An Enhanced Posterior Probability Anti-Collision Algorithm Based on Dynamic Frame Slotted ALOHA for EPCglobal Class1 Gen2

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Abstract—In a Radio Frequency Identification (RFID) System, collision between tags is one of the core problems that we must consider about. In general, a collision will occur when more than one tag communicates with the reader simultaneously, reducing the system efficiency. To solve this, dynamic frame slotted ALOHA (DFSA) is widely adopted nowadays, and as a variant of DFSA algorithm, *Q*-algorithm is accepted by the EPCglobal specifications for RFID air interface Class1 Gen2 protocol. Based on this, we provide a new algorithm called EPP-*Q* to adjust the parameter *Q* more accurate as well as maintain high system efficiency when tags are no more than 2^Q-1(*Q* belongs to 0 to 15). The simulation provides an obvious improvement when EPP-*Q* is compared with other two mainstream algorithms, not only in system efficiency, but also in the quantity of time slots used.

Index Terms—Tag anti-collision, RFID, Posterior probability, EPCglobal Class1 Gen2

I. INTRODUCTION

RFID technology with ultra-high frequency (UHF) passive tags is a powerful tool for automatic object identification, which enables the seamless and automatic connection between real-world objects and their virtual representations previously enabled by manual data entry. In recent years, since tags are much cheaper than before, the applications of RFID technology has become a viable alternative for identifying object automatically and widely deployed in inventory control, distribution industry, and supply chain management and so on. So far, RFID technology has been established in a lot of domains. For instance, GS1 Italy and GS1 Hong Kong have completed a project by using EPC Gen2 RFID tags and readers to track shipments of wine from Europe to Asia. However, before RFID technology becomes ubiquitous in the near future, there are also some problems need to deal with.

In RFID systems, if only one tag exists in reader's identification zone, tag can be identified easily. However, if two or more tags exist in zone and respond to reader simultaneously, no tags can be identified and this phenomenon is called tag collision.

To settle this problem, anti-collision algorithm is very necessary. Currently, RFID anti-collision algorithms can be categorized into two groups: tree-based and ALOHA-based ones [1].

Tree based algorithms [2]-[5], such as binary tree protocol (BT) and query tree protocols (QT), repeatedly separate collided tags into two subsets until each set has only one tag or no tag. The performance of these algorithms is stable, but IDs should not be long. Otherwise, it will cost too much time to identify all tags.

In ALOHA algorithms [6]-[8], tags respond to reader by transmitting IDs in a probabilistic manner. All tags will randomly pick a number, and if there is no more than 2 tags selecting the same number, this tag will be identified, otherwise nothing happens [9], [10]. The efficiency of ALOHA algorithm is low with high traffic load. Such as pure aloha (PA), slotted aloha (SA), basic frame slotted aloha (BFSA), dynamic frame slotted aloha (DFSA). Among these, DFSA algorithm will lead to a higher efficiency and a better stability because the reader regulates the frame size according to the number of tags. EPCglobal adopts the anti-collision algorithm called *Q*-algorithm [11], which is also a variant of DFSA algorithm.

However, *Q* value in *Q*-algorithm has to be adjusted frequently in the event of more than one tag choose the same random number. In order to decrease the frequency of *Q* adjustment, we proposed an enhanced posterior probability algorithm based on the *Q*-algorithm. In our algorithm, after making an assessment of the system's current state, we use a posteriori probability and take the past knowledge into consideration to estimate the tags quantity slot by slot and achieve in-frame *Q* adjustment. The incorporation of the past knowledge into the estimation will improve the accuracy, and the in-frame adjustment achieve the in-time adjustment when the frame size is not appropriate, reducing the unnecessary time waste. The in-frame adjustment in our algorithm depends on the accurate estimation results, instead of the

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fixed parameter C, which is more flexible. By simulation, it is testified that our algorithm improves the efficiency of the tag identification.

The rest of our paper is organized as follows: in Section II, we describe and analyze several algorithms based on Q-algorithm. In Section III, we propose and describe our algorithm. In Section IV, extensive simulations are done to compare those different algorithms. The number of slots to identify all tags and the system efficiency are adopted to measure the communication performance. Finally, conclusion is drawn in Section V.

