A Novel Query Tree Anti-collision Algorithm for RFID

Fan Yang [1,2], **Lei Zhao** [3], **Hu Chen** [1], **and Shuixia Hao** [1]

[1] Jiangsu Key Lab of Education Big Data Science and Engineering
Jiangsu Normal University, Xuzhou, Jiangsu 221116, China
yangfan@jsnu.edu.cn

[2] College of Engineering
Nanjing Agricultural University, Nanjing, Jiangsu 210031, China

[3] School of Information and Control Engineering
China University of Mining and Technology, Xuzhou, Jiangsu 221116, China
leizhao@cumt.edu.cn

Abstract **─** In order to further decrease the probability of the collision and reduce communication complexity, a new low complexity anti-collision algorithm for RFID is proposed using Query Tree. The proposed algorithm can reduce the probability of collision and the traffic of data communication by using tag grouping and setting rules, respectively. The simulation results show that the proposed scheme consumes fewer slots and has lower communication complexity.

Index Terms **─** Anti-collision algorithm, data clipping, Query tree, RFID.

I. INTRODUCTION

The Radio Frequency Identification (RFID) is an automatic identification system where the reader identifies the tags by radio waves [1]. In light of high-speed, feasible, convenient and contactless, RFID is one of the key technologies of the Internet of things (IoT) and is widely used in many fields, such as medical treatment, supply-chain management, transportation and item tracking. However, the rapid development of RFID technology gives rise to several problems, including data security, transmission distance, electromagnetic interference (EMI), antenna failure and tag collision etc. The last three issues seriously restrict the development of RFID [2,3]. In a frequency band such as 125khz, 13.56MHz, and 2.45GHz, a large amount of electromagnetic radiation is generated due to the simultaneous operation of many electronic devices. RFID system will interfere with adjacent electronic devices. Similarly, radiation from other electronic devices interferes with RFID systems as well. Thus, the performance of communication quality between reader and tag can be severely affected by EMI, which significantly increasing bit error rate of RFID system [4,5]. Moreover, the reader cannot receive data normally due to antenna failure, the failed antenna may cause deterioration of array performance [6]. But, an excellent anti-collision algorithm can alleviate the impact of EMI and antenna failure on the system. How to optimize anti-collision algorithm effectively is the key point of the research of RFID technology. To resolve this problem, many optimization anti-collision algorithms have been proposed, which are divided into two categories: Aloha-based probabilistic algorithms and tree-based deterministic algorithms.

Framed-Slotted Aloha (FSA) [7] method is a typical Aloha-based anti-collision algorithm and has been widely used in many RFID applications. In FSA, each unread tag randomly selects one slots in frame. Unless the reader receives the tag's information successfully, the tag will try again in the next frame. Aloha-based anti-collision algorithms work efficiently when the frame size matches with the number of tags. However, the performance of the algorithms becomes very poor when the number of tags changes in a wide range with the fixed size of frame. Therefore, many dynamic frame-slotted Aloha (DFSA) algorithms have been proposed to improve the system performance [8-11]. Since Aloha-based algorithms, however, cannot completely prevent collisions, they have a serious problem that a specific tag may not be identified for a long time, leading to tag starvation problem.

Tree-based algorithms including deterministic tree-based algorithm such as query tree algorithm (QT) [12,13], and probabilistic counter-based algorithm such as binary tree algorithm (BT) [14], repeatedly separate collided tags into two sets until each set has only one tag or no tag. BT adopts random binary numbers (0 or 1) to split the tag set while QT uses tag IDs. Although they have relatively long identification delay, they do

