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An Enhanced Tag Estimation Method Applied to Tag Anti-collision Algorithm in RFID Systems

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***Abstract*—In RFID systems, if two or more tags response a reader simultaneously, communication conflict or data interference (i.e. reader collision and/or tag collision) will occur. As a result, the reader cannot receive information of these tags correctly. In order to solve this type of tag collision problem, many tag anti-collision algorithms have been proposed, such as a series of Aloha-based algorithms and their varaties. As one of representatives of Aloha-based algorithms family, Dynamic Frame Slotted Aloha Algorithm (DFSA) is capable of changing the number of slots in a single frame dynamically according to the collision situation in the previous frame. When the number of slots in a frame equals the number of unidentified tags, the RFID system will win the best throughput. In this case, tag collision problem is focused on tag estimation. Because that the traditional Tag Estimation Method (TEM) ignores such information as number of empty slots and slots filled with only one tag, this paper proposes an enhanced tag estimation method (ETEM) to improve estimation accuracy. The simulation results indicate that the proposed ETEM algorithm performs better in both identification time and estimation error than the traditional TEM.**

I. INTRODUCTION

Radio frequency identification (RFID) is a kind of non-contacted automatic identification technique, which can be used to automatically identify the targets by RF signal. RFID has numerous advantages, such as fast data reading rate, large memory, strong penetrability, long service life, good safety performance, and has broad application prospect in manufacturing industry, commodity circulation, public management and many other fields. With the improvement in its reliability and usability, and the decreasing in production cost, RFID is becoming an indispensable emerging technique in Internet of things.

A typical RFID system consists of readers, tags, and an application system. While entering the read region of a reader, tags will be activated by means of electromagnetic coupling and send their information back to the reader. The reader receives information of tags and sends it to the application system to further identify these tags. The schematic description of a typical RFID system is demonstrated as in Fig.1[1].

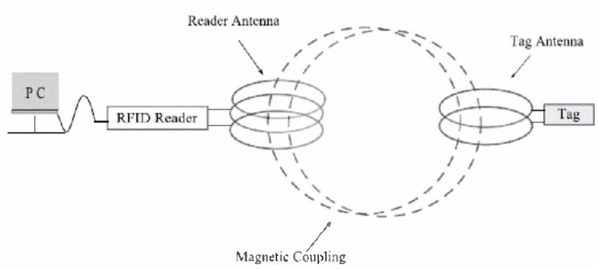

Fig.1 Schematic of a typical RFID system

In most applications of RFID systems, while there are two or more tags located in the read region of a reader and they respond the reader at the same time or one tag begins to respond when the other tags have not finished responding, the responses of the tags will collide and make the reader cannot receive the information from these tags. This problem is called tag collision, which will reduce the communication efficiency and reliability of RFID systems. Nowadays, many tag anti-collision algorithms have been proposed to solve this tag collision problem. Generally speaking, the tag anti-collision algorithms can be mainly classified into three types, Aloha-based [2]-[5], tree-based [6],[7], and hybrid algorithms [8],[9] which combine the thinking of Aloha and tree protocols.

Aloha algorithm is famous for its easy implementation and has several improved Aloha varieties. The typical version is Dynamic Framed Slotted Aloha (DFSA) algorithm which can change the number of slots in a single frame dynamically according to the collision situation in the previous frame. It is explored that when the number of slots in a frame equals the number of unidentified tags, the RFID system will win the best throughput. Therefore, many tag estimation methods come into being, such as Low Bound (LB) [2], Maximum Throughput (MT) [3], Tag Estimation Method (TEM) [4], Chebyshev-based [5], etc. The tree-based algorithms separate the collision tags into two groups, 0 and 1. The reader identifies the tags from group 0 and separate it into another two groups if collision happens again until all the tags from group 0 are identified, and then group 1. The hybrid algorithms bring time division in tree protocols such as

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BSQTA [8], or increase collision bit detection to Aloha protocols such as BFSA [9].

