A Novel Wireless MAC Protocol for RFID Networks

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Abstract

Because of absence of a unified standard for the communication between RFID nodes, it can be cut off due to protocol mismatch in case of movement of the RFID reader to a region of a different protocol. Moreover, centralized MAC schemes for RFID communication in previous studies have severe problems. For instance, if a RFID cluster header disappears from the cluster due to the cluster header's movement or a bad channel condition, the member RFID nodes of the cluster waste lots of time and energy to re-elect a new RFID cluster header. Therefore, in this paper, we propose a cooperative relay transmission scheme for WiMedia Distributed MAC (D-MAC) protocol for RFID networks and demonstrate performance improvement via simulation results.

Keywords: *WiMedia, Distributed MAC, RFID, Relay Transmission*

1. Introduction

The RFID (Radio Frequency IDentification) identifies a target using wireless radio and reads the target's information. A RFID system is composed of RFID tag and RFID reader. Current RFID technology is used in the area such as security, health care, and toll gate fee management systems. Especially, when it is applied into Warehouse Management Systems (WMS), management policies can be determined efficiently due to the fast understanding of inventory status [1, 2].

The RFID-based WMS can be composed of RFID tag, RFID reader, and server as in Figure 1. And when the WMS is combined with some infra-nodes, more efficient and stable networking can be guaranteed. The RFID reader identifies RFID tags, collects the related data, and delivers them to its server. By collecting information about environment such as temperature, humidity and air pressure, the whole WMS controls environment according to features of stocks through its attached RFID tag. Therefore, communications between the RFID reader and the infra-node or server, and communications between RFID readers should be energy-efficient and reliable. For the case where many RFID tags are located in the corresponding RFID reader's range, delivery of abundant information should be possible [1].

Recently, various RFID-based WMS are proposed in [1, 2]. In [1], an event-based information gathering method of RFID reader is proposed. In [2], efficient information routing scheme collected at 802.11 MAC structure is proposed. However, as in [2, 5], a centralized MAC-based scheme, generally applied to wireless sensor networks, is stable in information gathering and management, but it is not efficient when considering mobility and distributed characteristic of each node. For example, when communication is broken because the cluster header moves or because wireless channel is deteriorated, the information about nodes belonging to the corresponding cluster cannot be delivered to the WMS server. Furthermore, more time and energy are consumed during determination of a new cluster header. And for communication between RFID reader and tag, international standardization is under promotion. But for networking between RFID readers, no standard exists and an application-specific protocol is still adopted. Therefore, when an RFID reader in a stock container moves into a stock warehouse located in other range, the information in the RFID reader cannot be delivered to the WMS sever due to protocol mismatch. Therefore, in this paper, as a certified standard for communication between RFID reader nodes in the WMS, we combine the WiMedia Distributed MAC (D-MAC). The protocol layer structure of RFID reader combined with WiMedia D-MAC protocol is shown in Figure 2.

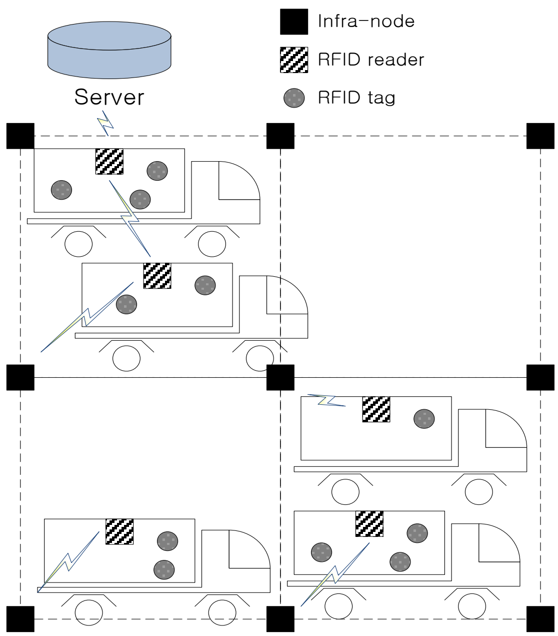


Figure 1. A RFID-based WMS configuration

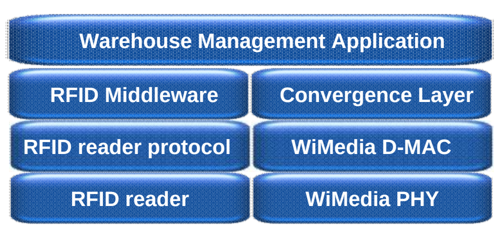


Figure 2. Protocol Layer Structure of RFID reader node combined with WiMedia D-MAC