Submitted On: October 30, 2018
Accepted On: November 24, 2018

not cause the tag starvation problem. In QT, the reader provides the tags with a query and the tags must respond with their full ID as a result of a successful matching of the query with their corresponding ID part. Since using prefixes, the performance of QT is sensitive to the distribution of IDs of tags. Collision tracking tree algorithm (CTTA) [15], which is modified from QT, is used to reduce the number of collisions in QT using a tree traversal path. CCTA takes the advantage of grouping in QT and cuts off the useless bits in each grouping round. In this way, CTTA decreases total data exchange in QT. Bit tracking technology is commonly based on Manchester code, which is often used to detect collision bits. Optimal Query Tracking Tree (OQTT) algorithm [16], which used bit tracking technology, tries to separate all of the tags into smaller sets to reduce collisions at the beginning of identification. Although solving high collision rate at the initial stage, the random number generation module and bit modulating module are added to increase the hardware cost. According to the characteristics of tree-based anti-collision algorithm, scholars have proposed a lot of improved algorithms. However, those algorithms are still inevitably cause lots of unsuccessful slots [17,18].

In this paper, a query tree with low complexity anti-collision algorithm (QTLC) is proposed to further decrease the probability of the collision and reduce communication complexity, which divides the traditional identification into tag grouping stage and tag identification stage. In the first stage, using the bit tracking technology, the reader determines the grouping prefix by sending a prefix query command and the tags with the same grouping prefix are in the same branch, in which a large search tree is divided into several branches to reduce the probability of the collisions. In the second stage, using the set of reply rules, the data replied by tag is clipped to decrease the transmission quantity of invalid data and reduce the communication complexity of the system. Simulation results show that the proposed algorithm takes great advantage of identification delay and communication complexity.

The rest of this paper is organized as follows: Section II introduces the theory and method of a query tree with low complexity anti-collision algorithm (QTLC) in brief. Section III derives the mathematical analysis of QTLC. Section IV presents analytical and simulation results. Finally, the conclusions are presented in Section V.

II. THEORY AND METHOD

The core of QTLC is tag grouping and data clipping. By the regrouping of the tags, the collision probability of the tags is decreased; the transmission of the invalid data in the channel is reduced by data cutting, and the communication complexity of the system is further decrease.

A. Tag grouping

The purpose of grouping is to divide the mass tags into several groups with the same ID prefix sequence, and each tag is identified in the group, resulting in the reduction of the collision probability in the initial stage. The reader gets the grouping prefix sequence of all the tag ID by sending query command to unread tags, and the tags with the same prefix sequence are divided into one group.

The length of grouping prefix sequence is $n=\lfloor \log_2^g \rfloor$, where $\lfloor * \rfloor$ is a rounded down operation and g is the initial groups. In initial stage of grouping, the reader first sends the k bit query sequence (11. 1000.. 0), where the length of ID and the length of 1 are k and n, respectively. While obtaining the query sequence, all tags encoded the former n bit data of ID to the decimal number m, then a 2^n bit data is generated, in which the m_{th} bit of the sequence is 1, and the remaining bits are all 0. After receiving the tag reply, the reader counts the number of the non-repeating sequence and gets the number of the actual grouping.

For example, there are 8 tags with IDs 00110101 (T1), 00111010 (T2), 00100100 (T3), 10101000 (T4), 10101101 (T5), 10110001 (T6), 11001111 (T7) and 11010100 (T8), respectively and g = 8. While obtaining the query sequence of 11100000, all tags convert the first 3-bit binary number of ID to decimal number, then replying 8 bits of binary sequence to reader, in which the 1th, 5th, 6th bit of the sequence is “1” respectively, and the other are 0. At the same time, the reader determines the 1th, 5th, 6th bit in this sequence to be “1” and converts it into the corresponding binary sequence, namely, “001”, “101” and “110”. The prefix, such as “000”, “010”, “011”, “100”, “111”, is eliminated. As a result, the prefix sequence of each group of tag is determined. Table 1 shows an example of tag grouping.