II. Background (Tag Anti-collision Algorithms in EPCglobal Class1 Gen2)

EPC Gen2 passive RFID systems operate on the UHF frequency with an effective identification range of 7 to 10 meters [11]. In order to ensure Q-algorithm could be achieved in EPCglobal Class1 Gen2 protocol, several commands are designed to realize it, including *Select*, *Query*, *QueryAdj*, *QueryRep* and *ACK*.

An identification process may begin with the *Select* command sending by reader, and the reader will select a particular tag group for recognition. After that, the reader will send a *Query* command to identify the selected tags. In this *Query* command, a primary parameter Q is contained, which is in the range of 0 to 15 and represents a frame length of 2^Q. When the *Query* command is received, each tag generates a 16-bit random number called *RN16*, and extracts a Q-bit subset from *RN16* as the tag's slot counter. This counter has to minus one immediately that a *QueryRep* is received. *RN16* will be transmitted as soon as the counter reaches to zero. Actually, the real *ID* of a tag is 96-bit EPC (electronic product code), and the 16-bit *RN16* could be viewed as tag's temporary *ID* to shorten the collision interval at the arbitrate state.

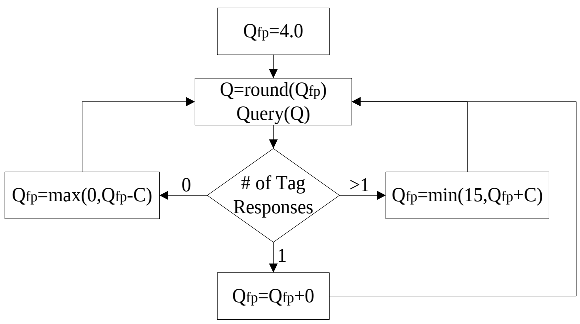

Fig. 1. Mechanism of Q-algorithm.

Since tags respond to a reader in a backscattered way, Q-algorithm contains 2 other variables besides Q, Q_{fp} stands for a floating-point Q and C is a very small constant for the frame length adjustment. Fig. 1 shows the basic mechanism of Q-algorithm. Details are described as follows:

- By *Query* command to initiate a new round, a slot-count parameter Q is contained, meaning that the frame size is $N=2^Q$, including 2^Q time slots. For instance, Q is given as 4, meaning that the frame size of this round is 16 and including 16 time slots.
- After receiving the *Query* or *QueryRep*(query repeat) or *QureyAdj*(query adjust) command, all tags will select a value in the range [0, N-1] randomly, and tags with value 0 could communicate with reader, otherwise, tags with nonzero values have to wait the next round to re-pick random numbers.
- During the response process, there could be 3 situations: empty, collision and success. In Fig. 1, Q_{fp} will minus C firstly and the maximum one between 0 and Q_{fp}-C will be chosen as a new Q_{fp} when empty situation happens; Different with the former situation, Q_{fp} will be selected the minimum one of 15 and Q_{fp}+C in the situation of collision; And in success situation, Q_{fp} will keep the same, reader will implement Select command to read the data of this successful tag. After any of these three, it will go back to Step.(2) till all tags are recognized.

Note:
Query A command sending by reader to initiate a round;
QueryRep A command sending by reader to repeat query without changing;
QueryAdj A command sending by reader to repeat query with increase or decrease Q by one.

It is important to emphasize empty slots S_E, successful slots S_S, and collisional slots S_C, should satisfy the equality that $S_E+S_S+S_C=N$.

Since Q-algorithm is a variant of DFSA, the difference is that the reader will estimate the number of unread tags and adjust the frame size. In [12], we see the following algorithms can be used in EPCglobal protocol, and it is concluded that the algorithm in Chen [13] is appropriate for populations over 300 tags and Vogt [14] is otherwise preferable. Therefore, we compare these two algorithms with our algorithm in the section 4.

