Scrutinizing Behavior of a Dynamic Framed Slotted Anti-collision Algorithm for RFID Systems

Xu Huang
School of Information Sciences and Engineering, University of Canberra
Canberra, ACT, 2601, Australia
Xu.Huang@canberra.edu.au

***Abstract*— Radio frequency identification systems with passive tags dramatically increase the ability of an organization to acquire a vast array of data about the location and properties of any entity that can be physically tagged and wirelessly scanned within certain technical limitations. However, if multiple tags are to be identified simultaneously, messages from the tags can collide and cancel each other out. One of the popular anti-collision algorithms is the ALOHA-type algorithm, which is simple and has good performance when the number of tags to be read is reasonable small. In this paper we extended our previous research [8, 17] to build a more efficient dynamic framed slotted ALOHA for passive tags in RFID systems under the condition titled "maximum efficiency" [8]. Also the behavior of the ALOHA for RFID passive tags is investigated, which facilitates the future relevant research projects.**

Keywords- RFID, passive tags, identifaction, anti-collision, ALOHA, efficient dynamicslotted frame

I. Introduction

Organizations utilize modern information systems (IS) to acquire, interpret, retain, and distribute information [1]. Technological innovations in information technology (IT) continue to improve the cost-performance capabilities of organizations to perform these four basic IS tasks. Intelligent agents and knowledge management systems allow managers to interpret data and information to create useful managerial knowledge [2-3]. Technical improvements in storage media allow firms to amass vast data warehouses, while ever increasing processing power allows managers to mine their data for useful information about their operations, existing customers and potential markets. Further, advances in technology-based real-time information gathering and decision support systems promote real-time decision making that allow organizations to refine their operational performance.

Recently RFID (radio frequency identification) has attracted considerable attention as an alternative to the bar code in the distribution industry, supply chain and banking sector. This is because RFID system that has the advantage of being contact-free and can hold more data than the bar code. However, if more than one tag responds to the reader, their responses can collide on the RF communication channel, and thus cannot be received by the reader. This is referred to as the "tag-collision", one of the most significant limitations of RFID systems [4-7].

Researchers have been addressing this problem in various ways; some methods seem to increase data transmission speed by extending the frequency bandwidth to increase tag identification efficiency via minimizing tag collisions. This is not a very satisfactory solution as the frequency band will always be limited. The most widely used techniques are the framed slotted ALOHA algorithm and binary search algorithm. Since it is simple implementation, the framed slotted ALOHA algorithm is the most frequently used [7, 9]. For example, Type A of ISO/IEC 18000-6 and 13.56 MHz ISM ban EPC Class 1 uses the Framed Slotted ALOHA algorithm and Type B of ISO/IEC 18000-6 and 900 MHz EPC Class 0 uses the binary search algorithm.

As most RFID systems use passive tags, frame sizes are limited in the framed slotted ALOHA algorithm [12-15, 17]. In this algorithm, 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 method, the probability of tag collision is low, so the time used to identify the all tags is relatively short. But as the number of tags increases, the probability of tag collision becomes higher and the time used to identify the tags increases rapidly. Su-Ryun et al. [10] raised an enhanced dynamic framed slotted ALOHA algorithm for RFID tag identification to obtain a slot efficiency of more than 85% for about 1000 tags with frame size up to 256 slots. Huang presented [8, 17] a close mathematic form and showed the method presented in [10] becomes a special case of [8, 17].

In this paper we first extend the results obtained [8, 17] from the case of a very large number of passive tags in an identification RFID system, based on dynamically maintaining maximum efficiency in the whole identification process. We shall also discuss and correct the problems and mistakes shown in the analyses in [11]. The final simulation results show that our method significantly improves the "identification time" in comparison with the other two discussed methods in this paper.