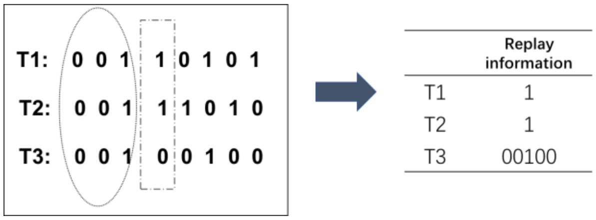
Table 1: An example of tag grouping

No.	The Prefix	Coded Information	Grouping No.
T1	001	00000001	1
T2	001	00000001	1
T3	001	00000001	1
T4	101	00010000	5
T5	101	00010000	5
T6	101	00010000	5
T7	110	00100000	6
T8	110	00100000	6

B. Data clipping

For NEAA [19] and CTTA [15], when there is a collision, the reader still receives the remaining ID data sent by the tag and this invalid data increases the communication complexity of the system. According to the above problem, QTLC sets up a data clipping mechanism. When the reader sends a query prefix sequence with *h* bits, if the former *h* bits of tag ID match this sequence and the $(h + 1)_{th}$ bit is 0, the tag will send the remaining $(k - h)$ bits to the reader; otherwise, it only replies 1 to reader. So the $(h + 1)_{th}$ bit can be defined as information bit. Using data clipping technology, QTLC can reduce the communication complexity of the system, and speeds up the identification.

For example, when the current query prefix is 001, T1, T2 and T3 will assigned to the same group. By detecting the information bit. T3 reply the remaining bits to the reader, it is “00100”. T1 and T2, however, reply “1” to the reader. Figure 1 shows an example of data clipping.



	Replay information
T1	1
T2	1
T3	00100

Fig. 1. Example of data clipping.

III. PERFORMACNE ANALYSIS

A. Identification delay

Being similar to the definition in [20], the identification delay of the anti-collision algorithm, denoted as *W*, is defined as the number of queries sent by the reader in order to identify tags. Given a distributed uniformly set of *N* tags, the initial group is *g*, since the tag ID is distributed uniformly, the tags are assigned to each group with the same probability. Thus,

$$p = 2^{-\lfloor \log_2^g \rfloor} = 2^{-n}. \tag{1}$$

So the probability of groups with idle, success and collision are:

$$P_I(0,N) = \left(1-2^{-n}\right)^N, \tag{2}$$

$$P_S(1,N) = N \times 2^{-n} \times \left(1-2^{-n}\right)^{N-1}, \tag{3}$$

$$P_C(m,N) = 1 - P_I(0,N) \text{-} P_S(1,N)\ . \tag{4}$$

Therefore, the number of groups with idle, success and collision are:

$$Q_I(0,N) = 2^n \times \left(1-2^{-n}\right)^N, \tag{5}$$

$$\begin{aligned} Q_S(1,N) &= 2^n \times N \times 2^{-n} \times \left(1-2^{-n}\right)^{N-1} \\ &= N \times \left(1-2^{-n}\right)^{N-1}, \end{aligned} \tag{6}$$

$$\begin{aligned} &Q_C(m,N) = 2^n \times \left(1 - P_I(0,N) \text{-} P_S(1,N)\right) \\ &1 < 2^n \le k. \end{aligned} \tag{7}$$

Obviously, the value of 2^n is affected by g and the minimum value of g is 2. With the increasing of *g*, the probability of grouping collision is decreases. However, *g* is not bigger is better. The larger value of *g* will increase the communication complexity of the system, which will affect the simulation experiment as well. So we assume that $1 < 2^n \le k$, the exact value of *g* will be discussed at next section.

In the application of Internet of things, the number of tags is massive, namely, the value of *N* can be assumed to be infinite; while $N >> g$,

$$\lim_{N \to +\infty} \left(1-2^{-n}\right)^N = 0,$$

$$\lim_{N \to +\infty} \left(1-2^{-n}\right)^{N\text{-}1} = 0.$$

By simplifying Equations (5-7) with the above two equations:

$$\lim_{N \to +\infty} Q_I(0,N) = \lim_{N \to +\infty} \left(1-2^{-n}\right)^N = 0, \tag{8}$$

$$\lim_{N \to +\infty} Q_S(1,N) = \lim_{N \to +\infty} N \times \left(1-2^{-n}\right)^{N-1} = 0, \tag{9}$$

$$\begin{aligned} &\lim_{N \to +\infty} Q_C(m,N) = \\ &\lim_{N \to +\infty} \left(2^n \times \left(1 - P_I(0,N) - P_S(1,N)\right)\right) = 0. \end{aligned} \tag{10}$$

