A Novel Approach to Mapped Correlation of ID for RFID Anti-Collision

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Abstract—One of the key problems that should be solved is the collision between tags which lowers the efficiency of the RFID system. The existed popular anti-collision algorithms are ALOHA-type algorithms and QT. But these methods show good performance when the number of tags to read is small and not dynamic. However, when the number of tags to read is large and dynamic, the efficiency of recognition is very low. A novel approach to mapped correlation of ID for RFID anti-collision has been proposed to solve the problem in this paper. This method can increase the association between tags so that tags can send their own ID under certain trigger conditions, by mapped correlation of ID, querying on multi-tree becomes more efficient. In the case of not too big number of tags, by replacing the actual ID with the temporary ID, the method can greatly reduce the number of times that the reader reads and writes to tag's ID. In the case of dynamic ALOHA-type applications, the reader can determine the locations of the empty slots according to the position of the binary pulse, so it can avoid the decrease in efficiency which is caused by reading empty slots when reading slots. Experiments have shown this method can greatly improve the recognition efficiency of the system.

Index Terms—RFID, mapping, correlation, anti-collision, ALOHA

1 Introduction

In recent years, under the banner of Internet of things (IOT), Radio Frequency Identification (RFID) technology has moved from obscurity into mainstream applications that help speed the handling of manufactured goods and materials. RFID enables identification from a distance, and unlike earlier bar-code technology, it does so without requiring a line of sight. RFID not only replaces traditional bar-code technology, it also provides additional features and removes boundaries that limited the use of previous alternatives. Printed bar codes are typically read by a laser-based optical scanner that requires a direct line-of-sight to detect and extract information. With RFID, however, a scanner can read the encoded information even when the tag is concealed for either aesthetic or security reasons. RFID tags can be used as environmental sensors on an unprecedented scale [1], [2], [3], [4], [5].

RFID technology can be used to improve the localization of mobile applications in their environment. The problem of localizing RFID tags with a mobile platform that is equipped with a pair of RFID antennas. The probabilistic measurement model for RFID readers that allow us to accurately localize RFID tags in the mobile environment [6], [7], [8], [9].

RFID systems with passive tags are powerful tools for object identification. However, if multiple tags are to be identified simultaneously, messages from the tags can collide and cancel each other out. Therefore, multiple read cycles have to be performed in order to achieve a high recognition rate. For a typical stochastic anti-collision scheme, it is one problem on how to determine the optimal number of read cycles to perform under a given assurance level determining the acceptable rate of missed tags. This yields an efficient procedure for object Identification [10], [11], [12], [13].

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RFID readers communicate with tags through short-range wireless communication. In order to solve the problem of collision between tags, anti-collision algorithms based on FDMA, CDMA, TDMA and SDMA are raised [14], [15], [16], [17]. FDMA (Frequency Division Multiple Access) is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. CDMA (Code Division Multiple Access) is a channel access method used by various radio communication technologies. Several transmitters of CDMA can send information simultaneously over a single communication channel. TDMA (Time Division Multiple Access) is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using its own time slot. SDMA (Space Division Multiple Access) is a channel access method based on creating parallel spatial pipes. In RFID system, one of the problems that we must solve is the collision between tags which lowers the efficiency of the RFID system. As RFID tags especially the passive tags are limited by power and function, its anti-collision algorithms are usually designed based on TDMA [18], [19], [20], [21].

The current problem of collision in RFID system can be divided into two categories [22], [23], [24]: one is the collision of reader, and the other is the collision of tags. The reader of RFID can communicate with only one tag at a time, but when there are many unidentified tags in the reader's work area, all the tags will send messages to the reader. On the other hand, the reader can't identify them, so collisions occur. The collisions of reader mainly have three types [25], [26]: the interference of frequency, the interference of tags, the interference of hidden terminals. If two RFID tags simultaneously transmit their identifiers to a reader, a broadcast collision occurs that prevents the reader from deciphering either response. To avoid this problem, RFID readers and tags engage in singulation anti-collision approach.

One of the popular anti-collision algorithms is ALOHA- type algorithms [27], [28], [29], [30], which are simple and shows good performance when number of tags to read is small. However, they generally require exponentially increasing number of slots to identify the tags as the number of tag increases. We propose a kind of innovative approach with mapped correlation of ID for RFID anti-collision, which increases the association between tags so that tags can send their own ID under certain trigger conditions, at the same time, we present a multi-tree search method for querying. When the number of tags is not too big, by replacing the actual ID with the temporary ID, it can greatly reduce the number of times that the reader reads and writes to tag's ID. Tags send data to the reader by the way of modulation binary pulses. It estimates the number of unread tags first and adjusts the number of responding tags or the frame size to give the optimal system efficiency.