Considering that the traditional TEM algorithm is regardless of such information as number of empty slots and slots filled with only one tag, this paper proposes an enhanced tag estimation method (ETEM) to further improve the accuracy of tag estimation and the identification efficiency of tags in an RFID system.

The remainder of this paper is organized as follows. Section II reviews the Aloha-based tag anti-collision algorithms and its variety series, and especially presents the main tag estimation methods in detail. Section III proposes an enhanced tag estimation method (ETEM) for higher identification efficiency. And Section IV makes some comparisons between the newly proposed ETEM algorithm and the traditional TEM algorithm by means of simulation experiments. Finally, Section V draws a conclusion.

II. Related Works of Aloha-based Tag Anti-collision Algorithms

A. *Aloha-based Algorithms Family*

The Aloha-based algorithms are the simplest among tag anti-collision algorithms. They are executed based on Time Division Multiple Address (TDMA) and probability. While accepting the commands from a reader, a tag will choose a random delay to response to the reader.

(a) Pure Aloha (PA) Algorithm

In the pure Aloha (PA) algorithm, when a tag is responding to a reader, if there is another one or more tags responding simultaneously, a collision will occur. The reader receives the signals from tags and finds out whether a collision occurs or not. If yes, the reader will command the tags to stop transmitting and wait for a random delay to mitigate this collision, or the reader will identify the single tag successfully. However, the efficiency of pure Aloha algorithm is very low, because there may be not only complete collision but also partial collision, when a tag responds while another one or more tags have not finished communicating with the reader, show as Fig.2(a) where black blocks denotes collision and white ones denotes successful identification, the same in (b), (c) and (d).

(b) Slotted Aloha (SA) Algorithm

The Slotted Aloha (SA) algorithm improves the pure Aloha algorithm by dividing the time into many separated slots. And tags can only answer the reader in slots synchronously, shown as Fig.2(b). Therefore, a partial collision is missing so that the collision probability would be greatly reduced. As a result, the utilization rate for the transmit channel is effectively improved.

(c) Framed Slotted Aloha (FSA) Algorithm

In pure Aloha and SA, if a tag responses very frequently, it will easily collide with other tags. In order to solve this problem, the FSA algorithm combines a fix number of slots into a frame and only allows tags to response once in a frame, shown as Fig.2(c) where F denotes frame size, the same in (d). However, because the number of slots in a frame is fixed, if the number of tags is much larger than that of slots, the collision probability will largely increase; and if it is much smaller, more slots will be wasted.

(d) Dynamic Framed Slotted Aloha (DFSA) Algorithm

In order to solve the problem of the FSA algorithm mentioned above, the DFSA algorithm is proposed by changing the frame size dynamically according to the collision situation in the previous frame, shown as Fig.2(d). Here, the frame size is decreased if the collision probability of the previous frame is very high; and the frame size is increased if the collision probability is very low. And the following parts will discuss the optimal size of a frame.

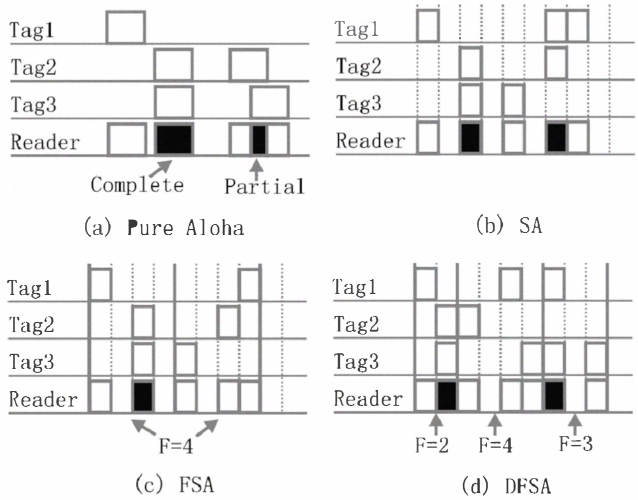

Fig.2 Schematic of Aloha-based algorithm family

B. *Optimal Slotted Frame Size*

Assume that there are L slots in a frame and n tags have not been identified. And then, the probability that no tag responds in a single slot (P_{idle}) is calculated as Eq. (1), where $p = 1/L$.

