Identification of RFID Tags in Dynamic Framed Slotted ALOHA

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***Abstract*—Passive RFID tags, which have no self-battery and just backscatter the energy from a reader, share a common channel. It causes a tag-to-tag collision problem when at least two or more tags communicate to the reader simultaneously. The dynamic frame slotted Aloha (DFS-Aloha) protocol is one of the well-known anti-collision algorithms to solve this problem. To maximize the system performance and enhance the reading speed of Aloha protocols, we propose a frame-size estimator which is a modified version of Q-algorithm. To maximize the system performance, the maximum system efficiency value is used by mathematical model of DFS-Aloha. Simulation results show that the proposed estimation algorithm enhances the system performance. The proposed estimation algorithm takes less identification time than DFS-Aloha with the existing Q-Algorithm based on EPC Class 1 Generation 2 protocol.**

I. Introduction

A radio frequency identification (RFID) system has attracted considerable attention in supply markets all over the world. It is perceived as a good substitute for bar code system because RFID tags are contactless types, and they can store and modify a lot of data in their memories. Nevertheless, it has some open problems to be solved especially in passive RFID tag systems. The most critical problem among them may be interference among tags because all tags share same bandwidth, and are not able to communicate with each other. When two or more tags transmit their data simultaneously, whole messages backscattered from the tags are corrupted, which is typically called a collision problem [1].

Dynamic frame slotted Aloha (DFS-Aloha) is one of the most widely used anti-collision algorithms in RFID systems [1]-[3]. In the DFS-Aloha algorithm, each tag transmits its data in a frame at a random slot to avoid collisions. Therefore, the system efficiency strongly depends on the frame sizes and the number of tags. The DFS-Aloha varies its frame size according to the current traffic. However, since the reader cannot have any information about the number of tags to read, it needs to estimate the number of tags by observing the collision pattern of the current frame and decide the next frame size which fits for the unread tags.

Most of the recent low-cost RFID systems follow EPCglobal Class 1 Generation 2 (Gen 2) protocol that is approved as RFID air-interface standard for ultra high frequency (UHF) band (ISO 18000-6 Type C) [4]. In this protocol, the DFS-Aloha is adopted as anti-collision algorithm. Q-algorithm is used as a frame-size estimator of DFS-Aloha in Gen2. It estimates not the length but the exponent of the next frame size. The estimator is simple because it just weights to the number of collided and empty slots. However, there have been no systematic ways to find the optimum weight for the estimator. In addition, in this protocol a tag randomly selects a slot number in the frame and responds to the reader using the slot number it selected. when the number of tags is small, in this protocol, the probability of tag collision becomes higher and the time used to identify the tags increase rapidly. Most of researches on this issue have been performed by brute-force searching using computer simulation. Unfortunately, it is hard to achieve theoretical maximum performance with the results.

In this paper, we propose a simplified frame-size estimator based on Q-algorithm which uses RFID system efficiency. The proposed estimator is very similar with Q-algorithm but uses the maximum efficiency when there are large numbers of tags. To find the maximum efficiency, we make the best use of [6] which algorithm improves the efficiency of tag identification. From this, the maximum efficiency can be achieved when the number of unread tags and the frame size are approximately 36.8 percentages. Using this data, we apply to the existing Q-algorithm and make the simplified version of the Q-algorithm instead of measurement for the number of collided and empty slots. The simulation results show that the proposed estimator is compared to the existing Q-algorithm. The proposed estimator also reduces the total number of slots for DFS-Aloha and identification time of Gen2-based protocol.

The rest of this paper is organized as follows. In Section II, Gen2 protocol, its frame-size estimator, and Q-algorithm are briefly explained to compare with the proposed scheme. In Section III, we introduce how to get the maximum efficiency of RFID system and the proposed frame-size estimator. The simulation environment and performance analysis are presented in Section IV. Finally, the conclusion is remarked in Section V.

II. Gen2 Protocol and Q-Algorithm

Gen2 is a global UHF air-interface protocol standard, where the DFS-Aloha is implemented as shown in Fig. 1 and 2. A reader transmits information about a frame with 22-bit Query. It notifies a beginning of the frame and the exponent of the frame size to the tags. At every beginning of the slot, the reader transmits 4-bit QueryRep to the tags. Then, the tags generate random number ranging from 0 to (frame size-1) and count the number of QueryRep. If the counted number matches to the generated random number, the tag responds to the query of the reader. To reduce the slot time, the tag transmits 16-bit temporary ID, RN16, during its slot time. Thereby, it can save the time for collided and empty slots. If a tag successfully transmits its RN16 without error or collision, the reader sends ACK to the tag to receive desired data including 96 or 256-bit Electronic Product Code (EPC) and 16-bit CRC.