2 Related Works

RFID is the wireless use of electromagnetic fields to transfer data for the purposes of automatically identifying and tracking tags attached to objects. RFID systems can be classified by the type of tag and reader [1], [2], [3], [4], [5]. The tags contain electronically stored information. Some tags are powered by electromagnetic induction from magnetic fields produced near the reader. Some types collect energy from the interrogating radio waves and act as a passive transponder. Other types have local power source such as battery and may operate at hundreds of meters from the reader. Unlike a barcode, the tag does not necessarily need to be within line of sight of the reader, and may be embedded in the tracked object. It is one method for automatic identification and data capture. An RFID tag attached to an automobile during production can be used to track its progress through the assembly line. RFID

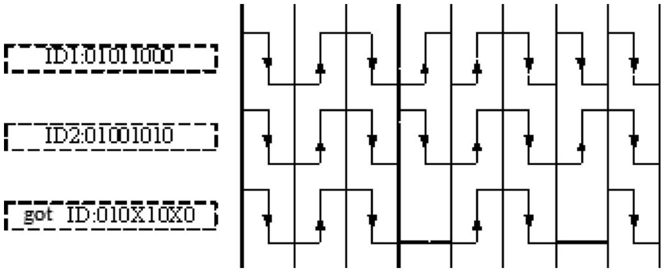

Fig. 1. Identify collision bit example of ME method.

tags can be either passive, active or battery-assisted passive [6], [7], [8], [9], [10]. Active tag has on-board battery and periodically transmits its ID signal. A battery-assisted passive has small battery on board and is activated when in presence of an RFID reader. Passive tag is cheaper and smaller because it has no battery. However, to start operation of passive tags, they must be illuminated with a power level roughly three magnitudes stronger than for signal transmission. That makes a difference in interference and in exposure to radiation. Passive reader active tag system has passive reader that only receives radio signals from active tags.

2.1 Manchester Encoding (ME)

Manchester encoding is a line code in which the encoding of each data bit has at least one transition and occupies the same time. Manchester code always has a transition at the middle of each bit period and may have a transition at the start of the period [11], [12]. The direction of the mid-bit transition indicates the data. Transitions at the period boundaries do not carry information. They exist only to place the signal in the correct state to allow the mid-bit transition. The existence of guaranteed transitions allows the signal to be self-clocking, and also allows the receiver to align correctly; the receiver can identify if it is misaligned by half a bit period, as there will no longer always be a transition during each bit period. When the receiver receives two or more than two different signals, the rising edge and the falling edge will offset each other, and then illegal status occurs, thus conflicts can be effectively identified. As the Fig. 1, If there are two tags in the reader's work area, and their IDs are: ID1:01011000; ID2:01001010. After Manchester encoding, the receiver ID is: 010x10x0. If we assume that the left side is the lower bit, we can find the conflict bits: D3 and D6.

2.2 QT Method

QT (Query Tree) method [13], [14], [15] is based on the binary ID tree. In this method, the reader initializes the Prefix to "0" and "1" in the stack. If the stack is not empty, the reader will send the query command, use the Prefix to query and then delete it from the stack. The identification is successful if only one tag responds. If no tags respond, it means the query channel is wasted, return to the previous and prepare for the next query. If two or more tags respond, the reader knows that tag collision occurs, and the current prefix used in the stack turns into Prefix+"0", Prefix+"1". Random Number 16 bits QT (RN16QT) method extends the classic QT method. Each tag in the work area will produce one 16 bits random number as temporary ID to respond the command of the reader as the Fig. 2. It decreases the communication number between the tag and the reader, so it decreases the wasted time. But it is valid for only 300 tags, when the number of tag is over 300, the performance is lowered. An extended Random Number 16 bits QT (EQT) method can be used. It divides the 96 bits ID into six groups: EPC1, EPC2, ..., EPC6. The 96 bits EPC coding format is as the Fig. 3. REX results can be produced by exclusive OR ($\oplus$) between RN16 and EPC as the Fig. 4.

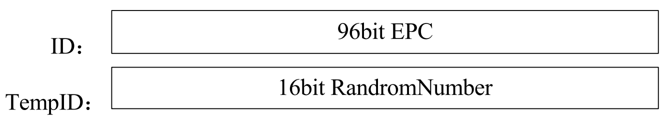

Fig. 2. Random Number 16 bits QT.

Head 8bits	Code of Producer 28bits	Classification code of object 24bits	Sequence Num 36bits

Fig. 3. The 96 bits EPC coding format.

2.3 ALOHA Approach

ALOHA [16], [17], [18], [19], [20], [21] approach is simple communications scheme in which each transmitter sends data whenever there is a frame to send. If the frame successfully reaches the receiver, the next frame is sent. If the frame fails to be received at the destination, it is sent again. ALOHA is based on time division multiple accesses. Both the throughput rate of the system and the efficiency are very low by pure ALOHA algorithm. To minimize the number of collisions, thereby optimizing efficiency and increasing the number of subscribers, a scheme called Slotted Aloha (SL) [22], [23], [24], [25] was developed. This system employs signals called beacons that are sent at precise intervals and tell each source when the channel is clear to send a frame. Further improvement can be realized by a more sophisticated protocol called Carrier Sense Multiple Access with Collision Detection [26], [27]. Slotted ALOHA method divides the time into many slots. One slot is larger than the communication time between the reader and the tag. Tags communicate with the reader only in the slot. So collision probability is lowered and the throughput has a certain improved. FSA (Framed Slotted Aloha) can be classified into the BFSA (Basic Framed Slotted Aloha) and the DFSA (Dynamic Framed Slotted Aloha) according to whether which uses fixed frame size or variable frame size. If the number of actual tags is unknown, DFSA can identify tags efficiently rather than BFSA by changing frame size since BFSA uses fixed frame size. In addition, BFSA and DFSA can be further classified based on whether they support muting or early-end features. The muting makes tags remain silent after being identified by the reader while the early-end allows a reader close an idle slot early when no response is detected. BIS (Basic Idle Slot) is a kind of ALOHA-based medium access control method, in which the time consumption of the empty slots had been reduced by empty slot scanning and dynamic frame size adjustment. This is kind of RFID anti-collision method can minimize cost of empty slots [28], [29], [30].

