred in Slot3 in which two tags select the same slot, so two collided tags have to be retransmitted in next reader's request ( $2^{nd}$  REQ).

|      |      |
|------|------|
| TAG1 | 1011 |
| TAG2 | 1010 |
| TAG3 | 0011 |
| TAG4 | 0101 |

**Table 2. Used tag ID**

| READER     | 1 <sup>st</sup> REQ | Slot 1 | Slot2 | Slot3  | Slot4  | 2 <sup>nd</sup> REQ |
|------------|---------------------|--------|-------|--------|--------|---------------------|
| STATE      |                     | 1011   | IDLE  | COLL   | 0101   |                     |
| TAG1(1011) |                     | → 1011 |       |        |        |                     |
| TAG2(1010) |                     |        |       | → 1010 |        | 1010                |
| TAG3(0011) |                     |        |       | → 0011 |        | 0011                |
| TAG4(0101) |                     |        |       |        | → 0101 |                     |

← Frame Size = 4 →

**Figure 1. The procedure of FSA**

## 4. DFSA Algorithms and Performance Analysis

In FSA algorithm, generally, when the number of tags is much higher than the number of slots, the delay to identify a set of tags increases substantially. On the other hand, in a situation that the number of tags is lower than the number of slots, the wasted slots can occur. Therefore, it needs to appropriately vary the frame size according to the number of tags. This kind of method is called as Dynamic Slot Allocation (DSA). DSA is introduced in [4],[7], but there are no detailed methods how to dynamically allocate the frame size. Because Vogt did not consider the inactivation, which is the state in which tags don't temporarily respond reader's next request[4], there is the limitation to apply for that method in RFID system. In this paper, we propose two DFSA algorithms using TEM and DSA. The proposed algorithms to estimate the number of tags using TEM I and TEM II are defined as DFSA I and DFSA II respectively.

### 4.1. Dynamic Slot Allocation (DSA)

In this section, we propose two methods to obtain the optimal frame size. First of all, we consider the delay ( $D$ ), which is the time taken by the tags to transfer their ID successfully and is defined as (1)

$$D = \text{number of retransmission} \times \text{frame size}. \quad (1)$$

Because the value of the frame size is already known after a round, we just need to find the number of retransmis-

sion to calculate the delay ( $D$ ). The probability ( $p$ ) that one tag transmits at the particular slot in a frame is  $1/L$ . Then the probability that one tag successfully transmits its ID during a slot is given by

$$P_{succ} = \frac{1}{L} \times \left(1 - \frac{1}{L}\right)^{n-1}. \quad (2)$$

And the probability that one tag successfully transmits its ID in a frame ( $L$ ) is given by

$$P_{succ,L} = \frac{1}{L} \times \left(1 - \frac{1}{L}\right)^{n-1} \times L = \left(1 - \frac{1}{L}\right)^{n-1}. \quad (3)$$

Let  $P_{succ}(k)$  be the probability that one tag transmits its ID successfully in  $k^{th}$  frame. Then  $P_{succ}(k)$  is

$$P_{succ}(k) = P_{succ,L} (1 - P_{succ,L})^{k-1}. \quad (4)$$

Using the mean of geometric distribution, the average number of retransmissions for one tag is

$$E[X = k] = \sum_{k=1}^{\infty} k P_{succ}(k) = \frac{1}{\left(1 - \frac{1}{L}\right)^{n-1}}. \quad (5)$$

Therefore, we get  $D$  from (1) and (5).

$$D = \frac{L}{\left(1 - \frac{1}{L}\right)^{n-1}}. \quad (6)$$

It now remains to derive the optimal frame size ( $L_{optimal}$ ). To calculate  $L$  when  $D$  is minimum, we differentiate (6) as follows.

$$\frac{d}{dn} D = \frac{d}{dn} \frac{L}{\left(1 - \frac{1}{L}\right)^{n-1}} = 0. \quad (7)$$

From (7), we get

$$L_{optimal} = n. \quad (8)$$

The second method to get the optimal frame size is to use the throughput of the system. The probability that no tag transmits its ID during a slot is

$$P_{idle} = (1 - p)^n. \quad (9)$$

The probability that one tag transmits successfully its ID during a slot is given by

