An Efficient Tag Identification Scheme in RFID Systems

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***Abstract*—RFID is a generic term for technologies which use RF waves to identify, track, or categorize any object. One of the research areas in RFID systems is a tag anti-collision protocol; how to reduce identification time with a given number of tags in the field of an RFID reader. There are two types of tag anti-collision protocols for RFID systems: tree based algorithms and slotted aloha based algorithms. Many anti-collision algorithms have been proposed in recent years, especially in tree based protocols. However, there still exist challenges on enhancing the system throughput and stability due to the underlying technologies having faced different limitation in system performance when network density is high. Recently, a *Wrap-Around Scan* (*WAS*) technique, which is a tree based approach, was proposed and aims to speedup tag identification in large scale RFID systems. The main idea of the Wrap-Around Scan is to limit the number of collisions by moving to next level as the number of collisions exceeds a predefined threshold. The WAS method indeed improves the efficiency in high density RFID systems. However, the reader using WAS scheme will spend some unnecessary queries for the idle response. In this paper, we proposed an intelligent wrap-around scan technique, which is called the iWAS scheme, to avoid those unnecessary queries. The simulation results show that the proposed techniques provide superior performance in high density environments. It is shown that the iWAS is effective in terms of increasing system throughput and minimizing identification delay.**

Keywords-Tag anti-collision; query tree; wrap-around scan.

I. INTRODUCTION

Radio Frequency IDentification (RFID) is an emerging technology that guarantees to advance modern industrial practices in object identification and tracking, asset management, and inventory control [14]. Recently, several identification systems such as barcodes and smart cards are incorporated for automatic identification and data collection. However, these systems have several limits in read rate, visibility, and contact. RFID systems are a matter of grave concern because they provide fast and reliable communication without requiring physical sight or touching between readers and tags.

One of the areas of research is the speed with which a given number of tags in the field of RFID readers can be identified. For fast tag identification, anti-collision protocols, which reduce collisions and identify tags irrespective of occurring collisions, are required [6], [7]. There are two types of collisions: reader collisions and tag collisions. Reader collisions indicate that when neighboring readers inquire a tag concurrently, so the tag cannot respond its ID to the inquiries of the readers. These collision problems can be easily solved by detecting collisions and communicating with other readers. Tag collisions occur when multi tags try to respond to a reader simultaneously and cause the reader to identify no tag. For low-cost passive RFID tags, there is nothing to do except response to the inquiry of the reader. Thus, tag anti-collision protocols are necessary for improving the cognitive faculty of RFID systems.

In general, the tag anti-collision techniques can be classified into two categories, aloha based and tree based protocols. Aloha-based approaches use time slot to reduce collision probability. Tags randomly select a particular slot in the time frame, load and transmit its identification to the reader. Once the transmission is collided, tags will repeatedly send its id in next interval of time to make sure its id is successfully recognized. Aloha based protocols can reduce the collision probability. However, they have the tag starvation problem that a particular tag may not be identified for a long time. For the consideration of performance, the tag collision rate is increased as the number of RFID tag increased, which may result a low tag recognition rate.

The tree based schemes use a data structure similar to a binary search algorithm. An RFID reader consecutively communicates with tags by sending prefix codes based on the query tree data structure. Only tags in the reader's interrogation zone and of which ID match the prefix respond. The reader can identify a tag if only one tag respond the inquiry. Otherwise the tags responses will be collided if multiple tags respond simultaneously.

Although tree based protocols do not bring the tag starvation problem, but they have relatively long identification delay. Recently, a Wrap-Around Scan (WAS) technique was proposed and aiming to coordinate simultaneous communications in high density RFID environments, to speedup tag identification and to increase the overall read rate and throughput in large-scale RFID systems [15]. The main idea of the Wrap-Around Scan technique is to limit number of collisions during the identification phase. When number of collisions larger than the predefined acceptable ratio, it reveals that the density in RF field is too high. In order to minimize unnecessary inquiry, the prefix matching will be moved to lower level of the query tree, alleviating the collision problems. The method of setting collision bound indeed improves the efficiency of large-scale RFID tag identification. However, the reader using WAS scheme will spend some unnecessary queries for the idle response. In this paper, we proposed an *intelligent Wrap-Around Scan technique* (i*WAS*) to avoid those unnecessary queries. To evaluate the performance of our proposed technique, we have implemented our proposed iWAS scheme along with previous proposed WAS method and the query tree protocol. The experimental results show that the proposed technique presents significant improvement in most circumstance.