3 Innovative Method with Mapped Correlation of ID for RFID Anti-Collision

The method can increase the association between tags so that tags can send their own ID under certain trigger conditions, at the same

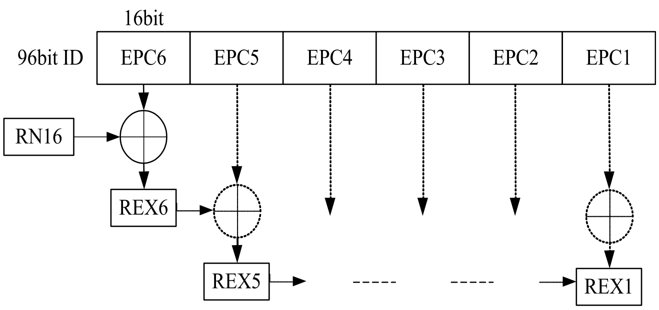

Fig. 4. Extended Random Number 16 bits QT (EQT) method.

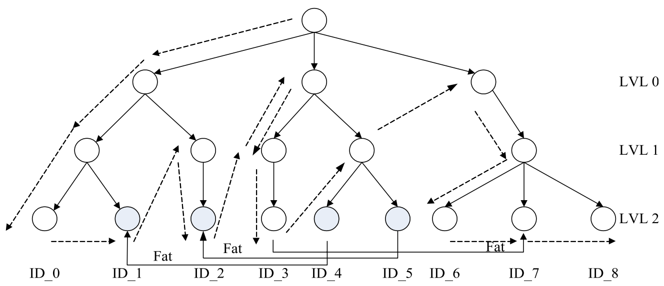

Fig. 5. Recognition path after introducing mapping relationship.

time, it uses a multi-tree search method for querying. The tags will send their IDs to the reader automatically under certain trigger conditions rather than being found by the reader. The trigger condition of a tag comes from other tags, some kind of parent and child mapping relationship between tags are created, when parent tag is found, child tag will be triggered to send its ID weather it is in dynamic changing cases or not.

3.1 Design of Method with Mapped Correlation of ID

Let us assume that there are nine tags numbering from ID_0 to ID_8, then the ID identification process introduced in the method is shown in the following Fig. 5. In the Fig. 5, the dotted line represents the recognition path of the algorithm. It is not hard to see that in this algorithm all the tags are included in the identification path. Assume the number of communication needed to successfully identify the nine tags is $N > 0$. We apply the mapping relationship of the tags to the multi-way tree algorithm. In order to ensure the reliability of design and analysis of this method, we use the nine IDs, and the mapping relationship of all the tags is generated randomly. Assume that the mapping relationship of ID and the recognition path along the arrow are shown in the Fig. 5.

The current location of the parent tag is the "Fat" sign in the Fig. 5. The ID_4, ID_5 respectively takes ID_1, ID_2 as the parent tag, and they are respectively identified when ID_1, ID_2 are identified. Thus the identification number is reduced by 1 and the recognition path is shortened.

In the Fig. 5, the relationship between the parent tag and the child tag is random mapping. The parent tag ID_7 is identified after its child tag ID_3, so the mapping relationship between the two tags doesn't work. Now we are going to discuss how to further optimize the mapping relationship between tags.

In order to use the mapping relationship as much as possible, the parent tag should appear before the child tag, which is not difficult to imagine. The mapping relationship can be restricted and adjusted, namely, all the randomly generated mapping relationships should guarantee that the parent tags' IDs of all the tags must be less than their own IDs except the first tag. In the following example, the tags' IDs selected are exactly the same as that in the Fig. 5 and the mapping relationship will be rebuilt according to the above constraints. The identification process of the tags is shown in the Fig. 6.

The ID_3, ID_4, ID_5 can be identified in advance, when the reader visits branch, so no tags reply. Therefore, compared with the original multi-way tree algorithm, the number of communication of the tags is reduced by 4. But compared with the optimized method shown in the Fig. 6, the number of identification is reduced by 3, so the efficiency is bound to become higher.

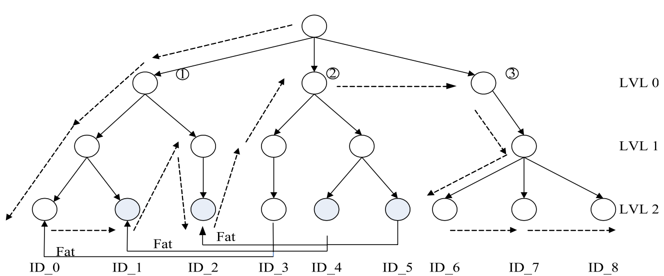

Fig. 6. Recognition path after introducing rebuilt mapping relationship.

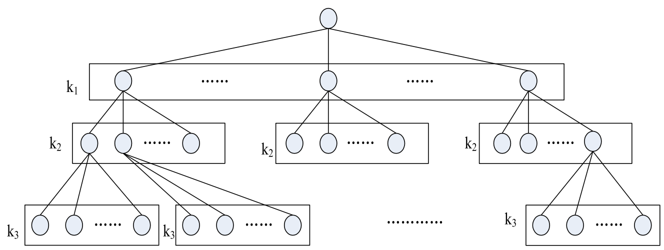

Fig. 7. 1:n distribution from parent tag to child tags.

3.2 Mapped Correlation of ID in Dynamic Changing Case

There is another problem on how to maintain the mapping relationships from parent tags to child tags in dynamic changing cases. In the above algorithm, the relationship is random mapping. In practical scenarios, the relative positions of the objects with RFID tags usually change frequently over time. They are packed or grouped with different objects when they arrive at different readers. How to maintain the mapping relationships or quickly self-organize new relationships? Now let's study this issue so as to improve the efficiency.

