ALOHA Algorithm considering the Slot Duration Difference in RFID system

Dan Liu, Zhongxiang Wang, Jie Tan, Hao Min, Junyu Wang

***Abstract*—when multiple RFID tag identification is becoming a commonplace, the anti-collision technology for multiple RFID tag environment has drawn mounting research interest in the RFID domain. Many published Aloha-based algorithms, assuming that all the slots have the same duration, tend to increase the number of successful slots by tag estimation and dynamic frame scheduling, and thus improve the system efficiency (the ratio of successful slots to all slots in each frame), which is limited by 1/e according to the theory of Probability. Whereas, in this paper, the effect of the empty slots and collided slots is analyzed and two novel methods based on the parameters of EPC Gen2 protocol, BIS and Collision Detection, are proposed, to improve the RFID system efficiency by reducing the cost of the none successful slots other than the successful slots. Moreover, a new approach to evaluate the system efficiency for multiple tag identification, taking consideration of the duration difference of the slots, is presented. According to the simulation and test results, the proposed methods, BIS and Collision Detection, can improve the system throughput by 120% and 30~40% respectively.**

***Index Terms*— Anti-collision, Framed-Aloha, Collision Detection, BIS, RFID Identification**

I. INTRODUCTION

RFID (Radio Frequency Identification) technology, which identifies electronic tags using RF signal without contact, is spotlighted as a promising technology for supply chain management and industry automation. A passive RFID system generally consists of a reader and many tags. The reader broadcasts the query message to the tags, and the tags send the response back to the reader in turn. If more than one tag responds to the reader simultaneously, a tag collision will occur on the communication channel and none of the tags can be recognized by the reader as a result. Many anti-collision algorithms for multiple tag identification have been published, which can be classified into tree-based deterministic algorithm and slot aloha-based probabilistic algorithm. The system efficiency and the identification throughput are usually used to evaluate the performance of a specific algorithm. The system efficiency is defined as the ratio of the successful slots to all slots, and the identification throughput is defined as the number of tags identified by the reader per second. In the recent years, lots of new methods to improve the multiple tag identification efficiency and throughput have been proposed, most of which aim to increase the number of successful slots in each frame to improve the system efficiency, and according to the Binomial distribution model, assuming the duration of all the slots is the same, the system efficiency is limited to 1/e [1]. That is to say, even with the highest efficiency, more than 60 percent of the slots, i.e. the empty slots and collided slots, do not make any contribution to the performance improvement.

Based on the parameters of an Aloha-Based protocol, EPC Gen2 [2], some practical solutions to improve the system efficiency by reducing the cost of none successful slots are proposed and verified by experiment or simulation in this paper. And, a new guideline to evaluate the system efficiency of the multiple tag identification is given, taking consideration of the non-equal factor of slot length.

This paper is organized as follows. In Section II, the fundamental knowledge of the probabilistic algorithm and the previous researches on anti-collision algorithms is reviewed, including both slot aloha-based probabilistic algorithms and tree-based deterministic algorithm. In Section III, the detailed explanations of our proposed methods are presented respectively, including BIS algorithm, Collision Detection technique and an optimized model to analyze the system efficiency of multiple tag identification. In Section IV, the performance of the proposed methods is presented and is compared with those of the related works. The last section gives the conclusions as well as the future works.

II. RELATED WORKS

Anti-collision algorithms for multiple tag identification can be divided into tree-based deterministic algorithms and slot aloha-based probabilistic algorithms. Deterministic algorithms form a binary tree with tag's identifier expressed in binary bits and identify tags through browsing the nodes in the tree. In this type of algorithm, the process of tag identification is predictable. Deterministic algorithms can also be divided into memory algorithms and memoryless algorithms. In memory

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algorithms, the response of the tag is determined by the reader's query and the current state of the tag and thus each tag must store and manage its state information. Splitting tree algorithm [3] and bit-arbitration algorithm [4] are typical memory algorithms. In memoryless algorithms, the response of the tag is determined only by the query to the tag. This type of algorithm is more popular in RFID system for its simple implementation in tags. Typical memoryless algorithm includes tree-walking algorithm [5], Query tree algorithm (QT) [6] and memoryless collision tracking tree algorithm (CTT) [7].