$$P_{idle} = (1-p)^n \tag{1}$$

Correspondingly, the probability of only one tag responding in a single slot (P_{succ}) is computed as Eq. (2).

$$P_{succ} = np(1-p)^{n-1} \tag{2}$$

In addition, the probability of two and more tags responding in a single slot (P_{coll}) is evaluated as Eq. (3).

$$P_{coll} = 1 - P_{idle} - P_{succ} = 1-(1-p)^n - np(1-p)^{n-1} \tag{3}$$

Therefore, the throughput (S) is formulated as Eq. (4).

$$S = \frac{P_{succ}}{P_{succ}+P_{coll}+P_{idle}} = np(1-p)^{n-1} \quad (4)$$

Thus, the maximum throughput can be computed by the following Eq. (5).

$$\frac{dS}{dn} = p(1-p)^{n-1} + np(n-1)(1-p)^{n-2} = 0 \quad (5)$$

And then, the optimal frame size ($L_{optimal}$) can be given as Eq. (6).

$$L_{optimal} = \frac{1}{p} = n \quad (6)$$

Seen from Eq. (6), an RFID system will win the maximum throughput if the frame size is equal to the number of unidentified tags [4]. So some DFSA-based algorithms attempted to use tag estimation methods to change the frame size dynamically.

(a) Low Bound (LB)

If a collision occurs in a single slot, there are at least two tags responding at the same time in the same slot. So LB estimates the tag number (n_{LB}) by means of Eq. (7), where C_{succ} denotes the number of slots when only one tag responses and C_{coll} denotes the number of slots when more than one tags response [2]. However, LB just uses the low bound of tag number, so it can not estimate tag number correctly.

$$n_{LB} = C_{succ} + 2 * C_{coll} \quad (7)$$

(b) Maximum Throughput (MT)

MT defines a collision rate (C_{rate}) in form of Eq. (8).

$$C_{rate} = \frac{prob.\ that\ there\ is\ a\ collision\ in\ a\ slot}{1-prob.\ that\ a\ tag\ transfers\ successfully} \quad (8)$$

And then, the optimal collision rate for the maximum throughput is given as Eq. (9).

$$C_{rate} = \lim_{n\to\infty} \frac{P_{coll}}{1-P_{succ}} = 0.4180 \quad (9)$$

So, MT estimates the tag number (n_{MT}) as Eq. (10) [3].

$$n_{MT} = \frac{C_{coll}}{C_{rate}} = 2.3922C_{coll} \quad (10)$$

MT can make the system win the best throughput, but if the data scale is not large enough, the tag estimation error will increase more.

(c) Chebyshev-based Method

The Chebyshev's inequality indicates that the result of a random experiment is approaching to its expectation. So the Chebyshev-based method estimates the tag number by minimizing the function given as Eq. (11), where C_{idle} denotes the number of empty slots and E_{idle}, E_{succ} and E_{coll} denote the expectation of number of empty slots, number of slots filled with only one tag and number of slots with collision, respectively, given as Eq. (12) [5].

$$\varepsilon(n, C_{idle}, C_{succ}, C_{coll}) = \min \left| \begin{pmatrix} E_{idle} \\ E_{succ} \\ E_{coll} \end{pmatrix} - \begin{pmatrix} C_{idle} \\ C_{succ} \\ C_{coll} \end{pmatrix} \right| \quad (11)$$

And

$$\begin{aligned} E_{idle} &= P_{idle}L = (1-p)^n L \\ E_{succ} &= P_{succ}L = np(1-p)^{n-1} L \\ E_{coll} &= P_{coll}L = (1-(1-p)^n - np(1-p)^{n-1})L \end{aligned} \quad (12)$$

Although Chebyshev-based method can estimate the tag number more accurately than LB and MT, it is more complex for calculation.