(a) Vogt presents two functions to estimate tags' number. One is based on the collisions' time slots which involved at least two tags, hence they used S_S+2S_C to estimate. On the other hand, Vogt proposes a different estimation function in [14], which uses the distance between the read result set (S_E,S_C,S_S) and the expected value to determine the value of n for which the distance becomes minimal. Then the Q parameter is derived according to the value of n.

(b) Chen presents a new estimation function in [13], which is the posterior probability function. This alternative estimation function utilizes the posterior probability $\rho(n|S_E,S_C,S_S,N)$ derived from the result set (S_E,S_C,S_S) to set the tag estimation, when $\rho(n|S_E,S_C,S_S,N)$ is maximum. Later, Bueno migrates the algorithm to EPC protocol in [12].

(c) In [15], Schoute analyzed the procedure of the DFSA algorithm, then claimed the number of competing tags follows a Poisson distribution. Therefore, they only use information of the latest frame to estimate of the number of tags by S_S+2.39S_C.

As shown in [12], the algorithm doesn't achieve good performance as the above two algorithms, but it is simple and easily implemented. Therefore, we adopted this approach in the case $S_C=N$ where the posterior probability approach cannot accomplish estimation.

III. Enhanced Posterior Probability Algorithm Based on Q-Algorithm

Based on the analysis above, Q value in Q-algorithm has to be adjusted frequently when more than one tag chooses the same random number, which of this will bring the negative influence for system efficiency and time cost. Therefore, to decrease the frequency of Q adjustment, we proposed an enhanced posterior probability algorithm based on Q-algorithm, called EPP-Q algorithm.

At the beginning, let's introduce several key part of our algorithm: the estimation of tag number, the approach for In-frame Adjustment, determination for next round. Then we will describe the general procedure, which is shown in Fig. 4.

A. The Estimation of Tag Number

Given frame *size=N* and the number of competing *tags=n*, the n tags are binomially distributed in the N slots with parameters n and $1/N$ [14], therefore the probability that one given slot is occupied by tags is as follow:

$$B(r)=C_n^r\left(\frac{1}{N}\right)^r\left(1-\frac{1}{N}\right)^{n-r} \tag{1}$$

It stands to reason that the probabilities of empty, success, and collision for the slot is:

$$\rho_{\mathrm{E}}=B(0)=\left(1-\frac{1}{N}\right)^n \tag{2}$$

$$\rho_{\mathrm{S}}=B(1)=\frac{n}{N}\left(1-\frac{1}{N}\right)^{n-1} \tag{3}$$

$$\rho_{\mathrm{C}}=1-\rho_{\mathrm{E}}-\rho_{\mathrm{S}} \tag{4}$$

As shown in [12], the approach proposed by Chen [13] represents the best performance. Chen's approach can be generalized to partly observed slots (M observed slots out of N slots) and indicates the path to take full advantage of the in-frame adjustment of the frame size enabled by EPCglobal protocol. With M slots out of N frame size, the probability, that exactly S_E empty slots, S_S successful slots, and S_C collisional slot where $S_E+S_S+S_C=M$, can be derived with the parameter as $\rho_{\mathrm{E}}+\rho_{\mathrm{S}}+\rho_{\mathrm{C}}=1$:

$$\rho\left(S_{\mathrm{E}},S_S,S_C,N,M\right)=\frac{M!}{S_{\mathrm{E}}!S_{\mathrm{S}}!S_C!}\rho_E^{S_{\mathrm{E}}}\rho_S^{S_{\mathrm{S}}}\rho_C^{S_{\mathrm{C}}} \tag{5}$$

From formulas (2) (3) (4) and (5), we can obvious derive the posterior probability as follow:

$$\begin{aligned}&\rho_i\left(n_i\middle|S_{\mathrm{E}},S_S,S_C,N_i,M_i\right)=\\&\frac{M!}{S_{\mathrm{E}}!S_S!S_C!}\times\left[\left(1-\frac{1}{N_i}\right)^{n_i}\right]^{S_{\mathrm{E}}}\times\left[\frac{n_i}{N_i}\left(1-\frac{1}{N_i}\right)^{n_i-1}\right]^{S_{\mathrm{S}}}\times\\&\left[1-\left(1-\frac{1}{N_i}\right)^{n_i}-\frac{n_i}{N_i}\left(1-\frac{1}{N_i}\right)^{n_i-1}\right]^{S_{\mathrm{C}}}\end{aligned} \tag{6}$$