As we know, RFID uses radio frequency signals to power a passive RFID tag or label attached to a product to capture the tags information. Some researchers [11], [12], [15] propose new framework for effectively and efficiently processing uncertain RFID data, and supporting a variety of queries for tracking and tracing RFID objects. They adopt different smoothing windows according to different rates of uncertain data, employ different strategies to process uncertain readings, and distinguish ghost, missing, and incomplete data according to their apparent positions. The comprehensive data model which is suitable for different in dynamic changing application scenarios. The path coding scheme is proposed to significantly compress massive data by aggregating the path sequence, the position, and the time intervals. The scheme is suitable for cyclic or long paths for group and independent objects.

In order to maintain the mapping relationships or quickly self-organize new relationships from the parent tags to the child tags in dynamic changing cases, we consider the following distribution of tags in work area and search tree structure as the Fig. 7. The Fig. 8 is a kind of 1:n distribution relationship from one parent tag to child tags, the 1:1 distribution relationship from one parent tag to child tag is as Fig. 8. we adopt serialization-encoding scheme [4], [24]. This is the tree-walking scheme, in which k-bit identifiers are viewed as binary tree leaves of depth k. In this tree, a node represents a binary identifier prefix. Its left child represents the prefix with a 0 appended; the right child, the prefix with a 1 appended. If it is multi-way tree, prefix with 00, 01, 10,11 can be appended according to 2n, $n > 0$. So it can solved.

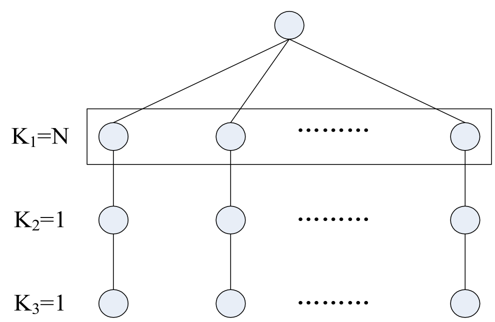

Fig. 8. 1:1 relationship from parent tag to child tag.

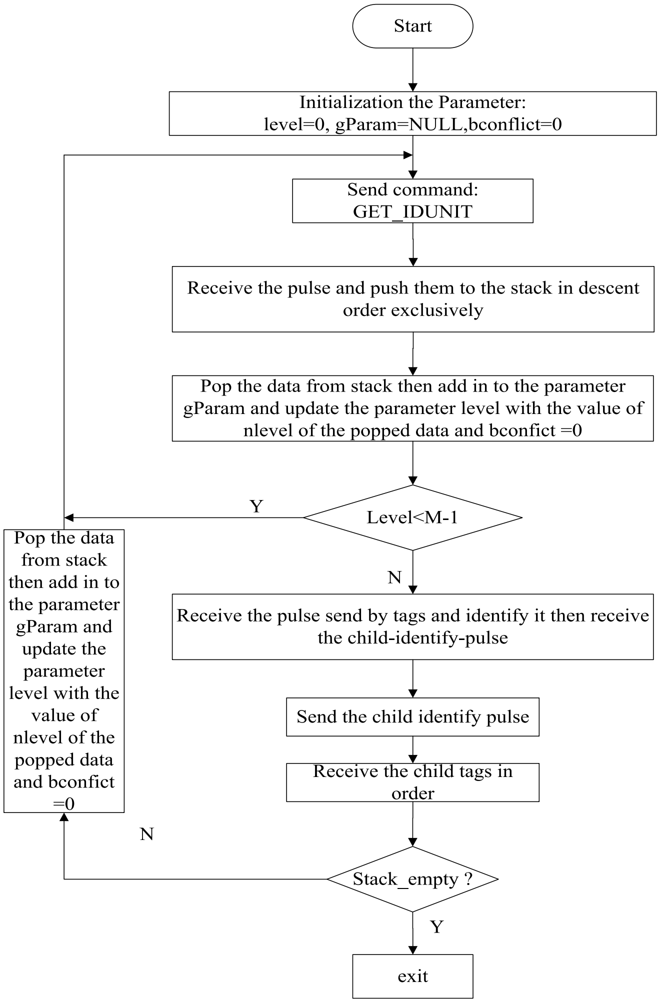

Fig. 9. The work flow chart of the reader.

In the Fig. 8, k1 is the number of first-level tree node. k2 is the number of sub-node of first-level tree node. k3 is the number of sub-node of second-level tree node. So the total number N of tree node is N = k1k2k3. The maximum value of k is 128. We set the communication number for successful identification tag by the reader Round. Round(n) is the number of read tags from the nth tree node (this is the parent tag of child tags) along the tree. Round (1) is the total communication number for successful identification the all tags. There is the following relationship as

$$Round(1) = 1 + k_1 Round(2) \tag{1}$$

$$Round(2) = 1 + k_2 Round(3) \tag{2}$$

$$Round(3) = 1 \tag{3}$$

$$Round(1) = 1 + k_1(1 + k_2) = 1 + k_1 + k_1 k_2. \tag{4}$$

The detailed work process is as the following section. The work flow chart of reader is shown in the Fig. 9. Based on the Fig. 9, we require that each tag will detect the identified tags to decide if there are its parent tags, if yes, set 1 on the corresponding pulse of the parent tag and send the binary pulse, which is called child tag identification pulse. After receiving the child tag identification pulse, the reader can judge if a tag has child tags and send the child tag identification pulse to all tags. All the child tags can judge which child tags could be read in this round, and set up the corresponding delay to send their own IDs according to the positions of all child tags in the pulse sequence.

