

# An Efficient Scheme for Multiple Access in a RFID System

**Wen-Tzu Chen**

Institute of Telecommunications Management  
National Cheng Kung University  
Tainan, Taiwan  
wtchen@mail.ncku.edu.tw

**Guan-Hung Lin**

Institute of Telecommunications Management  
National Cheng Kung University  
Tainan, Taiwan

**Abstract** - *In this paper, we present an anti-collision scheme in a RFID system. The scheme is based on dynamic framed ALOHA protocol developed for radio networks. In our scheme, we propose a method to estimate the number of tags and derive the optimal frame length. Simulation results indicate that the error of our tag estimate method can be less than 1%. The total number of time slots for reading all tags is about 4 times of the number of tags needed to be read, including acknowledgement time slots. The main advantage of our scheme is the easy implementation for both readers and tags.*

**Keywords:** anti-collision, RFID, framed ALOHA

## 1 Introduction

In a RFID system, when numerous tags are present in the interrogation zone of a single reader at the same time, the system requires a multiple-access scheme that allows the reader to read data from the individual tags. A technical scheme that handles multi-access without any interference is also called an anti-collision protocol. In reality, a reader is a powerful device having sufficient memory and computation power. On the other hand, a tag is usually a passive object and requires energy from the radio signal radiated by reader. The reader initiates reading process by broadcasting periodically a request command to the tags. Each tag can send its ID to the reader while it receives a request. If only one tag responds, the reader can receive the tag's ID. When more than two tags send its ID simultaneously, a collision occurs and the IDs need to be retransmitted according to an anti-collision scheme. The primary concern in anti-collision scheme is how to read multiple tags as fast and reliably as possible [1].

There are two main types of anti-collision algorithms in RFID systems: deterministic and stochastic models. Deterministic model resolves collisions by muting subsets of tags that are involved in a collision [1]-[3]. Successively muting larger subsets will finally lead to successful transmission of a tag's serial number. Binary tree and query tree algorithms are the two main methods for deterministic model. Stochastic model is often based on an ALOHA-like protocol in which the tags send their data at a random time period. When collisions occur, the tags that are involved in collisions retransmit their ID in the next

read cycle. The main advantage of deterministic model is its effectiveness that means all tags can be successfully read even when the number of tags is huge. However, it may spend much time to read all tags. Also, the tags require more complex circuits and memory, especially for the binary tree algorithm. On the other hand, the stochastic model, in general, can fast complete reading, but still has a probability of failing to read all tags in a limited time period. When the number of tags is not extremely large, the stochastic model is more efficient.

In [4], the author provided the foundation of applying framed ALOHA protocol to RFID systems and described the mechanism of how the protocol overcomes collisions. However, detailed descriptions of how to implement the protocol were not discussed. In [5], Vogt presented an anti-collision scheme through the use of framed ALOHA. His scheme can be implemented in the "I-code" system developed by the Philips Semiconductors. The author used a Markov process to optimize the frame size and to determine the number of read cycles for a given assurance level. To our knowledge, the Markov process may increase time consumption. Also, a tag that has successfully sent its ID may retransmit in the later read cycles. These duplicate transmissions reduce the reading performance.

In this paper, we present a more efficient scheme to overcome the anti-collision problem in a RFID system. Our scheme is based on the dynamic framed ALOHA protocol. An acknowledgement mechanism is designed to ensure the successful receptions and to disable the successfully transmitted tags. The mechanism can improve the read performance at the expense of the required time for the acknowledgements. We also provide a method to estimate the number of tags and derive the optimal frame length. The exact solution for the well-known occupancy problem [6] is applied to the development of our scheme. One of the advantages of our proposed scheme is that it is easy to be implemented in both reader and tag. Extensive simulations are performed to verify the availability and reliability of the proposed scheme.