Probabilistic algorithms are based on aloha protocol. Each tag in the work range selects one of the slots in a given frame to transmit its information and send its identifier. In probabilistic algorithms, the slots in each frame are divided into empty slots, successful slots and collided slots. The collision occurs when more than one tag answer in the same slot, called collided slot. A tag can be successfully identified when only one tag responds to the reader in a slot, called successful slot, and no tag replies in the empty slot. In a dynamic frame aloha anti-collision algorithm, the number of unidentified tags in the work range is estimated by a certain Tag Estimation Method (TEM), and then the fame size is dynamically scheduled to achieve the maximum system efficiency. For most TEMs, Binomial distribution model is applied to each slot in a frame and the expected number of slots with occupancy factor r is given by a_r [8].

$$a_r = L \times C_x^r (\frac{1}{L})^r (1-\frac{1}{L})^{x-r} \qquad (1)$$

Where L is the size of the frame, or the total number of slots, r is the number of tags which respond to the reader in certain slot and x is the total number of tags.

Accordingly, the expected number of empty slots a_0, where r is 0, successful slots a_1, where r is 1, and collided slots a_k, where r is k, are given by the following equations [1] [9]:

$$\begin{cases} a_0 = L(1-\frac{1}{L})^x \\ a_1 = x(1-\frac{1}{L})^{x-1} \\ a_k = L - a_0 - a_1 \end{cases} \qquad (2)$$

Assuming that every slot is of the same length, the system efficiency is given by η.

$$\eta = \frac{a_1}{L} = n\frac{1}{L}\left(1-\frac{1}{L}\right)^{n-1} \qquad (3)$$

It can be inferred that the maximum efficiency can be achieved if the frame length equals to the number of tags by the following equation.

$$\lim_{n\to\infty}\frac{\partial \eta}{\partial L} = 0 \qquad (4)$$

Assuming all the slots have the same duration, it can be inferred that the optimal size of the next frame is equal to the number of the unidentified tags in the work range of the reader [8].

In most aloha-based anti-collision algorithms, the numbers of the three kinds of slots in each frame are observed and the number of unidentified tags n is estimated by different TEMs. Lower Bound [10] is a simple method of TEM, which assumes that there are only two tags that collide with each other in each collided slot. Schoute [1] gives another method, which assumes that the number of collided tags in each collided slot is a Poisson distribution and the average number of collided tags in each collided slot is 2.39. Vogt [10] presents a tag estimation procedure which tries to minimize the error between the observed value, including number of empty slot a_0, successful slot a_1, and collided slot a_k, and the expected value $E(a_0)$, $E(a_1)$, $E(a_k)$ with N tags near the reader.

$$\min_N \left\| \begin{pmatrix} a_0 \\ a_1 \\ a_k \end{pmatrix} - \begin{pmatrix} E_N(a_0) \\ E_N(a_1) \\ E_N(a_k) \end{pmatrix} \right\| \qquad (5)$$

The collision ratio C_{ratio} [11] is introduced to estimate the number of tags n, which means the ratio of the number of the slots with collision to the frame size L, is given by

$$C_{ratio} = 1-\left(1-\frac{1}{L}\right)^n\left(1+\frac{n}{L-1}\right) \qquad (6)$$

Chen [12] estimates the Tag number based on the empty slot information. An improved algorithm considered special cases when each of the three kinds of slot is zero to estimate tag number is proposed in [13]. Christian proposed a TEM called Bayesian [14], which estimates the tag number according to the information of all the last z frames, while other TEMs do TEM based only on the last frame. Bayesian is also useful when the tag movement is considered. Our research work mainly focuses on probabilistic algorithms without tag movement.

III. THE PROPOSED TECHNIQUES

In this paper, two methods based on the parameters of EPC Gen2 protocol, BIS and Collision Detection are proposed to improve the identification efficiency for RFID system and a new model to analyze the system efficiency of the multiple tag identification is given when the non-equal factor in the length of different slots is taken into consideration.

According to EPC Gen2 protocol, a reader initiates a frame with a Query command which defines the size of the frame, L, which is equal to 2^Q where Q is a parameter in the Query command. The subsequent slots in the frame are initiated with a QueryRep command respectively. Each tag has a slot counter which is loaded independently with a random number no more than L when receiving the Query command and decreased by one when receiving a QueryRep command. The tag returns a 16 bit random number, RN16, when the value of its slot counter becomes zero. The reader issues an ACK command which