(d) Tag Estimation Method (TEM)

The tranditional TEM algorithm defines C_{rate} in form of Eq. (13) as the ratio of the number of slots with collision to the frame size, which can be deduced by Eq. (3).

$$\begin{aligned} C_{rate} &= 1-(1-p)^n - np(1-p)^{n-1} \\ &= 1-(1-\frac{1}{L})^n(1+\frac{n}{L-1}) \end{aligned} \quad (13)$$

Because the number of slots with collision has been already got after a frame, C_{rate} can be calculated by Eq. (14).

$$C_{rate} = \frac{C_{coll}}{L} \quad (14)$$

Therefore, the tranditional TEM algorithm estimates the tag number by solving the function equation $g(n)$ given as Eq. (15).

$$g(n) = \frac{C_{coll}}{L} - (1-(1-\frac{1}{L})^n(1+\frac{n}{L-1})) \quad (15)$$

Similar to TM and Chebyshev-based method, this tranditional TEM algorithm can perform well just when the frame size is large enough and have large data scale, or it will have large estimation error due to the small data scale.

III. The Proposed Enhanced TEM Method

As introduced above, the traditional TEM algorithm estimates the tag number only use the number of slots with collision. However, the number of empty slots and that of slots filled with only one tag can also be also got after the previous frame. Therefore, tag estimation methods which neglect these information can not have a high identification efficiency. So this paper proposes an enhanced tag estimation methid (ETEM) which makes full use of these information when estimating the unidentified tag number, to improve the accuracy of estimation and identification efficiency of the tranditional TEM algorithm.

Assume that there are L slots in a frame and n tags have not been identified. So n can be expressed as Eq. (16), where C_{tag} denotes the average tag number in a collision slot.

$$n = C_{tag} P_{coll} L + P_{succ} L \quad (16)$$

So according to Eq. (16), C_{tag} can be expressed as Eq. (17).

$$C_{tag} = \frac{n - P_{succ} L}{P_{coll} L} \quad (17)$$

Because C_{coll} and C_{succ} can be got after the previous frame, so n can be also expressed as Eq. (18).

$$n = C_{tag} C_{coll} + C_{succ} \quad (18)$$

And then, Equation Eq. (19) can be got from Eq. (17) and (18).

$$f(n) = C_{coll} \frac{n - n(1-p)^{n-1}}{L - L(1-p)^{n} - n(1-p)^{n-1}} + C_{succ} - n \quad (19)$$

The proposed ETEM algorithm estimates the tag number by solving the function $f(n)$. So the size for next frame (n_{est}) is determined by Eq. (20), where n_{ETEM} denotes the root of the function $f(n)$.

$$n_{est} = n_{ETEM} - C_{succ} \quad (20)$$

The flow of the proposed algorithm using ETEM is described as follow. At first, the reader initializes the frame size, such as 16, to identify the tags as the FSA algorithm. When a frame finishes, the reader updates the C_{coll} and C_{succ}, figures out tag number by solving function $f(n)$ shown as Eq. (18), and updates the frame size by Eq. (19). Repeat this process until C_{coll} is zero or all the tags have been identified. The flowchart is shown as Fig.3.