The remainder of this paper is organized as follows: Related work is discussed in Section II. In Section III, the tree based tag identification algorithm is introduced as preliminary of this study. In Section IV, our proposed query tree based algorithm, the intelligent Wrap-Around Scan (iWAS) is presented. Performance comparisons and analysis of the proposed technique will be given in Section V. Finally, in Section VI, some concluding remarks are made.

II. Related work

Many research results for collision avoidance have been presented in literature. The existing tag identification approaches can be classified into two main categories, the Aloha-based [3], [4], [8], [11], [14] anti-collision scheme and the tree-based scheme [1], [7], [9], [13]. RFID readers in the former scheme create a frame with a certain number of time slots, and then add the frame length into the inquiry message sent to the tags in its vicinity. Tags response the interrogation based on a random time slot. Because collisions may happen at the time slot when two or more tag response simultaneously, making those tags could not be recognized. Therefore, the readers have to send inquiries contiguously until all tags are identified. As a result, Aloha-based scheme might have long processing latency in identifying large-scale RFID systems [4]. In [14], Vogt et al. investigated how to recognize multiple RFID tags within the reader's interrogation ranges without knowing the number of tags in advance by using framed Aloha. A similar research is also presented in [11] by Zhen et al. In [3], Klair et al. also presented a detailed analytical methodology and an in-depth qualitative energy consumption analysis of pure and slotted Aloha anti-collision protocols. Another anti-collision algorithm called enhanced dynamic framed slotted aloha (EDFSA) is proposed in [5]. EDFSA estimates the number of unread tags first and adjusts the number of responding tags or the frame size to give the optimal system efficiency.

In tree-based scheme, such as ABS [7], IBBT [2] and IQT [10], RFID readers split the set of tags into two subsets and labeled them by binary numbers. The reader repeats such process until each subset has only one tag. Thus the reader is able to identify all tags. The adaptive memoryless tag anti-collision protocol proposed by Myung et al. [6] is an extended technique based on the query tree protocol. Choi et al. also proposed the IBBT (Improved Bit-by-bit Binary-Tree) algorithm [2] in Ubiquitous ID system and evaluate the performance along three other old schemes. The IQT protocol [10] is a similar work approach by exploiting specific prefix patterns in the tags to make the entire identification process. Recently, Zhou et al. [12] consider the problem of slotted scheduled access of RFID tags in a multiple reader environment. They developed centralized algorithms in a slotted time model to read all the tags. With the fact of NP-hard, they also designed approximation algorithms for the single channel and heuristic algorithms for the multiple channel cases.

Although tree based schemes have advantage of implementation simplicity and better response time compare with the Aloha based ones, they still have challenges in decreasing the identification latency. In this paper, we present an enhanced tree based tag identification technique aims to coordinate simultaneous communications in large-scale RFID systems, to speedup minimize tag identification latency and to increase the overall read rate and throughput. Simulation results show that our proposed technique outperforms previous techniques.

III. Tree Based Tag Anti-Collision Schemes

In this section, we present two tree based anti-collision techniques, namely the Query Tree algorithm (QTA) and the Wrap-Around Scan algorithm (WAS), that are most related to our work.

A. *Query Tree Algorithm*

The query tree algorithm (QT) uses binary splitting strategy to identify tags. A reader transmits the k-length prefix. Then tags send from $(k + 1)th$ bit to the end bit of tag IDs if the first k bits of tag IDs are the same as the prefix. Also, if the received tag IDs collide, the extended prefix attached '0' or '1' to the prefix is retransmitted. Furthermore, if there is no collision, the reader identifies one of the tags. Figure 1 shows an example of the query tree scheme. Table 1 summarizes the detail steps of communication between the reader and the tags with the example shown in Figure 1.

