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Anti-collision Algorithms for Multi-Tag RFID

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1. Introduction

RFID is one of automatic technology to identify and collect object data quickly through RF digital signals. RFID increases productivity and convenience. RFID is used for hundreds, if not thousands, of applications such as preventing theft of automobiles and merchandise; gaining entrance to buildings; automating parking. But one of the largest disadvantages in RFID system is its low tag (transponder) identification efficiency by tag collision.

Collisions are divided into interrogator collisions and tag collisions. Interrogator collisions occur when neighbouring interrogators interrogate a tag simultaneously. Tag collision is the event that the interrogator (reader) cannot identify the data of tag when more than one tag occupies the same communication channel simultaneously. The reason is that whenever two or more users are transmitting on the shared channel simultaneously, a collision occurs and the data cannot be received correctly. This being the case, packets may have to be transmitted and retransmitted until eventually they are correctly received.

As the most RFID systems use passive tags, frame sizes are limited in the framed slotted ALOHA algorithm. Especially, since low-functional passive tags can neither detect collisions nor figure out neighboring tags, a tag collision gives rise to the need for a tag anti-collision protocol that enables the recognition of tags with few collisions and also executes in real-time. Active RFID tags contain an on-board battery. They can communicate with interrogator in far distance. Active tags can provide anti-collision by using various combinations of some methods including time scope and frequency scope. When the number of tags is large, for the conventional RFID anti-collision algorithm, the number of slots required to read the tags increases exponentially as the number of tags does. Some methods can solve this problem with complex algorithm consuming long communication time.

Based on the analysis above, a good tag collision arbitration protocol for RFID tags should have the following characteristics: First, a interrogator ought to identify all the tags inside its own reading range. Since the interrogator cannot estimate the number of tags precisely, the guarantee of recognizing all tags must be taken into consideration in the design of the tag hard system and anti-collision protocol. Second, a tag should be identified while consuming a small amount of resource, since the tag has low power. Thus, the tag anti-collision protocol must load the tag with the least possible communication time.

This paper presents an improved dynamic framed slotted aloha algorithm (IDFSA) that may solve this problem by dividing frequency of tags that is grouping the tags in different

frequency channel, reducing the number of slots and saving the communication time of grouping with estimation. The interrogator requests every frequency in turn to check the tags. In every frequency channel, the optimal frame size was set to enhance the system efficiency. This Algorithm has been used in the 433MHz RFID system. The system identification efficiency shows good performance.

2. Overview of several RFID anti-collision algorithms

In general, tag anti-collision protocols can be grouped into two broad categories: aloha-based protocols and tree-based protocols. The former is composed of such as aloha, slotted aloha, and frame slotted aloha that reduce the occurrence probability of tag collisions since tags transmit at distinct times. The later is composed of such as the binary tree protocol and the query tree protocol, based on the collision resolution algorithm studied in.
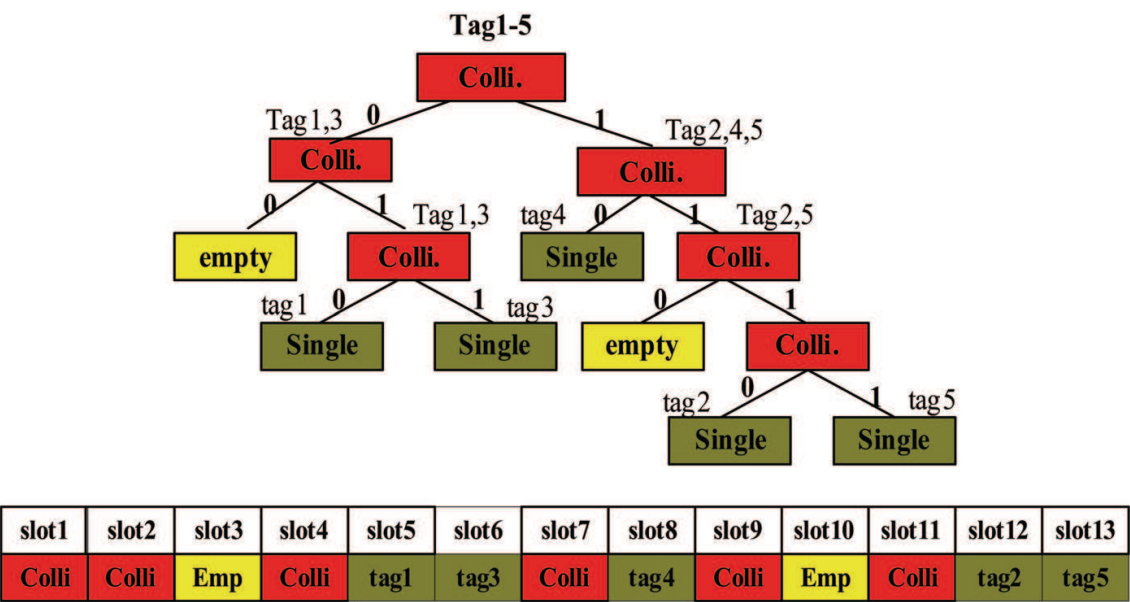
2.1 Tree-based RFID protocols