We use the posterior probability to determine the value of Q when the posterior becomes maximal. When $\rho_i(n_i\mid s_E,s_S,s_C,N_i,M_i)$ is maximum, we set $\tilde{n}_i=n_i$. The posterior probability function possesses a maximum for all possible results except for the case of $S_E=S_S=0$. The case of $S_E=S_S=0$ means all slots are collided.

Fig. 2 shows the posterior probability versus number of tags, using (6) when not all slots are in collision just as $S_E\neq0$ or $S_S\neq0$. Four different event set are outline in this figure, they are:

(a) <N=128, M=80, S_E=70, S_S=8, S_C=2>,
(b) <N=128, M=80, S_E=5, S_S=16, S_C=59>,
(c) <N=64, M=60, S_E=10, S_S=20, S_C=30>,
(d) <N=64, M=40, S_E=5, S_S=5, S_C=30>.

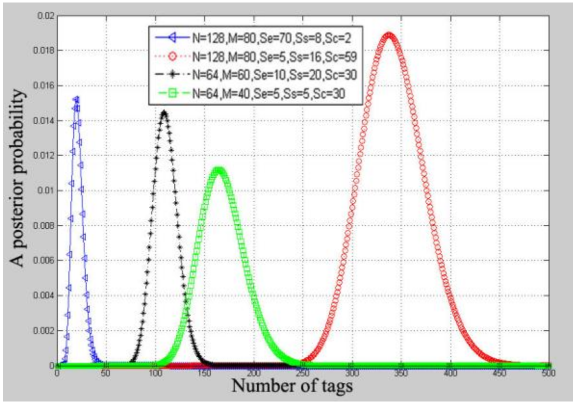

Fig. 2. The posterior probability for $S_E\neq0$ or $S_S\neq0$.

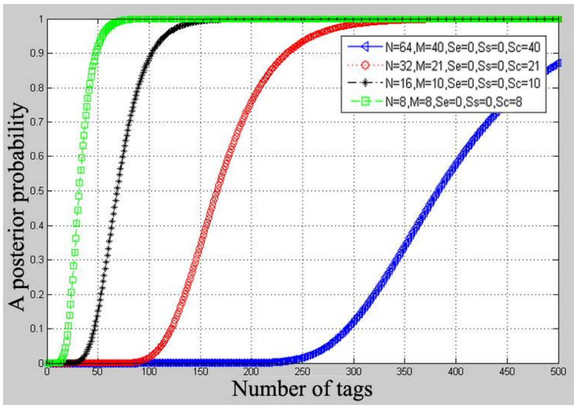

Fig. 3. The posterior probability for $S_E=S_S=0$.

From the shape of the function, we can see that a single maximum exists, a single n can be derived which is most close to the observed result when the probability is maximum. We will take this n as our estimation of the tag quantity. When $S_E=S_S=0$, the posterior probability function is a monotone increasing function and with n the value increasing, the probability is infinitely close to 1. This case was outlined in Fig. 3 for a different event, which are:

(a) <N=8, M=8, S_C=8>,
(b) <N=16, M=10, S_C=10>,
(c) <N=32, M=21, S_C=21>,
(d) <N=64, M=40, S_C=40>.

In this case, we cannot get the estimation value of n through the posterior probability function. Therefore we adopted the approach proposed by Schoute in [15] setting $\tilde{n}= S_S+2.39S_C$.

B. The Approach for In-frame Adjustment

In [2], the author made a lot of simulations and derived the appropriate Q set for different value of n as shown in Table I.

Let us denote the process by *ChooseQ(n)*.

After every slot of the a round, we will record the result (S_E,S_S,S_C,N,M), and use it to evaluate the current state.