$$P_{succ} = np(1 - p)^{n-1}. \quad (10)$$

Then, the probability that there is the collision in a slot is

$$P_{coll} = 1 - P_{idle} - P_{succ} \quad (11)$$

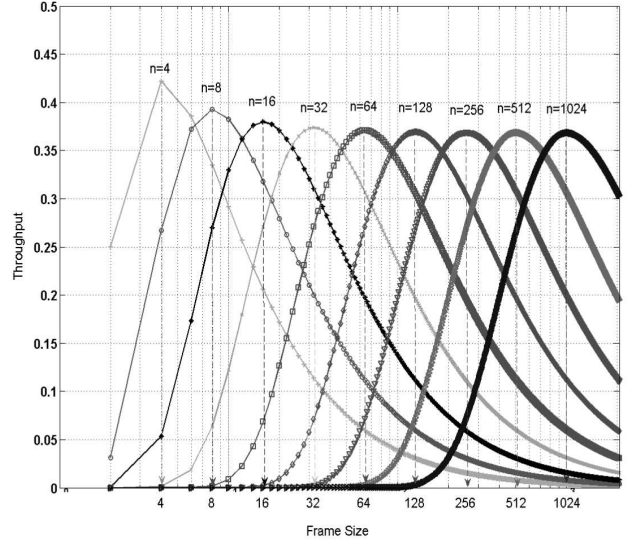


Figure 2. throughput vs. frame size

We now define throughput  $S$  as follows.

$$S = \frac{P_{succ}}{P_{succ} + P_{coll} + P_{idle}} = np(1 - p)^{n-1}. \quad (12)$$

The maximum throughput happens when

$$\frac{dS}{dp} = n(1 - p)^{n-1} - n(n - 1)p(1 - p)^{n-2} = 0. \quad (13)$$

From (13) we get

$$p = \frac{1}{n}. \quad (14)$$

Accordingly, we get the optimal frame size ( $L_{optimal}$ ) from (14) because the probability ( $p$ ) that one tag transmits at the particular slot in a frame is  $1/L$ .

$$L_{optimal} = n. \quad (15)$$

From (8) and (15) we found that the optimal frame size is the same considering the delay or throughput in a system.

Fig. 2 depicts the throughput of the system for the frame size. From Fig. 2, we can get the optimal frame size by determining the same value with the estimated number of tags.

## 4.2. Tag Estimation Method

**4.2.1. Tag Estimation Method I** Given  $L$  slots in a frame and  $n$  tags, the probability that  $r$  out of  $n$  tags transfers their ID in a slot is given by

$$P(X = r) = \binom{n}{r} \left(\frac{1}{L}\right)^r \left(1 - \frac{1}{L}\right)^{n-r}. \quad (16)$$

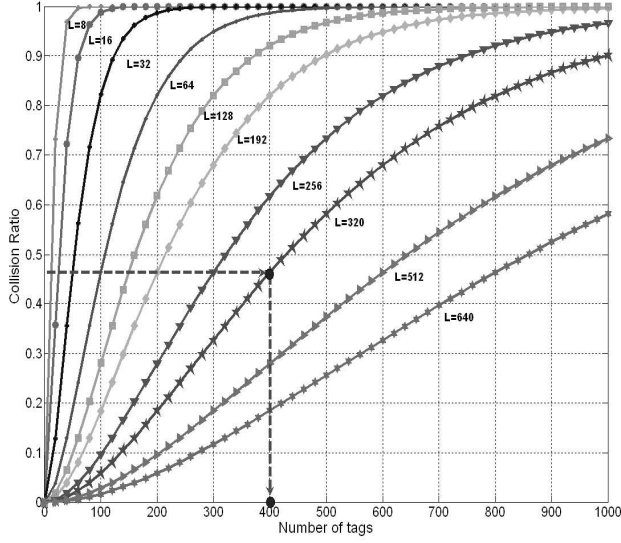


Figure 3. collision ratio vs. number of tags

The number  $r$  of tags in a particular slot is called the occupancy number of the slots[9]. The expected value of the number of slots with occupancy number  $r$  is given by

$$E(X = r) = L \binom{n}{r} \left(\frac{1}{L}\right)^r \left(1 - \frac{1}{L}\right)^{n-r}. \quad (17)$$

To estimate the number  $n$  of tags, we define the collision ratio ( $C_{ratio}$ ), which means the ratio of the number of the slots with collision to the frame size, is given by

$$C_{ratio} = 1 - \left(1 - \frac{1}{L}\right)^n \left(1 + \frac{n}{L-1}\right). \quad (18)$$

After a round, we know the frame size and the collision ratio. Based on this information, we can estimate the number of tags.

Fig. 3 shows the collision ratio for the number of tags. Let  $n_{est1}$  be the number of the tags estimated by (18). In Fig.3 if the frame size is 320 and the collision ratio is 0.46323 measured by the reader, the number of estimated tags  $n_{est1}$  is 400.

