Optimal Dynamic Frame-Slotted Aloha

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***Abstract*—Passive UHF RFID systems using Dynamic Frame-Slotted ALOHA (DFSA) adjust the frame size according to the number of tags, but frame size N is equals to 2^Q and cannot be adjusted exactly to the number of tags to be identified. In this paper, we propose an optimal Aloha algorithm (ODFSA), which uses probabilistic approach for tags to access the frame. The Query or Query Adjust packet contains both the parameter Q and P called frame access probability, which represents the ratio of number of active tags in the current frame to the estimated total number of tags which remain to be identified in the system. Estimation of number of unread tags is updated after end of each frame; parameters Q and P are calculated and informed at the beginning of each frame. Mathematical analysis and computer simulations show that the proposed Aloha achieves maximum system efficiency, utilizes less number of slots compared with other algorithms and also takes less identification time.**

Keywords— Passive UHF RFID , Anti-collision, EPC global class 1 Generation2, Maximum system efficiency.

I. INTRODUCTION.

RFID (Radio Frequency Identification) is a technology which uses radio waves to identify objects. RFID systems can be classified into three categories: active, passive, and half passive tags. Passive tags take the power from radio waves of the reader and backscatter the modulated waves, without any battery, therefore achieve more attention in the future applications.

In RFID systems there can be three types of collisions [1]: reader-to-reader collision, tag-to-tag collision, and reader-to-tag collision. In this paper we will focus on tag-to-tag collision, in which multiple tags respond to the same reader at the same time.The latest RFID standard announced by IEC and later on accepted by ISO is ISO/IEC 18000- 6C, also known as EPC Global Class -1 Gen 2 [2], which adopts ALOHA-based anti-collision schemes

In this paper we propose ODFSA algorithm purely built on EPC Global class-1 Gen. 2 standards. The proposed algorithm uses probabilistic approach instead of grouping [8][9]. At the beginning of each frame, the reader sends a Query or Query adjust packet as in EPC Global Class-1 Gen.2 does, but the packet contains also a field called frame access probability, P. When a tag receives the packet, the tag generates a random value p. If $p \leq P$, the tag participates into the current frame, otherwise it waits for the next frame. Estimation of number of unread tags is updated after end of each frame, parameters Q and P are calculated and informed at the beginning of each frame. Mathematical analysis and computer simulations show that the proposed Aloha achieves maximum system efficiency, utilizes less number of slots compared with other algorithms and also takes less identification time.

The rest of the paper is organized as following. Section II is a brief introduction to EPCglobal Class 1 Gen 2 protocol along with Q algorithm. In Section III we describe the proposed algorithm and some practical. The performance analysis and simulation results are presented in Section IV and finally conclusions are in Section V.

II. EPC GLOBAL CLASS 1 GENERATION 2 AND Q- ALGORITHM

EPCglobal class-1 Gen2 is a global UHF air-interface protocol standard which uses Dynamic frame slotted Aloha (DFSA) [3]-[7] based on Q-algorithm. The Inventory operations are based on slotted Aloha collision resolution. The reader issues a 22 bit QUERY command, and each tag randomly selects a number with a range between 0 to frame size $2^Q - 1$. A tag that rolls a 0, replies immediately by issuing a 16 bit ID, RN16; all tags that roll other numbers record those numbers in a counter and wait for their turn. If a tag successfully transmits its RN16 without error or collision, the reader sends 18 bit ACK (RN16) to the tag After receiving ACK from the reader the tag sends the data including 96 or 256-bit Electronic Product Code (EPC) and 16-bit CRC. The reader, after either receiving a reply or no response, can issue a 4 bit QUERY REP command, causing all the tags to decrement their counters by 1; any tag reaching a counter value of 0 responds. Fig.1 shows the example of EPCglobal Class 1 Gen.2 Protocol [2].