In other words, when the number of tags is very large, there are almost all of groups are collided. So the number of tags of each group can be assumed to:

$$t = \frac{N}{2^n} = \frac{N}{2^{\lfloor \log_2^g \rfloor}}. \tag{11}$$

For QTLC, the number of nodes in BT, generated by the QTLC, represents the identification delay. Each node in QTLC represents query command send by the reader, the intermediate node represents a collision and the leaf node represents a tag.

In the grouping phase, the reader only needs to broadcast a grouping query command to obtain the grouping information. So the identification delay of this phase is 1. In the identification phase, when collision occurring, QTLC divides the collision node into two subsets. Because of the properties of BT, the degrees of nodes only are 0 and 2. Meanwhile, the number of nodes with degree 2 is one less than nodes with degree 0. So the number of nodes with degree 0 and 2 in each group are:

$$w_0 = t = \frac{N}{2^{\lfloor \log_2^g \rfloor}}, \tag{12}$$

$$w_2 = t\text{-}1 = \frac{N}{2^{\lfloor \log_2^g \rfloor}}\text{-}1. \tag{13}$$

Therefore, the number of nodes in this current group is:

$$\begin{aligned} W_g &= w_0 + w_2 = \frac{N}{2^{\lfloor \log_2^g \rfloor}} + \frac{N}{2^{\lfloor \log_2^g \rfloor}} \text{-}1 \\ &= \frac{N}{2^{\lfloor \log_2^g \rfloor \text{-}1}} \text{-}1. \end{aligned} \tag{14}$$

QTLC divides the tags into $2^{\lfloor \log_2^g \rfloor}$ groups and the number of node in each branch is W_g. So the identification delay is:

$$W = 2^{\lfloor \log_2^g \rfloor} \times w_g + 1 = 2 \times N - 2^{\lfloor \log_2^g \rfloor} + 1. \tag{15}$$

B. Communication complexity

For an anti-collision algorithm in RFID, the communication complexity is the number of bits transmitted between the reader and tags. The reader communication complexity and the tag communication complexity represent the number of bits send by reader and tags, respectively. The tag communication complexity is more important than the reader, because it is desirable to minimize the power consumption of the tags [20].

Let $D(N)$ be the communication complexity of QTLC. $D_G(N)$ and $D_I(N)$ represents the communication complexity in the grouping and identification phase respectively:

$$D(N) = D_G(N) + D_I(N). \tag{16}$$

In the grouping phase, the reader only sends k bits grouping query sequence. Then tags reply with 2^n bits, so $D_G(N)$ is:

$$D_G(N) = k + N \times 2^{\lfloor \log_2^g \rfloor}. \tag{17}$$

In the identification phase, let j be the number of "0" in the same bit of the tag ID, so j also obeys the binomial distribution:

$$V(j, N) = C_N^j p^j (1-p)^{N-j}. \tag{18}$$

Because each bit has the same probabilities with "0" and "1", so p in Equation (18) is 0.5. When the same bit of tag ID is all "0" or "1" in N tags, this bit will not collide:

$$\begin{aligned} V(j = 0 \mid j = N, k, N) &= V(0, N) + V(N, N) \\ &= 2^{1\text{-}N}. \end{aligned} \tag{19}$$

Otherwise, it will be occurring collision:

$$V(j \neq 0 \mid j \neq N, k, N) = 1\text{-}2^{1\text{-}N}. \tag{20}$$

$F_R(u)$ is defined as the length of u_{th} query prefix. $F_{T0}(u)$ and $F_{T1}(u)$ represents the length of u_{th} reply for tags when information bit is 0 and 1 respectively. p_0 and p_1 represent the probability when the information bit is 0 and 1 respectively. So $F_{T0}(u) + F_{T1}(u) = k$, $F_{T1}(u)=1$.