The case of $S_E>S_S+S_C$ means that maybe the current value of Q is too large. Taken into consideration of the simplicity, we adopt the Schoute approach and the negation method to verify the hypothesis. On the negative limiting assumption that the remainder slots N-M are all in collision. With the approach proposed by Schoute in [15], an estimation of the tag quantity is n_E=2.39S_E+2.39(N-M)+S_S. If n_E is less than the left boundary that the current value of Q corresponds to, it verifies the hypothesis the current value of Q is too large and adjustment of Q is needed.

The case of $S_C>S_E+S_S$ means that maybe the current value of Q is too small. Similarly, we adopt the Schoute approach and the negation method to verify the hypothesis. On the negative limiting assumption that the remainder slots N-M are all empty. An estimation of the tag quantity is n_C=2.39S_C+S_S. If n_C is greater than the right boundary that the current value of Q corresponds to, it verifies the hypothesis the current value of Q is too small and Adjustment of Q is needed.

TABLE I: APPROPRIATE Q

Appropriate Q	Left Boundary	Right Boundary	n Range
0	0	1	n=1
1	1	3	1<n≤3
2	3	6	3<n≤6
3	6	11	6<n≤11
4	11	22	11<n≤22
5	22	44	22<n≤44
6	44	89	44<n≤89
7	89	177	89<n≤177
8	177	355	177<n≤355
9	355	710	355<n≤710
10	710	1420	710<n≤1420
11	1420	2839	1420<n≤2839
12	2839	5678	2839<n≤5678
13	5678	11357	5678<n≤11357
14	11357	22713	11357<n≤22713
15	22713	∞	22713<n

In all cases except for the two cases mentioned above, the reader will acquiesce that it is not necessary to adjust the value of Q and send a *QueryRep* command.

After estimating the value of competing tags, reader needs to choose an appropriate value of Q for this estimation result. With the estimated result $\tilde{n}_i$ and the appropriate Q for different n in the Table I, we can get Q_i corresponding to $\tilde{n}_i$. If Q_i is equal to the Q included in the *Query* command which initiated a round, the reader will send a *QueryRep* command to set up the next slot; conversely, if Q_i is different with the Q included in the initiated *Query* command, further estimation is needed and the past knowledge would be taken into count. The incorporating of the past knowledge will achieve some amendments to the estimation and lead to accuracies. With the observed results and the posterior probability approach, a series of estimated value of n can be derived as $\tilde{n}_1(N, M_1)$,..., $\tilde{n}_i(N, M_i)$. The estimation function is as follow:

$$\tilde{n}_{adjust} = \frac{\sum_{i=1}^{m} \frac{M_i}{N} \tilde{n}_i(N, M_i)}{\sum_{i=1}^{m} \frac{M_i}{N}} \tag{7}$$

Likewise, the value of Q_{adjust} can be obtained combining the value $\tilde{n}_{adjust}$ and Table 1. If Q_{adjust} is equal to the Q included in the *Query* command which initiated this round, the reader will send a *QueryRep* command to set up the next slot; Conversely, the reader will send a *QueryAdjust* command to adjust the Q value (frame size) for the unread tags.

C. Determination for the Following Rounds

After a round, the posterior probability is also used to estimate the number of tags, as shown in (8). Taken into account of the past knowledge, the formula is as follow:

$$\tilde{n} = \frac{\sum_{i=1}^{m} \frac{M_i}{N_i} \tilde{n}_i(N_i, M_i)}{\sum_{i=1}^{m} \frac{M_i}{N_i}} \tag{8}$$

Therefore, the reader can work out the number of unread tags by subtracting the singly occupied slots. The unread tag quantity is $\tilde{n}$-S_S, then the Q_{new} value for the next round is easy to drawn Q_{new}=*ChooseQ*($\tilde{n}$-S_S). A new round starts until all tags selected by *Select* command are identified.

The algorithm is sketched in Fig. 4.

1) Initialize Q=4.0.

2) Reader sends *Query(Q)* to activated tags based on the selected Q value.

3) Tags pick random values from 0 to 2Q-1 after Step. 2) and set variant *Step*=0.

4) Tags with the value 0 will communicate with reader and at the meanwhile Step adds 1.