## 2 System model

Our proposed anti-collision scheme for RFID is based on the dynamic framed ALOHA protocol where the frame length is variable. In order to apply the framed

ALOHA protocol to RFID multiple access, the protocol needs to be revised according to the specific characteristics of RFID. Tags in a RFID system are frequently passive devices and have limited resources such as memory and computation power. Readers, therefore, must dominate the multiple-access scheme. In our proposed scheme, readers must estimate the number of tags based on idle or collision information and must determine an optimal frame length for the next read cycle. The main operation of a tag is that it randomly selects a transmitting time slot based on a frame length received from the reader, and then sends data to the reader at the selected time. Such operation does not require extra memory or complex circuit.

In our protocol, a read cycle consists of three primary steps.

Step 1: The reader initiates a read cycle by broadcasting a request command to all tags under the reader's coverage. This request command also includes a dynamic parameter  $N$ , called frame size by which every tag generates a random number for transmission.

Step 2: Based on the frame size receiving from the reader, each tag generates a random number  $x$  uniformly distributed with the range from 1 to  $N$ , and transmits its ID at the  $x$ -th time slot.

Step 3: The reader sends acknowledgements to the tags whose ID has been successfully received. These acknowledgements are also used to disable the tags such that they can not respond the read request command in the next read cycle.

After complete a read cycle, the reader forecasts the number of tags according to the information of collisions or successful transmissions. Then, a new frame length depending on the number of tags is transmitted by the request command in the next read cycle. The read process will stop when there is no collision in a read cycle.

The acknowledgement command must consist of a payload used to store tag's ID. For simplicity, we assume that the interval of an acknowledgement command equals to a time slot. Thus, the total number of required time slots for all the acknowledgements is equal to the number of successfully transmitted tags.

An example shown in Fig. 1 illustrates the process of our proposed anti-collision scheme. In this example, we assume 4 tags need to be read, and the initial frame length is 4. In the first read cycle, the reader sends a request command together with an argument 4 as the frame length. Tags 1 and 3 transmit their ID in time slot 2. The transmissions cause a collision because they occur at the same time slot. Tags 2 and 4 send their ID in slots 4 and 3, respectively. Therefore, they can be successfully identified by the reader because the two slots are singly occupied. After successfully receiving the IDs, the reader sends acknowledgements to tags 2 and 4, and uses these acknowledgements to disable the two tags. Since a collision occurs in time slot 2, this case implies that there

exists at least one tag needed to be read. Hence, another read cycle is required. The second cycle uses a new frame size and completes the reading of all tags because no collision occurs in the cycle.

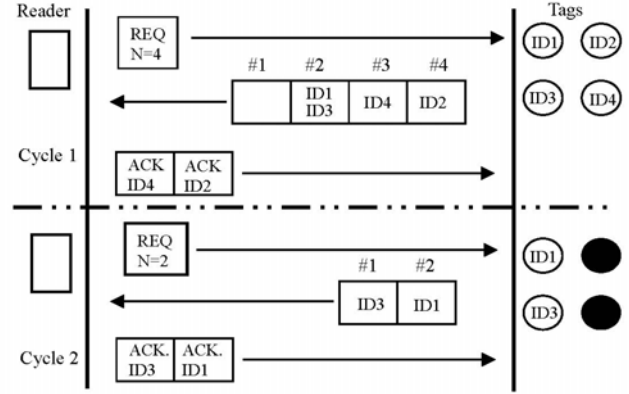


Fig. 1 Anti-collision process with dynamic framed ALOHA protocol.

For a given time slot, there are only three possible outcomes: idle, successful transmission, and collision. The channel is idle if no tag transmits its ID in the time slot. Successful transmission means exactly one tag sends its ID. If more than two tags transmit in the same time slot, the reader suffers from collision and no tag can be read. After finishing a read cycle with frame size  $N$ , the reader can observe  $E$  empty slots,  $S$  successful slots, and  $C$  collision slots, where  $E+S+C=N$ . After a read cycle, the reader estimates the number of unread tags according to the triple,  $(E, S, C)$ . Then, the reader determines an optimal frame length for next read cycle if necessary.