Fig. 1. An example of binary tree algorithm.

In tree-based RFID protocols, many protocols use binary tree algorithm. In this protocol, if a collision occurs in a timeslot, the colliding tags are randomly separated into two subgroups by independently selecting 0 or 1, until all tags are identified. The tags that select 0 transmit their IDs to a interrogator right away. If a collision occurs again, the collided tags are split again by selecting 0 or 1. The tags that select 1 wait until all the tags that select 0 are successfully identified by the interrogator. And if all the tags that select 0 are resolved, the tags that select 1 send their IDs to the interrogator. This procedure is repeated until there is no further collision.

An example presented in figure1 illustrates the process of the anti-collision scheme adopting the binary tree protocol. In the first timeslot, all tags select 0 or 1 randomly due to the collision. And tag 1 and 3 select 0. Both tags send their IDs at the next timeslot and are collided again. Tag1and 3 randomly select 1, no one select 0, then at the following timeslot,

it is empty. At the fourth timeslot, it is collided again. Tag1 transmits its ID at the fifth timeslot successfully by selecting 0, and the interrogator can then read the tag 3 because of no collision at the next timeslot. After the collision resolution of tag 1 and 3, tag2, 4 and 5 are collided at the seventh timeslot. Next, tag 4 selects 0 and tag 2and 5 select 1. Tag4 sends its ID at the eighth timeslot. Thus tag 2 and 5 send at the twelfth and thirteenth timeslot, respectively. Due to the no further collision, an interrogator finishes an identification process.

Figure 2 shows the procedure of query tree searching algorithm. At t0, the interrogator starts the anti-collision sequences by sending broadcast frame. Then at t1, the interrogator sends '0' to receive a tag's UID of the first bit equal to '0'. At stage t2, the interrogator sends '00' which is an accumulated UID stream that it is searching. By sending this accumulated UID stream, the tags are free for counting the stage information. Moreover, the only operations at tags are comparator or exclusive-OR operation. At stage t3, the interrogator receives '00XX' where 'X' means a collision. It sends '000' firstly, and then receives the first complete tag information '0000'. Again the reader sends '001' which results an identification if UID '0010'. This algorithm takes 8 stages to get the whole 4 UID stream. The de-activation frame transmission is omitted for the simplicity.

		Interrogator						
		t1	t2	t3	t4	t5	t6	t7
		Broad cast	0	00	000	001	01	1
Tag1	0000	□□	□	□	□			
Tag2	0010	□□	□	□		□□		
Tag3	0101	□□	□				□□	
Tag4	1100	□□						□
Iterrogator	receive	xxxx	0xxx	00xx	0000	0010	0101	1100

Fig. 2. Sequences of the query tree searching scheme.

When the number of tag is small, tree-based protocols exhibit a reasonable performance. If the number of tags is large, at the early stage, they may experience poor performance because they might waste timeslots due to many collision slots until all tags are identified.

2.2 Basic framed slotted Aloha algorithm

BFSA algorithms use a fixed frame size and do not change the frame size until the process of tag identification is over. When an RFID interrogator attempts to read tags, the interrogator offers necessary information to the tags, such as the frame size and the random numbers. Receiving this information, tags transmit their IDs at the computed timeslots in the frame. If a timeslot has collision, the tags retransmit in the next read frame.

