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ARTICLE

A Novel Anti-Collision Algorithm for Large Scale of UHF RFID Tags Access Systems

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ABSTRACT

When the radio frequency identification (RFID) system inventories multiple tags, the recognition rate will be seriously affected due to collisions. Based on the existing dynamic frame slotted Aloha (DFSA) algorithm, a sub-frame observation and cyclic redundancy check (CRC) grouping combined dynamic framed slotted Aloha (SUBF-CGDFSA) algorithm is proposed. The algorithm combines the precise estimation method of the quantity of large-scale tags, the large-scale tags grouping mechanism based on CRC pseudo-random characteristics, and the Aloha anti-collision optimization mechanism based on sub-frame observation. By grouping tags and sequentially identifying them within subframes, it accurately estimates the number of remaining tags and optimizes frame length accordingly to improve efficiency in large-scale RFID systems. Simulation outcomes demonstrate that this proposed algorithm can effectively break through the system throughput bottleneck of 36.8%, which is up to 30% higher than the existing DFSA standard scheme, and has more significant advantages, which is suitable for application in large-scale RFID tags scenarios.

KEYWORDS

Radio frequency identification; anti-collision; tags grouping; dynamic framed slotted Aloha

1 Introduction

Passive ultra-high frequency (UHF) RFID [1–3] has gained widespread use in the industrial sector due to its extensive communication range, rapid identification speed, strong reliability, ample storage capacity, and other benefits. In the process of transmission between tags and reader, interference and collision between data will be caused due to the sharing of the same wireless channel [4–6]. Currently, anti-collision algorithms utilizing RFID may be roughly divided into two categories: deterministic algorithm based on tree [7–10] and random algorithm based on Aloha class [11–15]. The tree-based anti-collision algorithm is a deterministic algorithm. Multiple tags are constantly grouped in the recognition process until there is only one tag in the group, at which point the reader can successfully identify it [16–17]. Random algorithms based on the Aloha class mainly include the pure Aloha algorithm (PA), slotted Aloha algorithm (SA), framed slotted Aloha algorithm (FSA), DFSA [18–20] and various enhanced algorithms [21–23].

The advantages of Aloha algorithms are low cost, easy implementation, and low hardware requirements for readers. This type of algorithm does not require the detection of specific collision locations, making it well-suited for application in UHF RFID systems. Chen et al. utilized the maximum a posteriori probability decision algorithm to estimate quantity of tags and proposed an enhanced Aloha algorithm to enhance the efficiency of RFID systems [24]. Zhang et al. put forward an Aloha algorithm for grouping adaptive time-slot allocation. The main concept is to pre-scan the time slots selected by tags so that they can adaptively choose and allocate time slots, thus avoiding extensive collision and idle time slots [25]. An anti-collision algorithm named Grouped Dynamic Frame Slotted Aloha (GDFSA) was also introduced in which the estimated tag number is first determined, followed by grouping and dynamic frame slot strategies to identify tags [26]. Chen et al. estimated unrecognized tags by observing collision and idle slots in subframes, dynamically adjusting the frame length range and proposing a dynamic frame slot Aloha algorithm based on a subframe observation mechanism with system throughput near optimal at 0.361 [27]. Mustapha et al. suggested an Aloha algorithm based on Bayesian tag estimation, which improved accuracy while maintaining system throughput optimality [28]. To improve identification performance in dense tag situations, Bai et al. modified tag set grouping using fuzzy C values and presented an anti-collision Aloha method based on EPC grouping [29]. Zahran et al. brought forth an Aloha algorithm for optimal frame length allocation adopting multi-factor estimation to dynamically adjust frame length gradually reducing invalid time slots [30]. The results indicated that the system efficiency could still be maintained even when there is large-scale access to tags.

In this paper, the SUBF-CGDFSA algorithm is proposed. In accordance with both experimental and theoretical analysis of the current anti-collision algorithm, this algorithm takes the grouping mechanism as the starting point and combines the sub-frame observation mechanism with the accurate tags number estimation method. On the basis of them, this paper optimizes and improves them. The large-scale tags grouping mechanism is used first, and then the sub-frame based DFSA (SUBF-DFSA) algorithm is used to identify intra-group tags. In contrast to current anti-collision algorithms, the suggested approach exhibits enhanced flexibility in recognizing a substantial quantity of tags. It effectively maintains high throughput, significantly improves slot efficiency, and conserves a substantial amount of system resources.

