A Collision and Tag Number Detector for UHF RFID Reader Conforming to EPC Gen2 Protocol

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Abstract

In this paper, a collision and tag number detector for Radio Frequency Identification (RFID) reader is introduced. In EPC Gen2 protocol, Frame Slotted Aloha (FSA) is applied for multi-tag anti-collision. In some state-of-the-art researches, collision recovery methods are developed to turn a collision slot into a successful slot. To reduce failing recovery, the reader needs to know if there is collision and the detail number of tags in the slot. A clustering method based on histogram is designed to detect collision and the number of tags in this work. The simulation result shows that the average accuracy of the method can be as high as 90%. The success ratio of collision recovery is promoted by over 10% and the accuracy of tag number estimation is improved.

Key words: RFID, anti-collision, collision detection, collision recovery, tag number detection

1. Introduction

Radio Frequency Identification (RFID) technology is widely applied in various fields, including logistic, warehouse management, retail, etc. In some scenarios, more than one tags need to be identified together. If there are two or more tags within the range of a reader, collision may happen and the reader cannot identify any one of them, so anti-collision methods are needed.

ISO18000-6C protocol, also known as EPC Class1 Generation2 (Gen2) protocol [1], is proposed by EPC Global for Ultra-High-Frequency (UHF) RFID reader and tag air interface communication, in which Dynamic Frame Slotted Aloha (DFSA) algorithm is applied for anti-collision. In DFSA, the reader launches a frame with certain number of slots, and each tag randomly selects a slot to respond to the reader. If there are two or more tags in a slot, collision still occurs and the collision slot is discarded. A new frame will be arranged until all the tags are identified. The performance of the anti-collision algorithm is evaluated by system efficiency, which is defined as the number of tag identified over total number of slots.

With collision recovery methods, the collision signals can be recovered and the tags can be decoded separately. Since the collision recovery process requires much time and computation, the reader needs to know if there is collision and the number of tags, in order to reduce inappropriate recovery and promote efficiency.

In this work, a collision and tag number detector suitable for hardware implementation is designed. With the clustering method based on histogram, the reader can know the number of tags in the slot and determine the next step of processing.

The remainder of the paper is organized as follow: Section 2 introduces the related work; Section 3 describes the collision and tag number detection methods; the simulation results are discussed in Section 4; and Section 5 concludes the paper.

2. Relate Work

In [2], the authors proposed a signal separation method for Low-Frequency (LF) RFID readers, and discussed the extension on High-Frequency (HF) readers. In [3], the authors introduced a method to extract information from tag collision for UHF RFID readers and the collision detection methods based on radar cross section (RCS).

In [4-6], the authors developed collision recovery methods in physical layer, and analyzed the scenarios with single and multiple antennas based on linear estimation methods. In [7], a collision recovery receiver is designed, and the optimization in MAC layer is developed to promote the system efficiency.

In [8], a collision detection method based on preambles is proposed. However, the detail number of tags is not detected. In [9], a tag number estimation method based on maximum likelihood is designed. The hardware implementation is not developed yet.

3. Collision and Tag Number Detection Method

3.1 Tag number estimation based on histogram

In the digital baseband of the reader, the signal received can be expressed as (1). In the equation, $s_1(k)$ to $s_n(k)$ represent the signal of each tag; the coefficients a_1

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to a_n indicate the distance and strength of the tags; and v(k) refers to white noise.

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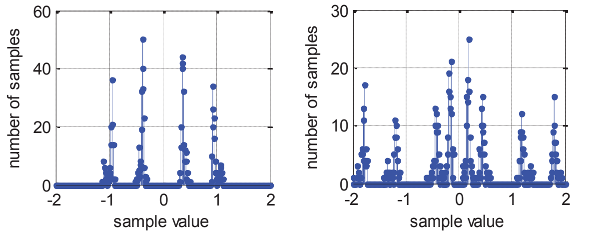
If there is only one tag, $s_1(k)$ has two possible values (high level or low level). With some noise, the distribution or the voltage samples will concentrate around two centers.

