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An efficient tag collection algorithm utilizing empty time slots in active RFID systems

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Abstract: We propose an efficient tag collection algorithm utilizing empty time slots in active RFID systems. In the proposed tag collection algorithm, the reader recognizes the existence of empty time slots via carrier sensing, and utilizes the redundant empty time slots to transmit sleep commands to the tags collected, resulting in performance improvement for tag collection. The simulation results show that the proposed tag collection algorithm can reduce the average tag collection time by 12.28%, 12.30%, and 13.31%, for the framed slotted aloha with the fixed 128 time slots and 256 time slots, and the dynamic framed slotted aloha anticollision protocols, respectively.

Keywords: tag collection, active RFID system, framed slotted aloha, anticollision protocol, empty time slot

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Multiple tag identification, referred to as tag collection, is one of the major concerns in RFID systems. With an efficient anticollision protocol, an RFID reader tries to identify multiple tags faster, by solving tag collision problems among multiple tag responses [1]. Anticollision protocols for RFID systems can be classified into two groups: tree-based and aloha-based protocols. Tree-based protocols use many reader queries and tag responses during tag collection, resulting in higher power consumption for the readers and tags [2]. This is a very significant problem in active RFID systems, where tags are powered by their batteries. Therefore, tree-based protocols are better suited to passive RFID systems, and aloha-based protocols are mostly used in active RFID systems. ISO/IEC 18000-7, which is a representative standard for active RFID systems that defines active air interface communications at 433 MHz, suggests a tag collection algorithm using the framed slotted aloha anticollision protocol [3].

The performance of the framed slotted aloha anticollision protocol is known to be optimal when the frame size is similar to the number of tags to be collected. Therefore, most related studies have addressed how to precisely estimate the number of the remaining tags and dynamically choose the optimum frame size, to improve the tag collection performance [4, 5, 6]. However, few studies have focused on performance improvement of tag collection that considers the characteristics of active RFID systems [7].

We propose an efficient tag collection algorithm utilizing empty time slots in active RFID systems. In the proposed tag collection algorithm, the reader utilizes empty time slots to transmit sleep commands to the tags collected, which reduces the number of redundant empty time slots and improves the tag collection performance. Via simulation experiments, we evaluate the tag collection performance using the proposed tag collection algorithm, by comparison with the performance of the basic tag collection algorithm.

2 Tag collection in active RFID systems and empty time slots

Figure 1 shows an example of the tag collection sequence and timing using the framed slotted aloha anticollision protocol in active RFID systems. Before a reader performs tag collection, it is necessary to wake all tags that are in sleep mode (to save their battery power) within the reader's RF communication range. The reader then collects all tags' data via iterative collection rounds. A single collection round is initiated by a collection command from the reader. The collection command contains a *frame size* parameter, which defines the total time for the reader to listen for multiple responses from tags. After receiving a collection command, tags randomly select a time slot

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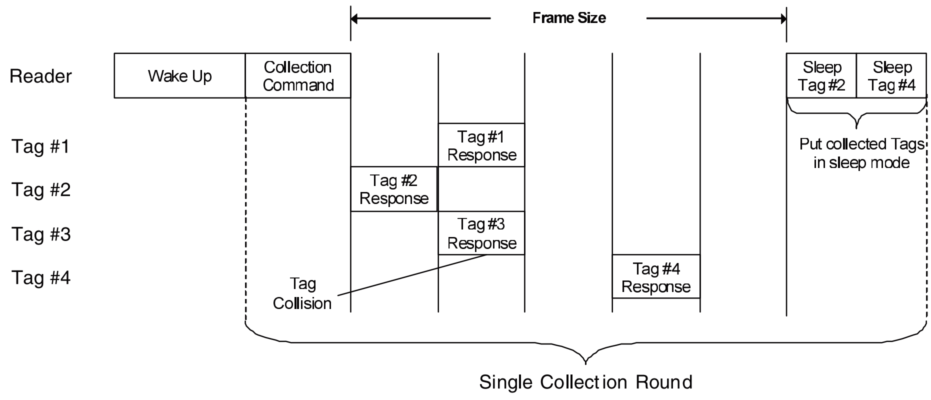

Fig. 1. Tag collection using the framed slotted aloha anticollision protocol in active RFID systems

and send their responses in the selected time slot. After the frame period has expired, the reader transmits sleep commands to all tags collected during the collection round. The tags that receive a sleep command shift to sleep mode, and do not participate in the subsequent collection rounds. When the collection round has been completed, the reader immediately starts the next collection round by transmitting a collection command. This process continues until no more tags are detected.