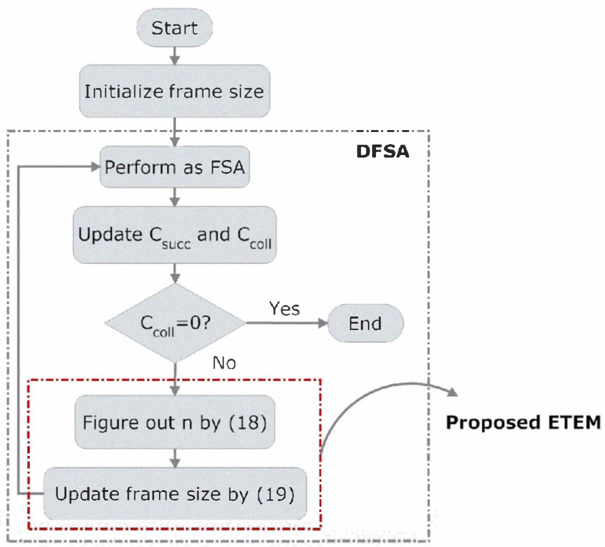

Fig.3 The flowchart of ETEM

IV. SIMULATION EXPERIMENTS

This section compares the performance between the tranditional TEM algorithm and the proposed ETEM algorithm in four sides, functions for estimation, estimation error, identification time or slots and system throughput. All the experiments are executed by means of numerical simulation. At first, we will analyze the two different functions for estimation in the tranditional TEM algorithm and the proposed ETEM algorithm. And then, we will compare their two key indices: estimation error and identification time. Finally, the throughput of the system is considered.

Fig.4 draws the two function curves, $g(n)$ shown in Eq. (15) and $f(n)$ shown in Eq. (19), for tag estimation using the tranditional TEM algorithm and the proposed ETEM algorithm with 100 tags and 100 slots in a frame. Although the two methods can both estimate the tag number with small error, they have different dependence on the computational accuracy. Because the slope of $g(n)$ is much smaller than that of $f(n)$, if the computational accuracy is not very high, the estimation error of TEM algorithm will increase much more than that of the proposed ETEM algorithm.

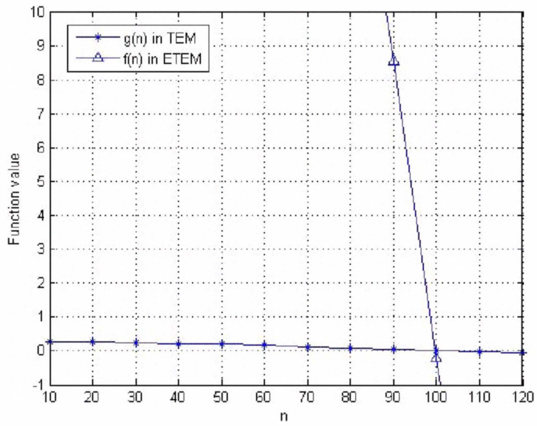

Fig. 4 Function curves of TEM and ETEM for tag estimation

Fig.5 depicts the average number of total slots used for tag identification for the number of tags. When the number of tags is less than 500, this proposed ETEM algorithm performs similarly to the tranditional TEM algorithm. However, while the tag number increases more such as more than 500, the tranditional TEM algorithm costs less slots or time to identify all the tags than the proposed ETEM algorithm obviously.