B. *Wrap-Around Scan algorithm*

In the environment with high tags density, collision may happen very frequently while using the query tree algorithm, and due to that, a lot of query time will be wasted. The main idea of Wrap-Around Scan algorithm is using a threshold jumping strategy in which a threshold of collisions is mainly used as the criterion of moving the identification process to the next level of a query tree. By using the collision threshold, when the collisions happen frequently in a level, the corresponding level of the query tree will be jumping over. As shown in Figure 2, when the number of collision exceeds the predefined threshold, prefix matching at the present level will be skipped in order to save unnecessary prefix inquires for the remaining part at the same level. Through the process, the number of inquiry message could be significantly reduced. The collision threshold in Wrap-Around Scan technique is set to $2^I/M$, where I denotes the level in the query tree and M is a pre-defined constant.

Let us use an example to demonstrate the WAS scheme. Figure 3 shows an example of an RFID network having 6 tags with 4-bits id length using WAS with $M = 3$. The WAS scans the query tree from left to right in level 1, the reverse in level 2, and reverse again in level 3, and so on. Since $M = 3$, the threshold of collisions are 1, 2 and 3 in level 1, level 2 and level 3, respectively. The only one collision happened in level 1 is node 0, the two collision nodes appeared in level 2 are nodes 10 and 11; while the three collision nodes in level 3 are happened at nodes 011, 101 and 110 in order. Table 2 summarizes the detail steps of communication between the reader and the tags with the example shown in Figure 3.

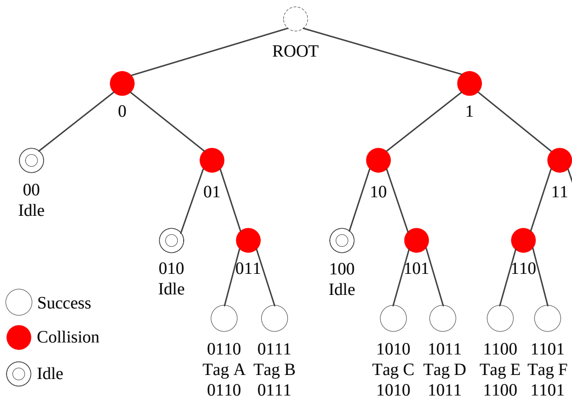

Figure 1. An example of query tree algorithm.

TABLE I. COMMUNICATION STEPS OF FIGURE 1.

Step	Broadcast	Status
1	0	Collision
2	1	Collision
3	00	Idle
4	01	Collision
5	10	Collision
6	11	Collision
7	010	Idle
8	011	Collision
9	100	Idle
10	101	Collision
11	110	Collision
12	111	Idle
13	0100	Identify Tag A
14	0111	Identify Tag B
15	1010	Identify Tag C
16	1011	Identify Tag D
17	1100	Identify Tag E
18	1101	Identify Tag F

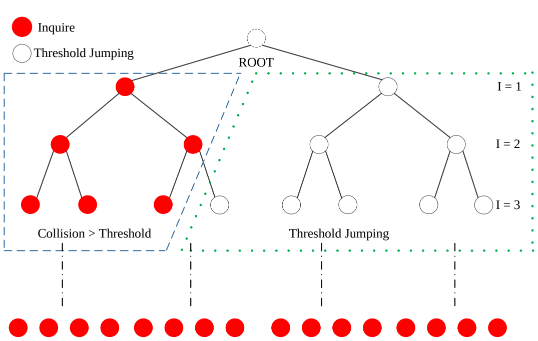

Figure 2. The paradigm of threshold jumping technique.

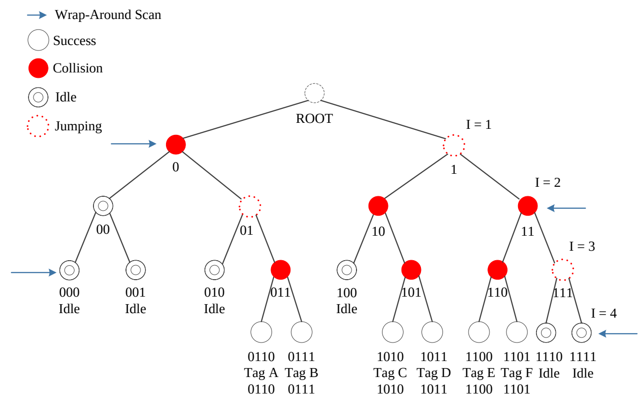

Figure 3. An example of WAS algorithm.