II. Improved Enhanced Dynamic Framed Slotted ALOHA Anti-collision algorithms

There are many papers discussing various framed slotted ALOHA anti-collision algorithms, including dynamic ones [8-15]. Generally, in the framed slotted ALOHA anti-collision method, the system efficiency decreases as the number of responding tags becomes larger. Following the paper [8, 17], assume that the reader uses a frame size of N slots and the number of responding tags is denoted by n. The probability

 Manuscript received May 1, 2007; revised October 28, 2007

that k tags exist in one given slot is a binomial distribution as below:

$$P(X = k) = \binom{n}{k} (p)^k (1-p)^{n-k} \quad (1)$$

Where X is random variable, p is a success probability. Since we are looking at one slot of the frame for the responding tag and every slot in a frame has equal probability to get the responding the tag means that we have $p = 1/N$. Thus we highlight the binomial with "B" having

$$B_{n,\frac{1}{N}} = \binom{n}{k} \left(\frac{1}{N}\right)^k (1-\frac{1}{N})^{n-k} \quad (2)$$

Therefore, the expected number of tags read during one read cycle is given by the following, where we are focusing on one tag responding:

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

Where, $a_k^{N.n}$ denotes the number of slots with k tags with the frame size of N and n unread tags. Therefore, following the definition of the system efficiency given in [8], we have

$$\text{system efficiency} = \frac{\text{the number of slots filled with one tag}}{\text{current frame size}} = \frac{a_1^{N,n}}{N} \quad (4)$$

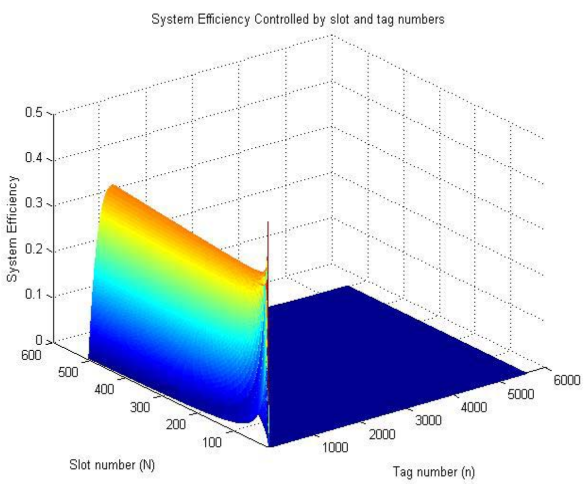

Figure 1: How the system efficiency is controlled by the unread tag number and the slot number.

To find the optimum condition for the unread tag number, n, in a system, we may let $d(a_k^{N.n})/(dn) = 0$, and from equations (3) and (4) we obtained:

$$n = -\frac{2\ln 2}{\ln W}, \quad \text{with } W = 1 - \frac{1}{N} \quad (5)$$

If we set $N = 256$, as the number presented in [10], we have $n = 354$, which comes from equation (12) in [10]. Figure 1 shows how the system efficiency is controlled by the two parameters, N and n as demonstrated in [8, 17].

If the number of tags is very large then the optimum system efficiency is about 35.5% for all the N and n as illustrated in Figure 1. We may keep this optimum system efficiency for all the frames when the tag numbers are so large such that they can be divided into multi-frames. Now we have an *i*mproved *e*nhanced *d*ynamic *f*ramed *s*lotted *A*LOHA (IEDFSA), namely we can use the previous information to estimate the unread tag number and make a decision in the beginning or we can use the optimum condition as the first reading and establish read information for the next step. Then, we keep the optimum condition as threshold to build a frame if there are a large number of tags (grouping the tags). If the numbers of tags are not so large, we can return to the method described in [8, 17].

III. Efficient dynamic framed slotted ALOHA for RFID passive Tags

Before we establish our efficient dynamic framed slotted ALOHA algorithm, let's have a look at the system efficiency with different frame sizes defined by equation (4) where we have picked five sizes, namely N $\in$ {32, 64, 128, 256, 512} shown in Figure 2.