According to Equations (18-20), the communication complexity in the tag identification phase is:

$$\begin{aligned} D_I(N) &= \sum_{u=1}^{T} \begin{pmatrix} F_R(u) + V(j \neq 0 \mid j \neq N, k, N) \\ \times \left(F_{T_0}(u) \times p_0 + F_{T_0}(u) \times p_0 \right) \end{pmatrix} \\ &= \sum_{u=1}^{T} \left(F_R(u) + \left(0.5 + (0.5)^{-N} \right) \times \left(k - F_R(u) + 1 \right) \right). \end{aligned} \tag{21}$$

So $D(N)$ is:

$$\begin{aligned} D(N) &= k + N \times 2^{\lfloor \log_2^g \rfloor} \\ & \sum_{u=1}^{T} \left(F_R(u) + \left(0.5 + (0.5)^{-N} \right) \times \left(k - F_R(u) + 1 \right) \right). \end{aligned} \tag{22}$$

IV. PERFORMACNE EVALUATION

In this section, theoretical analysis and simulation experiments were undertaken to validate QTLC algorithm. Compared with QT, NEAA and CTTA algorithm, QTLC is analyzed from aspects of identification delay and communication complexity. The simulation condition is as follows: the number of tags increases from 100 to 1000. The size of tag IDs is 96 bits. Tag IDs are distributed uniformly.

A. Selection of initial groups

The system efficiency represents the ratio of the readable slot to the identification delay, which is an important parameter to evaluate the performance of an anti-collision algorithm. In order to obtaining optimal g, the experiment was conducted. Fig.2 shows the system efficiency with different initial groups. The proposed algorithm gets a higher efficiency with a larger initial groups, and the cost will increase as well. Compared with g = 4, the system efficiency of g = 8 is about 0.5, this is still not ideal. The reason is that with the increasing number of tags in each group, the probability of collision in each group is high due to the small initial groups. Considering the cost of the tag with larger initial groups, the optimal initial group is g = 16.

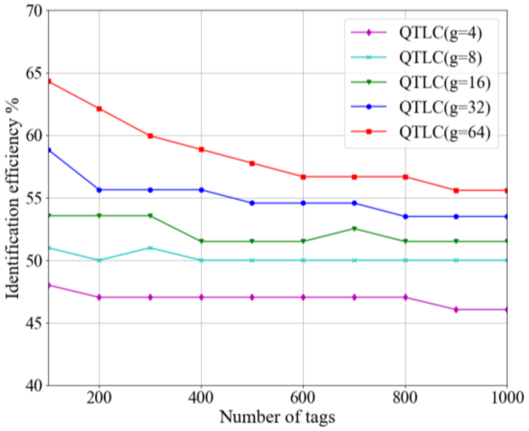


Fig. 2. The system efficiency of QTLC with different initial groups.

B. Communication complexity

(1) Reader communication complexity

Reader communication complexity refers to the total number of bits sent by the reader to all tags. Figure 3 shows the traffic of reader. The traffic of the four algorithms increases with the number of tags, and this pattern of growth is linear. QT algorithm has the fastest growth, CTTA is faster than NEAA, but all of them is slower than QT, and the proposed algorithm has slowest growth because it automatically generates valid query prefixes, which greatly reduces the number of queries sent by a reader. When N = 1000, the traffic of QT algorithm is 80968 bit, CTTA and NEAA is 59863 bit, 52469 bit respectively. However, QTLC is 49764 bit.

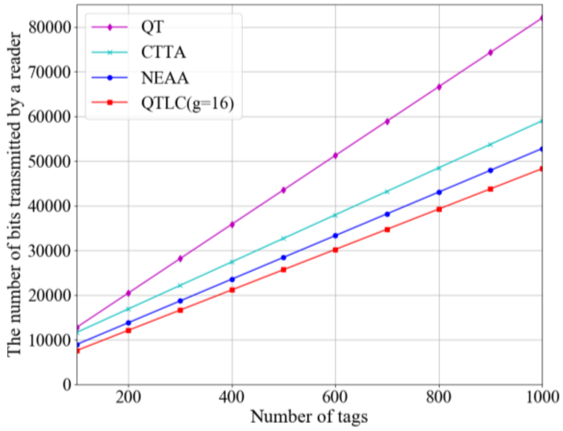


Fig. 3. The traffic of reader.