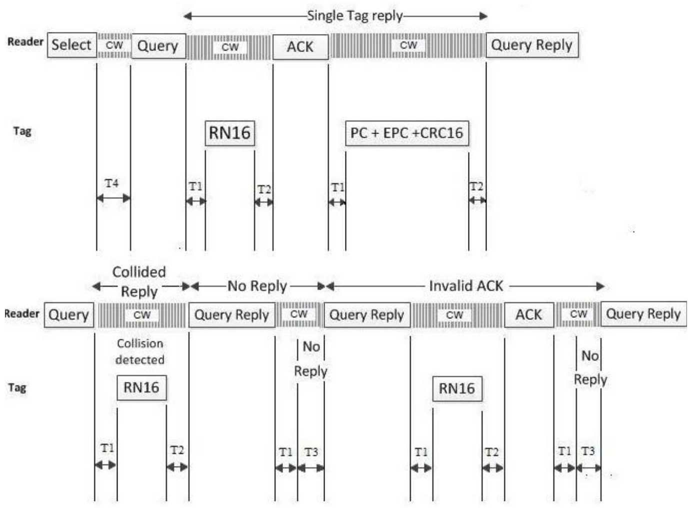

Figure 1.Example of EPC Class 1 Gen 2 Protocol

Frame sizing is the most important part of DFSA with Q-algorithm in EPCglobal class 1 Gen.2 but there are some negative sides of this protocol like, frame size cannot be linearly adjusted, an inventory round is equal to a complete set of 2^Q slots which means that Q cannot be changed even if we find extreme collision or extreme empty slots so that is why system efficiency decreases and identification time increases. The positive sides of Q-DFSA are that Q-Algorithm introduced in EPCglobal Class 1 Gen.2 protocol is very simple approach for DFSA unlike other methods with compact representation of N = $2^Q$with early end of slots using Query Reply and dynamic adjustment of Q by Query or Query Adjust compare to methods in [5]-[9] that require complicate computations or large memory.

III. THE PROPOSED OPTIMAL DYNAMIC FRAME -SLOTTED ALOHA (ODFSA)

In this section we first review the conditions for optimizing system performance, and then describe the optimal algorithms, and finally the practical considerations and implementation are included.

A. Preliminary Knowledge.

Suppose that the number of slots in a frame is N and the number of tags which access the frame is n, then the probability of k tags in one slot is.

$$C_k = \binom{n}{k}\left(\frac{1}{N}\right)^{k}.\left(1-\frac{1}{N}\right)^{n-k} \qquad (1)$$

The probability of non tag, one tag and more than one tag in one slot are respectively.

$$C_0 = \left(1-\frac{1}{N}\right)^{n} \qquad (2)$$

$$C_1 = n.\frac{1}{N}.\left(1-\frac{1}{N}\right)^{n-1} \qquad (3)$$

$$C_{>1} = 1 - C_0 - C_1 \qquad (4)$$

We define the system efficiency as the ratio of the average number of slots filled with one tag to the current frame size, that is,

$$\eta\,(n, N) = \frac{C_1 N}{N} = C_1 = n.\frac{1}{N}.\left(1-\frac{1}{N}\right)^{n-1} \qquad (5)$$

To find the maximum value of system efficiency, let $\frac{d\eta(N)}{dN} = 0$, that is

$$\frac{d\eta(N)}{dN} = n\left(-\frac{1}{N^2}\right)\left(1-\frac{1}{N}\right)^{n-2}\left[\left(1-\frac{1}{N}\right)-\left(\frac{1}{N}\right)(n-1)\right] = 0$$

If N≠ 1, we have the condition for maximum efficiency,

$$N = n \qquad (6)$$

and the maximum system efficiency is

$$\eta_{\max(n=N)} = \begin{cases} 1, & if\ N=1 \\ \left(1-\frac{1}{N}\right)^{N-1} & \text{otherwise} \end{cases} \qquad (7)$$

If N is large enough, then

$$\eta_{\max}(n = N \geq 64) = e^{-1} = 0.368 \qquad (8)$$

Table I lists the maximum system efficiency for the given values of n=N.

TABLE I.Maximum system efficiency.

n=N	1	2	4	8	16	32	≥64
$\eta_{\max}$	1	0.5	0.42	0.39	0.38	0.37	0.368

There are two conditions to achieve the maximum system efficiency. Firstly, the total number of tags to be read must be accurately estimated. We can use (2), (3) or (4) and the history record to find the number of tags which participate in the frame *i* to estimate the *n*. In this paper we assume a perfect estimation of the number of tags. Secondly how to implement n=N, that is, how to get the number of tags which participate in the current frame equal to the number of slots in the current frame of size 2^Q. The next sub-secton will answer this question.