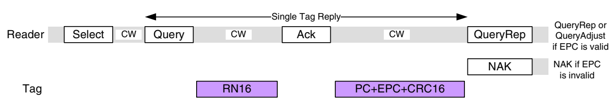

Fig. 1. Example of Gen 2 protocol for single tag reply.

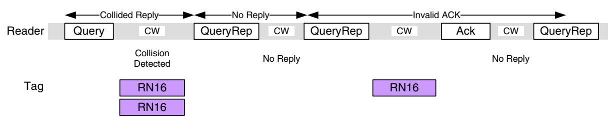

Fig. 2. Example of Gen 2 protocol.

A frame-size estimator is the most key part of DFS-Aloha because the reader is not able to know how many tags exist in its region. If the estimated frame size is too large with respect to the actual number of tags, the number of empty slots will be increased. On the other hand, if it is too small, most slots in the frame will be failed due to collision. Consequently, the imperfect frame-size estimation degrades the performance of DFS-Aloha. The Q-Algorithm introduced in EPCglobal Class 1 Gen 2 protocol is very simple estimator for DFS-Aloha unlike other estimators in [5]-[9] that requires complicate computations or large memory. The flow chart of Q-Algorithm is illustrated in Fig. 3.

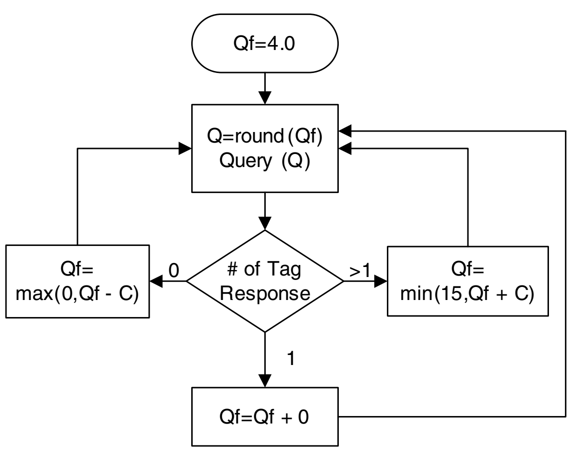

Fig. 3. Q-Algorithm in Gen 2 protocol.

Let 2^{Q_i} denote the i-th frame length, L_i, where Q_i represents the ith frame size, i.e.,

$$L_i = 2^{Q_i}. \qquad (1)$$

For Q-Algorithm, the collided or empty slots can be regarded as lack or excess of slots in the frame. Specifically, when collision occurs in the slot of the i-th frame, the Q-Algorithm increases the exponent of the i-th frame length value, Q_i. On the other hands, it decreases Q_i when the slot is empty. By doing so, if the i-th frame is finished, the exponent of the $(i+1)$-th frame length value, Q_{i+1} is determined by

$$Q_{i+1} = \mathrm{round}\left(Q_i + c\left(N_c - N_e\right)\right), \qquad (2)$$

where N_c and N_e are the respective number of collided and empty slots in the ith frame, round(x) represents the integer nearest x, and the parameter c means a bias term which plays an important role in the frame-size estimation.

Generally, the reader uses small value of c when Q is large but large value of c when Q is small. In Gen 2, c is a floating-point number ranging from 0.1 to 0.5. The lower constraint of c, i.e., $c = 0.1$, allows the estimator to escape the situation that the weighting never impact on the frame size because of its small value. For example, the frame size may not change well if the frame size is 4 and c is 0.1 even though all slots in the frame are collided or empty. In case of big frame size, however, the constraint is not necessary. Rather it restricts the performance of the estimator. Until now, although there have been several researches on the optimal value of c for the various frame sizes, most of them have been found not by systematic way but by exhaustive search with computer simulations. Thus, the estimation approach of the existing estimators may not be efficient enough, so we will introduce a new estimator using the system efficiency instead of the value c.

III. Proposed Algorithm for a Tag Identification

In this section, we propose an identification approach of RFID tags that assigns the efficient optimal system. Here the system efficiency is defined as a ratio of the slots filled with one tag to the current frame size and calculated using the number of estimated tags and the frame size in Gen2 protocol. Then the system efficiency can be calculated as follows

$$\text{System efficiency} = \frac{\text{the number of slots filled with one tag}}{\text{current frame size}}. \qquad (3)$$

By the system efficiency which is from an experience of each reader, Q-value may be replaced instead of Q-algorithm. From this, we can reduce the time of tags' identification so far from doing a change of Q-value for the estimation.

