Collision-Resilient Multi-State Query Tree Protocol for Fast RFID Tag Identification

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Abstract

RFID (radio frequency identification) is a RF based identification system, where RF reader reads (and writes) data from each entity (RF tag). Upon request from reader, tags in reader's accessible RF range will respond, and if the number of tags is larger than 2, the reader cannot identify tags (collision). To avoid the collision, there are two previous approaches: ALOHA based and binary tree algorithm. However, they are essentially collision avoidance algorithms, and require much overhead in retransmission time. In this paper, we present collision recovery scheme for RFID system. It uses 20 symbols, and each symbol is 16-bit vectors derived from (16, 4, 1)-BIBD (balanced Incomplete Block design) which is resilient to collision. Although our scheme can decrease the total number of support users, it shows good performance even with low SNR region.

1. Introduction

RFID (radio frequency identification) is a RF based identification system. The RFID system is compose of a reader (transceiver) and tags (transponder), where RF reader reads and writes data from each entity (RF tag).RFID Reader (transceiver): supplies energy for a tag using RF (radio frequency), requests information about tag and interpret received signal. RFID Tag (transponder) responds to reader and it has unique identification information.

But the RFID system has some problems. Without collision resolution, all tags in reader's radio range will respond to request of readers simultaneously. Therefore the reader can not identify any tag, when 2 or more tags are in its radio range.

To prevent collision in RFID system, there are two previous researches: (1) multiple access protocol which is known to ALOHA from networking, and (2) binary tree algorithm, which is relatively simple mechanism [1]. The ALOHA is a probabilistic algorithm, which shows low throughput and low channel utilization. To increase the performance, slotted ALOHA (time slotted, frame slotted, or dynamic frame slotted) protocol is suggested. Binary tree algorithm is a deterministic algorithm, which detects the location of bit conflict among tags, and partitions tags into two groups recursively until there are no collision. It requires as many as the length of ID to identify one tag in worst case.

In this paper, we propose a variation of query tree algorithm, but has collision free factor. When there is less than k responding tags in reader's radio range, our protocol can identify the tags without any re-transmission. In section 2, we review previous approaches for tag collision, and propose our scheme with simulation results in section 3 and section 4. We conclude in section 5.

2. Related work

In RFID system, there two type of collision resolution scheme: (1) Probabilistic algorithm, which is based on ALOHA protocol. (2) Deterministic algorithm which detects collided bits and splits disjoint subsets of tags. And there are two open standards from ISO and EPC organizations. ISO 18000-6 family standard uses probabilistic algorithm which is based on ALOHA procedure, and EPC family standard uses deterministic algorithm.

2.1 Probabilistic Algorithm

In ISO 18000-6, the frame slotted ALOHA is proposed. In this scheme, all the tags response within frame size slots. As the frame size is bigger, the probability of collision gets lower, but the response time gets longer. Figure 1 shows frame slotted ALOHA procedure. 5 tags will randomly select one slot from 3 (frame size). In this case, tag 1 and tag4 and tag 2 and tag 5 will

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collide by pigeonhole principle. When frame size equals to the number of tags, this scheme shows best high throughput [3].

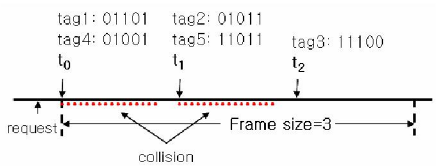

Figure 1 The example of frame slotted ALOHA procedure

In [3, 4], they suggest dynamic frame slotted ALOHA algorithm, which estimate the size of tags and dynamically change frame size. ALOHA based protocol, however, cannot perfectly prevent collisions. In addition, they have the tag starvation problem, where a tag may not be identified for a long time [6].

2.2. Deterministic Algorithm [5, 6, 7]

Deterministic algorithm, which has no starvation problem, is most suitable for passive tag applications. It is categorized into binary tree protocol and query tree protocol. Both of these protocols require all tags response at the same time and the reader identify corrupted bits [6]. In binary tree protocol, the tag has a register to save previous inquiring result. It has disadvantage of complicated tag implementation, and the tag in overlapped range of two readers will show incorrect operation. Query tree protocol does not require tag's own counter. Instead of using counter, the reader transmit prefix and tags are response their rest bits. The query tree protocol is memory-less protocol and tags has low functionality. However, it is slower than binary tree protocol for tag identification.

Figure 2 shows the difference between binary tree algorithm and query tree algorithm. In binary protocol [5], a reader broadcast 0 at t0, two tags whose IDs 0001 and 0011 will transmit next bit whose data are all 0 and increase their counters. Next time t1, the reader broadcast 0 (second bit data), and the two tags 0001 and 0011 also responds next bit and increase their counter. But, at this time, the reader detects collision. At t2, the reader broadcast 0 (third bit data) only 0001 transmits its data, in this step, 0011 reset it counter. In query tree protocol [6], the reader requests their ID with no prefix, and all tags transmit their ID. As a result, received four bits are totally corrupted. Next, the reader requests it with prefix 0, 0001 and 0011 transmit their bits [0X1]. The reader can know third bit is in collision, it request ID with prefix 000 and only one tag whose ID is 0001 transmit fourth bit as one.