B. Algorithm of Optimal dynamic frame-slotted Aloha (ODFSA).

The idea is very simple. At the beginning of each frame, the reader sends a Query or Query Adjust packet as in EPC Global Class-1 Gen.2 does, but the packet contains also a field of probability of tag access, P. When a tag receives the packet, the tag generates a random value p. If p ≤ P, the tag participates into the current frame, otherwise it waits for the next frame.

Suppose that P_{i-1} is the tag access probability at frame *i-1* and n_{i-1} is the estimated number of tags that participate in the frame -1 . Than the total number of remaining tags to be read in the system is,

$$n_i = \left(\frac{n_{i-1}}{P_{i-1}}\right) - N_{(succ),(i-1)} \quad (9)$$

Where the first part in (9) represents the total number of tags which either participated or did not participate in the frame $i-1$ and the second part is the number of tags that were successfully identified in the frame $i-1$.

Now we calculate Q and P in the frame i.

$$Q_i = \lfloor log_2 n_i \rfloor \quad (10)$$

$$P_i = \left(\frac{1}{n_i}\right).2^{Q_i} \quad (11)$$

Where ⌊X⌋ is the maximum integer such that ⌊X⌋ ≤ X.

Both Q_i and P_i are included in the Query or Query Adjust packet for frame i.

C. Practical Consideration.

Practically the value of the probability P is implemented as

$$\mathrm{P} = \frac{\mathrm{d}}{2^{\mathrm{m}}} \quad (12)$$

Where *m* is a predefined integer. Therefore, we have

$$d = [P.2^m] \quad (13)$$

Where [X] means round integer of X.

The m is a designed parameter. A greater m means more accuracy to the real percentage, for example, if m=8, the percent unit is $\frac{1}{256}$; if m=4, the minimum percentage is $\frac{1}{16}$. The d of $\frac{d}{2^m}$ needs m bits to be represented in Query or Query Adjust packets. Since tags already have the mechanism to implement the random number for slot selection and RN 16 generation, the mechanism can also be used to generate the random value p and compare the p with the frame access probability P.

Using formulas (10), (11) and (13) we can find the optimal pair (Q , d) and store them in a compact table of n ~ (Q , d) in the reader. Some examples are shown in Table II.

TABLE II. Various (Q , d) pair with m=4,6,8.

No. of tags (n)	m = 4	m = 6	m = 8
:	:	:	:
:	:	:	:
18	(4,14)	(4,57)	(4,228)
19	(4,13)	(4,54)	(4,216)
20	(4,13)	(4,51)	(4,205)
21	(4,12)	(4,49)	(4,195)
22	(4,12)	(4,47)	(4,186)
:	:	:	:
:	:	:	:
257	(8,16)	(8,64)	(8,255)
258	(8,16)	(8,64)	(8,254)
259	(8,16)	(8,63)	(8,253)
260	(8,16)	(8,63)	(8,252)
261	(8,16)	(8,63)	(8,251)
:	:	:	:

IV. Performance Analysis.

In this section, we make assumptions that all the parameters fit in the EPC class-1 Gen 2. All the tags to be read are static and in the radio range of the reader. Near-far-effect, mobility, channel noise and interference are not in the consideration. Tags that have been successfully identified become inactive and only one reader is involved in the process.

Fig.2 and Fig.3 show the relationship between system efficiency and percentage accuracy that is the parameter *m*. It is found that the maximum system efficiency can be achieved if m is greater or equal to 6. If m=4, the system efficiency is very close to the maximum value.

Fig.4 presents the average total number of slots needed to identify the tags in various algorithms. We can see that in case of ODFSA with m=4 the number of slots needed increase linearly with the number of tags. Our proposed ODFSA algorithm requires less number of slots to identify all the tags. ODFSA approaches to optimal performance as the probability level increases and approaches to Q. From the graph when the number of tags is 1000, ODFSA algorithm in comparison with Q-DFSA, DBQ-DFS, EDFSA and IDFSA, saves about 2600, 300, 200 and 100 slots respectively.