2 Preliminaries: Tags Estimation, Grouping Rules and Sub-Frame Observation Mechanism

An RFID reader typically deploys a large quantity of tags, with all tags sharing the same communication channel. This often leads to tag collision, resulting in increased collision time slots. The efficient identification of a large quantity of tags poses a significant challenge in RFID systems. Performance indicators are required in order to assess multi-tag anti-collision algorithms' macroscopic performance. The ratio of successful time slots needed by a reader to identify every tag in its working domain to the total quantity of time slots, also referred to as throughput, defines the system efficiency of an anti-collision algorithm in RFID systems. The system efficiency U may be stated as follows, assuming that there are n tags in the reader's working domain and N slots total needed to identify tags:

$$U = \frac{n}{N} \tag{1}$$

The more time slots the anti-collision algorithm utilizes, the lower the system efficiency it can achieve. Thus, system efficiency is one of the most crucial measures to assess the efficacy of RFID anti-collision algorithms.

2.1 Tags Estimation

When optimizing the system efficiency, it is essential to accurately estimate quantity of tags in the application scene and consider the algorithm complexity. This paper conducts research on system recognition efficiency based on the Schoute tags estimation method and the Vogt tags estimation method.

The Schoute tags estimation method is based on the Poisson estimation technique. The Poisson tags estimation function is proposed in accordance with the posterior probability of m tags choosing the same specific time slot i. This function calculates the posterior expected value of the tag collision time slot, which is found to be $m = 2.39$. In other words, 2.39 tags on average are reacting in each collision slot. Therefore, in accordance with the Schoute estimation method, the approximate quantity of system tags is:

$$N = S + 2.39C \tag{2}$$

where S is the quantity of tags successfully identified and C is the quantity of collision slots.

The Vogt algorithm is utilized to estimate the quantity of remaining tags in accordance with the tag recognition status from the previous frame. This algorithm is grounded in the Chebyshev inequality principle, which states that the results of random experiments on any random variable will eventually converge towards the expected value. In other words, the quantity of tags n that can minimize the distance between the experimental result (e, s, c) and the expected vector $(E(e), E(s), E(c))$ represents an estimation for the quantity of tags in the system using Vogt's method. Here, $(E(e), E(s), E(c))$ denotes the anticipated values for idle, successful, and collision slots, respectively.

$$\varepsilon(n, e, s, c) = \min_n \left| \begin{pmatrix} E(e) \\ E(s) \\ E(c) \end{pmatrix} - \begin{pmatrix} e \\ s \\ c \end{pmatrix} \right| \tag{3}$$

The system's frame length is represented as F and the quantity of tags is denoted as n. Probability statistics state that the likelihood of r tags selecting the same time slot inside the reader's reading range is:

$$P_{n,\frac{1}{F}}(r) = C_n^r \left(\frac{1}{F}\right)^r \left(1 - \frac{1}{F}\right)^{n-r} \tag{4}$$

Therefore, the expected value $E(e), E(s), E(c)$ of idle, successful, and collision slots are expressed as follows:

$$E(e) = F \cdot P(0) = F \cdot \left(1 - \frac{1}{F}\right) \tag{5}$$

$$E(s) = F \cdot P(1) = n \cdot \left(1 - \frac{1}{F}\right)^{n-1} \tag{6}$$

$$E(c) = F \cdot P(k) = F - E(0) - E(1) \tag{7}$$

2.2 Grouping Rules

Grouping rules are suggested to guarantee a high throughput rate while handling a large quantity of tags. This will enable the reader to maintain efficiency under such circumstances. If the quantity of tags is small, grouping is not necessary. However, if the quantity of tags is too large, it is advisable to arrange the tags based on the estimated range. This significantly reduces tag collisions. The electronic tag is the data carrier of the identification object, storing the information of the identification object and the tag, and generating a CRC code according to the data sequence after the data is written to the tag, which is used to verify the sequence in data communication. Moreover, CRC check codes have good pseudo-random characteristics, and the generated low-level CRC check codes are close to uniform distribution. The group identification algorithm uses the CRC codes of tags as the basis for grouping. In the algorithm, the generated CRC codes are used to generate a lower CRC code value as the group number of each tag.

In the existing RFID standards, 16-bit CRC code is generally used as the verification code, so the 16-bit CRC is discussed as an example. For example, after a tag receives a request to start recognition, it extracts its own 16-bit CRC code value, and it divided by the generator polynomial $G(x) = x^4 + x + 1$ is a 4-bit CRC code by modulo 2 division, so that the group in which each tag belongs is uniquely identified. The 4-bit CRC code value can be represented in the range of 0–15, so all tags are assigned to 16 groups. Therefore, a one-bit check code can be split into 2 groups, a two-bit check code into 4 groups, a three-bit check code into 8 groups, and so on.

According to the group processing of identification tags in the scenario, the algorithm maintains a high and stable throughput for each quantity of tags. The quantity of groups is determined in accordance with the quantity of tags, and it is significant to establish the critical value of tags for switching between the number of groups. Based on different sets of regulations, various critical values for tags can be established.