In the two-tag collision conditions, there are four possible values of $s_1(k)$ and $s_2(k)$ ([+1, +1], [+1, -1], [-1, +1], and [-1, -1]), thus the samples of voltage will concentrate around four centers. Similarly, in three-tag collision, there will be eight centers, as shown in Figure 1 [7].



(a) Histogram of two tags (b) Histogram of three tags

Figure 1. Voltage histogram of a collision signal

Based on this property, the number of tags involved in the signal can be detected with the voltage histogram. First, the voltage samples are stored in the memory. Then, the histogram of the samples is counted.

In the first step, if the slot is not empty, it is assumed that there is only one tag, and the distribution will concentrate around two values. One of the centers is positive and the other is negative. The average value of all the positive samples is considered as the positive center, and that of the negative ones as the negative center. Then, the average variation from each sample to the related center is counted. A certain threshold is set in advance, and if the average variation exceeds the threshold, the assumption of one tag fails and the next step is conducted. Is the variation is smaller than the threshold, no collision is detected and a standard decoding process is conducted.

In the second step, if there is more than one tag, it is assumed that there are two tags in the slot. Similarly, four centers could be found, and the average variation is counted and compared to a certain threshold. In this case, the centers are found from the distribution, and the four peaks in histogram plot are selected as centers. To make the result more accurate, a filter is applied to make the plot smoother. If the average variation exceeds the threshold, there are three or more tags; otherwise there are two tags in the slot.

Furthermore, by setting eight centers, it can be checked if there are three tags or more. Still, the process can be continued to find the detail number of tags, but it does not deserves. The accuracy of the process drops down significantly after three tags and the computation complexity increase seriously. Also, the incidents that there are more than four tags seldom happen.

Figure 2 shows the entire process of the detection.

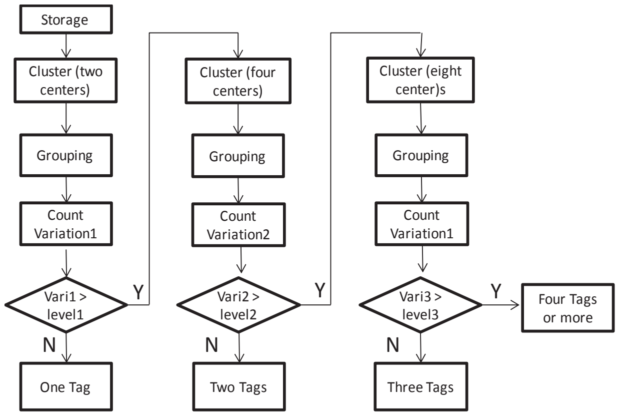


Figure 2. Work flow of the detector

3.2 Hardware Architecture

The design is based on a UHF RFID reader baseband, the collision and tag number detection modules are added compared to a standard reader, as shown in Figure 3. With this design, only minor modification is needed to fulfill the collision detection and recovery, and the design is flexible enough that it can be applied to a different reader without influence on the performance.

After the ADC, the digital baseband gets digital signals of I route and Q route. An IQ selector is applied to select the signal with better quality. Then the signal is sent to collision and tag number detector and collision recovery modules simultaneously. In the module separation2, the signal is treated as a two-tag collision signal and recovered accordingly, as introduced in [7]. In the module separation3, three-tag collision recovery is applied. The detectors can determine the number of tags in the slot. A digital receiver containing Rx Filter, Match Filter, Symbol Synchronization, Frame Synchronization and Decoder is adopted to decode the data. The protocol process is responsible for the commands processing conforming to the protocol. A controller is added between the digital receiver and separation modules to control the sequence of the input data.

The results of the detectors are delivered to the separation modules and the control module. The outputs of the collision recovery are delivered to the control module as well. The structure of the detectors is shown in Figure 4. The storage is shared by the three part of detectors and they can operate in parallel.