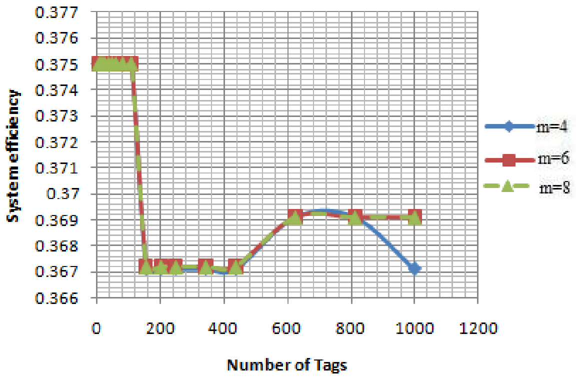

Figure 2.System efficiency vs. Number of tags with m=4,6,8.

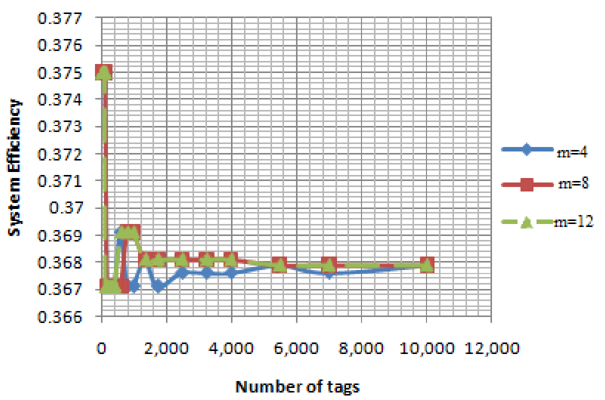

Figure 3.System efficiency (n= 0 ~ 10,000) with m=4,8,12

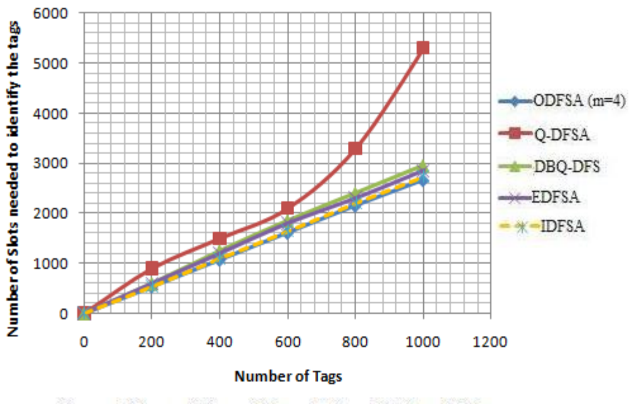

Figure 4.Number of slots need to identify the tags

Fig.5 shows the identification time required to identify all the given number of tags in the system. ODFSA reduces the time to identify the tags compared with Gen.2 based Q-DFSA

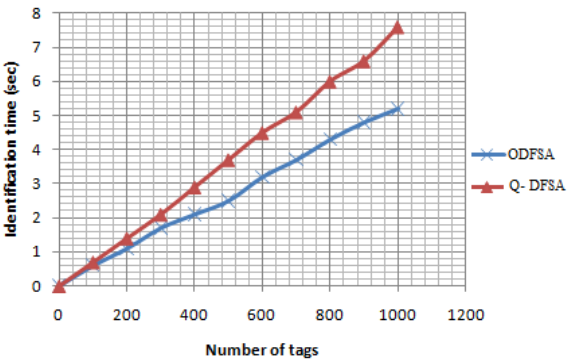

Figure 5.Identification time comparison.

V. CONCLUSION

Conventional Aloha-based RFID anti-collision algorithms mainly follow two techniques to identify the tags whether they may adjust the frame size or use equal grouping approach. Our algorithm is purely based on Gen.2 standard and uses probabilistic approach in order to achieve maximum system efficiency. This algorithm shows better performance of system efficiency and identification time, compared to other existing approaches. Since tags already have the mechanism to implement the random number for slot selection and RN 16 generation, the mechanism can also be used to generate the random value for probabilistic access. In addition, even if some tags have the same EPC code, the probability approach provides a chance to distinguish them. This algorithm might be used in EPCglobal Class1 Gen.2 to improve the performance with a little protocol change.

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