(2) Tag communication complexity

In the process of identification, the tag has a corresponding response to the different commands of the reader, and the sum of the bits send by tags is called the traffic of tag, which is closely related to the power consumption. The larger traffic is, the more power will consume. However, for the traditional tag, the power consumption is limited. In addition, by reducing the amount of data returned from tags, the security of system will be improved. Therefore, the traffic of tag should be reduced as much as possible. QTLC algorithm inherits the advantages of QT algorithm. It not only simplifies the design of tag, but also reduces the traffic. From Fig. 4, it can be seen that the traffic growth of QTLC is the slowest, which is significantly lower than the other three algorithms. When N = 1000, the traffic of tag for QT algorithm is 120800 bit, CTTA and NEAA is 112003 bit, 92560 bit respectively, but QTLC is 61976 bit.

C. Identification delay

The identification delay is defined as the number of queries that identify all tags successfully by the reader, namely the total slots, and it is a key parameter to measure the performance of an anti-collision algorithm. Figure 5 shows the identification delay. The total slots of four algorithms increases with the number of tags, but QTLC has slowest growth. As the number of tags increases, the advantages of QTLC algorithm are more obvious. When N = 1000, the total slots of QTLC algorithm is 1912, about 985 less than QT algorithm, 191 less than NEAA algorithm, and 159 less than CTTA algorithm.

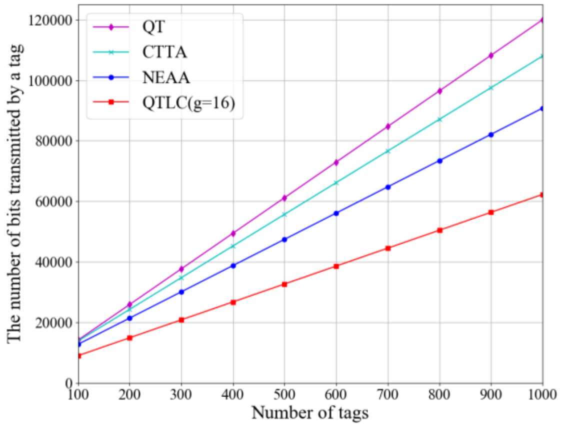


Fig. 4. The traffic of tag.

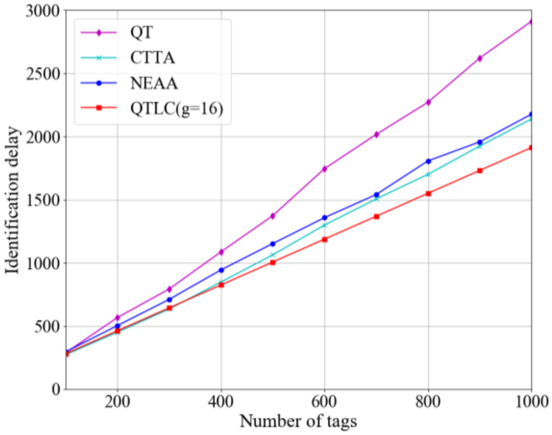


Fig. 5. The identification delay.

V. CONCLUSION

In this paper, a new anti-collision algorithm for RFID is proposed for decreasing the probability of the collision and reducing communication complexity by dividing the traditional identification stage into tag grouping and tag identification. Simulation results show that the proposed QTLC algorithm outperforms other existing algorithms, such as QT, CTTA and NEAA, regardless of the number of tags. QTLC is an efficient anti-collision algorithm for tag identification in an RFID system.