TABLE II. COMMUNICATION STEPS OF FIGURE 3.

Step	Broadcast	Status
1	0	Collision
2	11	Collision
3	10	Collision
4	000	No Response
5	001	No Response
6	010	No Response
7	011	Collision
8	100	No Response
9	101	Collision
10	110	Collision
11	1111	No Response
12	1110	No Response
13	1101	Identify Tag F
14	1100	Identify Tag E
15	1011	Identify Tag D
16	1010	Identify Tag C
17	111	Identify Tag B
18	110	Identify Tag A

IV. THE PROPOSED TECHNIQUE

Recall that, in WAS technique, the identification of tags in the right sub-tree could be advanced by reversing the direction of scan in each level alternatively. Figure 4 demonstrates the idea of wrap-around scan. The level ordered scans start from left to right in all “odd” (or even) levels and starts from right to left in all “even” (or odd) levels. Using wrap-around scan, the amount of prefix inquiries is expected to be decreased as the advance findings of the information of no response / collisions in the query tree could be in a balanced way. In WAS approach, jumping will reduce the number of collisions in a level. However, it will also cause unnecessary inquiry in the next level since some of inquires could be omitted once the status of the corresponding upper level is known. We describe our idea in the following sections.

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In query tree algorithm, every time when collision happened, the reader will add one bit for prefix matching at next level. In such way, it may waste too much time in scanning the entire binary tree. The main idea of our proposed technique is that, instead of adding one bit for prefix matching at next level as collision occurred in query tree algorithm, we first analyze the possible ways for causing the collision and take appropriate actions at next level. We study the relationship for a collision parent node and its two child nodes. In our observation, there are four possible ways causing the collision parent node: 1) two collision child nodes, 2) one collision child node and the other identifiable (success) child node, 3) one collision child node and the other idle child node, and 4) two identifiable (success) child nodes. Figure 4 shows the four possible cases for a collision.

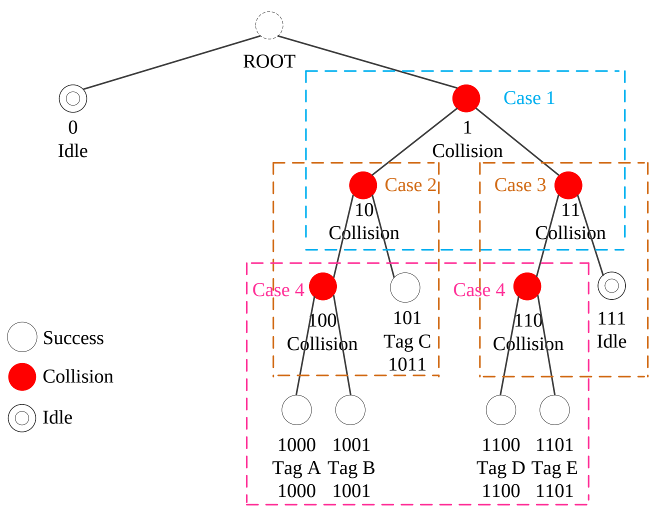

Figure 4. The four possible cases for a collision.

Based on the relationship between a collision parent node and its two child nodes, we observe that cases (3) and (4) can be used as a prior knowledge for deciding the status of a child node when the status of the sibling for the child node is known. For example, in case (3), once the result of the prefix matching is known to be idle, the prefix matching will be unnecessary for the sibling node since the status of their parent node is collided and as a result, the status of sibling node will be collided too. Another observation is that if a collision occurred at level (n-1), then, as we described in case (4), the two child nodes at level n must be identified.

