Collision Recovery Receiver for EPC Gen2 RFID Systems

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Hardware

Abstract

In this paper, a multi-tag anti-collision method with collision signal recovery for UHF RFID systems is proposed. Signal recovery of 2 tags or 3 tags is adopted in the algorithm and the frame size is optimized accordingly. Simulation results show that the average system efficiency of the proposed anti-collision algorithm can be up to 67%, while the system efficiency of the algorithms without adopting collision recovery is no more than 36.8%. The influence of non-ideal parameters in different scenarios, such as signal-noise-ratio (SNR) and frequency of clustering, is discussed as well.

1. Introduction

Radio Frequency Identification (RFID) technology is a contactless automatic identification technology. In an RFID system, tags are interrogated by an RFID reader through radio frequency signals, by which both data and energy are transmitted. If there are many tags within the working range of a reader, collisions will happen, and an anti-collision algorithm is needed.

The most commonly used anti-collision algorithms for ultra-high frequency (UHF) RFID are Dynamic Frame Slotted Aloha algorithms (DFS-Aloha). In these algorithms, the reader will perform interrogation by variable frames, and each frame will contain several slots. The time in each slot is enough to identify one tag. Every tag randomly selects one slot of the current frame to return its signal, and if more than one tag returns signals in the same slot, a collision occurs. If there are tags unidentified in the current frame, a new frame will be arranged, and the remaining tags (backlog) will randomly select slots to re-transmit in the following frames until all the tags are identified (Fig. 1). [1]

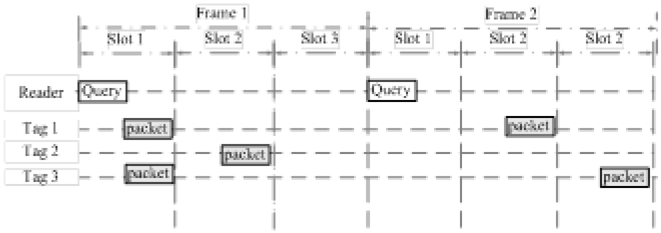


Fig. 1: Process of framed slotted Aloha [1]

The performance of anti-collision algorithms is evaluated by system efficiency, which is defined as the ratio of the number of successful slots to the total number of slots. It is well known that when the frame size (number of slots in one frame) equals the number of the backlog, the system efficiency approximates a maximum, 1/e (around 36.8%) [2].

In most IoT application scenarios, speed of identification is concerned. With the method in this paper, the system efficiency can be significantly promoted without much modification and the time to identify all tags will be reduced. The simulation result shows that the performance will be better with large population of tags, making it suitable for dense tag scenarios.

Different from those in traditional algorithms, one or more tags can be identified in a collision slot if collision recovery method is applied to the anti-collision algorithms [3] [4]. Reference [3] developed an algorithm for LF systems and indicated that it could be used in UHF systems. Reference [4] implemented a signal separation algorithm in a UHF system by software. In [5], the authors proposed a single antenna physical layer collision recovery method with I/Q plane analysis. In [6], method of physical layer collision recovery with multi-antenna was researched. Reference [7] proposed collision recovery model at physical layer with single and multiple antenna. Reference [8] researched channel estimation in multi-antenna collision recovery scenarios and proposed the concept of post-preamble to facilitate the processing.

A topic yet to be researched is how to combine the physical collision recovery method with the Media Access Control (MAC) layer anti-collision algorithms for overall system efficiency optimization in EPC Gen2 protocol. The influence of un-ideal reader and signal will decrease the actual performance of the method significantly and further research is required. To implement the algorithm in reader, the signal needs to be processed in hardware to meet the time requirement of Gen2 protocol, and the cost must be acceptable.

In this work, a collision recovery algorithm using signal separation method is proposed and evaluated with reader baseband. In the proposed algorithm, signal separation of 2 tags or 3 tags is adopted and the frame size is correspondingly optimized to improve the overall system efficiency with EPC Gen2 framework.

The rest of the paper is organized as follows: Section II introduces the signal separation algorithm applied in the work. Section III presents the signal processing method and optimization of frame length. In Section III, simulation results and the factors that influence the performance are discussed. Section IV concludes the paper.