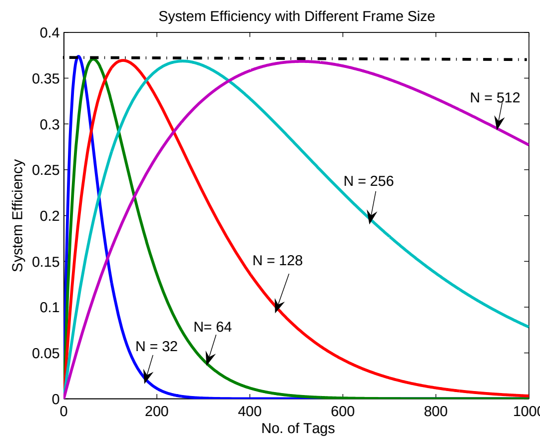

Figure 2: System efficiency with different frame size, N $\in$ {32, 64,128,256, 512}

It is important to note the dashed line at the system efficiency of 35.5% in Figure 2, which we can maintain while we dynamically change the frame size.

Now we need to establish a method to decide the frame size, in terms of the slot number N. If we know the unread tag number after the previous round, n. The first thing needs to be done is to determine the condition for which the system maintains its maximum efficiency. From equations (4) and (5), we have the following relation:

$$\frac{d}{dN}(\frac{a_1^{N,n}}{N}) = \frac{d}{dN}[N \cdot n \cdot (\frac{1}{N})(1-\frac{1}{N})^{n-1}] = 0 \quad (6)$$

which reduces to the condition $N \sim n$ as we expected. Since this would be the condition that maintains maximum efficiency. In fact we can re-write the relation equation (5) for n as follows:

$$N = \frac{1}{1 - e^{-\frac{2\ln 2}{n}}} \quad (7)$$

This relation shows that if n is known we can obtain the related value of N that keeps the system at maximum efficiency. Figure 3 shows this relationship.

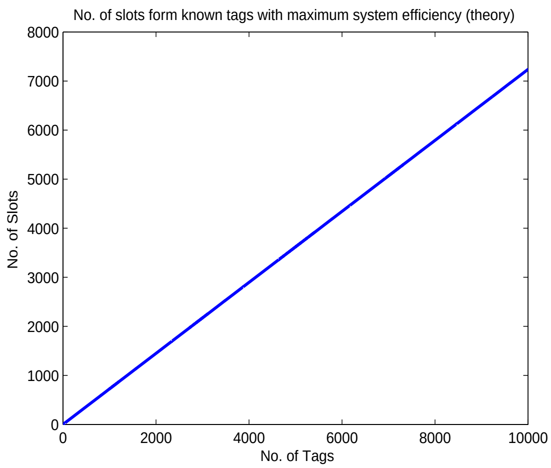

Figure 3: The relationship between the number of unread tags and the related frame size, in terms of the slot number.

Now we are going to investigate the method of determining the number of unread tags in an RFID passive system. Following the definition given by the paper [11], we have the collision ratio, C_{ratio}, as the ration of the number of the slots with collision to the frame size. As we know that [16] for the system we have discussed, there are three states at any time slot namely: 1. idle state that the system does not transmit at all (only ready state); 2. transmitting but failed with collision; 3. transmitting and successful. We statistically have the relation as follows:

$$P_{\text{idle}} + P_{\text{coll}} + P_{\text{succ}} = 1 \quad (8)$$

where P_{idle} = the probability of the system state being at idle, P_{coll} = the probability of the system transmitting but failed with collision; and P_{succ} = the probability of the system transmitting and successful.

If we assume that a probability that one tag transmits at a particular slot in a frame is p. We have the following equations:

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

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

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

Therefore, we have the mathematical expression for the collision ratio as follows:

$$C_{\text{ratio}} = \frac{P_{coll}}{N} \quad (12)$$

Substituting equations (9), (10), and (11) into equation (12), we have:

$$C_{ratio} = \frac{1}{N}[1 - (1 - \frac{1}{N})^n (1 + \frac{n}{N-1})] \quad (13)$$

It is worth noting that in [11] in their equation (18) the factor of inverted slot number was missed, increasing the collision ratio by a factor of N. The relationship between the collision ratio and the number of tags is shown in Figure 4, where the $N \in \{32, 64, 128, 256, 312\}$.