Combining the WAS algorithm with the enhancement technique, we develop an enhanced WAS algorithm with prior knowledge, called the *intelligent Wrap-Around Scan* (iWAS) algorithm to reduce the query time in identification process. Figure 5 shows an example to illustrate the performance of proposed iWAS technique. Table 3 summarizes the detail steps of communication between the reader and the tags with the example of Figure 5. As shown in Table 3, 6 tags can be identified in 9 steps by using iWAS algorithm while using original WAS technique, it will take 18 steps to identify 6 tags. It should be noticed that when the reader broadcasts prefix bit string 010 to tags, there is no response from tags since no tags match 010 in their ids. At this moment, the reader is aware that nodes 000, 001 and 010 are all in idle state and node 0 is in collision state. Thus, the reader can conclude that node 011 should be in collision state. As a result, tags A and B can be identified according to case (4). Similarly, as node 100 is in idle state, the reader is aware that node 10 is in collision state. Thus, node 101 can be recognized as in collision state. As a result, tags C and D can be identified at this moment. Therefore, the proposed iWAS technique can significantly reduce the query time. Simulation results show that our proposed iWAS algorithm outperforms the original WAS algorithm in many situations. We evaluate the performance in the following section.

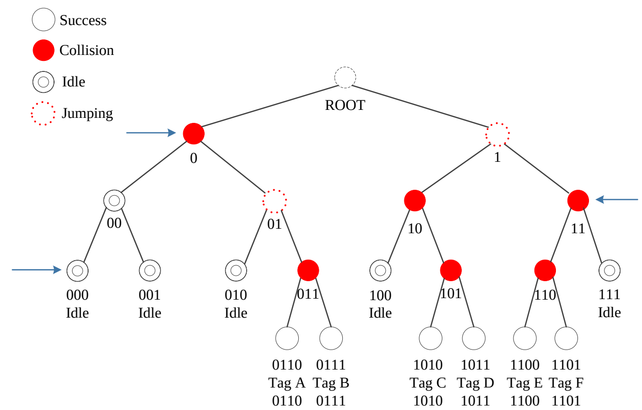

Figure 5. An example of iWAS technique.

TABLE III. COMMUNICATION STEPS OF FIGURE 5.

Step	WAS		iWAS	
	Broadcast	Status	Broadcast	Status
1	0	Collision	0	Collision
2	11	Collision	11	Collision
3	10	Collision	10	Collision
4	000	No Response	000	No Response
5	001	No Response	001	No Response
6	010	No Response	010	No Response Get info. 011 collision Identify Tags A and B
7	011	Collision	100	No Response Get info 101 Collision Identify Tags C and D
8	100	No Response	110	Collision, Identify Tags E and F
9	101	Collision	1111	No Response
10	110	Collision		
11	1111	No Response		
12	1110	No Response		
13	1101	Identify Tag F		
14	1100	Identify Tag E		
15	1011	Identify Tag D		
16	1010	Identify Tag C		
17	0111	Identify Tag B		
18	0110	Identify Tag A		

V. Performance Evaluation

To evaluate the performance of the proposed technique, we have implemented the iWAS scheme along with the query tree protocol (QT) and Wrap-Around Scan scheme (WAS). Figure 6 compares the number of inquires to identify different number of RFID tags. In this experiment, the tag id is set 8 bits length and density = 10% means that there are $2^8 \times 10\% = 26$ tags, and so on. All tags are randomly generated in a uniform distribution manner. As a result, a balance tree is generated as entitled in the figure. In this experiment, the threshold value M is set 3. As shown in Figure 6, the proposed technique iWAS can reduce the amount of inquiry messages. As we expected, the iWAS outperforms both the WAS and QT techniques. When network density increasing, the proposed iWAS method presents significant improvements to the traditional query tree protocol and WAS method.

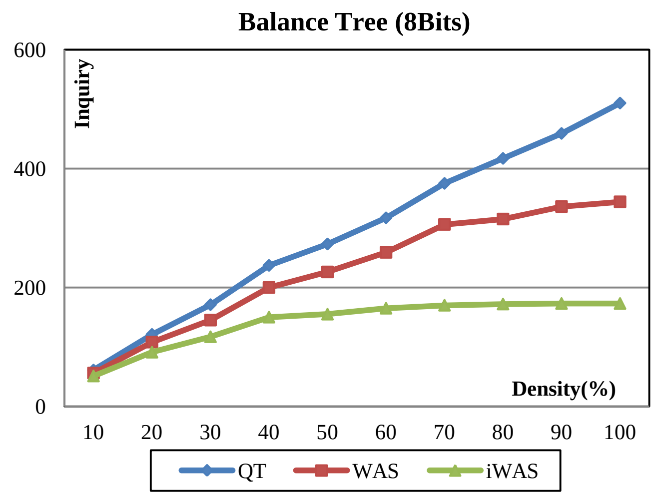

Figure 6. Performance comparison of the iWAS, WAS and QT with 8 bits RFID tags.