Figure 3 presents a process where tags are identified by BFSA. We assume that the frame size and the number of tags are 4 and 5, respectively. Firstly, Tag 4 transmits its ID at timeslot 1 of the frame 1. It is successfully identified. At the following timeslot, since a collision occurs, the interrogator can not read the tags correctly. Neither tag 3 nor tag 5 is identified by the interrogator due to the same reason. Thus, in the next frame, tag 1, 2, 3 and 5 must repeat the procedure until all tags are identified.

	T1	Frame1				T1	Frame2			
		Slot1	Slot2	Slot3	Slot4		Slot1	Slot2	Slot3	Slot4
	Que.	single	Colli.	Em.	Colli.	Que.	single	Colli.	single	Em.
Tag1			□					□		
Tag2					□			□		
Tag3			□						□	
Tag4		□								
Tag5					□		□			

Fig. 3. Basic framed slotted Aloha algorithm

Because of the fixed frame size of BFSA, implementation is rather easy. If there are too many tags, most of timeslots experience collisions, and none of tags may be identified during long time. And many timeslots may be wasted by idle slots if the number of timeslots in the frame is much larger than that of tags. Thus, it exhibits low performance of tag identification.

2.3 Dynamic framed slotted Aloha algorithms (DFSA)

Time Separation based anti-collision uses two or more different ID tags in which different tags have reply signals that occur in differing time positions. There are several methods of changing the frame size. One of the popular dynamic framed slotted ALOHA algorithm (DFSA) is that the interrogator regulates the number of slots of next frame using the last frame slots with collision, the number of the empty slots, and the slots filled with one tag.

In an RFID system, the interrogator can dominate the multiple-access procedure, including initiating communication, controlling read process, and receiving responses from tags. In a dynamic frame length ALOHA anti-collision algorithm, the interrogator initiates a read cycle by broadcasting a request command to all tags under its coverage. This request command also includes a dynamic parameter, called the frame length, by which each tag randomly selects one of the available time slots and transmits its ID at the selected time slot. For a given time slot, there are only three possible outcomes: idle, successful transmission (the slots filled with one tag), and collision. The channel is idle if no tag transmits its ID in the time slot. A successful transmission means one tag only sends it's ID. If two or more tags transmit in the same time slot, the interrogator suffers from collision and no tag can be read. After a read cycle, the interrogator can observe empty slots, singly occupied (or successful) slots, and collision slots. If the number of collision slots is greater than zero, the interrogator needs to estimate the number of tags that are present at the beginning of the read cycle according to the triple parameter and then to forecast the number of unread tags. According to the number of unread tags, the interrogator then determines an appropriate frame length for the next read cycle. When the number of slots with collision is over the upper threshold, the interrogator increases the number of slots. If the collision probability is smaller than the lower threshold, the interrogator decreases the number of slots. The read process stops when there is no collision in the read cycle. In the presence of a large amount of collision slots, it is reasonable to assume that the number of tags is great. In this case, the number of empty slots should be very small. In contrast, a large amount of empty slots means that just a few tags are present.
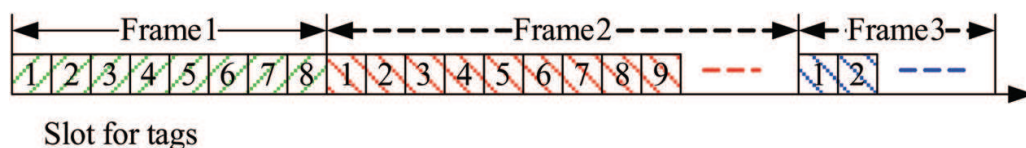
Fig. 4. Slots of Dynamic Framed Slotted ALOHA

DFSA algorithm can enhance channel usage efficiency and identify the tag efficiently because the interrogator regulates the number of slots according to the number of tags (see figure4). When the number of tags is small, DFSA algorithm can identify tags efficiently. However the maximum frame size for a concrete system is definite. When there are a number of tags, changing the frame size alone must be limited to the maximum frame size. So it is not fit for large tags system.

2.4 Enhanced dynamic framed slotted Aloha (EDFSA) algorithm

Collision efficiency is a function of the number of communicating tags presented within the interrogator communication range.