A. Calculation of the System Efficiency

Now we introduce how system efficiency changes through increasing the number of responding tags when we vary the frame size. Then, we derive a condition that will maximize the system efficiency.

In [5], the current i-th frame size, L_i, is composed of filled with one tag,N_s which is successful slots without collision, collided, N_c, and empty, N_e slots in the i-th frame. Therefore we can rewrite as follows

$$\text{System efficiency} = \frac{N_s}{L_i} = \frac{N_s}{N_s + N_c + N_e}. \quad (4)$$

In [6], when n is large, using Taylor series we can simplify the equation as follows from (4)

$$L_i \approx \frac{1 + \frac{1}{n}}{1 + \frac{1}{n} - 1} = n + 1, \ n \ >> 1. \quad (5)$$

The above equation tells us that when the number of tags and the frame size are approximately the same, the system efficiency becomes the maximum.

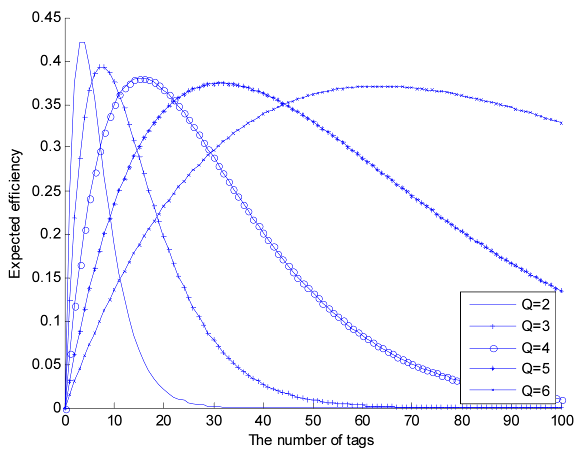

Fig. 4. System efficiency vs. frame size

Fig. 4 shows that the system efficiency as the number of tags increase when we vary the frame size. Here, we can see that the expected system efficiency can be achieved when the number of unread tags and the frame size are approximately the same and it is 36.8 percentages. To summarize, we can have the rule shown in Table I. It summarizes the optimum estimated frame length (size) for given the number of tags.

TABLE I
THE NUMBER OF UNREAD TAGS VS.OPTIMAL FRAME SIZE.

The number of tags	Optimum frame length (size, Q)
1-5	4 (2)
6-11	8 (3)
12-22	16 (4)
23-44	32 (5)
45-88	64 (6)
89-180	128 (7)
181-355	256 (8)
356-700	512 (9)
701-1420	1024 (10)
701-1420	2048 (11)

B. Enhanced Q-Algorithm

To find the optimum frame size for identified tags we should use the maximum system efficiency, because we always want to use most suitable for RFID system. To do this we need to transformation between 1 and 5 using the data which is the maximum system efficiency as follows

$$0.368 = \frac{N_s}{2^Q}. \quad (6)$$

From the above equation, we can get the Q-value that is the number of slot sizes' modulo in a frame as follows

$$Q = \ln \frac{N_s}{0.368}. \quad (7)$$

Finally we can derive the optimum modulo for a frame size responding Q-value with the number of slots filled with one tag and the maximum system efficiency. We can apply (7) to Gen2 protocol when it decides the frame size. When the reader transmits the Query at the start point of identified tags, N_s should be the average number of slots until now. Generally in the real RFID system, the reader uses to one or two environments that should have the number of tags. Therefore the average number of slots may be the optimum size for this reader. Otherwise, when the reader transmits the QueryRep to tags, N_s should be the number of successful slots before a frame. Thus, the reader's estimation approach of the efficiency estimator to be adapted in their states.

IV. NUMERICAL RESULTS

In this section, we consider a system equipped with a reader and multiple tags. The channel between the reader and the tags is considered to be ideal. It means that the error due to propagation delay, path loss, and noise is ignored. Thus, all signals from the tags are received with equal power to the reader. Here, we also assume that there are no tags that participate or go out during the inventory procedure. Identified tags are inactivated and do not attend to the next frames. The tested number of tags is increased from 0 to 1000. The frame size is chosen among powers of 2 to reduce feedback information from a reader.