Figure 7 uses the same configuration as that of Figure 6 except the length of tag ID is set 16 bits. The number of tags in this experiment is set from $2^{16} \times 10\% = 6554$ to $2^{16} \times 100\% = 65536$. This experiment has similar observations as those of Figure 6. The proposed iWAS has better performance compare to the WAS and QT in terms of the inquiry message. It should be noticed that the amount of inquiry messages of proposed iWAS method is almost the same when the network density exceeds 70%. This is due to that when the network density is high, the balance tree is almost full. As a result, the reader can obtain the collision state in the same level during the identification process of our proposed iWAS method. Therefore, the amount of inquiry message is almost the same when network density is high.

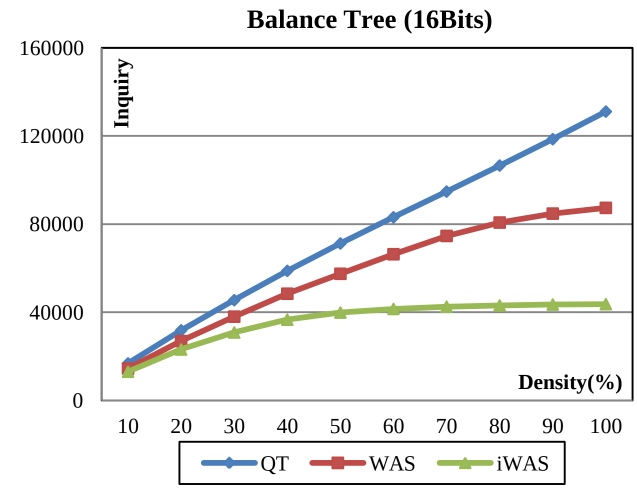

Figure 7. Performance comparison of the iWAS, WAS and QT with 16 bits RFID tags.

The last experiment was conducted with different distribution of ids among tags. The term Tree Balance Factor (TBF) defined in Figure 8 is used to indicate the percentage of tags distribution in left sub-tree and right sub-tree of a query tree. TBF = 10% means that number of tags in left sub-tree and right sub-tree are with the ration 1:9, TBF = 20% represents the number of tags in left sub-tree and right sub-tree are with the ration 2:8, and so on. As a result, an imbalance tree is generated as entitle in the figure. This experiment varies the tree balance factor from 10% which means an imbalance tree, to 50% which reflects a balance tree. The density is set 80% in the experiment. From the experimental results, the iWAS outperforms the WAS and the query tree methods in both imbalance and balance distributions.

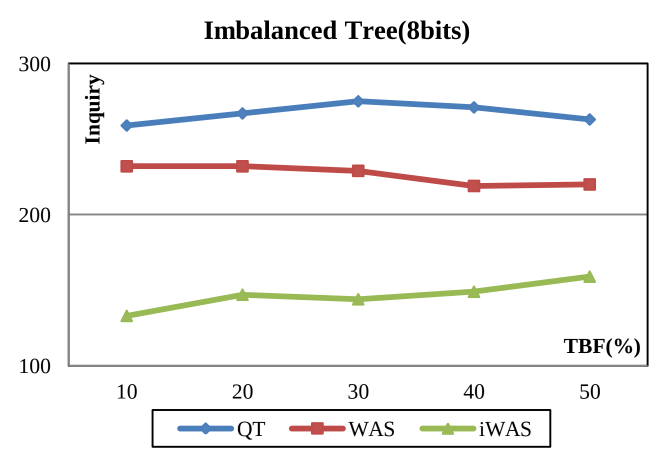

Figure 8. Performance comparison of the iWAS, WAS and QT in imbalance tree.