**4.2.2. Tag Estimation Method II** To obtain the number of tags ( $C_{tags}$ ) related with collision in a slot, we define the collision rate ( $C_{rate}$ ) as follows.

$$C_{rate} = \frac{\text{Prob. that there is the collision in a slot}}{1 - \text{Prob. that a tag transfers successfully}}. \quad (19)$$

From (14), we know that a system reaches maximum throughput when  $p$  is equal to  $1/n$ . Then, using (10), (11),

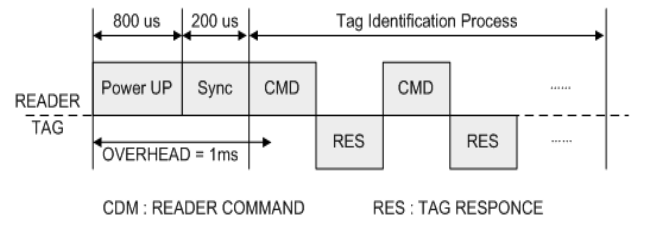


Figure 4. frame structure

and (19), we get optimal collision rate  $C_{rate}$  for maximum throughput.

$$C_{rate} = \lim_{n \rightarrow \infty} \frac{P_{coll}}{1 - P_{succ}} = 0.4180. \quad (20)$$

Using (20), the number of the collided tags in a slot  $C_{tags}$  is calculated by

$$C_{tags} = \frac{1}{C_{rate}} = 2.3922. \quad (21)$$

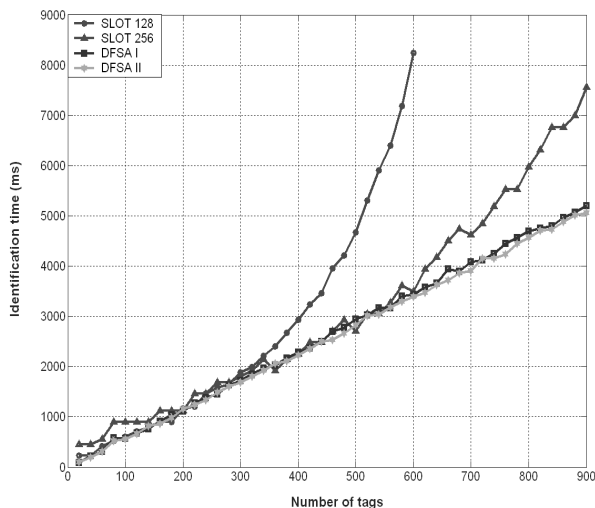
Let  $M_{coll}$  be the number of collided slots in a frame after a round and  $n_{est2}$  be the number of the tags obtained by both  $M_{coll}$  and (21). Then, the number of estimated tags  $n_{est2}$  is calculated by

$$n_{est2} = 2.3922 \times M_{coll}. \quad (22)$$

Fig. 4 shows the frame structure used for obtaining the tag identification time[6]. The algorithm is operated by the reader-driven method. It is assumed that the length of tag ID is 36 bits and there are no errors in wireless channel during the algorithm procedure.

## 5. Simulation results

Fig. 5 depicts the tag identification time for the number of tags. In Fig. 5, SLOT 128 and SLOT 256 mean conventional FSA algorithms using the fixed frame size with 128 slots and 256 slots respectively. And DFSA I and DFSA II represent the proposed DFSA algorithms using TEM and DSA. The performance of FSA algorithm varies according to the number of tags. In Fig 4, when the number of tags is in the range of 0 to 300 and the frame size is 128 (SLOT 128), FSA algorithm shows good performance. While the number of tag is more than 300, the identification time of SLOT 128 increases substantially according to the increase of the number of tags. Therefore, if FSA algorithm is used for the purpose of resolving anti-collision problem in RFID system, FSA algorithm may show the unstable performance as the number of tags increases. However, the proposed DFSA algorithms show better performance than conventional FSA algorithm regardless of the number of tags.



**Figure 5. tag identification time for the number of tags**

Although the proposed algorithms show the similar performance each other, DFSA II is better because it is easier to be implemented in the system and the complexity is lower.

## 6. Conclusion

We proposed and analyzed two Dynamic Framed Slotted ALOHA (DFSA) anti-collision algorithms using Tag Estimation Method (TEM) and Dynamic Slot Allocation (DSA) in RFID system. To derive optimal frame size, we used delay and throughput. And we used slots with collision in the system and the ratio of the number of collided slots to the frame size. We also compared the performance of the proposed DFSA algorithms with that of conventional FSA algorithm using OPNET simulation. The proposed DFSA algorithms show better performance regardless of the number of tags. Although the proposed DFSA algorithms in this paper are simple, the performance improvement is a lot. Consequently, if the proposed DFSA algorithms are used in RFID system where the ability to simultaneously identify many tags is crucial for many applications, they will contribute to improve the performance of RFID system because the reader can identify more tags with shorter time.

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