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Reader collision avoidance for multihop deployment of active RFID readers

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Abstract: RFID (Radio Frequency Identification) is an automatic identification technology using radio waves. RFID readers are high-technology automatic identification devices based on wireless networks and enable noncontact identification; however, they cannot be applied beyond their radio communication range. Considering this, the present paper proposes multihop deployment of active RFID readers in order to extend a reader's radio coverage. Further, when a multitude of RFID readers are deployed in an RFID field, RFID tags are easily collected multiple times. Considering this situation, in this paper, we also propose reader collision avoidance for multihop deployment of active RFID readers. The proposed method not only avoids multiple reads from a tag but also extends the tag's lifetime. For experimental tests and performance evaluation, this study implements a multi-hop active RFID reader, which complies with the ISO/IEC 18000-7 standard.

Keywords: reader collision, multi-hop deployment, active RFID

Classification: Electron devices, circuits, and systems

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1 Introduction

RFID is an emerging automatic identification technology wherein information is carried by radio waves. An active RFID tag can be read at distances of one hundred meters or more, greatly improving its utility; it may also include other sensors that can extend its application [1]. An ISO/IEC 18000-7 standard [2] defines the air interface for active RFID systems in the 433-MHz band. Even though an active RFID system based on the standard provides compatibility between heterogeneous systems and a long communication range, it is difficult to apply it to a large area such as a port and air logistics hub because of its limited radio communication range and obstacles. Hence, this paper proposes the multihop deployment of active RFID readers.

Although the proposed multihop deployment can be applied to a large area, it has the following serious drawback that degrades its performance: Because an active RFID originally focuses on a large number of tags within its communication range, the reader collision is likely to occur between readers when the coverage area of one reader overlaps with that of another reader. Multiple reads by the multiple reads in an active RFID system not only cause duplicated data also lead to a high power consumption of an RFID tag powered by a battery [3, 4, 5].

2 Reader collision avoidance for multihop deployment of active RFID readers

A traditional active RFID system has a limited communication range. In order to cope with a reader's communication range, this paper deploys RFID readers in a multihop pattern. This section is separated into two parts: multi-hop deployment of active RFID readers and reader collision avoidance.

2.1 Multihop deployment of active RFID readers

The concept of our multihop deployment of active RFID readers is to extend the communication range of a reader by deploying a multitude of RFID readers. Figure 1 depicts the proposed multihop deployment of active RFID readers. Basically, the RFID reader collects only two tags (*0xRR01, 0xRR02*) lying within its range. In order to collect information from other tags (*0xEE01, 0xEE02, 0xCC01*), it has to use other readers in a multi-hop pattern. Here, a basic assumption is that active RFID readers are deployed in the field and can communicate with their neighbor readers. The first step, which is called the "slave reader (SR) discovery phase," is to create a hierarchical topology from the root referred to as a master RFID reader so as to control all RFID readers. The required SR list can be gathered in on-demand fashion. First, the master reader initiates the SR discovery phase by broadcasting a discovery packet, which contains the identity and the sequence number. Each SR receiving a packet checks whether it receives a message with the same sequence number, and if not, it adds its own address to the route record of the packet and then forwards the packet along its outgoing links. To limit a broadcast storm, an SR only forwards a SR discovery packet if the packet

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has not yet been seen by the node and if the SR's address has not already appeared in the route record of the packet. A "SR REPLY" packet is generated when the SR discovery packet reaches the SR itself. Finally, the SR transmits a "SR REPLY" with its associated route record back to the master reader. This process is continued until eventually every SR in the network is assigned a sequence number. After being assigned a sequence number, a node neglects any such future packets, ensuring that no flooding congestion takes place in this phase. Thus, a hierarchical structure is created with only the master reader. Since the master reader will receive a reply message from a concerned SR, the master reader will therefore be aware of the possible routes.

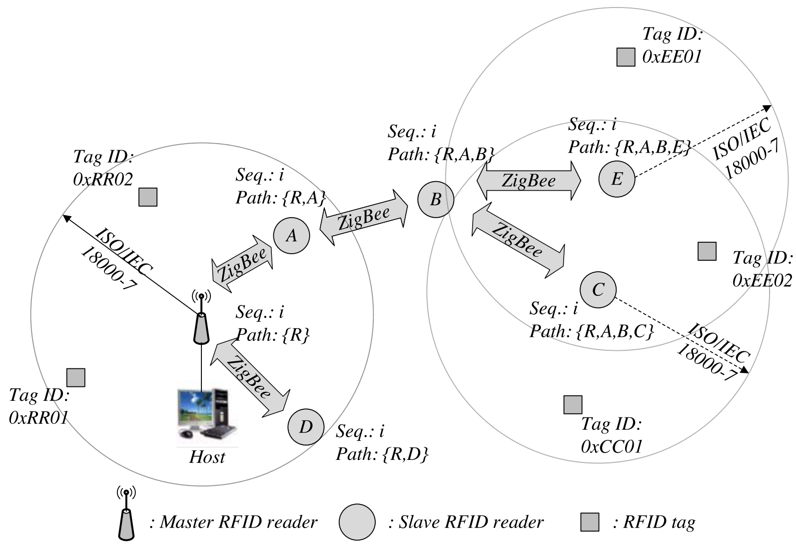

Fig. 1. Multihop deployment of active RFID readers and reader collision problem.