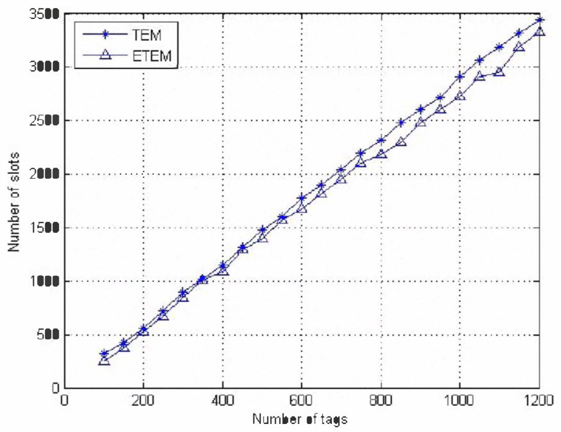

Fig.5 Number of slots vs. number of tags

Fig.6 to Fig.9 show the average estimation error for the number of tags for the number of tags, when the frame size is 50, 100, 500 or 800 slots. When the frame size is 50 slots, the proposed ETEM algorithm does not perform well especially with more than 500 tags. However, when the frame size reaches to 100 slots, the proposed ETEM algorithm has similar estimation error if the number of tags is less than 500, but when the number of tags increases more, the estimation error for the proposed ETEM algorithm is much less than that of the tranditional TEM algorithm. Especially when the frame size is larger than 100 slots, such as 500 slots shown in Fig.8 and 800 slots shown in Fig.9, the superiority of the proposed ETEM algorithm is much more obvious than the tranditional TEM algorithm.