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VI. CONCLUSION AND FUTURE WORK

With the emergence of wireless RFID technologies, identifying high density RFID tags is a crucial task in developing large scale RFID systems. In this paper, we have presented an enhanced tree-based tag identification technique for minimizing tag identification cost. By using a prior knowledge, many unnecessary inquires can be reduced. Together with the Wrap-Around Scan technique (WAS), the efficiency of tag identification can be significantly improved. To evaluate the performance of proposed techniques, we have implemented the iWAS technique along with the WAS and the query tree protocol (QT). The experimental results show that the proposed technique provides considerable improvements on the latency of tag identification. It is also shown that the iWAS is effective in terms of increasing system throughput and efficiency. It remains challenging, however, to find an optimal approach that would use least prior knowledge to reduce unnecessary inquires as many as possible.

REFERENCES

[1] J. I. Capetanakis, “Tree algorithms for packet broadcast channels,” *IEEE Transactions on Information Theory*, vol. 25, pp. 505–515, 1979.

[2] H. S. Choi, J. R. Cha, and J. H. Kim, “Improved Bit-by-bit Binary Tree Algorithm in Ubiquitous ID System,” in proceedings of the IEEE PCM2004, Tokyo, Japan, Nov. 29-Dec. 3, pp. 696–703, 2004.

[3] D. K. Klair, K. W. Chin, and R. Raad, “An investigation into the energy efficiency of pure and slotted aloha based RFID anticollision protocols,” in proceedings of the IEEE WoWMoM’07, June 18–21, Finland, pp. 1-4, 2007.

[4] C. Law, K. Lee, and K. Y. Siu, “Efficient Memoryless Protocol for Tag Identification,” in proceedings of the International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications, pp. 75-84, 2000.

[5] S. Lee, S. D. Joo, and C. W. Lee, “An enhanced dynamic framed slotted aloha algorithm for RFID tag identification,” in ACM Mobiquitous, pp. 166-172, 2005.

[6] J. Myung, and W. Lee, “An adaptive memoryless tag anticollision protocol for RFID networks”, IEEE INFOCOM’05, Poster Session, Mar. 2005.

[7] J. Myung, W. Lee, and J. Srivastava, “Adaptive binary splitting for efficient RFID tag anti-collision,” IEEE Communication Letter, vol. 10, no. 3, pp. 144–146, 2006.

[8] L. G. Roberts, “Aloha Packet System with and without Slots and Capture,” ACM SIGCOMM Computer Communication Review, vol. 5, pp. 28–42, 1975.

[9] J. Ryu, H. Lee, Y. Seok, T. Kwon, and Y. Choi, “A Hybrid Query Tree Protocol for Tag Collision Arbitration in RFID systems,” IEEE International Conference on Communications (ICC-07), pp. 24–28, 2007.

[10] A. Sahoo, S. Iyer, and N. Bhandari, “Improving RFID System to Read Tags Efficiently,” IIT Bombay, June: KRSIT Technical Report, 2006.

[11] B. Zhen, M. Kobayashi, and M. Shimizui, “Framed aloha for multiple RFID objects Identification,” IEICE Trans. on Comm, E88-B(3), pp. 991–999, 2005.

[12] Z. Zhou, H. Gupta, S. R. Das, and X. Zhu, “Slotted Scheduled Tag Access in Multi-Reader RFID Systems”, in proceedings of the IEEE International Conference on Networks Protocols (ICNP), pp. 61–70, 2007.

[13] F. Zhou, C. Chen, D. Jin, C. Huang, and H. Min, “Evaluating and Optimizing Power Consumption of Anti-Collision Protocols for Applications in RFID systems”, in proceedings of the International Symposium on Low Power Electronics and Design. California, USA, Newport Beach, pp. 357-362, 2004.

[14] H. Vogt, “Efficient Object Identification with Passive RFID Tags,” *Proc.* Inter. Conf. on Pervasive Computing, LNCS.2414, Springer-Verlag, pp. 98-113, 2002.

[15] C.-H. Hsu, H.-C. Chao, and J. H. Park, “Threshold jumping and wrap-around scan techniques toward efficient tag identification in high density RFID systems,” Information Systems Frontiers, Aug. 2009, doi:10.1007/s10796-009-9209-5. [retrieved: June, 2012]

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