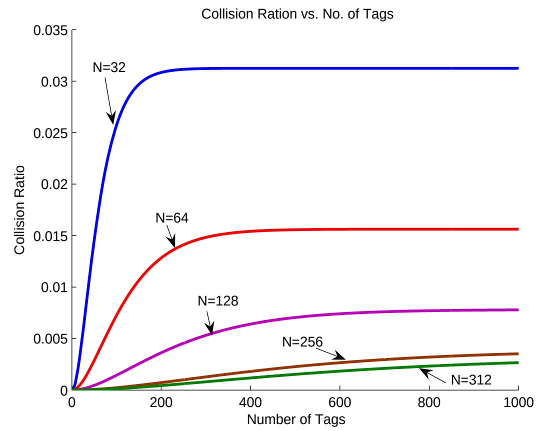

Figure 4: Collision ratio in an identification RFID passive system with various frame sizes N ∈ {32, 64, 128, 192, 256, 312}.

We can use equation (13) to identify the number of unread tags after the round just completed, since the used frame size, in terms of slot number, was used that must known. Or we can checked by the just completed round, the collision ratio should be known as well, say $C_{\text{ratio}} = 0.4$, which means that 40% of the last reading processing is in the collision state. If we used the frame size in the just completed round is N = 128 slots, we have about 180 unread tags (or if we used N = 256 slots for the frame size we just used, we have 360 unread tags). Therefore we have the unread tags from the just running. In terms of theory, we can obtain the following frame size from the relation shown in Figure 3. However, it is noted that in particle a frame size should be limited by other parameters in the system, such as the latency time, which highly depends on the frame size. If we take the frame size is too large we shall have very large time delay on the other hand, if we take too small of the frame size we shall have the collision problem. Therefore we need to used the obtained number to equation (7) and obtain the corresponding frame size. Here we use the word "corresponding" means that even we have 1000 unread tags, as an example. We may use $\forall N \in \{32, 64, 128, 192, 256, 312\}$ depends on the operating system. Then we can keep the system in maximum efficiency (~35.5%) to decide the next round frame size.

IV. SIMULATION RESULTS

We used the frame structure as shown in [16] to obtain the tag identification time. 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 the wireless channel during the algorithm procedure. The simulation results are shown in

Figure 5. We have used from zero to 900 tags. There are three cases with three different algorithms as follows:

1. Identification is run for a fixed frame size with slot number equal to 128, namely "frame = 128 slots" in Figure 5.
2. Identification is run for a fixed frame size with slots number equal to 256, i.e. "frame = 256 slots" in Figure 5.
3. Identification is run by our "efficient dynamic framed slotted ALOHA (EDFSA) algorithm, namely "dynamic frame" in Figure 5.

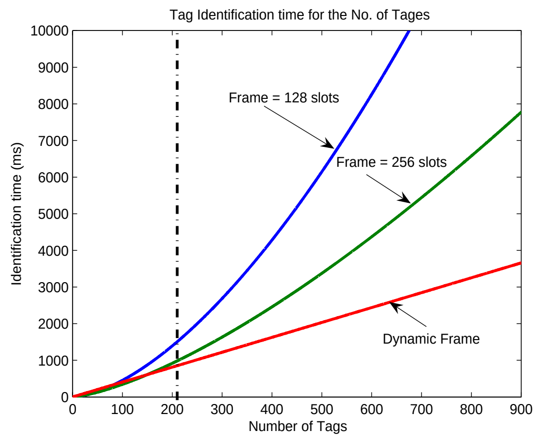

Figure 5: The simulation results with three different algorithms

We can clearly see, in Fig5, that when the number of tags is less than about 200, there are no significant differences between the three algorithms. This is because the number of tags is small enough to be handled by those algorithms. In fact the case with frame = 128 slots, is starting to be harder to handle. When the number of tags is increased, the differences between the algorithms become obvious. The identification time for the "dynamic frame" algorithm shown in Figure 5 is linearly proportional to the number of tags, which makes it the most efficient because it varies the frame size on a "round" by "round" basis corresponding to the unread tags determined in the previous round.