2. Signal Seperation Algorithm Based on Voltage Level

The problem of signal separation can be defined by (1):

$$X(k) = AS(k) + V(k) \quad , \tag{1}$$

Where vector X(k) is the signal observed, S(k) is a series of signal sources, A is related coefficient matrix which is unknown, and V(k) is added white noise. The objective is to identify A and S(k) from X(k).

For a single antenna RFID receiver, X(k) is the single observed value, which changes the problem to the summation of several AS(k) components shown by (2). In a multi-tag collision scenario, each si(k) presents for the backscatter signal of one tag in the slot, and coefficient ai indicates the strength of the signal.

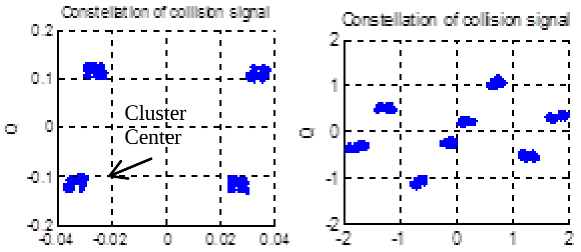
$$x(k) = a_1 s_1(k) + \cdots a_n s_n(k) + v(k) \tag{2}$$

For a binary signal, a simple method with low hardware cost can be applied, which is suitable for RFID systems.

In one signal, like s1(k), only two values are possible: d1 for 1, and –d1 for 0, for example. If two signals are added with coefficients, four values are possible. Though there will be some variation because of noise, the observed value will concentrate around four or eight cluster centers respectively, when two or three tags are colliding.

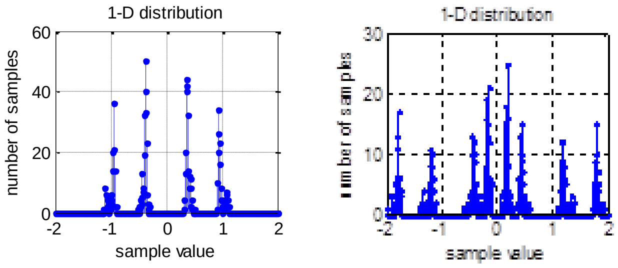
With I/Q demodulators, the received signal can be separated into an Inphase (I) signal and Quadrature (Q) signal, and each sample can be drawn in a constellation plot or I/Q plane. The collision signal with two tags will concentrate around four centers (cluster centers) in the constellation, and the three-tag collision signal forms eight centers in it. Figure 2 shows the cluster centers of collision signals, in which the horizontal axis indicates the Inphase signal, and vertical axis indicates the Quadrature signal.

In a 1-D distribution, the sample value will be around several cluster centers as well (Fig. 3), and this information can be used for collision signal separation in the next step.



(a) **(b)**

Fig. 2: Sample distribution on constellation plot



(a) **(b)**

Fig. 3: Sample 1-D distribution

In a two-tag-collision signal, the value of the perceived voltage at the antenna will concentrate around four center levels. With the method of clustering [5], we can obtain four cluster centers. The high voltage and low voltage of original signals are then determined, with which two signals are separated; the two signals can then be decoded, respectively.

3. Proposed Method for EPC GEN2 RFID Systems

3.1. Separation Process for Two-tag-collision

In this part, a system with signal separation algorithm for a two-tag-collision is developed. In this case, the separation method for a two-tag-collision is applied to every collision slot, regardless of the actual number of colliding tags.

A system model of a UHF RFID reader is designed according to [2], using Matlab. In the model, the antenna gets a signal from the channel, and after the RF & Analog frontend and ADC, the digital signal is received by the digital baseband. An IQ selector is applied to select the I signal or Q signal with better SNR. An Rx filter and a matched filter are used for higher SNR. A symbol synchronizer and a frame synchronizer are then used to synchronize the data. Next, a decision module is used to obtain FM0 coding from the data. The original data can be obtained by decoding the FM0 codes.