3.3 The Identification Process of This Method

In order to describe the identification process of this method, we set the parameter specifications of commands are as follows.

Set a tag which consists of L bits of binary number, and divide the binary sequence into L groups, then each group is composed of $N = L/M$ binary numbers. We define ID and *gParam* as

$$ID = LVL_0\_LVL_1\_LVL_2 \cdots \_LVL_k\_LVL_{k+1} \cdots LVL_{M-1}. \tag{5}$$

Where the LVL_x represents the bits grouped by x.

The command parameter *gParam as*

$$gParam = LVL_0\_LVL_1\_LVL_2 \cdots LVL_k. \tag{6}$$

The *gParam* represents a binary sequence which consists of $1 \sim K + 1$ binary group fetch from some ID.

The command parameter *level* represents the group number x of ID, and the relationship between the value of *level* and the command parameter is as

$$level = K + 1. \tag{7}$$

After the parameter level and the parameter *gParam* are sent by the reader as the command parameter and the tag receives it, and the tag compare *gParam* with its ID. The length of parameter *gParam* is *K + 1*. If the bits from LVL_0 to LVL_k in ID are all the same as them from *gParam*, then the tag should send LVL_{level} to the reader through binary pulse modulation.

We elaborate design identification process of the algorithm via 10 identification tags as example. Set the length of ID is 16 bits, and divide it into four *UNITS* named *LVL: 0–3*, and each *UNIT* consists of 4 bits. So the value of *M* in the process is 4. The general steps is as follows.

Step 1. The first command *GET_INPUT* with $level = 0$ and *gParam* = *NULL* is sent by the reader. After receiving the command, each tag should compare its ID with the *gParam* equaled with the prefix of ID. If they are the same, the tag will transform the *UNIT* corresponded by *level* to binary pulse and send it to the reader. In this command, because the value of level is 0, representing there is no prefix before LVL_0, so the parameter *gParam* is null and all tags will return LVL_0.

Step 2. All the result tag reply to stack will be push by the reader. The reader pops data from the stack and joins the data to the command parameter. Set level = 0 + 1. Set *gParam* with the value of *nIDUNITValue* with 1. Each tag will compare the *gParam* with its ID, if the prefix of certain ID is identical with *gParam*, so the tags send the level = 1 to the reader.

Step 3. The reader will pop the top unit from the stack and join the *nIDUNITValue* of the unit to the command parameter after receiving the data sent from the tag, then *level* + 1. Each tag will compare the *gParam* with its ID, if the prefix of certain ID is identical with *gParam*, so the tags send *level* = 2 to the reader.

Step 4. Repeat step 3 until the value of level is equal to $M = 3$, which means getting the last unit of the ID. After receiving the parameter *LVL*, the reader can get the complete ID of the tag on the basis of the gParam and the information sent by the tag at the latest time. The command is *GET_ID*. Each tag will compare the *gParam* with its ID, if the prefix of certain ID is identical with *gParam*, the tags send the *LVL* to the reader and complete a tag identification process.

Step 5. Goto step 1, the identification process of the remaining tags is basically the same.

4 EMBEDDED DFSA METHOD WITH MAPPED CORRELATION OF ID

The aforementioned method has some strict restrictions on the number of tags and the number of tags couldn't be more than 21

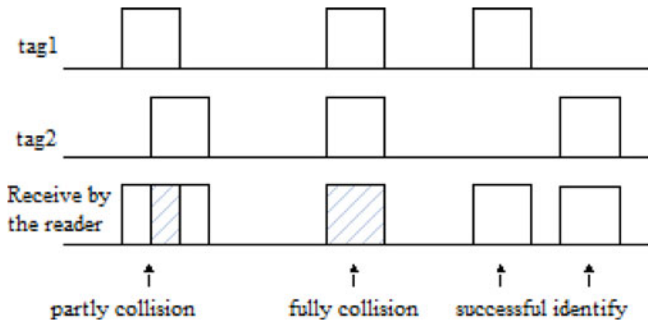

Fig. 10. The example for basic principle of the DFSA.

[22], [23], [24], [25]. The shortcomings are the efficiency of the method and the length of the pulse sent by tags. In addition, the method can only be applied to the closed-loop system based on short-ID. According to the international practical standard, the actual length of ID is 96 bits. On the other hand, the introduction of the mapped correlation of ID and modulation binary sequence can be tested to improve the efficiency enormously. Therefore, in order to make these two kinds of improvement available on a larger scale tags, we apply the modulation binary pulse, mapped correlation tag and the grouping to identify to dynamic frame slot ALOHA (DFSA) algorithm at the same time. The new improvement to the method can enormously improve the efficiency of the RFID tag identification, and improve the generality of the method. The following example as the Fig. 10 shows the simple basic principle of the DFSA. When the signal sent by tag 1 and tag 2 has overlapping, it is regarded as collision and collision message will be sent to the tags. The tags will pause. After a dynamic interval waiting time, the tags send the signal once again until the successful identification the tags.

4.1 DFSA Method with Mapped Correlation of ID

Frame Slotted ALOHA is based on Slotted ALOHA. But the optimum efficiency of the slot ALOHA algorithm is only 36.8 percent. The idle time slots almost account for half of all time slots, the waste of time slots is very serious. If the reader can avoid reading empty slots after tags acquire the time randomly, it could greatly improve the identification efficiency.

