Anti-collision Algorithm for RFID based on Continuous Collision Detection

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Abstract

Tag estimation can improve the throughput of the UHF passive RFID systems. It plays an important role in anti-collision algorithm. In order to reduce the complexity of the estimation algorithm and the hardware support, a new algorithm based on the continuous detection mechanism has been proposed. According to the different probability of the collision and idle, the number of the continuous detected slots must be set independently. This scheme can simplify the system and reduce the extra consumption by less detecting timeslot. Simulation results indicate the proposed scheme can improve the efficiency without complicate system.

Keywords: *RFID, Q-algorithm, tag estimation, continuous detection, probability of collision*

1. Introduction

Radio frequency identification (RFID) technology has been widely used as one of the key technology of the Internet of Things [1, 2]. Ultra high frequency (UHF) (860~960MHZ) identification with higher efficiency and further read range has been deemed to have bright future comparing with the lower one. In the RFID system, if there are multiple tags in the range of the antenna, tags will respond the reader simultaneously. Tag collision will happen inevitably. As a result, the collision problem has become the important factor that influences the efficiency and accuracy of RFID system.

The most popular international solution of anti-collision is the time division multiple access (TDMA) technology. Because the tag structure is simple and the TDMA scheme is convenient. In the low frequency band, mainly approaches include pure ALOHA algorithm, timeslot ALOHA algorithm, frame timeslot ALOHA algorithm, dynamic frame timeslot ALOHA algorithm, etc. In the high frequency band, the solution is the EPCglobal UHF Class1 Gen2 algorithm [3] (standard Q-algorithm) which has been promulgated by the International Organization for Standardization in 2005.Due to the standard Q algorithm has the problem that it adapt the Q value slowly especially there are massive tags [4], tag estimation mechanism has been introduced into the algorithm. Although, these algorithms will increase the complexity of the system unexpectedly. In order to solve those problems, a new improved algorithm called an anti-collision algorithm for RFID based on continuous detection has been proposed in this paper. This approach can determine the number of continuous detection slots independently according to the difference of the idle and collision probabilities.

2. Research Method

The standard Q-algorithm promulgated by the EPC Gen2 is general similar as the dynamic frame timeslot ALOHA anti-collision algorithm (DFSA) actually. Unlike the traditional DFSA, the Gen-2 algorithm allows early adjustment of frame length within each slot frame. The frame size can be decided by (1). This early adjustment can improve read performance when frame length is extremely appropriate.

$$Frame = 2^{Q} \tag{1}$$

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During the process of identification there will be three states: Idle state (idle), no tag response; successful state (succeed), only one tag response; collision state (collision), multiple tags response.

$$Q = round(Qfp) \tag{2}$$

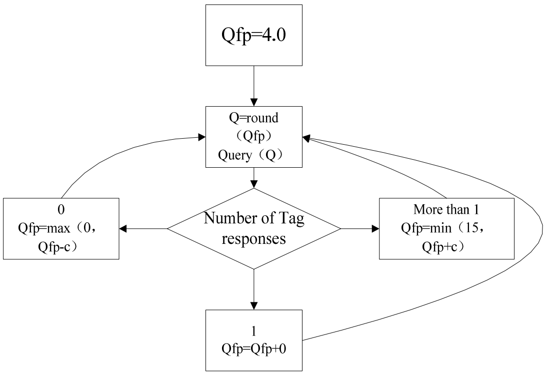

Figure 1. Q Value Adjustment Flow Chart

Studies have shown that when the number of slots that each identification frame contains is general equal to the number of tags, the system can achieve maximum recognition efficiency (36.8%) [5]. In order to adjust the length of identification frame, floating point number Q_{fp} and accumulating parameter C ($c\hat{I}\,[0.1,0.5]$) are used to adjust Q. Q value is calculated by round Q_{fp} (2) .When the interrogator observes collision state, the Q_{fp} value increases by C. When the interrogator observes idle state, the Q_{fp} value decreases by C.When the interrogator observes succeed state, the Q_{fp} value remains unchanged. The method for choosing the slot-count parameter is shown in Figure 1.