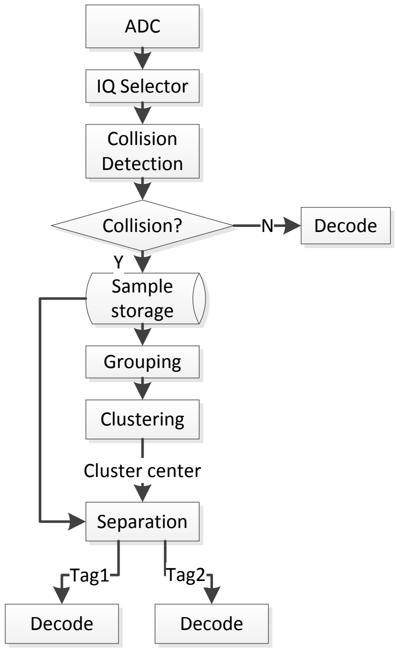


Fig. 4: Work flow of signal separation algorithm for two-tag-separation

Figure 4 shows the workflow of the process with the applied signal separation method. In this design, a signal with one or more RN16s is obtained from the ADC. We apply an IQ selector first, then take samples and record the values. If collision is detected, the signal will either be processed with signal separation algorithm or decoded directly.

Next, the voltage distribution of the samples is counted. In the simulation, the range is chosen from -2V to 2V, and the step is selected as 0.01V. The four peaks of the sample distribution are the four clustering centers needed. Since the two positive centers and the two negative centers are symmetrically distributed, only counting the positive centers is enough, and the opposite values represent negative ones. Thus, the absolute value of each sample is counted in the processing.

$$p_k = \frac{1}{16}\left(p'_{k-2} + 4p'_{k-1} + 6p'_k + 4p'_{k+1} + p'_{k+2}\right) \qquad (3)$$

Grouping and clustering is adopted to reduce variations, which may lead to incorrect peaks. Smoother distribution can be obtained using (3) [10], in which p_k is the data point after clustering, p_k' represents the data point before clustering, p'_{k-1} and p'_{k+1} represent the previous and next data points, and so on. Two peaks corresponding to the correct clustering centers, l1 and l2 will be formed after several times of clustering. The opposite values of l1 and l2 are the other negative centers l4 and l3. In the next step, every sample will be compared with the four cluster centers. If the sample value is more near to l1, then both signals indicate a high level, and the separation result will be [d1, d2] for two signals. If it is near to l2, the result will be [d1, -d2], assuming the absolute value of d1 is larger than d2, and so on.

Then each sample of the received signal will be considered again, to derive original voltage level of each signal. The signals of two tags are recovered and can be decoded respectively.

3.2. Separation Process for Three-tag-collision

The signal separation algorithm for the three-tag-collision is developed in a similar way. In this case, the step of estimating the tag number is needed. If collision is detected, the workflow may have three branches according to the number of tags in the slot. If there are two tags in one slot, the signal will be processed as workflow in part A. If there are three tags, it will be processed with another workflow. When more than three tags are colliding, the signal will be discarded. Figure 5 shows the entire workflow.

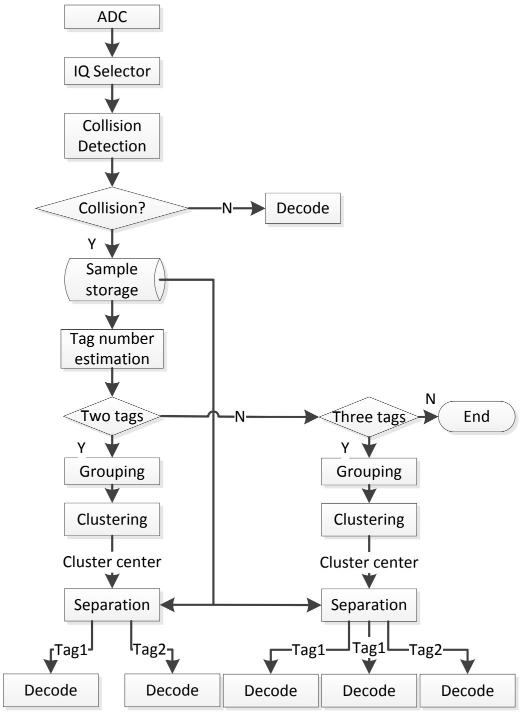


Fig. 5: Workflow with signal separation algorithm for two-tag-separation and three-tag-separation

3.3. Conversion of Collision Slots to Success Slots under EPC Gen2

The communication process between reader and tag is shown as below:

- Reader sends Query instruction.
- Tag returns its RN16.
- Reader sends ACK instruction with the RN16.
- Tag returns its EPC code.