According Chebyshev's inequality, the outcome of a random experiment involving a random variable X is most likely somewhere near the expected value of X. Thus estimation function (1) measures the difference between the real results and the expected values to estimate the number of tags for which difference becomes minimal.

$$\varepsilon_{vd}(N,C_0,C_1,C_c) = \min \left| \begin{pmatrix} a_0^{N,n} \\ a_1^{N,n} \\ a_c^{N,n} \end{pmatrix} - \begin{pmatrix} C_0 \\ C_1 \\ C_c \end{pmatrix} \right| \tag{1}$$

The number of tags is estimated using both the number of slots N used in the read cycle and the results of the previous read cycle as a triple of numbers $<C_0,C_1,C_c>$ that quantify respectively the empty slots, slots filled with one tag, and slots with collision as Equation (1). In Equation (1), $<a_0^{N,n},a_1^{N,n},a_{\geq 2}^{N,n}>$ respectively denote the empty slots, slots filled with one tag, and slots with collision where the number of slots is N and the number of tags is n. Given N slots and n tags, the number 0, 1, r of tags in one slot is binomially distributed, and the expectation value for them is given by the follow eqation

$$a_r^{N,n} = N \binom{n}{r} \left(\frac{1}{N}\right)^r \left(1 - \frac{1}{N}\right)^{n-r} \tag{2}$$

When n is large, the optimal number of slots can be obtained by

$$N \approx n + 1, n \gg 1 \tag{3}$$

The above equation tells us that when the number of tags and the number of slots are approximately the same, the system efficiency becomes the maximum. According this, if the number of unread tags is sufficiently large, the tags can be grouped and allowing only one group to respond. The number of groups can be obtained by Modulo operation.

$$M = unread\ tags/N \tag{4}$$

In a word, when the number of unread tags is large, EDFSA divides the tags into groups with estimation. However, in practical system, when EDFSA based estimation grouping the number of unread tags is used, the time of interrogator command is long that can prolong the time of communication, which will influence the number of slots in a frame. So a simple easily realized method that improved dynamic framed slotted aloha algorithm (IDFSA) is presented as follows.

3. Improved dynamic framed slotted ALOHA (IDFSA) algorithm

This system experiment is based upon the assumptions that (a) Lots of tags are presented in the interrogator's field at the same time, the number of tags being present is not known in advance. The number of tags for every test is not known in advance. (b) Capture effect is not taken into consideration. (c) Experiment is trying to identify all tags presented in the field of the interrogator.

3.1 The description of IDFSA

For a practical system, the maximum time of one tag communication can be known, and the maximum number of slots in a frame can be calculated. The maximum total number of tags can be known too. If the number of tags is large, from equation (3), when the frame size N is equal to or close to the number of tags, the system efficiency becomes the maximum. In practical system, many RF chips have many frequency channels (e.g. nRF905). The tags can be divided into groups in different frequency channel to enhance the identification efficiency and to save the time of the command of the EDFSA. Grouping the tags can be accomplished in the system design period. Every group of tags has their own frequency. The number of frequency channels can be gotten as follows

$$G = n_{total} / N_{max} \qquad (5)$$

Where n_{total} is the number of system maximum total tags; N_{max} is the number of system maximum frame size. G is the number of frequency channels.

The maximum number of tags in every group is approximate to the maximum frame size. In one frame, according to the number of identified tags, C_1 the number of slots given one tag can be known. The collision C_c can be known by the difference of number of address match (AM) and data ready (DR). C_c is divided by frame size N_i, and then collision efficiency P_r can be gotten. Next frame size N_{i+1} can be known from (4). If 15%< C_c/ N_i <40 %, next frame size N_{i+1} does not change. If C_c/N_i<15%, next frame size N_{i+1} is $N_{i/2}$. If C_c/N_i>40%, next frame size N_{i+1} is $2N_i$. Until the interrogator identifies all tags in one channel, another channel can start to check.

$$N_{i+1} = \begin{cases} N_i / 2, & C_c / N_i < 15\% \\ N_{i,} & 15\% < C_c / N_i < 40\% \\ 2N_i & C_c / N_i > 40\% \end{cases} \qquad (6)$$

The frequency channel group can be made in the system design period not in the communication period, and the real-time estimation method is not used by the IDFSA. It not only saves the time of grouping with estimation during the communication, but also enhances the identification efficiency.