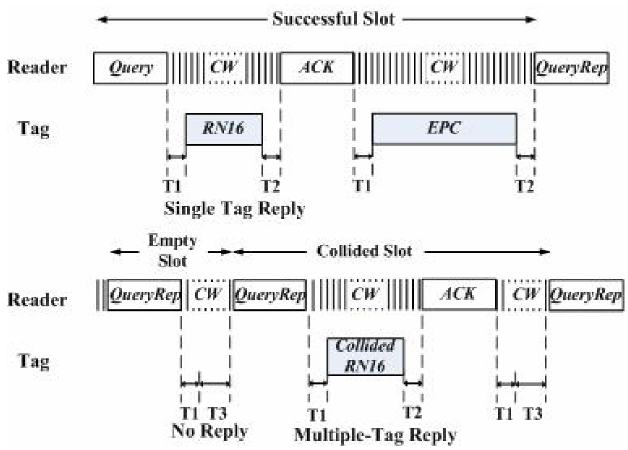

Fig. 1 Identification procedure in the EPC Gen2 protocol.

contains the received RN16. The tag whose RN16 is the same as that in the ACK command backscatters its EPC code. According to the link timing requirement, the successful slot, empty slot and collided slot are presented in Fig. 1. *T1* is the time from reader transmission to tag response. *T2* is the time from tag response to reader transmission. *T3* is the time a reader waits, after *T1*, before it issues another command. *CW* means the continuous wave of the RF signals from the reader.

A. BIS to Reduce the Cost of Empty Slots

Combining the empty slot scanning process, based on bit-slot scheme [15], with the dynamic framed aloha anti-collision procedure, BIS algorithm can lower the cost of the empty slot and thus improve the system efficiency. During the empty slot scanning process, every tag in the work range responds the reader with a bit of 1, in stead of a RN16, in a randomly selected slot of the frame with *L* slots. As a result, the reader can perceive the distribution of the empty slots. Then in the next step, the frame length is dynamically adjusted to *L'*, in which the empty slots are deleted. The detail procedure is described as follows.

1. Empty Slot Scanning
   1) The reader broadcasts a SCAN command, which contains the current frame length L;
   2) When receiving a SCAN command, each tag independently picks up a random number which is no more than L, and loads the number into its slot counter. Tag backscatters one bit of "1" when the value of the slot counter decreases to zero. At the end of the frame, the reader receives a L bit string with c_0 bits with a value "0" and $(L-c_0)$ bits with a value "1", as shown in Fig. 2. Bit with a value "0"implies an empty slot.
   3) The reader issues a command named RESPONSE_BIT_SLOT, in which the L bit string generated in step 2) is included.
   4) On receiving RESPONSE_BIT_SLOT, each tag adjusts its slot counter according to the received string. As shown in Fig.2, the slot counter of Tag1 changes from 3 to 1, and Tag1 will respond to reader's query in the first slot other than in the third slot. Accordingly, Tag 2 and Tag 3 will respond in the second slot and Tag 4 will respond in the third slot. The frame length therefore has been decreased to $L' = L-c_0$, in which the empty slots are cancelled.
2. Tag Identification

This process is similar to that of the conventional slotted-ALOHA, except that the frame size is $L-c_0$ now. Each tag responds according its adjusted slot counter in the previous step. As in EPC Gen2 protocol (Fig. 2), a reader can use "Query" and "QueryRep" commands to identify tags during a frame. If the slot is a successful one, the EPC number will be received by the reader.

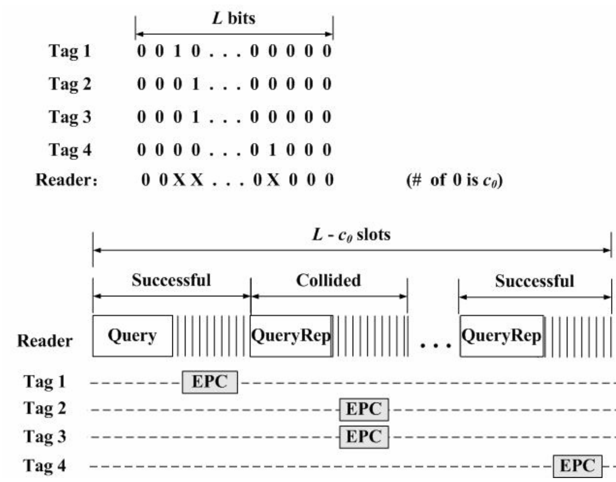

Fig.2 BIS algorithm

3. Dynamically Frame Scheduling

At the end of each frame, reader estimates the number of unidentified tags in the work range, n , then calculates the size of the next frame L by $L=m\times n$ ($m\in$ natural number). The parameter *m* is introduced here to make the frame larger, so that there will be less collided slots than that of the fame with only *n* slots. The effect of the parameter *m* will be analyzed further in the section IV. When all tags have been identified, the process is finished; otherwise the iteration will be repeated. All TEMs proposed in the literature can be adopted in this step to calculate n.