As shown in Figure 1, time slots can be categorized into three groups: identified time slots that are filled with one tag response (first and fourth), collided time slots where two or more tags send responses simultaneously (second), and empty time slots that are not chosen by tags (third and fifth). Among these, empty time slots are highly redundant, because these are consumed without any operations. However, multiple empty time slots are always produced throughout the tag collection process, because of the nature of the frame slotted aloha anticollision protocol that is based on the probabilistic approach. Furthermore, as the frame size increases to support a large number of tags, the number of empty time slots also increases. Therefore, if the redundant empty time slots can be reduced, the tag collection performance may be improved.

3 The proposed tag collection algorithm

We propose an efficient tag collection algorithm to reduce the redundant empty time slots and improve the tag collection performance. In the proposed tag collection algorithm, the reader utilizes the redundant empty time slots to transmit sleep commands to the tags collected during the collection round. The reader determines the existence of the empty time slot via carrier sensing.

For the proposed tag collection algorithm, the operation algorithm on the reader for a single collection round is as follows. After transmitting a collection command to start a collection round, the reader senses carrier signals in the early stage of every slot during the frame period. If there is no carrier signal in a certain time slot, this implies that there is no tag response in the time slot, which is an empty time slot. Otherwise, it can be considered

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that one or more tags are transmitting their responses in the time slot. In the case that a carrier signal is detected in a certain time slot, and a tag response is identified successfully, the reader processes the tag response and then inserts the corresponding tag's ID into the sleep queue. On the other hand, in the case that the reader recognizes the existence of the empty time slot via carrier sensing, it checks the sleep queue to determine if there exists any tag that was previously collected but has not received a sleep command. If so, the reader gets the tag's ID from the sleep queue and transmits a sleep command to the corresponding tag within the empty time slot. Because the packet format for a sleep command is generally simpler than that for a tag response to a collection command, the time required for transmitting the sleep command is relatively small, compared to the tag response. Therefore, the sleep command can be successfully transmitted within an empty time slot, without interfering with other tag responses. After the frame period has expired, the reader completes the current collection round by transmitting sleep commands to any remaining tags in the sleep queue.

```
// Operation algorithm on the reader for a single collection round
Transmit a collection command
For i ← 1 to N do                                  // N: number of time slots
    If (carrier sense = true) then
        If (tag response = valid) then             // identified time slot
            Process a tag response
            Insert the corresponding tag's ID into the sleep queue
    Else                                           // empty time slot
        If (sleep queue ≠ empty) then
            Get a tag's ID from the sleep queue
            Transmit a sleep command to the corresponding tag
Transmit sleep commands to the remaining tags in the sleep queue
```

Figure 2 shows an example of tag collection using the new tag collection algorithm proposed in this paper. After a collection command is transmitted, the reader successfully receives a response from tag 2 in the first time slot, and catches a tag collision caused by tag 1 and 3, in the second time slot. In the third time slot, the reader recognizes the existence of an empty time slot, and then transmits a sleep command to tag 2, which was identified in the first time slot. Similarly, the reader identifies tag 4 in the fourth time slot and transmits a sleep command to tag 4 in the fifth empty time slot. In the example, no additional time is required for transmitting sleep commands after the frame period, unlike Figure 1, because all sleep commands were previously transmitted to the collected tags during the frame period.

The noteworthy characteristic of the proposed tag collection algorithm is that it does not require modification on the tag side. Therefore, it can easily be applied to the conventional active RFID systems, such as ISO/IEC 18000-7 compliant systems.

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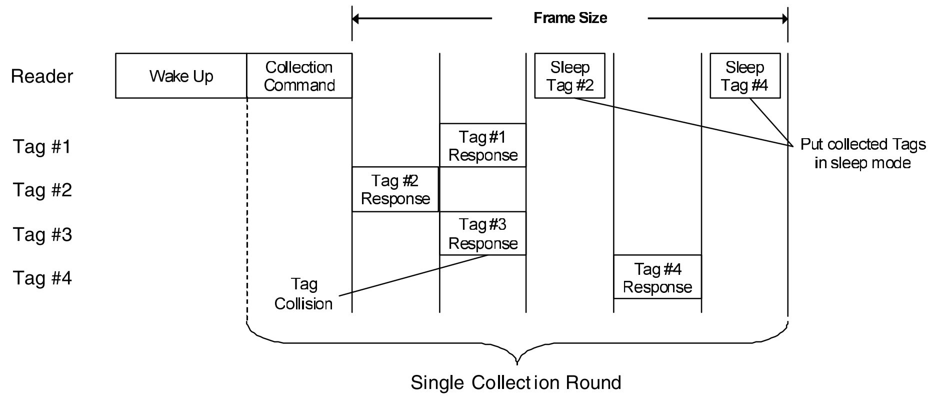

