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Threshold jumping and wrap-around scan techniques toward efficient tag identification in high density RFID systems

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Abstract With the emergence of wireless RFID technologies, the problem of Anti-Collision has been arousing attention and instigated researchers to propose different heuristic algorithms for advancing RFID systems operated in more efficient manner. However, there still have challenges on enhancing the system throughput and stability due to the underlying technologies had faced different limitation in system performance when network density is high. In this paper, we present a *Threshold Jumping* (*TJ*) and a *Wrap-Around Scan* (*WAS*) techniques, which are query tree based approaches, aiming to coordinate simultaneous communications in high density RFID environments, to speedup tag identification, to increase the overall read rate and to improve system throughput in large-scale RFID systems. The main idea of the *Threshold Jumping* is to limit the number of collisions. When the number of collisions exceeds a predefined threshold, it reveals that tag density in RF field is too high. To avoid unnecessary enquiry messages, the prefix matching will be moved to next level of the query tree, alleviating the collision problems. The method of setting frequency bound indeed improves the efficiency in high density and randomly deployed RFID systems. However, in irregular or imbalanced RFID networks, inefficient situation may happen. The problem is that the prefix matching is performed in single direction level-order scheme, which may cause an imbalance query tree on which the right sub-tree always not been examined if the identification process goes to next level before scan the right sub-tree due to threshold jumping. By scanning the query tree from right to left in alternative levels, i.e., wrap-around, this flaw cold be ameliorated. To evaluate the performance of proposed techniques, we have implemented the *TJ* and the *WAS* method along with the query tree protocol. The simulation results show that the proposed techniques provide superior performance in high density environments. It is shown that the *TJ* and *WAS* are effective in terms of increasing system throughput and minimizing identification delay.

Keywords Tag anti-collision · Query tree · Wrap-around scan · Threshold jumping

1 Introduction

Radio Frequency Identifier (RFID) system is an automatic technology to identify objects, record metadata or control individual target through radio waves. The RFID system is mainly composed by three components, tags, readers and host system. An RFID tag is comprised of integrated circuit

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with an antenna for storing information and communication, respectively. An RFID reader is capable of reading the information stored at tags located in its sensing range. The host system is a control center that provides services and management. The electronics in the RFID reader use an outside power resource to generate signal to drives the reader's antenna and turn into radio wave. The radio wave will be received by RFID tag which will reflect the energy in the way of signaling its identification and other related information. In matured RFID systems, the reader's RF can also instruct the memory to be read or written from which the tag contained.

Many applications, such as supply chain automation, identification of products at check-out points, security and access control, localization and object tracking have been developed to take the primary function of RFID systems. Advantages of RFID technologies, such as price efficiency, fast deployment, reusable and accuracy of stock management also broaden the scope of applications of RFID systems. Advanced characteristics of recent RFID readers, like size miniaturization and capabilities of Wi-Fi or cellular also motivate the development of large scale RFID systems.

In recent RFID technologies, it is motivated that an RFID system can be integrated with wireless sensor network by interfacing RFID tags with external sensing capabilities, such as light, temperature or shock sensors; forming a hybrid infrastructure that combines advantages of both technologies. Similar to wireless sensor network, RFID tags can be deployed in an ad-hoc fashion instead of pre-installed statically. As a result, RFID has gradually been applied to our daily lives so that some identification problems might be happened. When a reader simultaneously communicate with multiple tags that are in the same interrogation zone, the tags responses might be collided because the tag could not be aware the existence of neighboring tags due to it has no carrier sense ability. Therefore, efficient methods for identifying multiple tags simultaneously are of great importance for the development of large-scale wireless RFID systems.

In general, the tag anti-collision techniques can be classified into two categories, aloha based and query 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 nay not be identified for a long time. For the consideration of performance, when number of RFID tag increased, the tag collision rate will be increased as well; this may result a low tag recognition rate.

The query 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. In this paper, we present a *Threshold Jumping (TJ)* and a *Wrap-Around Scan* (*WAS*) techniques aim 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. The main idea of the proposed 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. Together with the concept of wrap-around scan, the tag anti-collision problem could be significantly ameliorated. To evaluate the performance of proposed techniques, we have implemented the *TJ* and the *WAS* method along with other tag identification approaches. The experimental results show that the proposed techniques present significant improvement in most circumstance.