2.2.1 Critical Value to Determine Scheme I

The critical value for grouping tags is chosen in accordance with the quantity of tags and the reading throughput, taking into account varying numbers of groups. For instance, assuming *n* tags are to be identified in an RFID system with a frame length of *F*, the system throughput rate in the Aloha algorithm is represented as:

$$U = \frac{n}{F} * \left(1 - \frac{1}{F}\right)^{n-1} \tag{8}$$

The frame length is fixed at a value of $F = 256$, and the critical value for switching between two adjacent tag grouping schemes is determined using the formula mentioned above. This involves considering the quantity of tags with consistent throughput when the number of groups varies.

In formula (9), *a* and *b* represent the quantity of tag groups. By adjusting the values of *a* and *b* in the equation above, one can determine the number of tag groups. Table 1 outlines the corresponding relationship between the quantity of groups and the quantity of tags.

$$\frac{\frac{n}{a}}{256} \times \left(1 - \frac{1}{256}\right)^{\frac{n}{a}-1} = \frac{\frac{n}{b}}{256} \times \left(1 - \frac{1}{256}\right)^{\frac{n}{b}-1} \tag{9}$$

Table 1: Mapping between the quantity of groups and tags

Quantity of groups	1	2	4	8	...
Minimum quantity of tags	1	355	709	1418	...
Maximum quantity of tags	354	708	1417	2834	...

2.2.2 Critical Value to Determine Scheme II

Maximum throughput in the traditional DFSA method is reached when the quantity of tags is equal to the original frame length. For an original frame length of 256, the generated CRC check code consists of 1 bit and is divided into two groups. The theoretical maximum throughput is achieved when there are $2 * 256 = 512$ tags present, resulting in a generated CRC check code of 2 bits divided into four groups. This pattern continues, with maximum throughput being achieved at $4 * 256 = 1024$ tags and so on.

The quantity of tags corresponding to the optimal throughput of adjacent grouping schemes is determined, and the median value of the two is identified as the critical value. For instance, if there are $256 * 2^1 = 512$ tags for the two groups and $256 * 2^2 = 1024$ tags for the four groups, the critical value would be the median of these two numbers, which is $(512 + 1024)/2 = 768$. Table 2 can then be filled in accordingly.

Table 2: Mapping between the quantity of groups and tags

Quantity of groups	1	2	4	8	...
Minimum quantity of tags	1	385	769	1537	...
Maximum quantity of tags	384	768	1536	3072	...

2.2.3 Critical Value to Determine Scheme III

When categorizing tags in the scene, the quantity of bits generated by different CRC check codes determines the quantity of groups. The simulation of throughput based on CRC check grouping combined with the traditional DFSA algorithm indicates that as the quantity of tags continues to increase, the system throughput will decrease. To ensure optimal grouping performance, with an initial frame length $F = 256$, the relationship between the quantity of distinct groups and system throughput as the quantity of tags increases is depicted in Fig. 1.

According to the simulation outcomes, the critical value of the number of tags for different grouping schemes is determined. This corresponds to the quantity of tags at the intersection point of the throughput rate of adjacent grouping schemes, and is recorded in Table 3.

At the onset of the initial RFID system identification and at the conclusion of each round of identification, an estimation is made regarding the number of tags that remain unidentified. Based on these predictive results, a determination is made as to whether it is necessary to group the tags. In cases where tags must be sorted into multiple groups for identification purposes, the reader employs an identification frame with the maximum quantity of time slots in order to identify tags. This approach allows for control over the quantity of tags in each group within a higher reading throughput range, thereby preventing significant tag collisions during identification. Consequently, these three strategies effectively maintain a high throughput rate for the system and reduce tag recognition time.

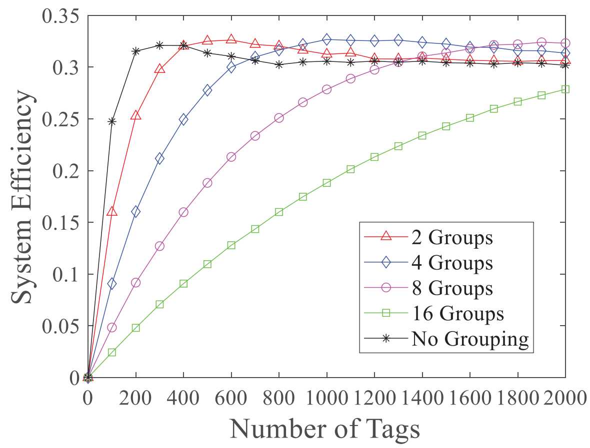


Figure 1: Performance comparison of traditional DFSA in different grouping schemes

Table 3: Mapping between the quantity of groups and tags

Quantity of groups	1	2	4	8	...
Minimum quantity of tags	1	401	801	1601	...
Maximum quantity of tags	400	800	1600	3200	...