Once the hierarchical topology has been established, the master reader initiates the second stage, which is called the "tag collection phase". In this phase, the master reader collects active RFID tags that are within its communication range; it requests the slave readers to collect active RFID tags that are outside its communication range and eventually collects them from the slave readers. In general, both of RFID readers act as a traditional RFID reader does, and the communication between RFID readers for collecting tag information and exchanging control messages should be achieved by a separated channel in order to avoid signal interference.

2.2 Reader collision avoidance

The proposed multihop collection can efficiently collect a number of active RFID tags scattered in a wide area. However, reader collision occurs in a multihop collection system when the coverage area of one reader overlaps with that of another reader. For example, in figure 1, readers C and E collide. The reader collision problems are classified into two types: signal interference between readers and multiple reads of the same tag [5].

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This paper proposes a method for reader collision avoidance in order to eliminate multiple reads. The proposed method is based on the concept of learning the collection commands. When the master reader initiates RFID collection, it generates a heuristic number that is similar to a sequence number. Collection command messages in the ISO/IEC 18000-7 include a 1-byte packet option field. The 5 MSB bits of the packet option field are reserved for future work. Hence, in this study, we can assign the heuristic number to reserved fields and send collection commands to the RFID tags. After the master reader finishes its collection round, it forwards the heuristic number with collection commands to slave readers according to the hierarchical topology established by the first phase. The slave reader collects tags by using the same heuristic number. In this case, the readers can collide with each other by the signal interference of ISO/IEC 18000-7. This signal interference problem of readers can be solved by having the readers programmed to read at fractionally different times. However, this paper does not deal with the signal interference problem but rather multiple reads. After collecting all RFID tags, the master can request a point-to-point communication with individual RFID tags by using previously collected tag IDs, the routes to the tags.

Pseudo code 1 Active RFID tag operation

Let *Heu_No* be the heuristic number in the collection command message from the RFID reader
Let *BDT_Heu_No and P2P_Heu_No* be the last heuristic number received from the RFID reader

```
BEGIN
Detect "wake-up signal"
State ← WAKEUP
While(IS_RECEPTION){ /*receive a command */
   If (protocol_ID == 0x04) && ( BROADCAST) then
      If BDT_Heu_No < Heu_No then /* heuristic number check */
         Response(random(seed, WIN_SIZE)) /*response */
         tmp_BDT_Heu_No ← Heu_No
      End if
   Else if (protocol_ID == 0x04) && (POINT-TO-POINT) then
      If P2P_Heu_No < Heu_No then
         If response() then /* if response is success */
            tmp_P2P_Heu_No ← Heu_No
         End if
      End if
   Else if (protocol_ID == 0x04) && (SLEEP) then
      BDT_Heu_No  ← tmp_BDT_Heu_No /* maintain heuristic number */
      P2P_Heu_No  ← tmp_P2P_Heu_No
      setTagStatus(SLEEP);
   End if
}
setTagStatus(SLEEP);
END
```


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When, an active RFID tag receives a collection command from the reader, after waking up, the tag first checks the heuristic number. If the heuristic number received from the reader is the same as the recorded number maintained by the tag, the tag directly moves into the sleep state. Otherwise, it acts on the reader command according to the standard protocol. Below, Pseudo code 1 demonstrates how an active RFID tag is operated to avoid multiple reads.

This approach is possible because an active RFID tag is powered by a battery and can hence maintain some information in its internal memory. The proposed method can also maintain compatibility with ISO/IEC 18000-7 and can prolong a tag's life time by avoiding multiple reads.

3 Experiments and performance evaluation

In order to deploy the proposed method to a real RFID field, we designed and implemented an RFID reader capable of performing multihop collection. Figure 2 (a) depicts a prototype of the RFID reader. The reader comprises two parts: an RFID subsystem and a ZigBee subsystem. The RFID subsystem acts as the RFID reader, and the ZigBee subsystem performs mul-