Main command of inventory round: Query, QueryRep, QueryAdjust [6].

Query: Initialize identification program. Set the initial Q of each tag. Each tag counter will select a number in the range $[0, 2^Q - 1]$ randomly. Tags with the random number zero will reply the reader in this timeslot immediately.

QueryRep： Auto decreased command. If tags receive this command, their counters will be decreased by 1. Tags with the number zero will reply the reader.

QueryAdjust: Adjust the value of Q. When the value of Q has been changed by (2), reader will send this command. Tags choose another number between $[0, 2^Q - 1]$, then a new round of identification will start.

QueryRep command will be sent after the idle and succeed state. If the round value of Q_{fp} is different from the current Q value, the interrogator will send the QueryAdjust command to adjust the Q value for identifying unread tags. Call these commands in accordance with the provisions of the order. The reader will identify the tags constantly until all tags are identified.

3. An Anti-collision Algorithm based on Continuous Detection

Although the EPCglobal Gen-2 provides early adjustment of frame length for anti-collision algorithm, the parameter Q can't obtains appropriate initial value quickly especially in the excessive tags situation. So estimation number of tags should be executed before the identification started. The value of Q will be selected by the estimation result. Studies have provided the relationship between timeslot number and tag number. When the timeslot number is equal to the unread tags, the system will reach the maximum efficiency [7]. These methods which provided by previous studies mainly include the lower limit value algorithm (Low Bound, LB) [8], Schoute estimation algorithm [9], chebyshev inequality estimation algorithm [10], etc.

But these tag estimation algorithms need a strong hardware support and will bring huge additional power consumption in reality. Relative to the simple structure of reader, it will bring lots of operation cost.

In order to solve this problem, a more simple tag estimation method called anti-collision algorithm based on continuous detection is proposed. Basic idea: Set the first m slots as estimating timeslots and monitor them. Get the communication state (free, success, collision) of the first m slots. If the continuous idle slots or collision slots have been detected, the value of Q will minus or plus 1 immediately. In this way, the interrogator can adjust the frame length only after three or four time slots. So identification process will be more effective. Unlike previous algorithm, this approach determine the number of continuous detection slots independently.

Next three parts, the principle of the continuous detection mechanism will be given. Then according to the principle the number of monitoring timeslots can be calculated.

3.1. Difference of the Monitoring Slots

Suppose there are n tags to be read. According to the Bernoulli experiment, if there are x tags choose a same slot, the probability will be calculated by:

$$P_e = C_n^x (\frac{1}{N})^x (1 - \frac{1}{n})^{n-x} \quad (3)$$

The probability of the idle slot is calculated by:

$$P_{id\text{le}} = C_n^0 (\frac{1}{N})^0 (1 - \frac{1}{n})^n \quad (4)$$

The probability of the success slot is calculated by:

$$P_{suc} = C_n^1 (\frac{1}{N})^1 (1 - \frac{1}{n})^{n-1} \quad (5)$$

The probability of the collision slot is calculated by:

$$P_{col} = 1 - P_{id\text{le}} - P_{suc} \quad (6)$$

Calculate the derivative of P_{suc} and set it equal to 0.

If P_{suc} want to approach the maximum, there must be $N = n$ and $P_{suc}(\max) = 0.368$.

When $N = n$, $P_{idle} = (1 - \frac{1}{n})^n$ and $P_{suc} = (1 - \frac{1}{n})^{n-1}$.

If n is big enough, $P_{suc} » P_{idle}$,then

$P_{col} = 1 - P_{id\text{le}} - P_{suc} = 1 - 0.368 - 0.368 = 0.264$

Obviously, in the condition of high efficiency the probability of collision time slot is less than the probability of idle time slot, $P_{col} < P_{idle}$. So the detected number of continuous idle slots (m_i) should bigger than the collision ones(m_c).

$$m_i > m_c \quad (7)$$

3.2. Analysis of the Continuous Idle Slots

Suppose n' is the estimated number of tags. Then define the estimate error as:

$$dev(n') = \frac{|n - n'|}{n} \quad (8)$$

$dev(n')$ is used to measure the deviation of tag estimation.