Admittedly, though it can reduce the cost of empty slots, the BIS algorithm will introduce new cost in the empty slot scanning process. The concept of equivalent empty slot is introduced here to imply the extra time cost in BIS. Let p be the duration of the EPC numbers of the tags and the system efficiency is given by:

$$\eta = \frac{c_1}{L'+2L/p} = \frac{c_1}{c_1+c_k+2L/p} \tag{7}$$

The part of "2L/p" is the number of the equivalent empty slots. The parameter of L is the actual frame length in the second step and L is the estimated frame length.

Considering the practical radio environment, when a "0->1" error occurred to a bit of the L bits received by reader in step 2), an empty slot is added to the current frame; when a “1->0” error occurred, the tags expected to reply in the related slot should stay quiet and wait to be read in the next frame. Let c0 be the empty slot before empty slot cancellation, k is error-code quotiety, e(1->0) is the ratio of the “1->0” error to the total error (assumed to be 0.5). The system efficiency can be given by:

$$\eta' = \frac{c_1}{L' + 2L/p + e(1\text{-}>0)kc_0} = \frac{c_1}{c_1 + c_k + 2L/p + kc_0/2} \tag{8}$$

According to the calculation, the system efficiency decreases less than 1.0e-4 when the error-code quotiety is 0.1%, which means the effect on the system efficiency is neglectable.

B. An Optimized Model to Evaluate the System Efficiency

In the conventional framed aloha based anti-collision algorithms, the durations of empty slot, successful slot and collided slot are assumed the same when the system efficiency is calculated. But, in fact, they are different, and can be variable within some range according to a given protocol. In this chapter, the effect of the different slot duration is analyzed and an optimized model to evaluate the system efficiency is proposed considering the actual duration of different kinds of slots.

The parameters under discussion are based on EPC Gen2 protocol, and the erroneous factors in the communication channel are taken into consideration as well. The erroneous link might result in receiving wrong information from the tag.

Let l_0 and l_k denote the duration of empty and collided slots respectively, l_1 denote the duration of a successful slot, $l_{invalidACK}$ denote the duration of successful slot but encountered invalid ACK, $l_{QueryRep}$, l_{RN16} and $l_{QueryRep}$ denote the durations of transmitting a QueryRep, a RN16 and an ACK commands, and then they can be given by:

$$\begin{cases} l_0 = l_{QueryRep} + T_1 + T_3 \\ l_1 = l_{QueryRep} + l_{RN16} + l_{ACK} + l_{EPC} + 2T_1 + T_2 \\ l_k = l_{QueryRep} + l_{RN16} + T_1 + T_2 \\ l_{invalidACK} = l_{QueryRep} + l_{RN16} + l_{ACK} + 2T_1 + T_2 + T_3 \end{cases} \tag{9}$$

The parameter $p_{invalidACK}$ or $p_{invalidEPC}$ denotes the probability that an invalid *ACK* or *EPC* occurs in a successful slot because of random error environment. Compared with the simple model for different slots in [16], e.g. $l_0 = l_1 = \kappa l_k$, equation (9) gives a more accurate model for different slots.

According to (2), the expected system efficiency η' of framed Aloha algorithm with *n* tags and *L* slots are given by:

$$\eta' = \frac{a_1(1 - p_{invalidACK} - p_{invalidEPC})l_1}{a_0 l_0 + a_k l_k + a_1[(1 - p_{invalidACK})l_1 + p_{invalidACK} l_{invalidACK}]} \tag{10}$$

To calculate the maximum η', we have:

$$\frac{d\eta'}{dL} = 0 \tag{11}$$

Then,

$$n = \frac{lambertw[-L \cdot (l_0/l_k - 1) \cdot e^{L \cdot \ln(\frac{L-1}{L})} \cdot \ln(\frac{L-1}{L})] + L \cdot \ln(\frac{L-1}{L})}{\ln(\frac{L-1}{L})} \tag{12}$$

Where $f(x) = lambertw(x)$ is the inverse function of $f(x) = xe^x$.

Given the number of unidentified tags, *n*, and the ratio of empty slot length to collided slot length, l_0/l_k, and the optimized frame size *L* can be determined by (12). Note that the optimized frame size has nothing to do with the duration of successful slot and random error link because the time spent on each successful slot is invariant whereas the time spent on empty and collided slots are not. The fact that $p_{invalidACK}$, $p_{invalidEPC}$, and l_1 do not affect the value of *L* where the maximum system efficiency η' occurs can also be proved from the simulation results of Fig. 3.