2.3 Sub-Frame Observation Mechanism

In order to simplify the tags number estimation algorithm, it is recommended to avoid using methods that require extensive computation. By doing this, we may increase the tags number estimate algorithm's time efficiency and lower its computing complexity. The traditional DFSA algorithm estimates the quantity of unrecognized tags in accordance with the relationship between successful, collision, and idle slots in the entire frame, in order to adjust the size of the next frame length. However, if the frame length in the previous recognition cycle was not appropriate, it may negatively impact the next recognition cycle and significantly reduce system recognition efficiency. Therefore, a new mechanism will be introduced to estimate the quantity of unrecognized tags using only a portion of the current frame, namely a subframe.

The algorithm calculates the estimated quantity of tags to be identified in accordance with the statistics of idle, successful, and collision slots observed in subframes, as well as the relationship between subframes and current frames. Assuming that n tags are allocated in F slots, the probabilities of idle slots occurring e times, successful slots occurring s times, and collision slots occurring c times in subframe F_{sub} can be expressed using formula (10).

$$P\left(F_{sub}, e, s, c\right) = \left(\frac{F_{sub}!}{e!\,s!\,c!}\right) P_0 P_1 P_2 \tag{10}$$

where P_0, P_1, P_2 are the occurrence probabilities of idle, successful and collision slots. The specific calculation formula is as follows:

$$P_0 = \left(1 - \frac{e}{F_{sub}}\right)^n \tag{11}$$

$$P_1 = \binom{n}{s}\left(\frac{s}{F_{sub} - e}\right)^s\left(1 - \frac{s}{F_{sub} - e}\right)^{n-s}\frac{s!}{s^s} = \binom{n}{s}\left(\frac{(F_{sub} - e - s)^{n-s}}{(F_{sub} - e)^n}\right)s! \tag{12}$$

$$P_2 = \sum_{k=0}^{c}\sum_{v=0}^{c-k}(-1)^{(k+v)}\binom{c}{k}\binom{c-k}{v} \times \frac{(n-s)!}{(n-s-k)!}\frac{(c-k-v)^{(n-s-k)}}{c^{(n-s)}} \tag{13}$$

When the value of $P(n|e,s,c)$ is maximal, the quantity of tags involved in the subframe is determined. Given that the tag estimation result in the subframe is n_{sub}, the total tags number involved in the entire frame n_{est} can be estimated using the following formula:

$$n_{est} = n_{sub} \times \left(\frac{F}{F_{sub}}\right) \tag{14}$$

The frame length is modified based on the above-mentioned tag estimate findings, with the subframe F_{sub} representing the first m time slots in the inventory cycle. In accordance with the EPC global C1 Gen2 standard, the frame length $F = 2^Q$ (Q is an integer ranging from 0–15), so the value of subframe F_{sub} is usually *F/2*, *F/4*, *F/8*, *F/16*, etc. [31]. Table 4 lists the subframe F_{sub} of different frame length F:

Table 4: Settings of sub-frame F_{sub} in different frame length F

F	8	16	32∼128	256∼512	1024	>1024
F_{sub}	*F/2*	*F/4*	*F/8*	*F/16*	*F/32*	*F/64*

In accordance with EPC global C1 Gen2 standard, frame length $F = 2^Q$ (where Q is an integer from 0–15), so frame length F sometimes cannot be strictly equal to tag number n. To achieve a stable throughput, it is necessary for the reader to appropriately adjust the frame length in accordance with the estimated quantity of tags. The specific calculation method is as follows:

Given a tag number n^*, the throughput at F_L ($F_L = 2^Q$) is equal to the throughput at F_H ($F_H = 2^{Q+1}$). F_L and F_H are two adjacent frames. According to formula (8), it can be got:

$$\frac{n^*}{F_L} \cdot \left(1 - \frac{1}{F_L}\right)^{n^*-1} = \frac{n^*}{F_H} \cdot \left(1 - \frac{1}{F_H}\right)^{n^*-1} \tag{15}$$

where n^* represents the critical value of the quantity of tags, which determines whether adjustment of the frame length is necessary. After the deformation of formula (15), it can be obtained that:

$$n^* = 1 + \frac{\ln\left(\frac{F_H}{F_L}\right)}{\ln\left(\frac{F_L}{F_H} \cdot \frac{F_H - 1}{F_L - 1}\right)} \tag{16}$$

In the actual RFID system, tag number n must be an integer. It allows us to determine the optimal frame length for a given quantity of tags, which can be expressed as:

$$F_{opt} = \begin{cases} 2^{Q}, & n = \lfloor n^{*} \rfloor \\ 2^{Q+1}, & n = \lceil n^{*} \rceil \end{cases} \tag{17}$$

where $\lceil n^{*} \rceil$ and $\lfloor n^{*} \rfloor$ represent rounded up and down, respectively. According to formulas (16) and (17), the optimal frame length corresponding to any quantity of tags can be derived and filled in Table 5.