Identifying tags is a Poisson process. Due to the concept of the timeslot, the process has been simplified. The number of the estimated value is n'.Each frame has N slots. If the system detects idle time slot, it will call the QueryRep command automatically. Then tag counters will be decreased by 1. For monitoring timeslot, the probability for first m_i continuous idle slots is:

$$P_{m_i} = (1 - \frac{m_i}{N})^n = (1 - \frac{m_i}{N})^{\frac{N}{m_i} * \frac{m_i n}{N}} » (\frac{1}{e})^{\frac{m_i n}{N}} \qquad (9)$$

Set $l = n/N(l > 0)$,then $P_{m_i} = (1/e)^{m_i l}$ (m is positive integer), In $(0, +¥)$ area, P_{m_i} is monotone decreasing function.

Then the critical value of $dev(n')$ will be calculated as:

$$dev(N) = dev(N / 2)$$

Then,

$$dev(N) = \frac{|n - N|}{n} = \frac{N - n}{n} = \frac{1}{l} - 1$$

$$dev(\frac{N}{2}) = \frac{\left|n - \frac{N}{2}\right|}{n}$$

As $\frac{N}{2} £ n £ N$,then $dev(\frac{N}{2}) = \frac{n - \frac{N}{2}}{n} = 1 - \frac{1}{2l}$. Set $dev(N) = dev(\frac{N}{2})$,so $l = 0.75$.

As a result, when $l < 0.75$, $dev(N)\ ^3\ dev(\frac{N}{2})$.

Set $l = 0.75$, then:

$$P_{m_i} = (1/e)^{0.75 m_i}$$

In the probability theory, if the probability is very close to zero (which means event appears with very low frequency in a large number of repeated tests), this event will be called as the small probability event. Range $(0.01, 0.05)$ is commonly used as the standard range.

$$m_i = 3 , P_{m_i} » 0.1054 ; m_i = 4 , P_{m_i} » 0.0498$$

When $m_i = 4$, P_{m_i} achieves the requirement and choose 4 as the continuous idle slots finally. So m_i is set to 4,which means that when 4 continuous idle slots are detected $l > 0.75$ would be the small probability event. Then $l £ 0.75$ can be inferred. The slots number of each frame will be $N / 2$ and that will perform better than N .Q will minus 1, $Frame = N/2$.

3.3. Analysis of the Continuous Collision Slots

When collision happen, there must be multiple tag counters value are zero. Then the system will start the collision algorithm. Processing method: Change collision tags counters value from 0 to 0XFFFF. These collision tags will stay in epicyclic inventory and wait for the system adjusting Q and dispersing the collision tags. This process continues until the whole inventory cycle is end.

Because $m_i > m_c$, the range of m_c can be inferred. The value range should be $\{2, 3\}$.

The probability for first m_c continuous collision slots is:

$$P_{m_c} = P_c^{m_c} = [1-(1-\frac{1}{N})^n - \frac{n}{N}(1-\frac{1}{N})^{n-1}]^{m_c}$$
$$=[1-(1-\frac{1}{N})^{N*\frac{n}{N}} - \frac{n}{N}(1-\frac{1}{N})^{N*\frac{n-1}{N}}]^{m_c} \qquad (10)$$
$$=[1-(\frac{1}{e})^{\frac{n}{N}} - \frac{n}{N}(\frac{1}{e})^{\frac{n}{N}-\frac{1}{N}}]^{m_c}$$

As $l = \frac{n}{N}(l > 0)$, then:

$$P_{m_c} = [1-(\frac{1}{e})^{l} - l(\frac{1}{e})^{l-\frac{1}{N}}]^{m_c}$$

In $(0,+¥\ )$ area, P_{m_c} is monotone increasing function.