In traditional methods, when collision is detected in RN16, the slot will be ended.

With the two-tag-separation method, when the reader receives the collided RN16, the reader will separate the signal into two separate RN16s and send two ACK commands in succession to identify the two tags.

EPC Gen2 protocol requires that the reader should send ACK within a certain time (T2), otherwise the tag will return to the arbitrate state and there will be no reply. To solve the problem, the second tag should be informed of the situation and the waiting time needs to be extended. Thus, a collision slot is converted to a slot in which more than one tag can be identified. Figure 6 shows the process.

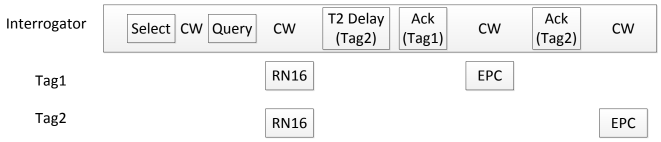


Fig. 6: Process of two-tag-collision in EPC Gen2

3.4. Determination of Frame Size

In traditional DFS-Aloha algorithms, it can be demonstrated that maximum system efficiency is achieved when frame size equals the number of backlog tags.

In the design with the collision recovery algorithm, the optimum frame size L can be smaller to increase the two-tag collision situation. The performance of collision recovery will influence the choice of frame size so coefficients indicating recovery performance is defined to solve the issue.

Determination of frame size is shown in (4), in which n indicates the number of tags and αe1 is the effective success ratio, as shown in (5). C2 indicates the number of slots with two tags returning their signals, and ck indicates the total number of collided slots.

$$L = n - \alpha_{e1}(n - 1) \quad (4)$$

$$\alpha_{e1} = \frac{c_2}{c_k}(2\alpha_d + \alpha_s) \quad (5)$$

In (5), αd and αs can be counted beforehand, and c2 and ck can be considered as approximately constant. Thus, αe1 is determined, and the optimum frame size L can be calculated.

Note that, the number of tags to be identified (n) is not known in advance, and estimation algorithms are adopted. Vogt algorithm [10] and Schoute [11] are the most efficient algorithms and are used in the simulation. After one frame, the reader can re-estimate the remaining number of tags based on the numbers of success slots, empty slots, and collision slots, and then adjust frame sizes accordingly. In Gen2 protocol, the frame size should be the power of 2 (2Q), and tags are informed of the value of Q only. So the nearest Q should be chosen based on the estimation after each frame.

4. Simulation Results

4.1. Factors Influencing Performance

To evaluate the performance of the method, two success ratios are defined. One is the ratio indicating that both of the signals are decoded correctly (αd for short); the other ratio indicates that one of the two signals has been decoded correctly (αs for short). The average number of tags that can be identified in one slot (αt for short) can be calculated with (6). Success ratio αd indicates the accuracy of the method, while αt approximately shows the increase in efficiency. The result may be different with different SNRs and times of clustering.

$$\alpha_t = 2\alpha_d + \alpha_s \tag{6}$$

4.1.1. Influence of SNR

The performance of our design is highly dependent on the SNR. Table I shows the trend of αd and αt in a different SNR.

When the SNR is larger than 20 dB, the result is acceptable, but the performance decreases significantly with a decrease in SNR when the SNR is smaller than 20 dB. If the SNR is smaller than 15 dB, the performance is quite poor, and it is no longer appropriate to apply this method. With too much noise, some samples will be misidentified as neighbor cluster centers and the result will be incorrect.

SNR(dB)	**10**	**15**	**20**	**25**	**30**	**35**
αd	**0.002**	**0.052**	**0.154**	**0.238**	**0.462**	**0.485**
αt	**0.71**	**0.86**	**1.04**	**1.17**	**1.39**	**1.43**

Table 1: INFLUENCE OF SNR

4.1.2. Influence of clustering

The time of clustering is a design-dependent factor that has influence on the performance of our method as well. Table II shows the result of αd when SNR is 25 dB. Note that, the αd increases significantly with the increase of times of clustering when times of clustering are less than 20. The increase in performance increase is slow when the time of clustering is above 24. With a higher SNR, fewer times of clustering are needed. As large numbers of clustering will increase the hardware cost, 10 to 20 times of clustering is recommended.