3.2 Performance analysis of IDFSA algorithm

For example, this system has total 210 tags; the maximum number of a frame size is 64 (see table 1). (3) is used in the condition that the number of tag is very large. According (3) the number of frequency channels is $210/64 \approx 3$.

In this system, the frequency channels of tags are 433 MHz, 433.4 MHz and 433.9MHz. For every frequency channel, the number of real time slots can be decided by IDFSA. The interrogator requests every frequency by turns to check different frequency tags. This can enhance the system efficiency.

n_{total}	N_{max}	$G_{channel}$
210	64	3

Table 1. The total system tags vs. maximum number of a frame size

Figure 5 is the system efficiency vs. groups and tags number. With the number of tag increasing, it can be seen that system efficiency of 3groups is higher than that of 2 groups; System efficiency of 2groups is higher than that of 1 groups.

In figure 4, it can be seen that the line groups 1, 2, 3 have two crossing point A, and B. According this, n_A and n_B can be obtained by

$$a_1^{N,n} / N = a_1^{N,n/2} / N \tag{7}$$

$$a_1^{N,n/2} / N = a_1^{N,n/3} / N \tag{8}$$

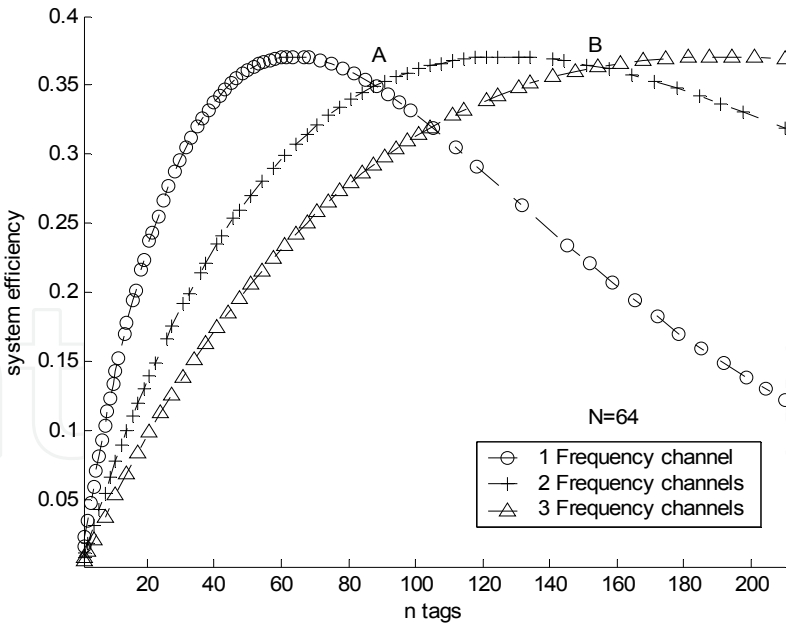When N is 64 slots, n_A =88 and n_B=155.

Fig. 5. System efficiency vs. frequency channels

When N is 64 and 89≤n≤154, to achieve the optimal system efficiency, the number of frequency channels can be 2. Similarly, when N is 64 and 155≤n≤218, to achieve the optimal system efficiency, the number of frequency channels can be 3. The result can be seen in table 2.

N_{total}	G	N/G	P_r
…	…	…	…
156~219	3	64	0.19516~0.31621
88~155	2	64	0.15061~0.34476
45~87	1	64	0.15606~0.40053
23~44	1	32	0.16073~0.40157
…	…	…	…