Time of DFS-Aloha is measured based on Gen2 specification. Lengths of commands, temporary ID (RN16), and Q-algorithm follow Gen2 in Fig. 1 and 2. Both data rates of up and downlink are set to be 80 Kbps. Hence, the tag spends 0.2 ms (i.e., 16-bit time) for one slot time. Note that in the simulations, the initial frame sizes of all are fixed to 16.

Fig. 5 presents the performance of each algorithm when the number of tags increases from 0 to 1000. We can observe that, as the number of tags increases, for both DFS-Aloha (DFSA) and the increase methods the number of slots needed to read the tags increases exponentially while it increases linearly for the Enhanced DFS-Aloha (EDFSA) in [6] and the proposed method. As the number of tags increases, most of the slots are wasted by tag collision because compared with the frame size too many tags are accessing the slots. The proposed method, however, is the best performance that the slots are wasted among their method.

The increased methods, EDFSA and the proposed, show better performance than DFSA because the increased method

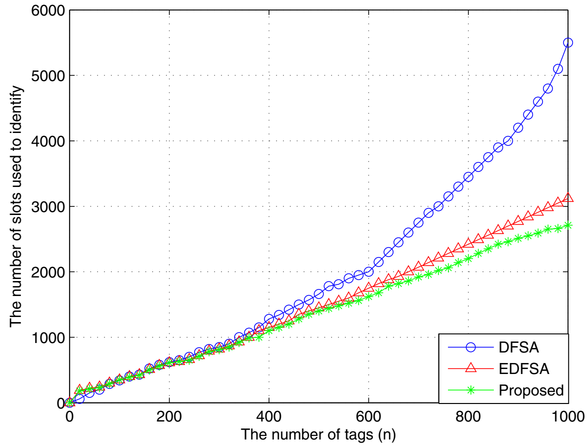

Fig. 5. The number of total required slots

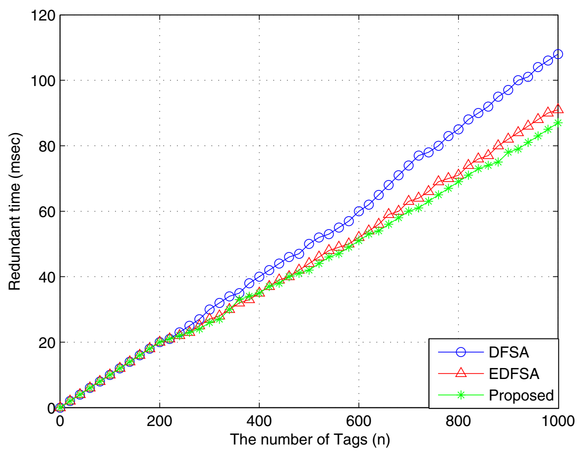

Fig. 6. Redundant time for DFS-Aloha

can decrease the frame size when the number of unread tags becomes small. To read the tags, the number of slots increases linearly as the number of tag does in the proposed method. This is because it can maintain the system efficiency to 36.8 percentages. In Fig. 5, if the number of tags becomes larger, we will be able to observe more dramatic performance improvement, because in our algorithm the number of slots needed increases linearly while it does exponentially as the number of tags increases.

Fig. 6 shows the redundant time of Gen2 protocol. It means the time to communicate between reader and tags except time for transmitting the real data (i.3. 96-bit or 256-bit EPC). Because the time for transmitting EPC is fixed for the given number of tags, the redundant time shows the information overhead of DFS-Aloha. Hence, the result does not depend on the length of EPC. As shown in Fig. 6, the proposed method reduces the redundant time of DFSA and EDFSA with the same pattern as Fig. 5.

V. Conclusion

For the RFID anti-collision algorithm, the number of slots required to read the tags increases exponentially as the number of tags increases. Q-algorithm introduced in Gen2 protocol is very simple frame-size estimator. It does not need complicate computations and large memory capacity. In Q-algorithm, weight c plays an important role for its identification speed. However, there have been no systematic approaches to find its optimum values. As a result, Q-Algorithm shows irregular performance.

The EDFSA algorithm is by estimation the number of unread tags and allowing only a fraction of tags to respond so as to give the optimal system efficiency, when the number of tags is too large for the given maximum frame size. For the proposed algorithm, we used to the result that is a data about the maximum system efficiency, 36.8 percentages. When the number of tags are too small for the given frame size, the system efficiency is not optimal. Otherwise, the algorithm then decreases the frame size so that the system efficiency can be maintained optimally. From the numerical result we can improve the performance of the proposed algorithm when we apply to the EPC Class 1 Gen2 protocol.

Acknowledgment

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