The analysis for the anti-collision problem can be divided into two primary parts. The first part is how to estimate the number of tags according to the triple  $(E, S, C)$ . Since at least two tags are involved in a collision, a lower bound on the estimate of the number of tags is  $S+2C$ . However, more precision estimates are required to improve tag estimate performance. The other part is to determine an optimal frame size to achieve maximum channel efficiency while the number of unread tags is forecasted. Both of the two parts must be performed by the reader and are critical to the performance of anti-collision protocol.

The allocation of  $n$  tags into  $N$  time slots is equivalent to the well-known occupancy problem. Feller [6] presented a solution to determine the probability of finding exactly  $m$  boxes (slots) occupied by exactly  $k$  balls (tags). The probability is

$$P(k, m) = \frac{(-1)^m N! m!}{m! N^n} \sum_{j=m}^{\min(N, \lfloor n/k \rfloor)} (-1)^j \frac{(N-j)^{n-jk}}{(j-m)!(N-j)!(n-jk)!(k!)^j} \quad (1)$$

where the notation " $\lfloor \cdot \rfloor$ " denotes the largest integer less than or equal to its argument. Based on the exact solution of the occupancy problem, we develop tag estimate schemes and derive the optimal frame size.

We focus on the probability of finding  $E$  empty time slots after completing a read cycle. Let  $k=0$  and  $m=E$  in (1). Then we have

$$P(E) = \frac{(-1)^E N! n!}{E! N^n} \sum_{j=E}^N (-1)^j \frac{(N-j)^n}{(j-E)!(N-j)!(n)!} \quad (2)$$

After getting the estimate on the number of unread tags, it is important for the reader to determine an optimal frame size for the next read cycle. Too small frame size increases collision probability. Then, plenty of retransmissions are required and result in inefficient performance. On the other hand, too large frame size may produce a lot of idle slots, and thus decrease channel throughput. Proper frame length can be derived from either throughput or channel usage efficiency.

Consider the exact probability of the occupancy problem mentioned before. Replacing  $k$  by 1 in (1), we have the probability of finding exactly  $m$  slots occupied by exactly one tag

$$P(m) = \frac{(-1)^m N! n!}{m! N^n} \sum_{j=m}^{\min(N, n)} (-1)^j \frac{(N-j)^{n-j}}{(j-m)!(N-j)!(n-j)!} \quad (3)$$

The expected value of the number of successful transmission slots is given by

$$E(m) = \sum m \cdot P(m) \quad (4)$$

The channel usage efficiency is defined as the expected value divided by the frame size

$$U = E(m)/N \quad (5)$$

For a given tag number, we want to determine a frame size  $N$  such that the usage efficiency has maximum value. This frame size can be obtained by numerical computation.

### 3 Results

Equation (1) provides a foundation for the first tag estimate method we proposed. For example, if we have a frame length of 16 and observe 8 empty slots in a read cycle, we can use (1) to calculate the probability of finding 8 empty time slots versus the number of tags. The probability is shown in Fig. 2. The maximum probability occurs at  $n=10$ . Hence, we estimate the number of tags as 10 in this case.

Fig. 3 shows our tag quantity estimates for different number of empty slots ( $E$ ). Note that when  $E$  is close to zero, this situation implies that the tag quantity is too many to find any empty slot. In this case, the estimate for the number of tags is significantly high. In contrast, large  $E$  implies there are few tags in the reader's coverage.