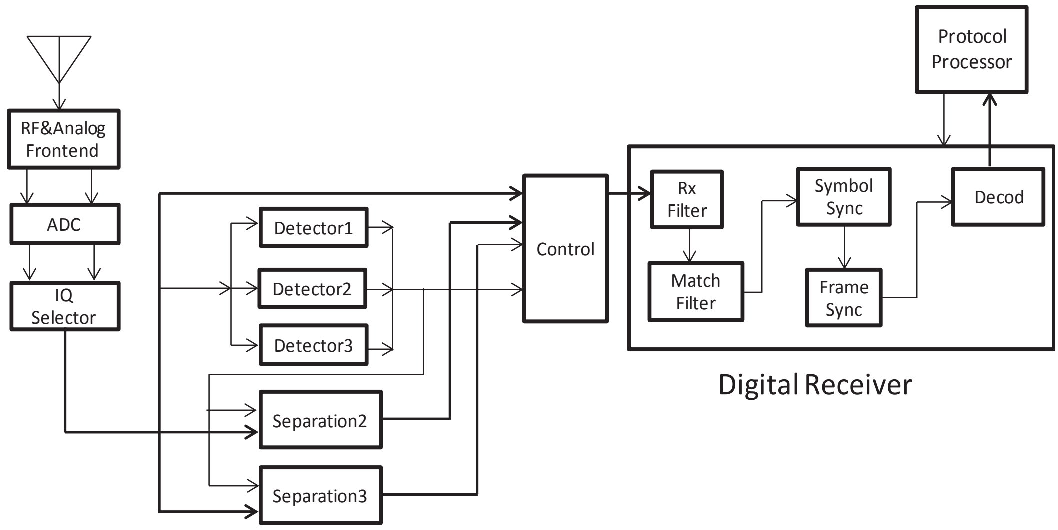


Figure 3. System architecture of digital baseband with collision detector and recovery

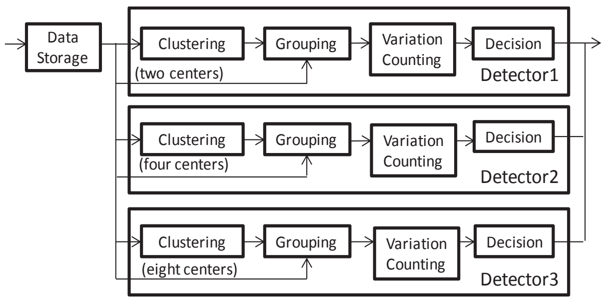


Figure 4. Hardware structure of the tag detector

4. Simulation Results

4.1 Accuracy in Determining Number of Tags

The performance of the design is evaluated by accuracy or the correct rate, which is defined as the number of correct experiments over the total number of experiments. In the simulation, the frame length L equals to the number of tags n. When n is large enough, the distribution of tags in a slot is shown in Table 1.

Table 1. Distribution of number of tags

Number of Tags in one slot	0	1	2	3	4 or more
Probability	0.368	0.368	0.184	0.061	0.019

So the correct rate can be counted by (2), where s1, s2, s3 and s4 indicate the correct rate when there are 1, 2, 3, or 4 tags in the slot.

óÕÃ (πϐσφψÓ˳ πϐρψτÓ. πϐπφρÓ˻ πϐπρωÓ˲) / (πϐσφψ πϐρψτ πϐπφρ πϐπρω) ς

In the algorithm, the selection of the thresholds has great influence on the accuracy. In the simulation, level1, level2, and level3 are defined as the thresholds in detector1, detector2, and detector3, respectively. Taking level2 for example, it has to be small enough, so that most of the variations of the three-tag collisions exceeds it; and large enough that most of the variations of two-tag collisions are smaller than it. Figure 4 shows the success rates of two-tag collision and three-tag collision scenario versus level2. The success ratio of two-tag collision (suc2) increases with the increase of level2, and that of three collision (suc3) decreases. The entire success ratio (suc) has an optimum value with certain parameters.

Optimizing the parameters comprehensively, it is known that the average success rate can be as high as 90%, when level1, level2, and level3 are selected as 0.003, 0.008, and 0.008 respectively.