Table 5: Mapping the correlation between the optimum frame length and the quantity of tags

Tag number range (n_1~n_2)	Optimum frame length ($F = 2^{Q}$)	Q value
1~3	2	1
4~5	4	2
6~11	8	3
12~22	16	4
23~44	32	5
45~89	64	6
90~177	128	7
178~355	256	8
356~710	512	9
711~1420	1024	10
1421~2839	2048	11
2840~5678	4096	12
5679~11357	8192	13
11358~22713	16384	14
22714~45426	32768	15

3 Proposed SUBF-CGDFSA Description

Using the large-scale tags grouping technique is the initial step if a large quantity of tags needs to be identified in the scene. Subsequently, the SUBF-DFSA algorithm is employed to identify intra-group tags. Combined with the tags number estimation method, tags grouping method and sub-frame observation mechanism, this paper proposes a novel Aloha algorithm, namely SUBF-CGDFSA algorithm. The SUBF-CGDFSA algorithm flow is shown in Fig. 2.

In this algorithm, the frame length is adjusted in accordance with the statistical results of subframe F_{sub}, which is the first m time slots of the whole frame. It adjusts the frame length by collecting the information of successful and collision slots in subframes. The quantity of tags detected by observing subframe information is as follows:

$$n_{est} = (S_{sub} + 2.39 \cdot C_{sub}) \times F/F_{sub} \tag{18}$$

where S_{sub} is the quantity of successful slots in the subframe, C_{sub} is the quantity of collision slots, and F is the frame length.

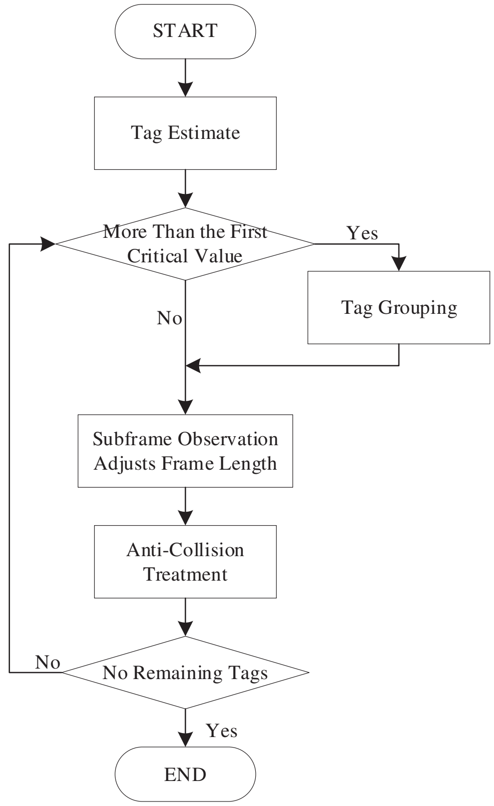


Figure 2: Flow chart of SUBF-CGDFSA algorithm

Since the frame length is constantly changing, so is the sub-frame F_{sub}. According to the estimation result of the above equation, if the estimated tag number n_{est} does not correspond to the current frame length F, the current round of recognition will finish and a new round will begin with a frame length adjustment. When the quantity of tags n_{est} matches the current frame length F, the identification of the current round will continue. When a suitable frame length is detected, the reader continues the current recognition cycle. After reading all the time slots, the average quantity of tags for each collision time slot is estimated. The average quantity of tags within each collision slot can be expressed as the formula (19).

$$n_{\text{ave}} = \left\lfloor \frac{n_{est} - S}{C} \right\rfloor \tag{19}$$

where $n_{est} - S$ is the quantity of remaining tags estimated by the reader, and C is the quantity of collision slots counted. The reader adjusts the optimal frame length corresponding to the size of n_{ave}, and takes it as the initial frame length to identify each collision slot, respectively.

The SUBF-CGDFSA algorithm flow is as follows:

Step 1: The reader sets the frame length F and subframe length F_{sub}, gives the tags the inventory instruction, and, depending on the tag response result, determines how many tags to recognize in the following round;

Step 2: In accordance with the quantity of tags to be identified, the reader sends grouping instructions to judge the interval where the quantity of tags is located. If the quantity of tags does not fall in the first interval, the group operation is performed, otherwise, the fourth step is entered;

Step 3: When the tag obtains the instruction from the reader, it also acquires the group number i sent by the reader, and receives the query instruction from the reader, including the query group number j. When $i = j$, the tag will reply to the reader's inquiry;

Step 4: The reader transmits query commands to tags within the operational domain, specifying frame length F, subframe length F_{sub} and slot counter t;

Step 5: The tag response is received by the reader in each slot, $t++$. After reading F_{sub} slots, the reader can estimate the remaining quantity of tags based on the statistical findings. If it is zero, it sends query command with frame length $F = 1$; if it is not zero, will proceed to the next step;