Furthermore, for more reliable and stable information delivery in WiMedia D-MAC based WMS, we propose a relay-based cooperative communication algorithm. As shown in Figure 3, if the wireless channel status is bad between Sender node (S-node) and Receiver node (R node), the direct communication between S node and R node causes inefficient time delay and power consumption. In this case, an indirect communication via S node, R node with good channel status, and R node is more efficient. Recently, in the aspect of cost or power consumption, for the efficient communication of devices, some multi-hop relay cooperative communication schemes are proposed. In [4], it increases throughput through an efficient relay communication by proposing the CoopMAC scheme. However, CoopMAC scheme needs additional CSMA-CA based HTS(Helper ready To Send) signaling overhead for delivery of relay confirm/deny messages from a helper station. Furthermore, because this CoopMAC algorithm is proposed for WLAN systems, this algorithm is not adequate for the RFID-based WMS. Therefore, in this paper, a Relay DRP (Distributed Reservation Protocol) scheme is proposed as an efficient relay-based cooperative communication algorithm for the WiMedia D-MAC based WMS.

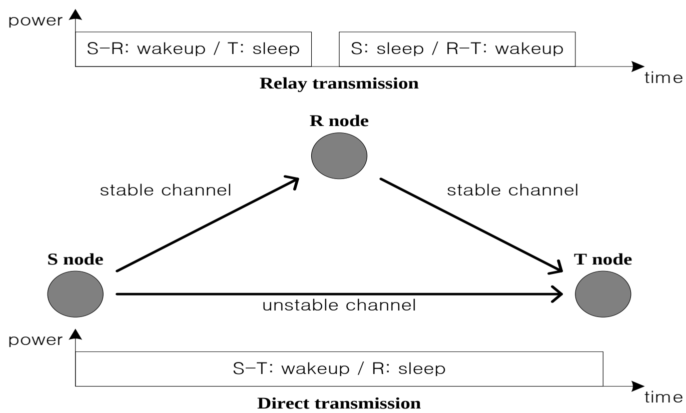


Figure 3. Relay-based Cooperative Communication

This paper is organized as follows: In Section 2, we describe the WiMedia D-MAC protocol. In Section 3, a relay-based cooperative communication algorithm is proposed to solve the broken link problem between RFID readers which occurs in the WiMedia D-MAC based RFID WMS. In Section 4, a simulation model for the proposed scheme is proposed and its performances are demonstrated. Finally, in Section 5, concluding remarks are presented.

2. WiMedia D-MAC Protocol

As in Figure 4, WiMedia D-MAC operates per a time unit called a superframe. A superframe is divided into a BP (Beacon Period) and a DTP (Data Transfer Period). Unlike other MAC protocols, this BP of WiMedia D-MAC consists of beacon slots, and each device sends its own beacon in a non-overlapping beacon slot. This feature of the BP helps to find other devices fast and to synchronizes time with other devices. Also, it provides information of power control and reservation status for each MAS.