V. Conclusions

We have carefully investigated and established a dynamic framed slotted anti-collision algorithm for passive tags in RFID systems under the maximum efficiency obtained in our previous paper [8]. Also the behavior of the ALOHA for RFID passive tags is presented, which facilitates the future relevant research projects. The results from the three cases were investigated as shown in Figure 5. It is worth noting that we have use the "identification time" as a quantitative criterion to the "efficient" behavior of an algorithm. The algorithm of the "dynamic frame" always obtained better results than others as shown in Figure 5.

References

[1] G. P. Huber, "Organizational Learning: Contributing Processes and the Literatures," Org. Sci., vol. 2, no. 1 pp88-115, 1991.

[2] V. Standford, "Pervasive Computing Goes the Last Hundred Feet with RFID Systems," IEEE Perv. Comp. April-May 2003.

[3] R. Angeles, "RFID Technologies: Supply-Chain Applications and Implementation Issues," Info. Sys. Mgmt. , Winter pp51-65, 2005.

[4] C. A. Thompson, "Radio Frequency Tags for Identifying Legitimate Drug Products Discussed by Tech Industry," Amer. J. Health-Sys. Pharm., 61, 14. July 15, pp1430-1431, 2004.

[5] G. Yang and S. I. Jarvenpaa, "Trust and Radio Frequency Identification (RFID) Adoption within an Alliance," In R. Sprague (Ed.), Proc 38th Hawaii Intl. Conff. Sys. Sci., Big Island, HI, January, pp855-864, IEEE Comp. Soc. Press. Los. Alamitos, CA, USA. 2005.

[6] P. Singer, "A new Approach to Low Cost RFID Tags," Semiconductor Intl., Feb. 2005.

www.reedelectronics.com/semiconductor/article/CA499653?pubdate=2%2F1%2F05

[7] E. K. Clemons and Y. Wang, "Special Issue: Tchnology Strategy for Electronic Marketplaces," J. Mgmt. Info. Sys. vol 17, no.2, pp.5, 2000.

[8] Xu Huang, "An Imporoved ALOHA Algorithm for RFID Tag Identification," to be published in the Proceeding of the KES2006, the 10th International Conference on Knowledge Based & Intelligent Information & Engineering Systems, Bournemouth, UK, 9-11 October 2006.

[9] K. Finkenzeller. RFID handbook. 2nd edition. John Wiley & Sons, 2003.

[10] Su-Ryun Lee, Sung-Don Joo, and Chae-Woo Lee, "An Enhanced Dynamic Framed Slotted ALOHA Algorithm for RFID Tag Identification," The Proceeding of the 2nd Annual International Conference on Mobile and Ubiquitous Systems, 2005.

[11] Jae-Ryong Cha and Jae-Hyun Kim, "Novel Anti-collision Algorithms for Fast Object Identification in RFID System", Proceeding of the 2005 11th International Conference on Parallel and Distributied Systems.

[12] R. Rom and M. Sidi, "Multiple Access Protocols/Performance and Analysis." Springer-Verlag, pp47-77, 1990.

[13] H. Vogt. Efficient, "Object Identification with Passive RFID Tags," Proc. Pervasive pp.98-113, 2002..

[14] J. E. Wieselthier, A. Ephermides, and L. A. Michels, "An exact Analysis and Performance Evaluation of Framed ALOHA with Capture," IEEE Tans. on Communications. 37(2), pp125-137 Feb. 1989.

[15] H. Vogt., "Multiple Object Identification with Passive RFID Tags," 2002 IEEE International Conference on Systems, Man and Cybernetics. 2002

[16] ISO/IEC 18000-6:2003(E), part 6: Parameters for air interface communications at 860-960 MHz, Nov. 26, 2003.

[17] Xu Huang and Son Le "Efficient Dynamic Framed Slotted ALOHA for RFID Passive Tags," IEEE the 9th Imnternational Conference on Advanced Coimmunication Technology (ICACT 2007), Feb. 12th - 14th, Korea, 2007. IEEE Catalog Number 07EX1671, Proceedings Vol. I, pp.94-97.