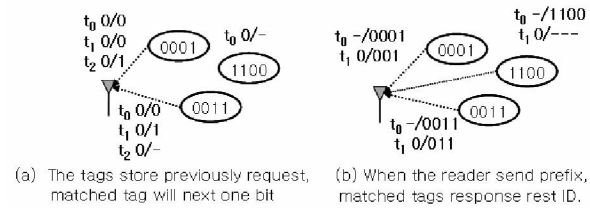

Figure 2 he difference between binary tree algorithm (a) and query tree algorithm (b)

3. Collision Resilient Multi-State Query Tree Scheme

In this paper, we propose multiples query tree algorithm. Even there are two or more tags in radio range we represent multiple tag identification scheme no more than two transmission using the balanced incomplete block design (BIBD).

3.1. Collision Resilient Symbol Design

The definition of (v, k, λ)-BIBD code is set of k-element subsets (blocks) of v-element set χ, such that each pair of elements of χ occurs together in exactly λ blocks. The (v, k, λ)-BIBD has total of $n= \lambda (v^2-v)/(k^2-k)$ blocks, and we can represent (v, k, λ)-BIBD code an v*n incident matrix, where C(i,j) is set to 1 when the i-th element belongs to the j-th block and set to 0 otherwise [8].

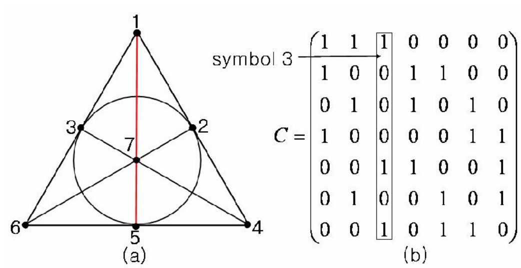

Figure 3 Geometric (a) and incident matrix (b) representation of (7, 3, 1)-BIBD

Figure 3 shows the example of (7, 3, 1)-BIBD which can identify up to 3 symbols at one transmission. For example, when the 1-st, 2-nd and 3-th symbols (column) collide, the first bit remains one. On the contrary, if one bit is set to one and the others are collapsed, the reader knows that what three symbols really sent. If one or more bits are not corrupted, we can make partition into two disjoint subsets and the one has less than 3 tags and it has unique elements. e.g) when third bit is 1, the subset has first, sixth and seventh symbols. In figure 3, (7, 3, 1)-code can represent only 7 symbols and identify up to 3 symbols within one transmission, we can redesign the parameter (v, k). (16, 4, 1)-BIBD can support n = (16*15)/4*3=20 symbols.

Although it lacks supported tags, it has strong advantage in identification speed, low power consumptions and robustness under low SNR region. To solve the small number of tags and compatibility with the electronic product code, we can compose of multiple BIBD codes. For instance, 32bits are divide into two 16 bits, and two 16 bits are (16, 4, 1)-BIBD codes, to support 20*20 users, or adopt hybrid scheme where small part uses BIBD scheme for compatible EPC Global Code.

3.2. Multi-State Query Tree Protocol

To identify tags, we suggest multiple state query tree protocol, which is variation of query tree protocol. The query tree algorithm consists of rounds of queries and response. In each round the reader asks the tags whether and of their IDs contains a certain prefix. If more than one tag answer, then the reader knows that there are at least two tags having that prefix. The reader then appends symbol 1, 2, □□□ or 20 to the prefix, and continue to query for longer prefix. When a prefix matches a tag uniquely, that tag can be identified. Therefore, by extending the prefixes until only one tag's ID matches, the algorithm can discover all the tags.

In the query tree protocol, a reader detects collision bit by bit. But in our scheme can detect collision with 16 bit vector symbols which have twenty symbols. And all tags which are matched the prefix, transmit their remained bits in query tree protocol, but in multiple states query tree protocol, they transmit their next one symbol which is 16 bits. The following describes the protocol:

```
Set the prefix empty
Begin until
    rx-signal = request (with the prefix)
     If (rx-signal is no response ) then
         If (the prefix is not empty) then
              delete last symbol in the prefix
         Else
              no response with empty prefix
         Endif
     Else
         Symbol = decode (the rx-signal)
         add symbol in to end of the prefix
     Endif
     If (size of prefix == size of tags symbol) then
         ensure that existence of the tag and
         make it not response
         delete last symbol in the prefix
     Endif
Until (there are no response with empty prefix)
```