ACKNOWLEDGMENT

This work was supported in part by the National

Science Foundation of China under Grant No. 61771226, 61372057, and 61671223, in part by the Natural Science Foundation of the Jiangsu Higher Education Institutions of China under Grant No. 18KJA110001, and in part by the Science and Technology Innovation Project of Xuzhou in 2018 under Grant No. KC18004.

REFERENCES

[1] G. Orecchini, L. Yang, A. Rida, F. Alimenti, M. M. Tentzeris, and L. Roselli, "Green technologies and RFID: Present and future," *Applied Computational Electromagnetics Society Journal*, vol. 25, no. 3, pp. 230-238, 2010.

[2] K. Finkenzeller, "RFID handbook: Radio-frequency identification fundamentals and applications," 2003.

[3] J. Banks, M. Pachano, L. Thompson, and D. Hanny, *RFID Applied*. Wiley Publishing, 2007.

[4] S. P. Gao, H. Zhao, H. W. Deng, B. Wang, and W. J. Zhao, "Estimating interference to airborne patch antenna with limited information," *IEEE Transactions on Electromagnetic Compatibility*, vol. 58, no. 2, pp. 631-634, 2016.

[5] H. Zhao, S. P. Gao, W. J. Zhao, Y. Zhang, J. Hu, and Z. Chen, "Fast prediction of coupling coefficient between monopole antennas on electrically large cylindrical platforms using a linear parametric model," *Applied Computational Electromagnetics Society Journal*, vol. 32, no. 5, pp. 418-423, 2017.

[6] H. Zhao, Y. Zhang, J. Hu, and Z. Chen, "Hybrid sparse reconstruction-method of moments for diagnosis of wire antenna arrays," *Applied Computational Electromagnetics Society Journal*, vol. 32, no. 10, pp. 882-887, 2017.

[7] W. T. Chen, "Optimal frame length analysis and an efficient anti-collision algorithm with early adjustment of frame length for RFID systems," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 5, pp. 3342-3348, 2016.

[8] F. U. Yu, Z. H. Qian, M. Jie, and W. Xue, "FSA anti-collision algorithm based on continuous slot prediction," *Acta Electronica Sinica*, pp. 0-0, 2016.

[9] S. U. Jian, L. B. Xie, Y. Yang, G. J. Wen, and Q. W. Meng, "Idle slots elimination based anti-collision algorithm for UHF RFID," *Acta Electronica Sinica*, vol. 45, no. 2, pp. 307-314, 2017.

[10] J. Vales-Alonso, V. Bueno-Delgado, E. Egea-Lopez, F. J. Gonzalez-Castano, and J. Alcaraz, "Multiframe maximum-likelihood tag estimation for RFID anticollision protocols," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 3, pp. 487-496, 2011.

[11] Y. Sun, P. J. Hawrylak, Z.-H. Mao, and M. H. Mickle, "Collision resolution in ISO 18000-6c passive RFID," *Applied Computational Electromagnetics Society Journal*, vol. 25, no. 3, pp. 239-262, 2010.

[12] C. N. Yang and J. Y. He, "An effective 16-bit random number aided query tree algorithm for RFID tag anti-collision," *IEEE Communications Letters*, vol. 15, no. 5, pp. 539-541, 2011.

[13] Y. C. Lai and C. C. Lin, "Two couple-resolution blocking protocols on adaptive query splitting for RFID tag identification," *IEEE Transactions on Mobile Computing*, vol. 11, no. 10, pp. 1450-1463, 2012.

[14] Y. C. Lai and L. Y. Hsiao, "General binary tree protocol for coping with the capture effect in RFID tag identification," *IEEE Communications Letters*, vol. 14, no. 3, pp. 208-210, 2010.

[15] F. Zhou, D. Jin, C. Huang, and M. Hao, "Optimize the power consumption of passive electronic tags for anti-collision schemes," in *International Conference on ASIC, 2003, Proceedings*, vol. 2, pp. 1213-1217, 2003.