The principle of Frame Slotted ALOHA can be shown as the Fig. 11. If there is six tags in the reader area, each frame has four equal slots, the communication between the reader and the tags will have three kinds of cases: successful identification in slots 1 and 2 of frame1, in slots 1 and 4 of frame2; collision in and slot 3 of frame1, in slot 2 of frame2; idle slot in slot 4 of frame1, in slot 3 of frame2. The shortcoming of this method is difficult to select the length of one frame.

H. Vogt's algorithm shows poor performance when the number of tags becomes large because the variance of the tag number estimation is increased according to the number of tags increase. Therefore, to handle the poor performance of large number of tag identification DFSA algorithm restricts the number of responding tags as much as the frame size. Conversely, if the number of tags is too small as compared with the frame size it reduces the frame size. Our designed DFSA method with mapped correlation of ID estimates the number of unread tags instead of number of tags to determine frame size.

We put forward the following solution to identify empty slots by the way of binary modulation pulse sequences. First, the reader sends command to select time slot; then all the tags select time slot randomly, modulate the number of the slot into binary sequence and send it; send a binary pulse whose length is L, and the bit corresponding to time slot number will be set to 1, others to 0; finally, after receiving signal, the reader can avoid the empty time slots to improve efficiency.

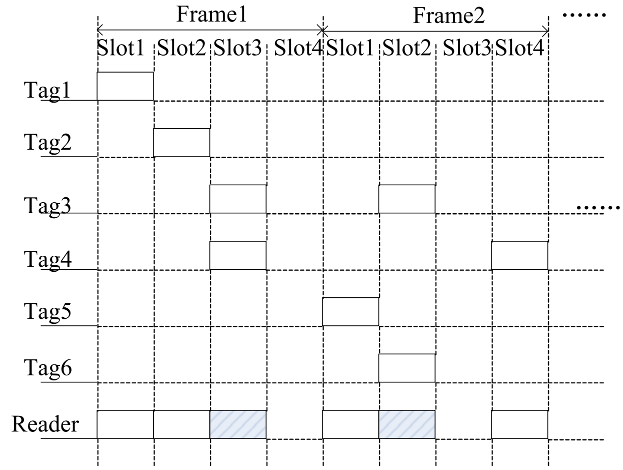

Fig. 11. Work example of FSA approach.

According to the analysis of basic theory of knowledge, when the length of frame is L and the number of tags is N, the efficiency of dynamic frame slot ALOHA algorithm is

$$\eta = \frac{success\_tag\_number}{frame\_len} = N\frac{1}{L}\left(1-\frac{1}{L}\right)^{N-1}. \tag{8}$$

Where the success_tag_number means the number of tags that had been identified successfully and the frame_len means the length of the total frame.

After the algorithm is improved, the efficiency is

$$\eta' = \frac{N\left(1-\frac{1}{L}\right)^{N-1}}{L-L\left(1-\frac{1}{L}\right)}. \tag{9}$$

Obviously, $\eta` > \eta$, because the denominator namely the total frame has declined. The improved efficiency is:

$$\varepsilon = \eta' - \eta = L\frac{N\left(1-\frac{1}{L}\right)^{2N-1}}{L-L\left(1-\frac{1}{L}\right)^{N}}. \tag{10}$$

It states that the increment of efficiency of the ALOHA that we have improved is in direct proportion to L, from the expression of the number of time slots which have successfully received the tags $C_1 = L(1-\frac{1}{L})^N$, we can see that with the increase of L, the number of successful identification will also increase. But with the increase of the value of L, the recognition time will be longer, namely the long single sent bits of data will increase the overall recognition time, and it is not realistic to increase the value of L infinitely. In order to balance the two sides, the algorithm still sets the value of L the same as the number of tags.

4.2 The Designed Algorithm

The steps of algorithm implementation are as follows:

Step 1. Send the grouping command SPLIT_GROUP and initialize the number of groups to 10 as we assume there are 1,280 tags. The method of grouping is that each tag randomly selects a number between $0 \sim 9$ and this unique number is its group number.

Step 2. Make the first set of responses by sending the command WAKE_GROUP+*Param*, where the parameter *Param* represents the unique number of the group that will be recognized. Set it to 0 as all groups sleep except the first one.

Step 3. Send the time slot selection command to the tags. All the tags in the current group randomly select different time slots, and send the modulation sequence.

TABLE 1
Identified tag By Parent-Child Relationship

i	*Numbers*	*test1*	*test2*	*test3*	*test4*	*test5*	*test6*	*test7*	*test8*	*test9*	*test10*	*avg*
1	500	70	82	86	85	79	85	87	74	80	76	81.5
2	450	82	81	79	79	72	86	83	87	71	80	78.6
3	400	64	66	67	75	67	69	65	63	67	60	66.8
4	350	54	64	44	57	57	59	61	52	52	57	56.1
5	300	57	46	54	49	43	49	42	41	56	55	49.3
6	250	40	48	46	47	42	40	47	42	39	48	43.6
7	200	28	22	36	31	31	33	36	36	37	28	32.1
8	150	24	27	29	17	28	22	20	24	24	23	23.5
9	100	14	20	13	20	20	18	19	21	17	17	17.6
10	50	8	8	4	10	9	12	8	8	4	11	8.5

Step 4. The reader accomplishes the recognition of the first frame and estimates the number of tags in the first group. If there are about 128 tags in this group, enter Step 5 and continue to identify this group, otherwise return to Step 1 and regroup.