Times of clustering	8	12	16	20	24	28	32
α_d	0.232	0.259	0.263	0.295	0.344	0.353	0.363

Table 2: Success Ratio vs Clustering

4.2. System Efficiency with Two-tag-separation

In the simulation process in Matlab, a certain number of tags is set to be identified, and the frame size of the first frame is determined by the initial setting. In one frame, each tag randomly selects a slot to return the signal, and the number of tags in each slot can be counted and used to calculate the number of tags identified in this frame.

In the simulation of two-tag-separation algorithms, it is assumed that no tag is identified in slots with more than two tags colliding. In a successful slot, only one tag returns the signal and it can be identified. In two-tag-collision slots, the number of tags to be identified is counted by the number of slots times the ratio in (6).

Another frame will be started and the frame size will be decided according to the estimation. The process will iterate until all the tags are identified.

To measure system efficiency, the total number of slots needs to be known. When two tags are identified in one slot, the time cost of the slot is almost doubled, and the slot is counted as two slots to make the result fair. The Vogt algorithm [10] and Schoute algorithm [11] are used to estimate the number of backlog tags. The simulation is repeated by 10000 times to count average performance.

Note that with two-tag-separation algorithms, the average system efficiency of Vogt algorithm and Schoute algorithm increases by 17% and 13%, respectively, and maximum system efficiency of Vogt algorithm can be over 55% when the number of tags is around 300 (Fig. 7). In the simulation, the frame size is chosen as 256 (28) in the beginning, which is suitable for a large tag population. When the number of tags is small and the frame size is far from the optimum, the system efficiency is low and, thus, a smaller Q (Q=4 for example) will be better.

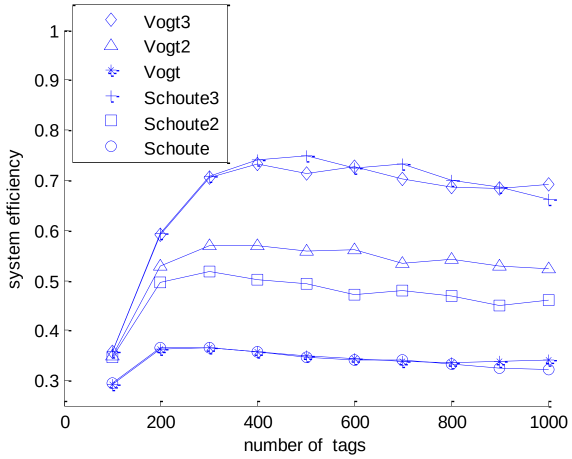


Fig. 7: System efficiency of simulation results (Vogt2 and Vogt3 stand for two-tag-separation vogt algorithm and three-tag-separation vogt algorithm respectively. Same to Schoute2 and Schoute3.)

4.3. System Efficiency with Three-tag-separation

With three-tag-separation algorithms, when the SNR is 35 dB, the possibilities of correctly obtaining three, two, and one RN16s are 3.6%, 31.2%, and 64.1%, respectively. Note that, with the three-tag-separation algorithm, the average system efficiency of the Vogt algorithm can be up to 67%, which is 18% more than that of the algorithm with only two-tag-separation.

However, with only the two-tag-separation method, we can still possibly identify one or two tags when three tags collide. Given a three-tag-collision RN16 signal, the possibility of identifying two of them is 6.9%, and the possibility of identifying one tag is 59.4%; therefore, the average system efficiency of two-tag-separation method is 62%, and the overall system efficiency increase is 5%.

In order to separate three tags, a tag number estimation module and another set of separation modules are needed, though the memory to store the samples, which takes a large area, can be reused. As the three RN16s are decoded serially, the separation process has to meet the timing requirement, which is defined as T2 in the EPC Gen2 protocol.

5. Conclusions

In this paper, a collision recovery algorithm suitable for EPC Gen2 RFID systems is proposed. Signal procession technology of the 2-tag-collision or 3-tag-collision is adopted based on the traditional anti-collision algorithms, and the average system efficiency almost doubles from 34% to 67%. As for the hardware cost, the design is suitable to implement in RFID readers, and times of clustering should be determined according to the SNR. In future work, we will implement the design in hardware and make more optimizations for the algorithms.

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