When the number of tags is large enough, (12) can be simplified as the following equation:

$$n \approx L \cdot \{lambertw[e^{-1}(l_0/l_k - 1)] + 1\} \tag{13}$$

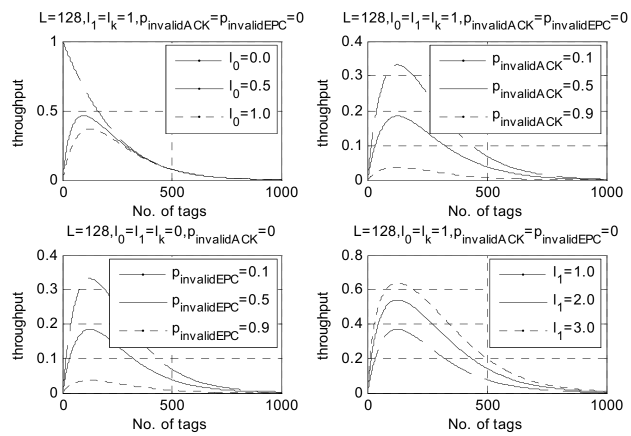

Fig. 3 Novel throughput equation

As a result, the optimized system efficiency occurs when

$$L = \frac{n}{q} = \frac{n}{lambertw[e^{-1}(l_0/l_k - 1)] + 1}, \tag{14}$$

The difference between the conventional model and the optimized one lies in the parameter *q*, which is called the factor of non-equal slot duration. The system efficiency η' is 1/e when *n* is large enough with $l_0/l_k = 1$, so, the conventional TEM model to analyze the maximum system efficiency is an instance of the optimized analysis model.

C. Collision Detection to Reduce the Cost of the Collided Slots

Collision detection is essential to the implementation of the framed aloha anti-collision algorithm since most aloha-based algorithms estimate the number of unidentified tags in the work range based on the number of collided slots in each frame. The cost of the collided slots in the identification throughput is determined by both the number of collided slots and the duration of each collided slot. Since the former is determined by the frame size and the behavior of tags, the effort to decrease the cost of collided slots is focused on the latter one.

In the EPC Gen2 protocol, since there is no extra check digit for the RN16. The reader will receive a mixed RN16, sent by more than 2 tags, in the collided slots, if the phase and power of the tags are of no big difference. Without the detection of tag collision, the duration of collided slot is given by: $l_k = l_{QueryRep} + T_1 + l_{RN16} + T_2 + l_{Ack} + T_1$ (in (8)). That is to say, the collision can only be detected after an invalid ACK command is detected, i.e. the reader can not receive an EPC number when it sends out the ACK with the collided RN16.

In order to reduce the duration of the collided slot, the proposed collision detection technique tends to detect the collision by hardware, so that the reader can perceive whether the received RN16 is from a single tag or from multiple tags, without issuing the ACK command.

One possible implementation is as follows: the collision of received signal (RN16) can be inferred if the reader can detect the corruption of the received signal, since the waveform of the received signal from multiple tags might be corrupted. The corruption of the signal of tags can be detected based on its coding characteristics. Here we take the FM0, one of the required coding in the EPC Gen2 protocol, as an example in the following analysis.

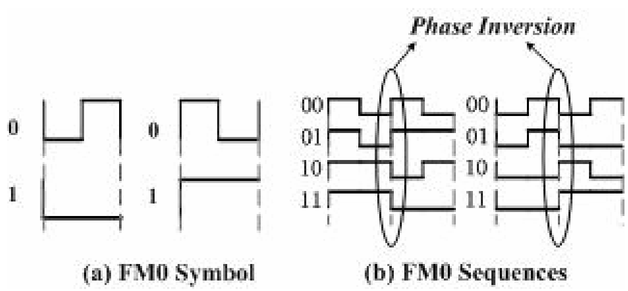

Fig. 4 FM0 coding

According to the Gen2 protocol, FM0 has an important feature that there must be a phase inversion between two bits in a sequence of symbols, as shown in Fig.4 (b). The comparison of a valid RN16 with a collided RN16 that violates the phase inversion principle in FM0 coding is shown in Fig.5.

The collision detection is done in the decode module of the reader's digital receiver. Correlation demodulation is used to demodulate and detect the tag's backscattered signal. A collided slot can be detected through the following steps:

(1) A sequence of valid FM0 symbols, called the local sequence, is to be correlated with the received sequence from the tag.