Step 6: The reader updates frame length F and subframe F_{sub} according to the statistics of subframe F_{sub}. If the present frame length is appropriate, continue to adjust $F_{sub} = F$ until a complete frame is identified. The index number of the collision slot is recorded and then pushed onto the stack; Otherwise, the frame length F is improperly set, and the identification of the epicycle is terminated and Step 4 is returned;

Step 7: According to the formula (19), the average tag number n_{ave} in each collision time slot is determined, and the initial frame length F_{ini} for each collision time slot is established;

Step 8: Verify if the stack is empty. If it is, the identification process concludes. This group identification is over, and the value of j will be increased by 1. The step 11 is entered. Otherwise, the reader extracts the new slot index number from the stack;

Step 9: The label broadcast query command, which may result in slot conflicts, includes the initial frame length F_{ini} and slot index number;

Step 10: After reading a time slot, the reader calculates statistics (S, C) to determine whether the collision time slot C is zero. If it is, return to step 6 and continue to determine whether the stack is empty. If no, it estimates the remaining quantity of tags based on $n_{rst} = round\,(2.39 * C)$, sets a new frame length, assigns F_{ini} to return to step 7, and then continues to identify until the tags colliding in this time slot are identified;

Step 11: After each round of recognition, it is essential to estimate the quantity of remaining unrecognized tags. If it is zero, the whole recognition process will be finished. Otherwise, the next round of recognition will be carried out.

Compared to the existing Aloha anti-collision algorithm, SUBF-CGDFSA algorithm has better stability. In addition, the determination of tag quantity and the establishment of frame length during the recognition process are accomplished through table lookup. This only requires a single judgment in each recognition cycle, with the evaluation process involving only addition, multiplication, and comparison operations, resulting in minimal complexity.

4 Simulation Results

Using MATLAB simulation platform, according to ISO18000-6C (EPC C1G2) standard, all tag lengths are standardized to 128 bits. The initial frame length F is set at 256, and tag IDs are spread uniformly. The quantity of tags to be identified in the inventory process is estimated based on both Schoute tags estimation and Vogt tags estimation. The error between the estimated tag value and the actual quantity of tags present in the scene is calculated, and the simulation results can be seen in Fig. 3.

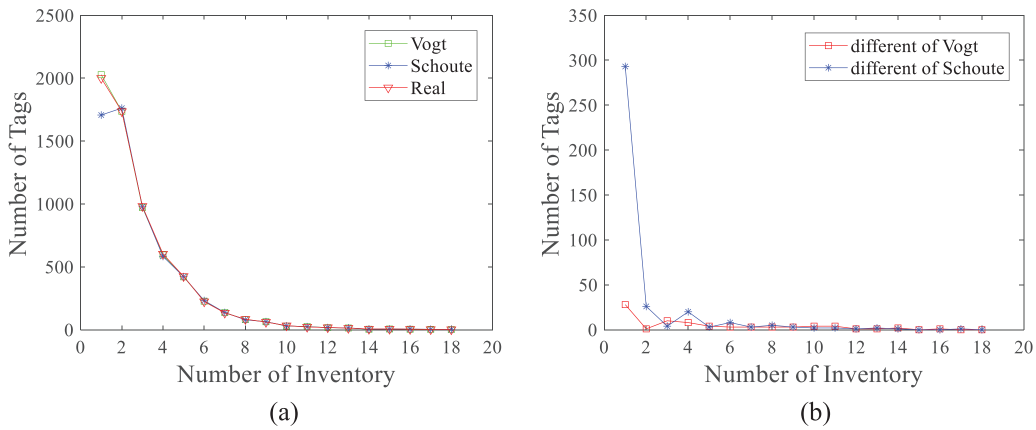


Figure 3: Comparison of tags estimation results (a) estimated result of tags; (b) the error between the estimated and actual quantity of tags

The simulation results indicate that with the inventory times increasing, the quantity of tags to be identified in the scene gradually decreases. For this reason, the tags estimation results based on the above two tags estimation algorithms show that the tags estimation based on the Vogt algorithm is more accurate than the Schoute algorithm, especially in the initial inventory.

Based on sub-frame observation, the initial frame length is adjusted and the quantity of tags in the collision time slot is processed. The SUBF-DFSA algorithm is employed for tags in the collision slots, and the Schoute and Vogt estimation method are utilized to estimate the remaining quantity of tags, which are then used as the initial frame length for the next frame. In our simulation, we set the initial frame length F to 32, 64, 128, and 256, respectively. Fig. 4 presents the outcomes of the simulation.

Simulation outcomes indicate that the SUBF-DFSA anti-collision algorithm can break through the bottleneck of 36.8%. With the increase of the quantity of tags, the system throughput rate remains above 40% after stabilization. Significantly improve the recognition performance of the system. When the initial frame size is set to 32, 64, 128, and 256, the system recognition efficiency does not decrease. In addition, the frame length of the SUBF-DFSA algorithm is slightly adjusted to the integer power of 2, which conforms to the EPC global C1 Gen2 protocol standard.