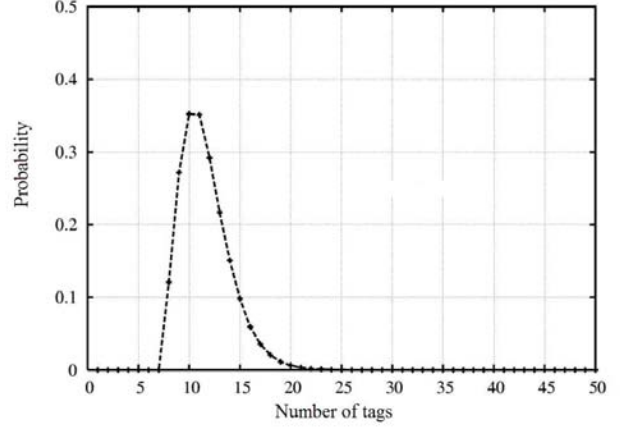


Fig. 2 Probability of finding 8 empty time slots for  $N=16$ .

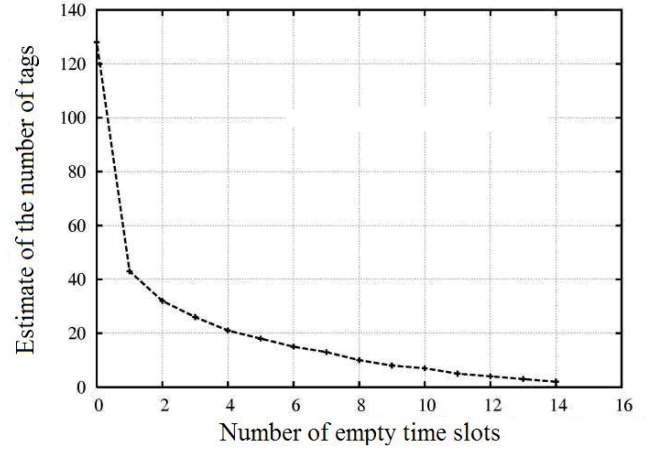


Fig. 3 Tag estimate through the use of the maximum probability of finding empty slots, when  $N=16$ .

In order to examine the performance of the proposed anti-collision scheme, we also carry out extensive simulations with C++ code. The initial frame length is set to be 16 slots. Fig. 4 presents the error for estimating the number of tags. The results indicate that our method has estimate error about 1%. Although the method uses only one element,  $E$ , in the triple  $(E, S, C)$ , it can still gain lower estimate error. This considerable low error can facilitate the operation of RFID anti-collision with satisfied precision. The use of lower bound in tag estimates, however, causes higher error when the number of tags is considerable large as compared with the frame length. The lower bound method represents a conservative but simple estimate.

Fig. 5 shows the channel usage efficiency for various frame lengths. We observe that the maximum efficiency occurs when the frame length equals the number of tags. Hence, in our scheme, we set the frame length for the next read cycle, if necessary, to be the estimate number of unread tags.

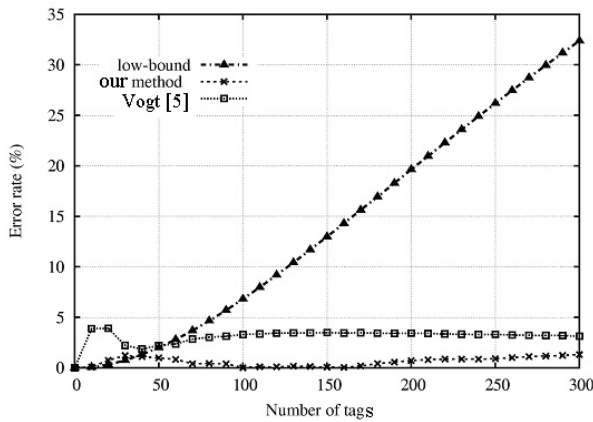


Fig. 4 Simulation results for tag estimate error.