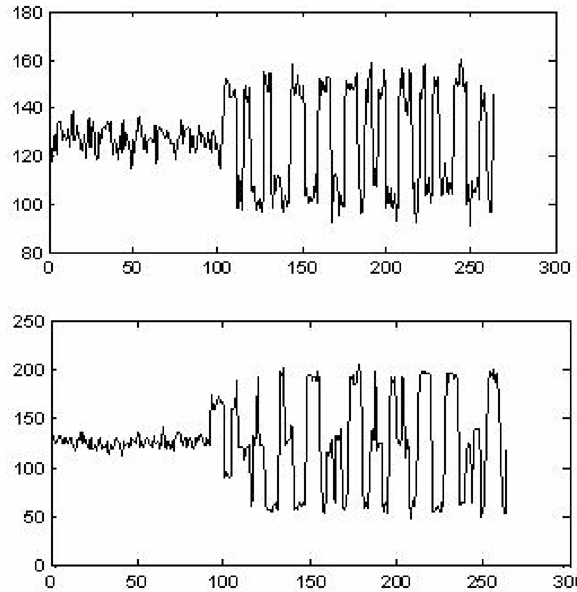

Fig. 5 Waveforms of the valid RN16 (upper) and the collided RN16 (lower) signals of FM0 coding

(2)The type of FM0 symbols, as shown in Fig.4 (a), can be determined when the related correlation result is the maximum one among all possible values.

(3)The type of the last symbol is recorded and compared with that of the current symbol. The collision is detected when a violation of the phase inversion occurs.

Hence, the duration of the collided slot is given by $l_k^{'} = l_{QueryRep} + T_1 + l_{RN16}$ when collision detection is used, which is much shorter than that of the collided slot without collision detection, i.e. $l_k = l_{QueryRep} + T_1 + l_{RN16} + T_2 + l_{Ack} + T_1$.

IV. PERFORMANCE SIMULATION AND ANALYSIS

In this section the proposed methods to improve the RFID system identification throughput are verified by simulation or experiments, and are analyzed with the comparison to the conventional solutions.

A. The Simulation of BIS

In the simulation of BIS, the ID of each tag is 96 bits and randomly generated. The simulation does not consider tag movement, random error communication link and EM holes, for simplicity. The total tag number varies from 100 to 1000.

(1) The Parameter *m* in BIS

According to the third step of BIS, the estimated size of the next frame is given by $L=m\times n$ ($m\in$ natural number), in which the parameter n is the estimated number of unidentified tags. Usually the parameter m is larger than one to decrease the collision. This parameter must be chosen carefully because it affects the performance of the next frame directly. Fig.6 shows the performances of different m in BIS. It can be seen that the identification throughput is the lowest when the length of the

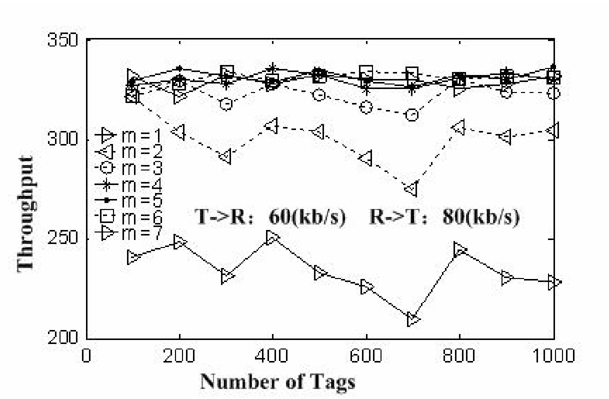

Fig. 6 Identification throughput of BIS algorithm VS. *m*

next frame equals to *n* (*m=1*), and it goes up to the maximum value when *m=4*. When *m* becomes even larger, the throughput does not increase obviously. So the parameter *m* is set to be 4 in the following simulation.

(2) System Efficiency

Table 1 compares the system efficiency of BIS to that of Vogt. It shows that BIS algorithm costs several extra empty slots in the empty slot scanning step (1st step in BIS) compared to Vogt. However, BIS has no empty slot in the tag identification step while Vogt has 121 empty slots with100 tags and 499 empty slots with 500 tags. The simulation shows the sharp improvement in the system efficiency of BIS from 36%~37% to 80%~81%, improving by about 120%.