Step 5. After identification of the group, continue to identify the next group until all the tags are identified.

5 Analysis of the Efficiency

In FSA, tags are randomly assigned to slots of a frame and if some tags collide in a slot, the collided tags in the slot will be resolved by binary tree splitting while the other tags in the subsequent slots will wait. Our method utilize dynamic, adaptive method to adjust the frame length to a value close to the number of tags. In DFSA, the identification efficiency can achieve an optimal value only when the frame length is close to the number of tags. The efficiency of our proposed method is close to the optimal value. The advantages of our method are that the efficiency is not affected by the variance of the number of tags, but mainly depending on the relationship between tags. if we can calculate the number of the tags identified due to this relationship, we can analyze the efficiency improvement ratio due to the introduction of this relationship.

Statistical regression analysis can be used to get the performance of our method. The following Table 1 shows the number of tags identified through the mapped correlation of ID in ten experiments. We have done 100 experiments, and only 10 experiments are listed in the Table 1. The average of 100 experimental results is given at last.

Now we set up one linear regression equation as

$$y = ax + b, \tag{11}$$

y represents the number of successful association ID identifications, and x is the number of tags. a and b are relative parameters for statistical regression analysis. We can use the maximum likelihood estimation method to estimate the values of a and b as formula (12) and formula (13)

$$S_{xx} = \sum_{i=1}^{n}(x_i - \overline{x})^2 = \sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2 \tag{12}$$

$$S_{xy} = \sum_{i=1}^{n}(x_i - \overline{x})^2(y_i - \overline{y})^2 = \sum_{i=1}^{n} x_i y_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right) \tag{13}$$

(x_i, y_i) is the coordinate of splashes in Fig. 13, then the estimated values of a, b are:

$$\hat{a} = \frac{S_{xy}}{S_{xx}} = 0.17 \tag{14}$$

$$\hat{b} = \frac{1}{n}\sum_{i=1}^{n} y_i - \left(\frac{1}{n}\sum_{i=1}^{n} x_i\right)\hat{a} = 0.0048. \tag{15}$$

Estimate σ^2using the following formula as

$$\sigma^2 = \frac{1}{n-2}(S_{xx} - \hat{a}\, S_{xy}). \tag{16}$$

In order to estimating the validity of aforementioned results, hypothesis test can be used to verify whether it is really so in the practice. Now we can suppose $H_0 : a = 0$, $H_1 : a \neq 0$. We use t method to examine the result, then

$$\hat{a} \sim N(a, \sigma^2/S_{xx}). \tag{17}$$

When H_0 is true, $a = 0$ then

$$t = \frac{\hat{a}}{\hat{b}}\sqrt{S_{xx}} \sim t(n-2). \tag{18}$$

Then $E(\hat{a}) = 0$, the rejection region of H_0 is

$$|t| = \left(\left|\hat{a}\right|/\sigma\right)\sqrt{S_{xx}} \geq t_{\frac{\alpha}{2}}(n-2). \tag{19}$$

In it the significance level is $\alpha = 0.01$. Here α is a critical probability value. In the test of statistical hypothesis, it represents the possibility of assume-refuse by using the sample information. The smaller the value of α is, the smaller the possibility of assume-refuse will be. So the assume-refuse value is $H_0 : \hat{a} = 0$. And we deem the linear regression effect is significant. This states that the application of correlation ID to the algorithm makes the efficiency increase by at least 15 percent.

In order to show how to maintain the mapping relationships or quickly self-organize new relationships from parent tags to child tags in dynamic changes, we have adopted aforementioned encoding scheme. In this tree-walking scheme, k-bit identifiers are viewed as binary tree leaves of depth k. In this tree, a node represents a binary identifier prefix. Its left child represents the prefix with a 0 appended; the right child, the prefix with a 1 appended. If it is multi-way tree, prefix with 00, 01, 10,11 can be appended according to 2n, n > 0. Since RFID tags are serialized, several tags can be read at once and the serial numbers are recorded and stored in a database. The data encoded to the tag or label helps identify and track that object. The ability to track the dynamic object via RFID allows parent tags to identify child tags. Each tag consists of a data identifier followed by a serial number, allowing the RFID reader to easily identify the object and associate it with a unique identification.

According to the Fig. 7, during maintaining the mapping relationships or quickly self-organizing new relationships from parent tags to child tags in dynamic changes, the searching efficiency of

TABLE 2
Data for Comparison of the Efficiency

Algorithm Tag number	DFSA + modulation of binary		DFSA + modulation of binary + correlation ID	
	Reading times	efficiency	Reading times	efficiency
50	74	0.6756	58	0.8621
100	150	0.6667	115	0.8696
300	454	0.6608	333	0.9009
400	590	0.6779	434	0.9216
500	736	0.6793	549	0.9107
600	883	0.6795	655	0.9160
700	1,031	0.6689	770	0.9091
800	1,178	0.6791	875	0.9143
900	1,325	0.6792	983	0.9156
1,000	1,470	0.6802	1,094	0.9141

the reader can be calculated by formula (20)

$$\eta = \frac{N}{1 + k_1 + k_1 k_2} = \frac{N}{1 + N + N} = \frac{N}{2N + 1}. \tag{20}$$

So the minimum searching efficiency is close to 50 percent.