Fig. 2. Tag collection using the proposed tag collection algorithm

4 Simulation results

Via the simulation experiments, we evaluated and compared the performances of the basic tag collection algorithm and proposed tag collection algorithm. For simulation, we developed an active RFID system model consisting of a reader and tags, written in the C language. Three anticollision protocols were used in the simulation: the framed slotted aloha with the fixed 128 time slots (FSA128) and with the fixed 256 time slots (FSA256), and the dynamic framed slotted aloha (DFSA). The method to estimate the number of the remaining tags and determine the optimum frame size for DFSA was adopted from that proposed in [5]. According to the ISO/IEC 18000-7 standard [3], the time required for transmitting a collection command and a sleep command were set to 5.232 ms and 5.88 ms, respectively, and a time slot size was set to 9 ms. We performed 10,000 simulation trials in each case, varying the number of tags from 0 to 500, and measured the average time required for tag collection, and the average number of empty time slots without a tag response or reader sleep command throughout the tag collection process.

The simulation results are shown in Figure 3. The proposed tag collection algorithm shows better performances than the basic tag collection algorithm in all cases. As shown in Figure 3 (b), for the basic tag collection algorithm, the total number of empty time slots increases as the number of tags to be collected increases. In contrast, for the proposed tag collection algorithm, the total number of empty time slots only increases slightly if the number of tags exceeds a certain value. This is because a maximum of 85% of empty time slots are used for transmitting sleep commands by the reader. For this reason, as the number of tags increases, the performance improvement of the proposed tag collection algorithm also increases, as shown in Figure 3 (a). The proposed tag collection algorithm can reduce the average time required for tag collection by 12.28%, 12.30%, and 13.31%, for the FSA128, FSA256, and DFSA anticollision protocols, respectively.

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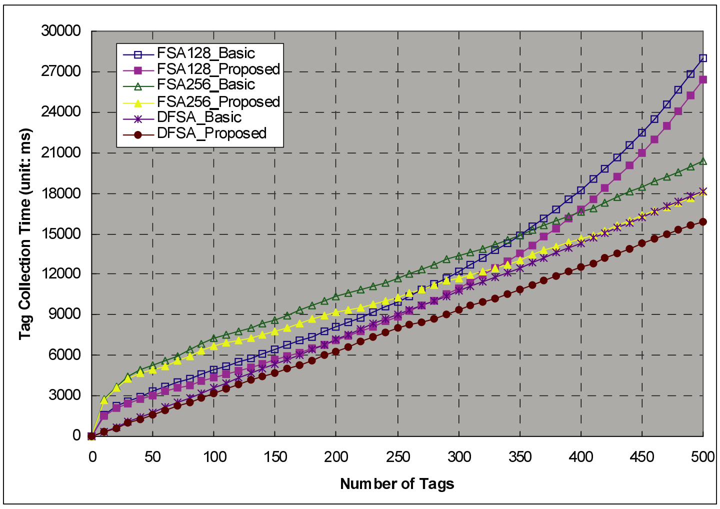
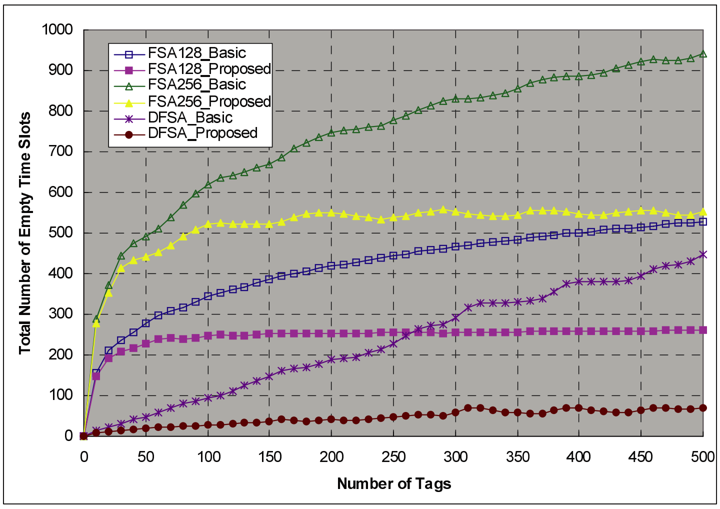


(a)



(b)

Fig. 3. Simulation results: (a) Average time required for tag collection, (b) Average number of empty time slots

5 Conclusion

We have proposed an efficient tag collection algorithm utilizing empty time slots in active RFID systems. In the proposed tag collection algorithm, the reader recognizes the existence of empty time slots via carrier sensing, and utilizes the redundant empty time slots to transmit sleep commands to the tags collected, resulting in performance improvement for tag collection. The simulation results showed that the proposed tag collection algorithm can achieve better tag collection performance than the basic tag collection algorithm in all cases. In this paper, we performed simulation experiments to evaluate the performance of the proposed tag collection algorithm. In our future work, we plan to implement an active RFID reader and tags that support the proposed tag collection algorithm, and evaluate the performance via experiments in a real-world environment.

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