(3) System Throughput

In Fig.7, the system throughputs of several anti-collision algorithms are compared when the number of tags varies. The forward link frequency is 80kb/s (reader to tag) and the backward link frequency is 60kb/s (tag to reader). BIS shows the best performance among all the algorithms. The system throughput can be improved by 26%, compared to the conventional framed aloha anti-collision algorithms, such as

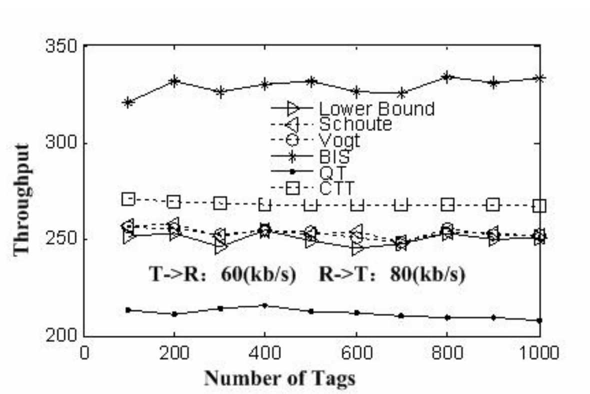

Fig.7 Identification throughput of different algorithms

Lower Bound, Schoute and Vogt. However, the identification throughput will decrease when the ID of the tag becomes longer and the backward link frequency becomes lower in BIS.

B. The Simulation of the Optimized Model to Analysis the Maximum Identification Efficiency

Considering the duration differences of different slots, the optimized algorithms with the TEMs in the conventional Framed-Aloha algorithms, e.g. Lower Bound, Vogt, are simulated, and the performance comparison between the conventional algorithms (*q*=1) and the optimized algorithms (*q*<1) is given in this section...

The forward link frequency is 125kb/s and the backward link frequency is 60kb/s. The length of the initial frame is 127. The following parameters can be calculated according to the EPC Gen2 protocol and (11): l_0=140μs, l_k=546μs, l_1==3128μs, l_0/l_k =0.257, *q*=0.586.

In Fig. 8, the X-axis denotes the total number of tags near the

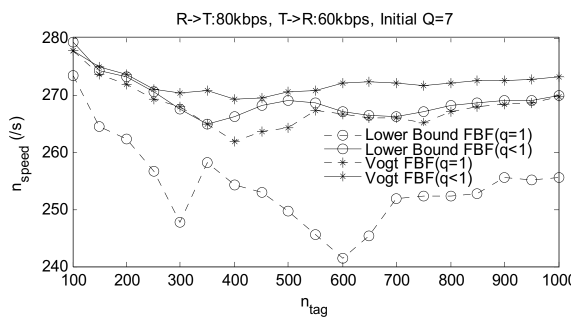

Fig. 8 Performance comparison between the conventional algorithms and the optimized algorithms

RFID reader and the Y-axis denotes the number of tags identified by the reader during one second or called system throughput. Four algorithms have been evaluated in this simulation. The optimized algorithms of Lower Bound and Vogt are presented by *q*<1 while the conventional ones by *q*=1.

It can be seen that for both Lower Bound algorithm and Vogt algorithm, the system throughputs are increased when the slot duration difference is taken into account, especially when the number of tags is large enough.

C. The Implementation and Test of the Collision Detection

The hardware collision detection technique defined in the section III is implemented in a RFID prototype system

Fig. 9. Prototype UHF RFID reader enabled with Collision Detection

compliant with the EPC Gen2 protocol, as shown in Fig. 9. The reader is connected with a circularly polarized antenna with 6dBi gain. The reader's transmitting power is 36dBm EIRP and the frequency band is from 902.75MHz to 927.25MHz, divided into frequency channels with a bandwidth of 500 KHz each. The temperature is 25℃and there is no interference from other readers or tags. The collision flag of the collided slot is generated by the decode module of the digital receiver of the reader through detecting the received signals' violations against the data encoding characteristics. The hardware cost for the collision detection is just about hundreds of equivalent gates.

The accuracy of the collision detection and the performance improvement have been tested and analyzed in this section.

(1) The Accuracy of the Collision Detection

The accuracy of the collision detection means the accuracy of the decision made by the reader enabled with the collision detection techniques. Experiments are set up to verify whether the received "RN16" by the reader is come from more than one tag when the collision flag in the reader's digital receiver is set to be "1". Several EPC Gen2 tags are put near the reader and all of them are configured to respond to every query command from the reader, which means all the slots in each frame are to be collided slots ideally. However, there might be a few empty slots due to the none-ideal factors, such as tag bad position, EM holes and EM interference, etc. Moreover, there might be some successful slots because some tags might be recognized because their signals are stronger than those of the tags reply in the same slot, i.e. capture effect [17]. The total number of querying by the reader is 1000 and the test is done in various distances between tags and the reader (table 2). The parameter *ck2* and *c2* are the observed number of collided and successful slots within 1000 repeated querying when there are two tags near the reader respectively, while *ck3* and *c3* are the observed number of collided and successful slots within 1000 repeated querying when there are three tags near the reader respectively The accuracy can be expressed by: $P = \{{}^{(ck_i - c_i)}\!/_{ck_i}\} \times 100\%$.