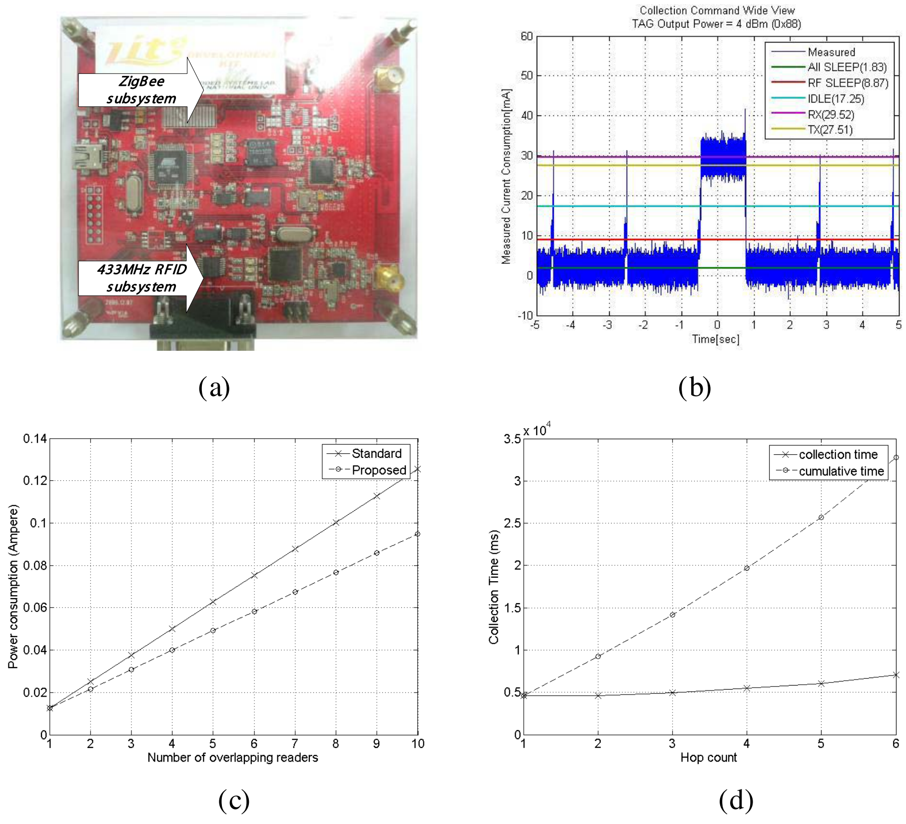

Fig. 2. Performance evaluation: (a) RFID reader prototype for multihop collection, (b) power consumption of the RFID tag designed to support ISO/IEC 18000-7, (c) power consumption of the tag vs. the number of overlapping readers, (d) required time to collect RFID tags.

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tihop operation, control, and data aggregation. The RFID subsystem uses an AVR processor and CC1100 RF transceiver to support ISO/IEC 18000-7. The ZigBee subsystem uses an ARM-based microcontroller and CC2420 RF transceiver. Communication via ZigBee networks has the advantage that wireless sensor networks can be used for a bridge to connect a user or a host system with RFID fields.

For performance evaluation of the proposed reader collision avoidance method, we first measured the power consumption of the active RFID tag, which complies with ISO/IEC 18000-7. The active RFID tag uses an AVR processor and a CC1100 radio transceiver. Figure 2 (b) shows the power consumption and required time for a collection round. After wake-up, the standard active RFID tag consumes 8.87 mAh during 20 ms for the processor-on mode, 17.25 mAh during 17 ms for an idle time, 29.52 mAh during 1.5 s for the reception mode, and 27.51 mAh during 14 ms for the transmission mode. However, the proposed method maintains the reception mode during 1.1 s and not the transmission mode when the active RFID tag receives a duplicated message from the reader. The active RFID tag used for performance evaluation maintains the reception mode during approximately 1 s because it has to wait for a command from the reader after a wake-up period.

Figure 2 (c) depicts the power consumption of the RFID tag when the number of RFID readers that communicate with it increases. When there are two overlapping readers, the tag consumes approximately 21.7 mA during the collection period. The more the number of RFID readers, the higher the energy consumption of the tag. When there are 10 overlapping readers, the proposed method consumes 95 mA, while the original standard consumes 125 mA. Further, the original standard and the proposed method include approximately 1 s reception time as a part of the wake-up period. This implies that if the part of the wake-up period is removed, the performance of the proposed method will dramatically be increased.

To measure the require time to collect RFID tags, we deployed RFID tags in the indoor environment. There are one master reader, 5 slave readers, and 30 RFID tags in the field. Each reader has 5 tags in its 433 MHz communication range. Figure 2 (d) shows the time for collecting RFID tags via the multi-hop environment. The system consecutively collects RFID tags according to the hierarchical topology to avoid the signal interference. The collection time from two-hop coverage is approximately 4.63 seconds whereas one-hop collection from the reader takes 4.60 seconds. However, when the hop count is increased up to 6, the collection time is increased up to approximately 7.1 seconds. The collection time is dependent on the hop count and the packet size. The packet size is also dependent on the collected RFID tag information. The cumulative time means the required time from every reader within the hop count. The require time to collect RFID tags is increased according to the number of the reader because every reader broadcast a wake-up signal before sending collection commands. However, an assumption that there is no signal interference can enable to collect RFID tags simultaneously in a short term.

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4 Conclusion

This paper proposed a multihop deployment of active RFID readers in order to extend a reader's radio coverage and suggested a method to avoid multiple reads from a tag. For the experimental tests and performance evaluation, this study implemented a multihop active RFID system, which complied with the ISO/IEC 18000-7 standard. The proposed method can prolong a tag's lifetime by eliminating multiple reads and represents a milestone for a large-scale RFID deployment. we expect the proposed method to have significant impact on the efficiency of many civil applications such as field surveillance, logistics, and asset management.

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