The probability of the distribution as minimum efficiency is as formula (21)

$$p_{\eta\min} = 2^{k1+k2}\left(\frac{1}{2^{k1}} \times \frac{1}{2^{k2}}\right)^N = \left(\frac{1}{2^{k1+k2}}\right)^{N-1}. \tag{21}$$

When the searching level is four levels, the searching efficiency of the reader can be calculated by formula (22)

$$\eta = \frac{N}{1 + k_1 + k_1 k_2 + k_1 k_2 k_3}. \tag{22}$$

If $k_1 = k_2 = k_3 = 1$ the minimum searching efficiency is close to 33 percent.

In practical applications, if the length of ID is 21 bits, the ID will be divide into three groups, and each group has 7 bits. The length of pulse of tag is $2^7 = 128$. In the worst case, there is $2^7 = 128$ tags in one reader work area, at this time, there is the following relationship as formula (23) and formula (24)

$$Round(1) = 1 + k_1 + k_1 k_2, \quad N = k^3 \tag{23}$$

$$\begin{aligned} \eta &= k^3/(1 + k + k^3) = N/(1 + \sqrt[3]{N} + N) \\ &= (N\sqrt[3]{N} - N)/(N\sqrt[3]{N} - 1). \end{aligned} \tag{24}$$

When the number of tag N > 2 is larger, the efficiency is much higher. Generally, the following efficiency case as formula (25) can not occur because the formula (24) decides the efficiency.

$$\eta = \sqrt[3]{N} - 1. \tag{25}$$

By analysis, we know that based on our scheme, RFID is able to provide precise identification information about an object, the risk of delivering the wrong mapping from parent tags to child tags in dynamic changes is dramatically reduced, the RFID system can keep its reader to accurately locate the correct tag. While we have demonstrated this technology with a few common objects, RFID tags can uniquely identify hundreds of different objects with essentially zero false positives.

6 Simulation Test and Analysis

In our proposed method, we use more "space" to make its efficiency better than others (aforementioned QT, EQT, DFSA and BIS) under using a little more time for mapped correlation of tag ID relationship [22], [23], [24], [25], [26], [27], [28], [29], [30]. Based on our experimental results, we know the time used to mapping tags is very small, so it can be ignored. The specific parameters for the simulation results are as Table 2.

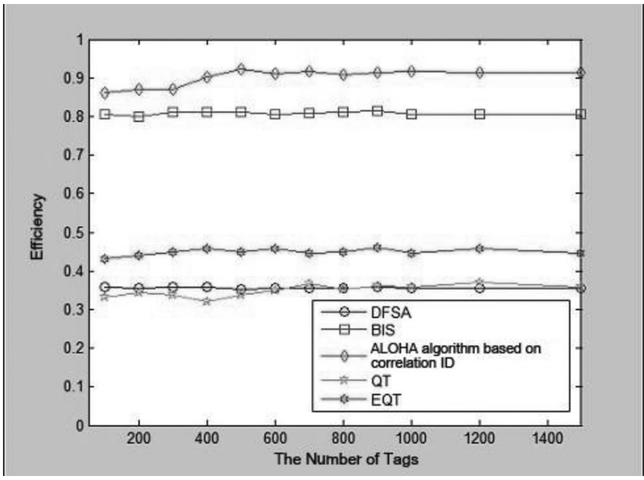

Fig. 12. Efficiency comparison of the algorithms.

The performance tests of the multi-way tree algorithm based on the mapped correlation of ID for many applications of Internet of Things are done between our method and multi-way tree anti-collision algorithm based on the conflict ID. Our experiments have shown that the efficiency of the multi-way tree anti-collision algorithm based on mapped correlation of ID is much higher than that of multi-way tree anti-collision algorithm based on conflict ID. Especially when there are 1,500 tags, the efficiency is about 15 percent higher. Compared with QT and EQT algorithms, the multi-way tree anti-collision algorithm based on correlation ID is more efficient.

The performance tests of DFSA anti-collision algorithm based on the mapped correlation of ID are done among aforementioned QT, EQT, DFSA and BIS. We simulate the method performance from efficiency parameter. We set up the simulation conditions as the method of estimation of the residual tags is Vogt algorithm [7], [8]. On the basis of DFSA algorithm [25], [26], [27], [28], [29], [30], the data of simulation experiment is shown in Table 2. The Fig. 12 has shown the efficiency performance of the method We introduce the representative algorithms such as aforementioned BIS, DSFA, QT and EQT. The method adopts the 96-bit ID generated randomly. According to the simulation results, the method proposed in this paper is better than the other algorithms in efficiency.

As is shown in theory and experiment, we can see that the efficiency of the our method has improved by 28 percent than that of QT and DFSA. This is due to the introduction of modulation binary sequence, the reader avoids the query of empty slots, so the efficiency has improved. Our method is not affected by the length of ID and the recognition efficiency is high. In the case of multi-tag or that the number of tags is small, the recognition efficiency is over 88 percent, and when the number of tags is large, the efficiency can be more than 93 percent.

7 Conclusion

In order to overcome the shortcomings of existed anti-collision methods on the efficiency of recognition is very low, we propose a novel approach to mapped correlation of ID for RFID anti-collision. This method can increase the association between tags so that tags can send their own ID under certain trigger conditions, by mapped correlation of ID, querying on multi-tree becomes more efficient. In the case of not too big number of tags, the method can greatly reduce the number of times that the reader reads and writes to tag's ID. In the case of dynamic ALOHA-type applications, the reader can determine the locations of the empty slots according to the position of the binary pulse, so it can avoid the decrease in efficiency which is caused by reading empty slots when reading slots. Experiments have shown it can greatly improve the recognition efficiency.

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