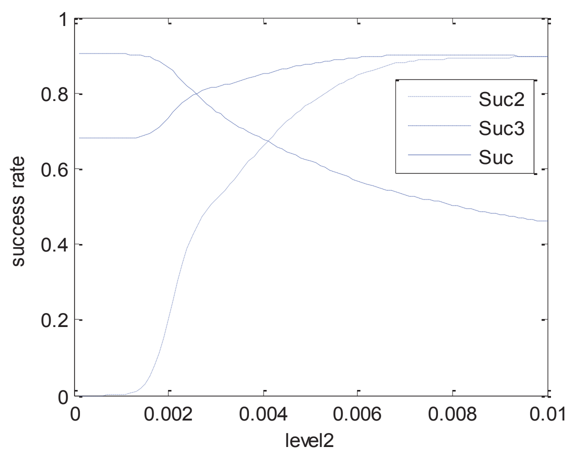


Figure 4. Success rates of two-tags and three tags scenarios vs. level2

4.2 Promotion for collision recovery

In the two-tag collision recovery, the success rate that both of the tag can be identified is 0.51, and the rate that one of them can be identified is 0.44, when SNR is 35db [7]. Thus, the average number of tags identified per slot (throughput) is 1.46, or the efficiency is 73%.

In the reading process, some of the slots contain three or more tags, instead of two tags, and the success ratio is decreased if all the collision signals are recovered by two-tag recovery method without detection. A simulation process is conducted on Matlab platform, and the overall efficiency is 64%.

With tag number detector, the slots with more than two tags are treated by three-tag recovery or discarded, and less failing recovery is conducted, leading to higher success ratios. When level2 is set as 0.006, the efficiency is 75% and about 33% of the collision slots are discarded. Thus the efficiency is promoted by 11%.

Figure 5 shows the number of slots needed to identify N tags with different methods. If no collision recovery is applied, the number of slots is the largest, and the throughput is the lowest. The slot consumption with tag detector is slightly better than that without it. Considering the reduced time of recovery process, the speed and comprehensive performance is much better.

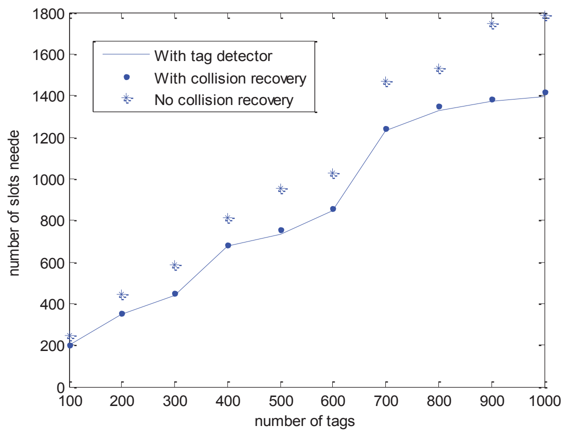


Figure 5. Average number of slots needed to identify N tags with different methods

4.3 Tag estimation with tag number detector

In the FSA, the numbers of empty, successful, and collision slots are used to estimate the number of tags. In Schoute algorithm, for example, the number of tags in a slot is considered as Poisson distribution, and the rest number of tags is estimated as $2.39*c_k$, where c_k refers to the number of collision slots in a frame. In some cases, one tag can still be identified even in a collision slot (capture effect), thus the number of collision slots is underestimated, resulting in estimation error.

With the tag number detector, the number of tags in each slot is detected. The comparison of the estimation error is shown in Table 2. The error rate of Schoute increases significantly as the number of tags is larger; while the estimation error with the detector in this work is much lower than that with Schoute.

Table 2. Tag estimation error

Number of Tags	100	500	1000
Estimation Error (this work)	0.6%	1.4%	3.9%
Estimation Error (with Schoute)	3.4%	16.3%	29.9%

5. Summary

In this paper, a collision and tag number detector is designed and the performance is evaluated. With the detector, the reader can know the detail number of tags in a slot. According to the simulation and optimization, the average accuracy can be as high as 90%. The efficiency of collision recovery can be promoted by at least 10%. Compared with a standard RFID reader, only minor modification is needed to fulfill the methods.

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