5) After the former steps, if *Step*=2Q and S_C=0, which means all tags have been recognized and no collision occurred, the process could be ended; else if *Step*=2^Q but collision still happen, Q should be reassigned based on estimated n minus S_S and then go back to Step.(2); else Q

might be unsuitable, which means Q might be too large or too small, Q_i will be decided by n_i.

6) If Q_i equals to current Q, reader will send *QueryRep* to activated tags and go back to Step 4); else, a further estimation, incorporating the past knowledge is needed to obtain the amendatory Q_{adjust} and if Q_{adjust} is equal to current Q, reader will also send *QueryRep* to activated tags and go back to Step.(4), but if Q_{adjust} is different from current Q, reader will send *QueryAdjust* to activated tags and go back to Step 3).

Note:

n Estimated number of tags;

n_i Estimated number of tags in *Step=i*;

n_{adjust} Estimated number of tags by further estimation;

S_E The expected number of no tag response;

S_S The expected number of tags recognized;

S_C The expected number of more than two tags response;

Q_i Q value decided by n_i;

Q_{adjust} Q value decided by n_{adjust}.

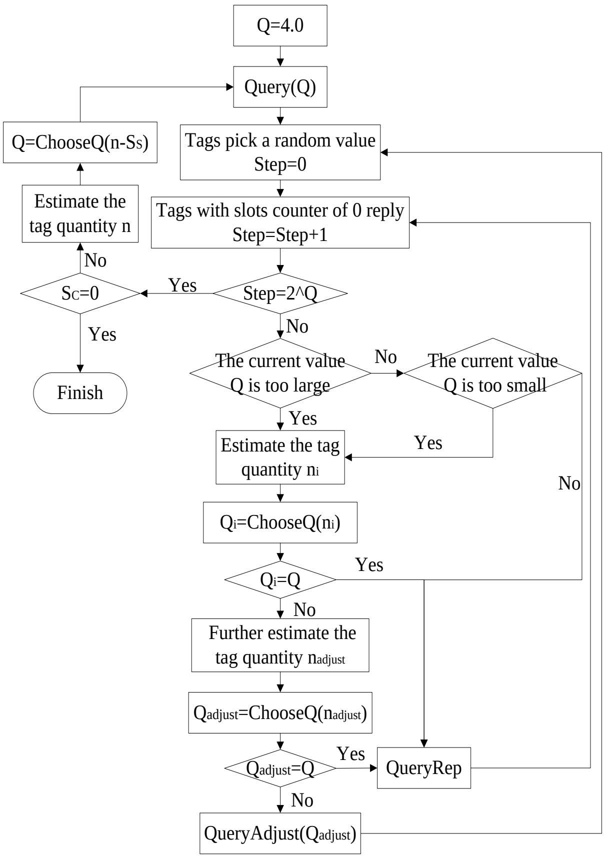

Fig. 4. EPP-Q algorithm's procedure to read tags.

IV. Simulation Results and Performance Verification

We compared the performance of two algorithms (Vegt's and Chen's) with EPP-Q algorithm in the total number of slots for identifies all given n tags and the system *efficiency*. The simulation environment is matlab 2009 with windows 7. In our simulation, the initial value of parameter Q is set to 4.0 as in the EPC protocol.

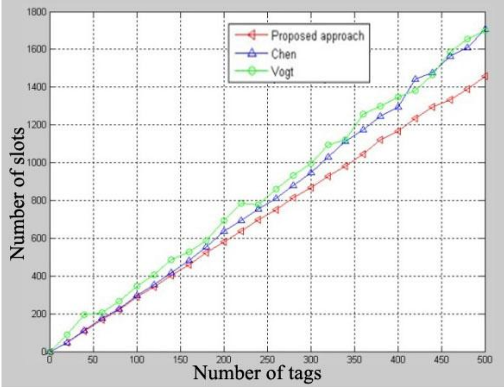

Fig. 5. The number of slots needed versus the number of tags.