According to the scheme to determine the tags grouping critical value obtained from the grouping theory analysis above, grouping scheme switching is carried out when the quantity of tags is in different intervals. The simulation results of SUBF-CGDFSA anti-collision algorithm were compared with the existing algorithms, such as SUBF-DFSA, GDFSA [26], traditional DFSA and FSA. Fig. 5 illustrates a comparison of the system efficiency for these various algorithms.

The simulation outcomes indicate that the system efficiency of SUBF-CGDFSA algorithm is almost unaffected by the number of tags. In large-scale tags scenarios, the three grouping schemes can all maintain high system efficiency and stable performance. For the actual large-scale tags access scenario, grouping mismatch will cause a series of problems. If there are too many groups, a large quantity of idle time slots will be produced within the group, leading to time slot waste and decreased algorithm performance. Conversely, if the quantity of groups is too small, frequent collisions will occur within the group. Even if the group is divided, desired system efficiency cannot be achieved and algorithm performance will deteriorate. Simulation results show that dynamic grouping based on the critical value obtained from theoretical analysis can flexibly avoid the above problems. The algorithm can achieve high throughput and maintain stability in each tag number interval. When compared to the method without grouping, the grouping algorithm performs noticeably better.

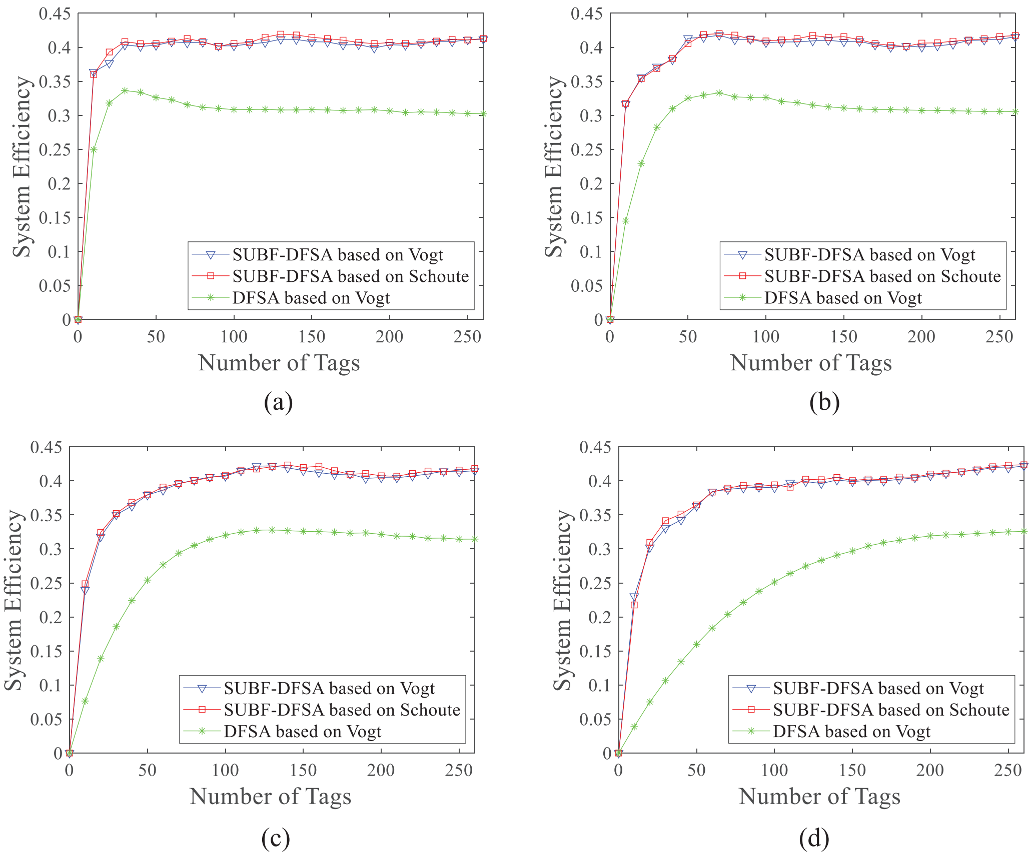


Figure 4: Simulation of SUBF-DFSA algorithm based on two tags estimation methods (a) $F = 32$; (b) $F = 64$; (c) $F = 128$; (d) $F = 256$