As $N £ n £ 2N$,

$$dev(2N) = \frac{2N-n}{n} = \frac{2}{l} - 1$$
$$dev(N) = \frac{|n-N|}{n} = \frac{n-N}{n} = 1 - \frac{1}{l}$$

Set $dev(N) = dev(2N)$,then $l = 1.5$ When $l > 1.5$, $dev(N)\ ³\ dev(2N)$.

Set $l = 1.5$,then P_{m_c} value can be calculate, When N is big enough, there is $l - 1/N » l$.

$m_c = 2$, $P_{m_c} » 0.1957$; $m_c = 3$, $P_{m_c} » 0.0866$

When $m_c = 3$, P_{m_c} is very near to the range $(0.01, 0.05)$ and it has achieved the requirements of the range of m_c $(\{2,3\})$. Choose 3 as the continuous collision slots finally. So m_c is set to 3, which means that when 3 continuous collision slots are detected. $l < 1.5$ will be the small probability event. Then $l\ ³\ 1.5$ can be inferred. The slots number of each frame will be $2N$ and that will perform better than N . Q will plus 1, $Frame = 2N$.

3.4. An Anti-collision Algorithm based on Continuous Detection

In conclusion, the process of the new algorithm can be described as follow: In the beginning of each inventory cycle, the reader will monitor the first four slots. If there are four continuous idle slots or three continuous collision slots be detected, the reader will order Q minus or plus 1. Then the reader send the Query Command again and start a new inventory round. This continuous detection mechanism is shown in Figure 2. According to this method, the interrogator can adapt the frame length only after 4 slots which is more quickly than the normalized rule.

4. Simulation Result and Performance Comparison

We use MatLab to simulate the improved algorithm and compare it with the conventional Q-algorithm.

G (the average packet exchange capacity) is offered traffic and it indicate the load of the interrogator. Define the system efficiency(S) as follows:

$$S = \frac{Splen}{Srate} / now\_time \qquad (11)$$

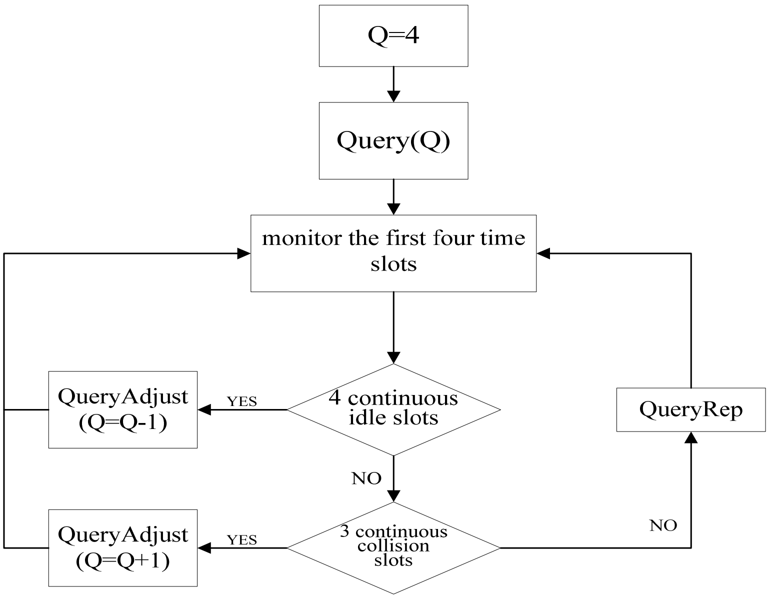

Figure 2. The Proposed Continuous Detection Mechanism

Splen is the sum of packet length. Srate is the symbol rate. now_time is the time that identify all of tags. So S can also be described as:

$$S = \frac{Packet\ transmission\ time}{Tag\ identification\ time} \quad (12)$$

When simulating this program, the scope of G is $[0.5, 2.0]$. 100 times tests have been done for each tag. The bit rate is 512kbps and the symbol rate is 256kpbs, packet length is 128, normalized transmission delay is 0.01s. Then simulate the standard Q-algorithm in the same experiment environment.