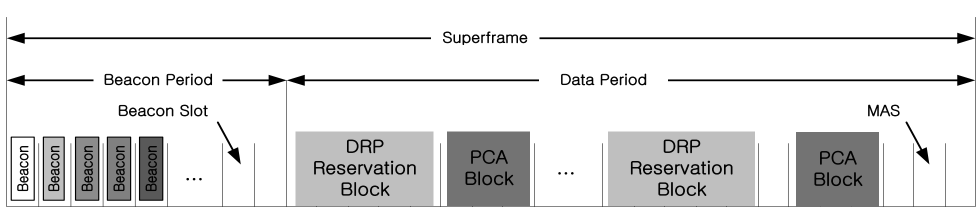


Figure 4. Superframe structure in WiMedia MAC

The current WiMedia D-MAC exchanges resource reservation and control information among the devices via DRP IE and DRP Availability IE. The DRP IE illustrated in Figure 5 is used to negotiate a reservation for certain MASs (Medium Access Slots) and to announce the reserved MASs for a traffic stream. The DRP Availability IE notifies the current status of the MAS utilization by 1-hop neighbors of the sender device, using the 256-bit long bitmap field in which one bit per each MAS in a superframe (One superframe consists of 256 MASs) is filled by combining all the DRP IEs transmitted by the 1-hop range neighbor devices.

In Figure 5, the DRP Control field contains the information to detect and resolve the conflicts among DRP blocks and to identify the stream to be sent in the reserved MAS block. The Target/Owner DevAddr field shows the DevAddr (Device Address) of the corresponding device, *i.e.*, it is set to the DevAddr of the reservation target (Receiving device) if the device transmitting this DRP IE is the reservation owner (Transmitting device) and vice versa. The Reason Code is used by a reservation target to indicate whether a DRP reservation request was successful or not, and it is encoded as shown in Table 1.

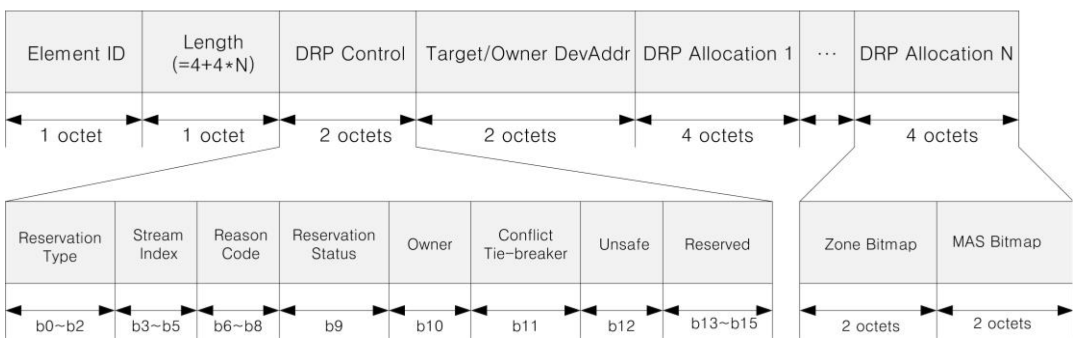


Figure 5. The format of DRP IE

Table 1. Reason Code Field Encoding

Value	Code	Description
0	Accepted	The DRP reservation request is granted
1	Conflict	The DRP reservation request or existing reservation is in conflict with one or more existing DRP reservations
2	Pending	The DRP reservation request is being processed
3	Denied	The DRP reservation request is rejected or existing DRP reservation can no longer be accepted
4	Modified	The DRP reservation is still maintained but has been reduced in size or multiple DRP IEs for the same reservation have been combined
5-7	Reserved	Reserved

3. Novel Wireless RFID D-MAC Protocol

WiMedia specification provides the DRP Availability IE to indicate its view of the current utilization of resources [3]. WiMedia nodes can be aware of existing neighbors' resource utilizations through the DRP Availability IE included in beacon frame. However, since the DRP Availability IE can't reflect the mobility or interference occurred by devices out of communication range, I need new resource selection scheme considering the mobility and interference. In previous section, we proposed the 2-hop DRP Availability IE generated by receiving and combining all DRP Availability IEs and DRP IE from all neighbor devices in communication range. The 2-hop DRP Availability IE depicted in Figure 6 includes a bitmap field of 256 bits long, one bit per each MAS in a superframe. If the corresponding resource is available for a resource reservation in 2-hop range area from a device, each bit is set to 'one', otherwise it is set to 'zero'.