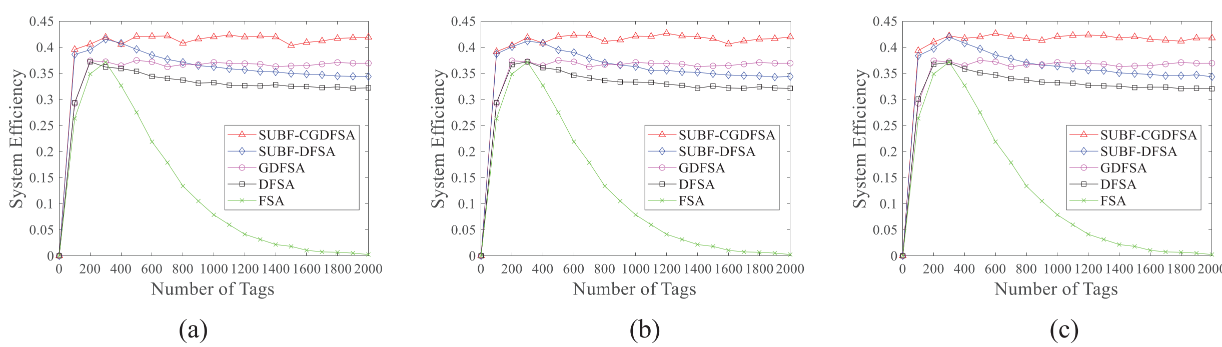
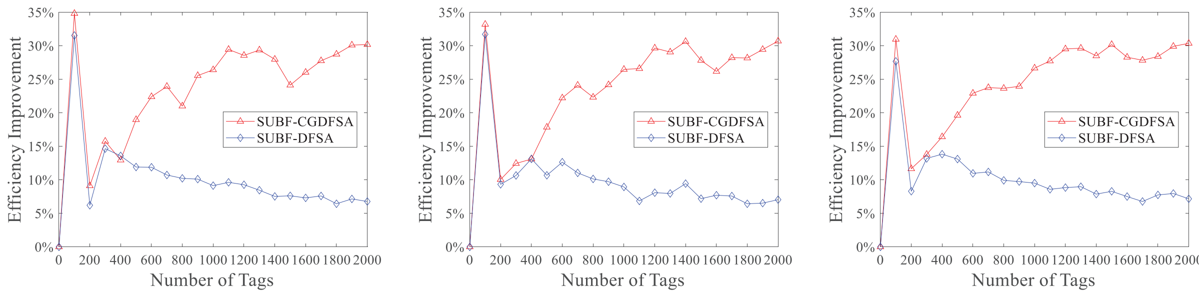


Figure 5: Comparison of system efficiency of different algorithms (a) critical value to determine scheme I; (b) critical value to determine scheme II; (c) critical value to determine scheme III

Taking the performance of traditional DFSA as the benchmark, the improvement of system efficiency of each algorithm compared with traditional DFSA algorithm was investigated. The outcomes of the simulation are depicted in Fig. 6.



(a) (b) (c)

Figure 6: Comparison of performance improvement of each algorithm compared with traditional DFSA algorithm (a) critical value to determine scheme I; (b) critical value to determine scheme II; (c) critical value to determine scheme III

The simulation outcomes indicate that the performance of the SUBF-DFSA algorithm is remarkably enhanced compared with the traditional DFSA algorithm in large-scale tag scenarios. Furthermore, the SUBF-CGDFSA algorithm has further improved the throughput index under different grouping schemes. When the quantity of tags is low and frequent collision is absent, both algorithms perform similarly and demonstrate a substantial improvement in system efficiency compared to the traditional DFSA. However, when the quantity of tags exceeds 300, the throughput of the SUBF-DFSA algorithm can be increased by approximately 10%. Moreover, when there are more than 1200 tags, the throughput performance of the SUBF-CGDFSA algorithm consistently increases by over 30% after grouping using three distinct schemes. Specifically, with grouping scheme 3 for identifying 1500 tags, the maximum throughput rate can be increased by around 32%. As evident from these findings, as the quantity of tags increases, there is a more pronounced improvement in throughput, thus indicating its suitability for large-scale tag access systems.

5 Conclusion

In this paper, an innovative anti-collision algorithm named SUBF-CGDFSA for large scale of UHF RFID tags access systems is proposed. The large-scale tags grouping mechanism is first used to group tags, and the sub-frame observation mechanism is introduced in order to support massive tag identification scenarios. The intra-group identification is accomplished by estimating the number of tags in the subframe and optimizing the frame length settings through the preset configuration table, reducing system complexity. The results indicate that the novel RFID anti-collision algorithm proposed in this paper, namely SUBF-CGDFSA, can break through the bottleneck of 36.8% of the system throughput. With the increase in the quantity of tags, the system's throughput rate remains stable at over 40%. At the same time, the algorithm is not affected by the initial frame length and exhibits excellent robustness. The proposed anti-collision algorithm has a broad application prospect in intelligent detection. Through reasonable selection and optimization algorithm, real-time perception of the surrounding environment and prediction of collision risk can be realized, enhancing the convenience of people's daily lives and work. With the ongoing development of artificial intelligence technology, it is believed that the implementation of this anti-collision algorithm utilizing artificial intelligence will lead to significant breakthroughs and innovations in the field.

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