The rest of this paper is organized as follows: In Section 2, a brief survey of related work will be presented. Section 3 introduces the tree based tag identification algorithm as preliminary of this study. In section 4, two query tree based algorithms, the *Threshold Jumping* (*TJ*) and *Wrap-Around Scan* (*WAS*) are proposed. Performance comparisons and analysis of the proposed techniques will be given in Section 5. Finally, in Section 6, some concluding remarks are made.

2 Related work

Many research results have been proposed in literature, such as security and privacy related research (Weis et al. 2004) focuses on methods of preserving and protecting privacy of RFID tags; the RFID reader collision avoidance and hidden terminal problems were firstly addressed in (Engels et al. 2002) aiming to enhance accuracy of RFID systems; the energy saving and coverage problems (Namboodiri and Gao 2007; Zhang and Hou 2005; Ching-Hsien et al. 2008) were extensively studied in order to improve lifetime of wireless RFID networks.

Research efforts for collision avoidance have been also presented in literature. Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA) (Jain and Das 2006) are four basic access methods to categorize MAC-level protocols. Standard collision avoidance protocols like RTS-CTS (Sobrinho et al. 2005) cannot be directly applied in RFID systems due to the reason, in traditional wireless networks, the CTS are sent back to the sender. Similar situation in RFID system, when a reader broadcasts an RTS, all tags in the read range need to send back CTS to the reader. It then requires another collision avoidance mechanism for CTS, and it will make the protocol more complicated. Techniques for resolving RFID reader collision problems are usually proposed as reader anti-collision techniques or tag anti-collision solutions. The *Colorwave* (Waldrop 2003) is a scheduling-based approach prevents RFID readers from simultaneously transmitting signal to an RFID tag. The *Colorwave* is used as a distributed anti-collision system based on TDMA in RFID network. The *Pulse* protocol (Shailesh et al. 2005) is referred as a beacon broadcast and CSMA mechanism. Readers periodically send a "beacon" during communication with tags in separate control channels. The *contend_back-off* and the *delay_before_beaconing* in the protocol are similar in wireless networks. If a reader receives a beacon, the residual back-off timer will be stored and kept until the next coming chance. This process is expected to achieve the fairness among all readers. A coverage-based RFID reader anti-collision mechanism was proposed in (Joongheon et al. 2546). Kim et al. (Joongheon et al. 2546) presented a localized clustering coverage protocol for solving reader collision problems occurring among homogeneous RFID readers. In (Cha et al. 2006), Cha et al. proposed two ALOHA-based algorithms with a Tag Estimation Method (TEM) for speedup object identification in RFID systems. Hsu et al. (Ching-Hsien et al. 1007) proposed a two phase dynamic modulation (*TPDM*) scheme to coordinate communications between multiple readers and tags. In *TPDM*, the scheduling is divided into two phases, the regional scheduling and the hidden terminal scheduling.

The existing tag identification approaches can be classified into two main categories, the Aloha-based (Klair et al. 2007; Law et al. 2000; Roberts 1975; Vogt 2002; Zhen et al. 2005) anti-collision scheme and the tree-based scheme (Capetanakis 1979; Myung et al. 2006; Ryu et al. 2007; Zhou et al. 2004). 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 sending 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 (Law et al. 2000). In (Vogt 2002), 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 (Zhen et al. 2005) by Zhen et al. In (Klair et al. 2007), 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 (Lee et al. 2005). 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* (Myung et al. 2006), *IBBT* (Choi et al. 2004) and *IQT* (Sahoo et al. 2006), 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. (Myung & Lee 2005) is an extended technique based on the query tree protocol. Choi et al. also proposed the *IBBT* (Improved Bit-by-bit Binary-Tree) algorithm (Choi et al. 2004) in Ubiquitous ID system and evaluate the performance along three other old schemes. The *IQT* protocol (Sahoo et al. 2006) is a similar work approach by exploiting specific prefix patterns in the tags to make the entire identification process. Recently, Zhou et al. (Zongheng et al. 2007) 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 two enhanced tree based tag identification techniques aim to coordinate simultaneous communications in large-scale RFID systems, to speedup minimize tag identification latency and to increase the overall read rate and throughput.

3 Query tree based tag anti-collision

Radio Frequency IDentification (RFID) system is operated with the identification function through radio frequency, but