According to the test results, the accuracy of the proposed method is up to 99 % on average, which makes it a reliable foundation for the implementation of ALOHA-based anti-collision algorithms in RFID readers.

(2) The System Throughput of the Collision Detection

As explained in previous section, the length of the collided slots can be reduced from $l_k = l_{QueryRep} + T_1 + l_{RN16} + T_2 + l_{Ack} + T_1$ to $l_k' = l_{QueryRep} + T_1 + l_{RN16}$ after implementing the collision detection method in the reader. Thus the system efficiency of the reader can be increased. In this section, several anti-collision algorithms, FIX_Q, LB, Schoute and Vogt, are implemented and compared. FIX_Q means the frame length is fixed; LB is short for Lower Bound. An EPC Gen2 compatible reader and 150 tags have been used and the distance between tags and the reader is about 0.5 meter.

The throughputs of the above algorithms with hardware collision detection and those without collision detection are compared in the same circumstances, as shown in Fig.10. The identification throughput of the reader with the above algorithms can be improved by about 30%~40% on average when the proposed collision detection technology is adopted. However, according to the test result, the accuracy of the proposed collision detection technology may be decreased when the experiment environment changes, e. g. temperature, tag movement and interference.

TABLE 1
SYSTEM EFFICIECY OF BIS WITH 100 AND 500 TAGS

# of tags	algorithms	# of extra equivalent empty slots	# of empty/collided/successful slots in identification step	ystem efficiency
100	Vogt	0	121 / 43 / 100	37%
100	BIS	7	0 / 15 / 100	81%
500	Vogt	0	499 / 361 / 500	36%
500	BIS	27	0 / 55 / 500	80%

TABLE II
THE ACCURACY OF THE PROPOSED COLLISION DETECTION TECHNIQUE

Tag destance （m）	ck2	c2	P (%)	ck3	c3	P (%)
0.3	825	4	99. 5	826	9	98. 9
0.5	941	6	99.4	723	16	97. 8
0.75	789	6	99. 3	838	11	98. 7
1	865	9	98. 9	890	6	99. 3

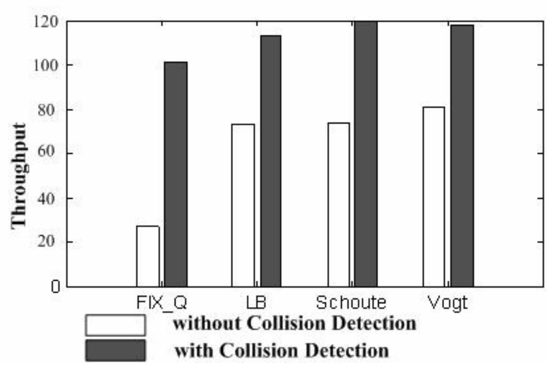

Fig. 10 Identification Throughput without Collision Detection VS. Reader with Collision Detection

V. Conclusion

The maximum system efficiency of the conventional Framed-ALOHA anti-collision algorithms is assumed to be no more than 1/e, since the durations of all the slots, including empty slots, collided slots and successful slots, are assumed to be the same, and efforts are devoted to schedule the frames size in order to increase successful slots in a frame, or called the system efficiency. In this research, from a practical view, we explored various optimization methods to improve the performance of the aloha-based RFID system when the durations of different slots are different, based on the parameters of EPC Gen2. The BIS algorithm combines the empty slot scanning process with the framed aloha anti-collision procedure, which lowers the cost of the empty slots and improves the system efficiency dramatically. A new guideline to analyze the system efficiency of the multiple tag identification is given when the non-equal factor of length of the empty, collided and successful slots is taken into consideration. A collision detection technology is proposed to detect the collided slot, in order to reduce the duration of the collided slot and thus improve the identification throughput. According to the simulation and test results, the proposed methods are effective in the multiple tag application.

Besides the duration difference of the slots, there are many other none ideal factors or phenomenon, such as multi-path effect, capture effect, etc. The optimization methods taking consideration of other none ideal factors will be studied in our future work.

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