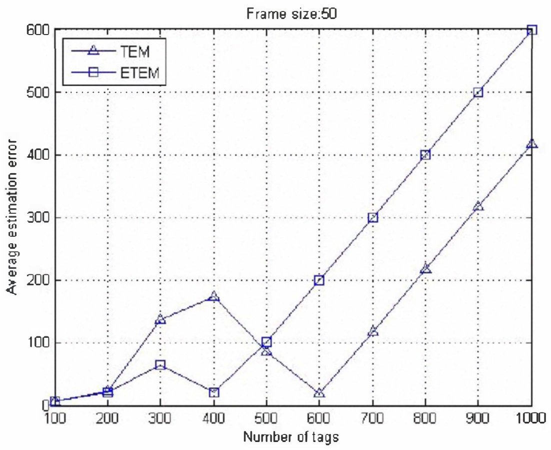

Fig.6 Average estimation error vs. tag number for frame size 50

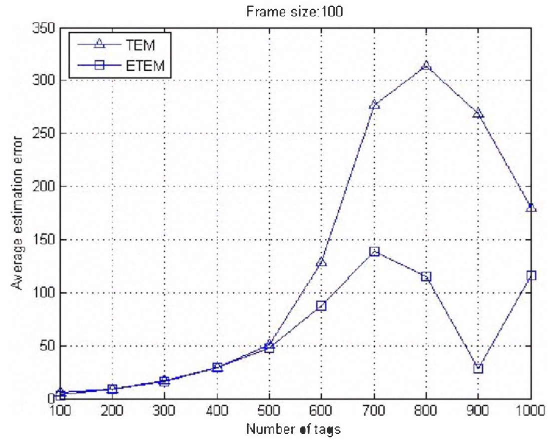

Fig.7 Average estimation error vs. tag number for frame size 100

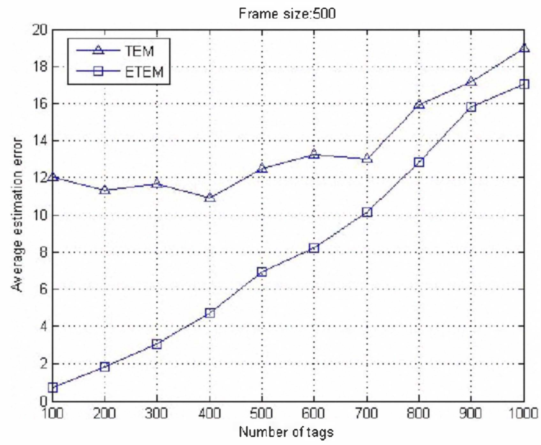

Fig.8 Average estimation error vs. tag number for frame size 500

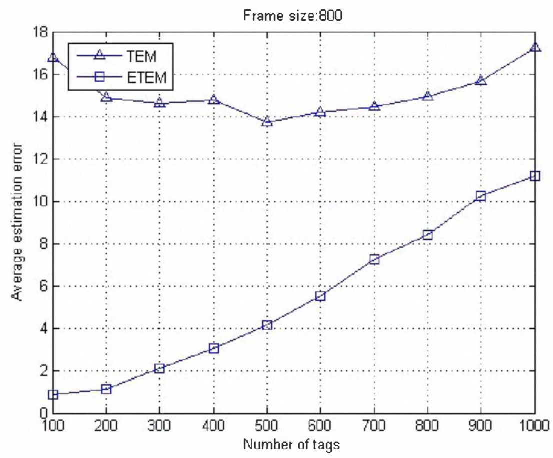

Fig.9 Average estimation error vs. tag number for frame size 800

Fig.10 shows the estimation error for the slot number in a frame to identify a fix number 500 of tags. When frame size is smaller than 250 slots, this proposed ETEM algorithm and the tranditional TEM algorithm have a similar performance. But while the frame size is larger than 250 slots, the estimation of the proposed ETEM algorithm decreases observably and is much smaller than that of the tranditional TEM algorithm.

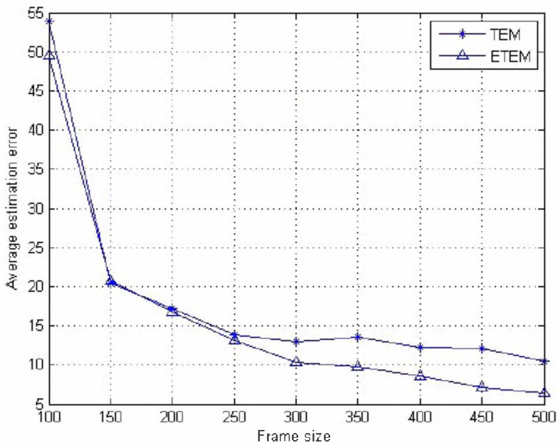

Fig.10 Average estimation error vs. frame size for 500 tags

Another performance index for an RFID system is the throughput defined as Eq. (21).

$$Throughput = \frac{time\ to\ identificate\ tags\ successfully}{total\ time\ to\ identificate\ all\ tags} \quad (21)$$

Assume that every slots cost the same time for communication, so slot number can be replaced by time to calculate the throughput with the formula of (22).

$$Throughput = \frac{\sum C_{succ}}{\sum (C_{succ} + C_{coll} + C_{idle})} \quad (22)$$

Fig.11 gives the system throughput for the number of tags. When the tag number is more than 500, the proposed ETEM algorithm has a larger throughput than the tranditional TEM algorithm. So the proposed ETEM algorithm is suitable for the environment with large number of tags. Overall, the proposed ETEM algorithm has a better performance than the tranditional TEM algorithm, especially for large scale of tags.

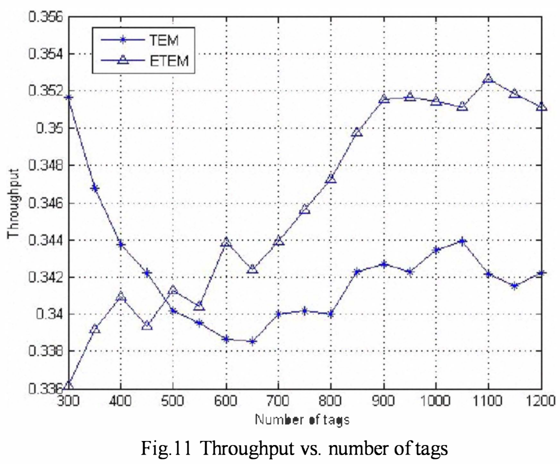

Fig.11 Throughput vs. number of tags

V. CONCLUSIONS

This paper first presents the main tag anti-collision algorithms based on Aloha and tag estimation methods for Dynamic Frame Slotted Aloha (DFSA) algorithm. And then, considering that the tranditional TEM algorithm is regardless of the information of the slot number filled with only one tag, an enhanced TEM (ETEM) algorithm is proposed to improve the traditional TEM algorothm. And the simulation results indicate that the estimation error of the proposed ETEM algorithm increases less if the accuracy of calculation is not very high, and it costs less identification time and has smaller estimation error and larger throughput than TEM, especially for large scale of tags.

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