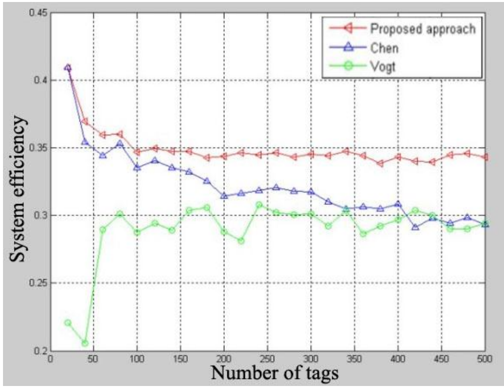

Fig. 6. The system efficiency versus the number of tags.

Fig. 5 shows a comparison of time slots needed to identify *all* tags in three different approaches, that is the approach derived by Vogt in [14], the approach proposed by Chen in [13] and the approach we proposed in this paper(which is called EPP-Q). Generally to say, the number of slots needed is positive correlated to the number of tags. In details, recognizing more tags will require more time slots in total. It is observed that our proposed approach takes the minimal slots to complete this procedure and this drop is more and more dramatically since the number of tags increase. For example, Vogt's will need 1,350 slots in total to recognize 400 tags and Chen's will require 1,450 time slots in the same tag size; however, it will only use less than 1,200 time slots when identifying 400 tags by using the EPP-Q algorithm. In total, fewer time slots needed means less time cost, and with the growth of the number of competing tags, the advantage of our approach has become increasingly evident.

In [16], Chen claimed that the RFID systems with dynamic frame-slotted algorithm without capture effect reach their theoretical maximum 36.1% for an EPCglobal UHF Class1 Gen2 system. Compared with this maximum throughput, the easy-to-implement advantage of EPP-Q algorithm comes at the expense of only 1% reduction. Fig. 6 shows the system efficiency for identifying all tags. It is obviously that EPP-Q is closest to the theoretical maximum throughput in every horizontal axis. What's more, with the increasing of tags' quantity, EPP-Q could still output satisfactory system efficiency. More specifically, there is a brief comparison among these three algorithms showing in Table II and Table III. By adopting EPP-*Q* algorithm, the system efficiency has different degrees of increase no matter comparing with Vogt's or Chen's.

TABLE II: SYSTEM EFFICIENCY COMPARISON BETWEEN VOGT'S AND EPP-Q'S

Number of Tags	Vogt's	EPP-Q's	Efficiency Increase
200	28.8%	34.6%	20.1%
250	30.4%	34.6%	13.8%
300	30.0%	34.8%	16.0%
350	29.6%	34.7%	17.2%
400	29.9%	34.5%	15.4%
450	29.6%	34.3%	15.9%
500	29.5%	34.5%	16.9%

TABLE III: SYSTEM EFFICIENCY COMPARISON BETWEEN CHEN'S AND EPP-Q'S

Number of Tags	Chen's	EPP-Q's	Efficiency Increase
200	31.3%	34.6%	10.5%
250	32.1%	34.6%	7.8%
300	32.0%	34.8%	8.7%
350	30.5%	34.7%	13.8%
400	30.6%	34.5%	12.7%
450	29.7%	34.3%	15.5%
500	29.5%	34.5%	16.9%

V. CONCLUSION

EPP-*Q* represents a better performance than other ones, and it loads to accuracies of the estimation to take into consideration of the knowledge from the past slots. When frame size is too small or too large, the adjustment in-frame will reduce unnecessary waste and improve the efficiency of the system. Our result is simulated in matlab, however, in real applications the efficiency would be better due to capture effect (The capture effect on RFID refers to the event that one of multiple tags is able to transmit with the reader successfully because it has a higher transmission power in spite of that multiple tags try to transmit simultaneously to a reader). In conclusion, more researches are required to reach the future that RFID systems become ubiquitous. For example, the initial *Q* value (frame size) will affect the performance of anti-collision algorithms. Maybe some researches are needed to tune the initial *Q* according to the contextual information.

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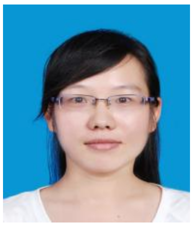

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