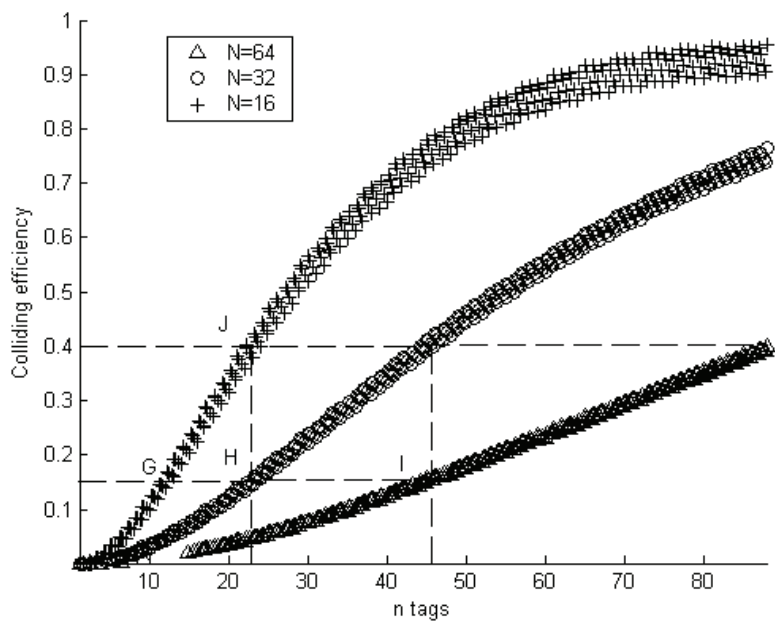Table 2. Tags、 frequency channels、 the number of slots and collision efficiency

Fig. 6. The collision of slots number is $2N_i$、 N_i、 $N_i/2$

Figure6 is the collision efficiency of $2N_i$, N_i and $N_{i/2}$. When the collision efficiency is 15%, the number of tags is near to the down threshold the same as the table 1. When the collision efficiency is 40%, the number of tags is near to the upper threshold the same as the table 1. System identification efficiency is between 34.94% ~37.085% in one frame once a time.

Figure 7 is the collision efficiency and identification efficiency. The collision efficiency of the traditional method is between 30%-70%, and the system identification efficiency is the line between EF in figure 3. The collision efficiency of IDFSA is between 15%-40%, and the system efficiency is between 34.94% ~37.085% in one frame once a time. It is the line between CD in figure 7. It can be seen that system identification is higher than the traditional method.

4. Conclusion

It is an important problem to enhance the tag identification efficiency. When the number of tags is large, for the conventional RFID anti-collision algorithm the number of slots required to read the tags increases exponentially as the number of tags does. The proposed IDFSA algorithm may solve this problem by grouping the tags in different frequency channel, saving the time of grouping with estimation. In every frequency channel, DFSA is used to

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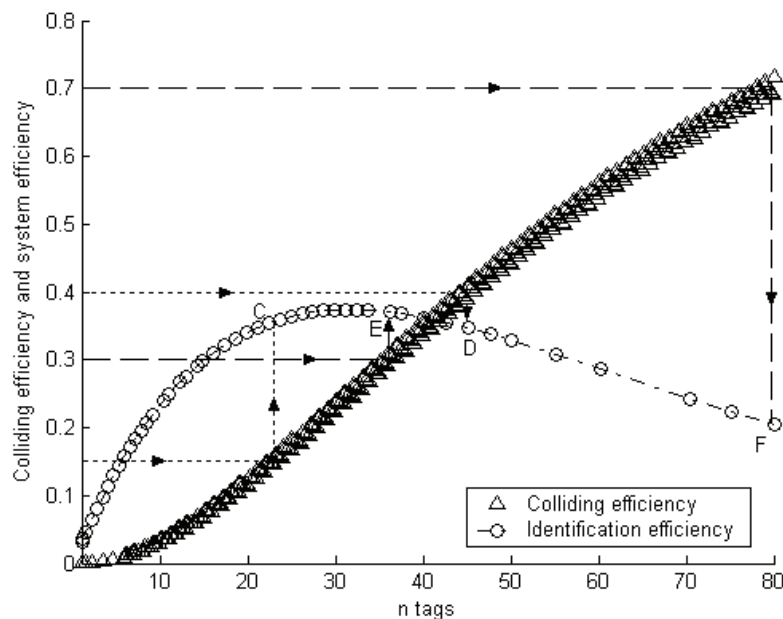

Fig. 7. Collision efficiency and identification efficiency

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The number of different applications for RFID systems is increasing each year and various research directions have been developed to improve the performance of these systems. With this book InTech continues a series of publications dedicated to the latest research results in the RFID field, supporting the further development of RFID. One of the best ways of documenting within the domain of RFID technology is to analyze and learn from those who have trodden the RFID path. This book is a very rich collection of articles written by researchers, teachers, engineers, and professionals with a strong background in the RFID area.

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