From Figure 3 we can get conclusions as follows: (1) When the offered traffic G is same, the improved algorithm identification efficiency S is higher than standard Q value algorithm. It is closer to the theoretical optimum. The improved quantity is about 3%; (2) With G (number of tags) increasing, throughput will increase firstly but then decrease. The decline of the improved algorithm is less than standard Q-algorithm.

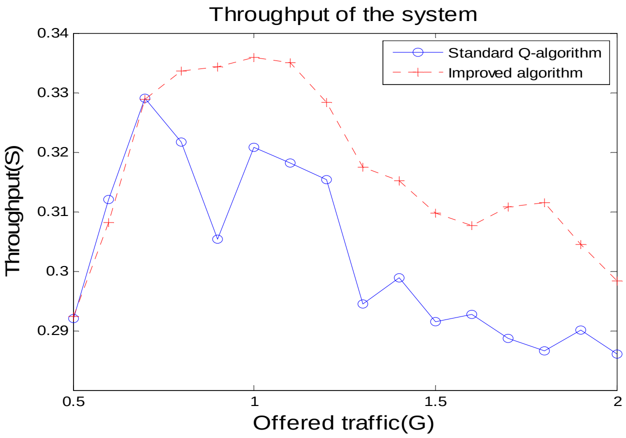

Figure 3. Throughput of System

The influence of increasing number of tags is smaller than the standard Q-algorithm. System has better stability comparing to the pure ALOHA, timeslot ALOHA (SA), frame timeslot ALOHA (FSA) algorithm. These algorithms will make the identification efficiency decline seriously when tags increase rapidly [11]. The improved algorithm has advantages.

Average Delay time is defined as:

$$ADT = \frac{Tplen}{Srate * spend} * \frac{Srate}{plen} \qquad (13)$$

Tplen is the sum of all the identify date length, spend is the number of packet. Then ADT is normalized.

From Figure 4 we can get conclusions as follows: (1) Continuous detection mechanism has decreased average time delay of the system significantly, which also means that it won't bring much extra consumption and the system become more efficient. (2) With G (tags number) increasing, the average delay of the system would decrease gradually. So advantages of the new algorithm will become more and more obviously especially for the massive tags.

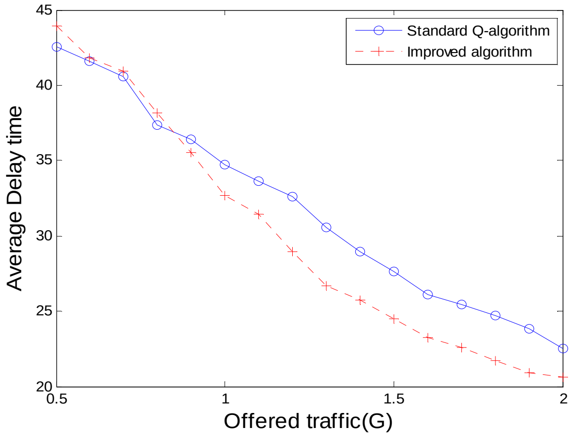

Figure 4. Average Delay Time of System

We can draw the conclusion through the experimental results: The new algorithm not only improves the system efficiency but also enhances the ability to confront the problem of tags increasing quickly.

5. Conclusion

Tag estimation algorithm plays an important role in the anti-collision algorithms of RFID UHF systems. In order to reduce the complexity of the tag estimation and the demand of high-level hardware support, the continuous detection mechanism has been introduced into the tag collision algorithm. The difference between the collision probability and idle probability has been proved by the math analysis. Then the number of the continuous frame must be considered independently (3 and 4). Simulation results prove that the new algorithm speeds up the frame length adjustment and improves the recognition efficiency without increasing any complexity of the system. It can also reduce the average delay time and enhance the ability for dealing with the surging tags.

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