[16] Y. C. Lai, L. Y. Hsiao, H. J. Chen, C. N. Lai, and J. W. Lin, "A novel query tree protocol with bit tracking in RFID tag identification," *IEEE Transactions on Mobile Computing*, vol. 12, no. 10, pp. 2063-2075, 2013.

[17] Y. Jiang, R. Zhang, W. Cheng, B. Li, and W. Sun, "An adaptive ternary query splitting based tag anti-collision protocol for mobile RFID systems," in *Vehicular Technology Conference*, pp. 1-6, 2017.

[18] S. U. Jian, G. J. Wen, and J. L. Han, "An efficient RFID anti-collision algorithm for ISO18000-6b protocol," *Acta Electronica Sinica*, vol. 42, no. 12, pp. 2515-2519, 2014.

[19] Y. H. Chen, S. J. Horng R. S. Run, J. L. Lai, R. J. Chen, W. C. Chen, Y. Pan, and T. Takao, "A novel anti-collision algorithm in RFID systems for identifying passive tags," *IEEE Transactions on Industrial Informatics*, vol. 6, no. 1, pp. 105-121, 2010.

[20] C. Law, K. Lee, and K. Y. Siu, "Efficient memoryless protocol for tag identification (extended abstract)," in *International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications*, pp. 75-84, 2000.

Fan Yang received the B.S. from Nanjing University of Posts and Telecommunications in 2011 and received the M.S. degrees from Nanjing Agricultural University in 2014. He is currently working toward the Ph.D. degree in the College of Engineering at Nanjing Agricultural University, China. His research interests include performance analysis and protocol design on networks, Wireless Sensor Networks and IoT.

Lei Zhao received the B.S. degree in Mathematics from Jiangsu Normal University, China, 1997, the M.S. degree in Computational Mathematics, and the Ph.D. degree in Electromagnetic Fields and Microwave Technology from Southeast University, Nanjing, China, in 2004 and 2007, respectively.

He joined the Jiangsu Normal University, Xuzhou, China, in 2009, where he is currently the Professor and the Director of Center for Computational Science and Engineering. From Aug. 2007 to Aug. 2009, he worked in Department of Electronic Engineering, The Chinese University of Hong Kong as a Research Associate. From Feb. 2011 to Apr. 2011, he worked in Department of Electrical and Computer Engineering, National University of Singapore as a Research Fellow. From Sep. 2016 to Sep. 2017, he worked in Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, USA as a Visiting Scholar. He has authored and coauthored over 50 referred journal and conference papers. His current research interests include antennas design and its applications, computational electromagnetics, electromagnetic radiation to human's body, and spoof surface plasmon polaritons design and its applications.

He serves as an Associate Editor for IEEE Access, an Associate Editor-in-Chief for ACES Journal and a Reviewer for multiple journals and conferences including the IEEE Trans. Antennas and Propagation, IEEE Access, IEEE Antennas and Wireless Propagation Letters, Progress In Electromagnetics Research, ACES Journal, and other primary electromagnetics and microwave related journals.

Zhao was the TPC Chair of the 2018 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference. He was elected TPC Member of IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications since 2013, the TPC Member of 2010 International Conference on Microwave and Millimeter Wave Technology, the TPC Member of 2012 International Conference on Microwave and Millimeter Wave Technology, the TPC Member of 2013 Cross Strait Quad-Regional Radio Wireless Conference, the TPC Member of 2014 Cross Strait Quad-Regional Radio Wireless Conference..

Hu Chen was born in 1975. He received the Ph.D. degree from Xidian University in 2016. Now, he is an Associate Professor of Jiangsu Normal University. His main research interests include cryptography and information security.

Shuixia Hao is an Associate Professor in the School of Mathematics and Statistic, JiangSu Normal University. Her research interests include parallel computing, heterogeneous computing and big data. She received her B.S. degrees in Information Management and Science from Beijing Normal University in 1997; and received her M.S. degrees in Computer Department from Soochow University in 2004; received her D.S. degrees in Computer Department from Tongji University in 2014.