Suppose that the RFID system use 48 bits for IDs, which consist of three symbols and supports 8000 tags. Each tag has unique path in the query tree and its depth is 3. Therefore we can identify one tag at most 3 times transmission. When a reader request next symbol with prefix, the tags transmit their next 16-bit symbols and the prefix matches with one tag's all symbol, the tag must send conform message. For example, there 4 tags whose ID are [4 18 5], [4, 18, 7], [8, 9, 2], [6 8 3] in the reader, the readers requests command bellows:

iteration	Reader request	Tags response	Memo
1	null	[4]	
2	[4]	[18]	
3	[4 18]	[5]	Identified
4	[4 18]	[7]	Identified
5	[4 18]	null	
6	[4]	Null	
7	null	[8]	
8	[8]	[9]	
9	[8 9]	[2]	Identified
10	null	[6]	
11	[6]	[8]	
12	[6 8]	[3]	Identified
13	[6 8]	Null	
14	[6]	Null	
15	null	Null	

To support 8000 tags, the other protocol needs 13 bits (8192 tags) and 13 iterations to identify one tag in worst case but our scheme needs only 3 iterations in worst case.

4. Experimental Results

In our experimentation, we assume AWGN (additive white Gaussian noise) model without fading for radio channel, and used (16, 4, 1) BIBD code to identify maximum 20 symbols (i.e. 20 = 16*(16-1)/(4*(4-1))) for collision case. We repeat 10,000 times randomly select symbols and collides. We assume that when reader transmits RF with power 1, tags will share fairly 1/k. Figure 4 shows the symbol error rate over various RF channel environments (signal to noise ratio between tags and reader). Our scheme shows better ID identification over increased SNR, and it gets worse as the number of symbols in a RF reader zone and SNR decreases. Simulation results show that we can achieve successful identification for maximum 4 symbols using (16, 4, 1) BIBD code. Mathematically, (16, 4, 1)-BIBD can 4 symbols at once, interference and fading degrade performance when 4 symbols. Depending on the RF environments, we can choose the parameter (v, k, λ)

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for better coverage and symbol identification performance.

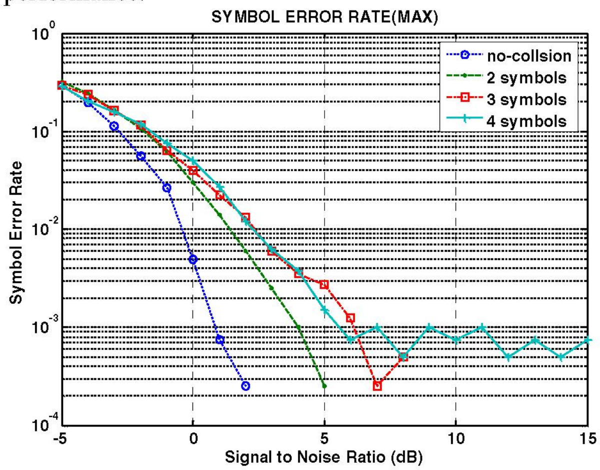

Figure 4 Symbol Error Rate, using (16, 4, 1)-BIBD

Figure 5 shows that our scheme has no degradation of performance when the power of signal is bigger then noise and operates well even extremely low signal to noise ratio (SNR). It support 6.4*10^7 tags. When 100 tags are one reader range under low SNR (-5dB), our scheme needs 6*10^4 bits between reader and tags to identify all tags. According to protocol for 900Mhz class 0 RFID [5], the transmission time between reader and tag is 12.5 microsecond, Our scheme can identify 100 tags within 0.75 (6*10^4*12.5*10^-6) second. Although it wastes bits, the identification speed is very fast. It can be adopted small/medium domain real time tracking system.

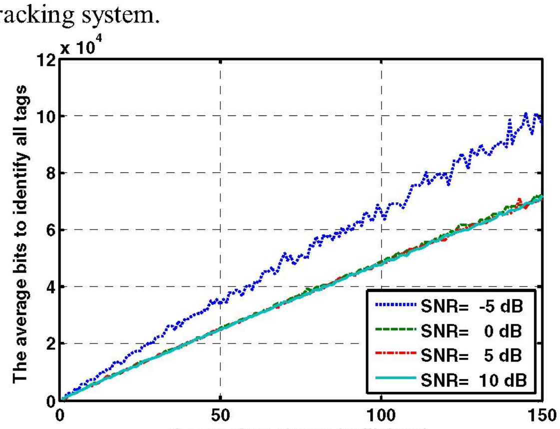

Figure 5 The tag identification performance using 6 symbols (16*6=96 bits) for one tag

5. Conclusions

In this paper, we proposed a collision detection and recovery algorithm for RFID tag collision cases. We designed the basic code using (v, k, λ) BIBD (balanced incomplete block design) code, and it can identify symbols when up to k symbols are collapsed. Our scheme does not require re-transmission, which costs power consumption. We simulated our scheme over various radio environments using AWGN channel model. Our scheme shows good collision detection and ID recovery (average k symbols for bad radio environments).

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