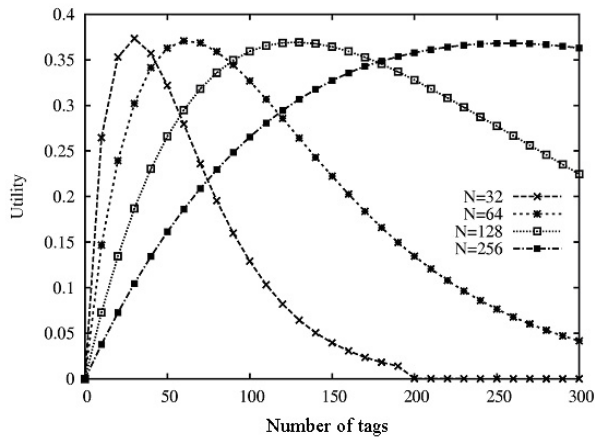


Fig. 5 Channel usage efficiency for various frame lengths.

Fig. 6 shows the total time slots to read all tags. The total slots also include the acknowledgement slots in each read cycle. In our proposed method, the total number of required acknowledgements is equal to the total number of tags. Note that the duration of an acknowledgement is assumed to be a time slot. From Fig. 6, we find that the total required slots linearly increase with the number of tags and are about 4 times of the tag quantity. For example, if there are 100 tags, the required slots are approximately equal to 400. Note that the required slots include 100 slots for acknowledgement sending from the reader. In other words, if we focus on uplink transmissions (from tags to reader), the channel usage efficiency of our scheme can achieve about 33%. This efficiency is very close to the maximum throughput of framed ALOHA applied in radio networks.

## 4 Conclusions

In this paper, we have presented a detailed description for using dynamic framed ALOHA to solve the anti-collision problem in a RFID system. A reliable procedure for reading all tags has been proposed, which consists of broadcasting a read request, sending tags' ID at randomly selected time slot, and acknowledging and disabling the

successful transmission tags. A method for estimating the number of tags was proposed. We have also derived the optimal frame length from channel usage point of view. The major advantage of our scheme is the easy implementation for both reader and tag. The reader performs two important functions; tag estimates and determinations of an optimal frame length. The two functions highly affect the performance of anti-collision protocol.

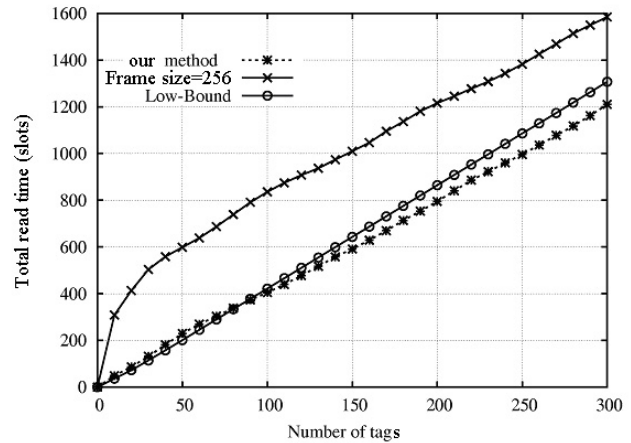


Fig. 6 Simulation results for total read time slots required.

## 5 References

- [1] D. R. Hush and C. Wood, "Analysis of tree algorithm for RFID arbitration," *Proc. of IEEE International Symposium on Information Theory*, pp. 107, 1998.
- [2] C. Law, K. Lee, and K.-S. Siu, "Efficient memoryless protocol for tag identification," *Proc. of the 4<sup>th</sup> ACM International workshop on Discrete algorithms and methods for mobile computing and communications*, Aug. 2000, pp. 75-84.
- [3] M. Nanjundaiah and V. Chaudhary, "Improvement to the protocol specification for 900MHz class 0 radio frequency identification tag," *Proc. of 19th International Conference on Advanced Information Networking and Applications*, vol. 2, pp. 616-620, 2005
- [4] K. Finkenzeller. RFID handbook, 2<sup>nd</sup> edition, John Wiley and Sons, 2003.
- [5] H. Vogt, "Multiple object identification with passive RFID tags," *IEEE International Conference on System, Man and Cybernetics*, 2002.
- [6] W. Feller, *An Introduction to Probability Theory and its Applications*, vol. 1, 3<sup>rd</sup> edition, New York: Wiley, 1970.