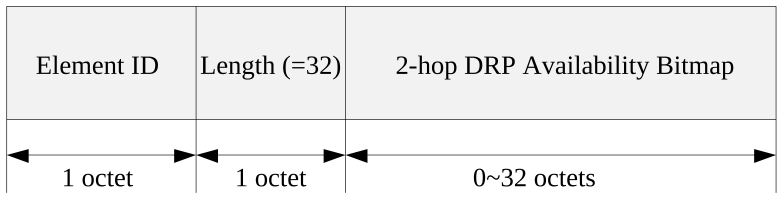


Figure 6. A format of proposed 2-hop DRP Availability IE

Since nodes can be aware of the information of resource utilization out of communication range through proposed 2-hop DRP Availability IE, it can select the safe channel from interference and mobility of outside nodes. Figure 8 shows the scenario of resource selection considering mobility and interference from outside nodes.

WiMedia Specifications provides the Link Feedback IE that advertises information on the data rate and transmit power level of neighboring nodes [3]. Since all devices in WiMedia network include the Link Feedback IE in its own beacon frame, they can be used to select a potential relay node that can relay data transmission. Figure 7 shows the frame format of the Link Feedback IE.

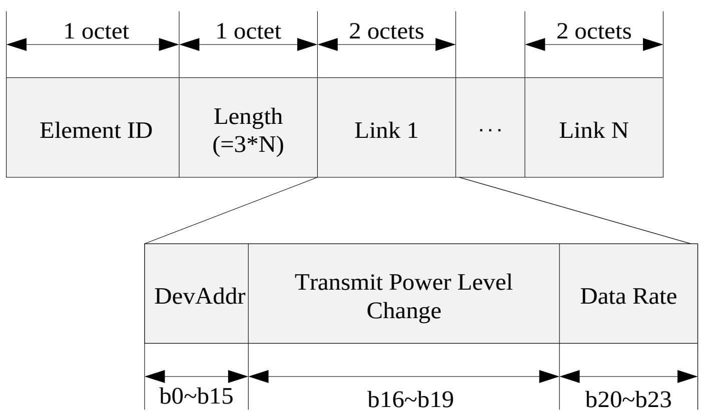


Figure 7. The frame format of the Link Feedback IE

The DevAddr field is set to the address of the source device for which the feedback is provided. The Transmit Power Level Change field is set to the change in transmit power level that the recipient recommends to the source device. The Data Rate field is set to the data rate that the recipient device recommends that the source device use.

After archiving all information for data rate between neighbor device and target device, source device determine the transmission scheme spending the minimum time.

In this paper, we will use three transmission schemes: direct transmission (DT), relay transmission (RT), cooperative transmission (CT). Figure 8 shows the example of three transmission schemes.

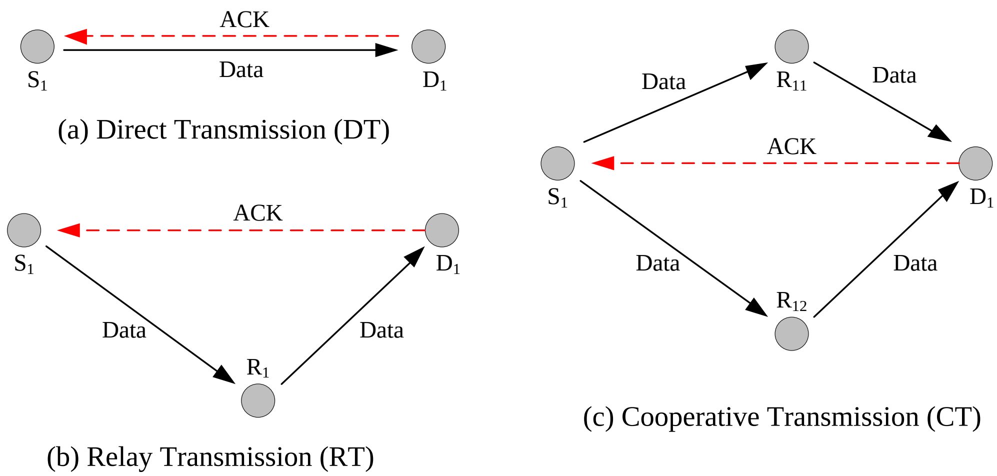


Figure 8. The example of three transmission schemes

In Figure 8, if the link quality between source node S_1 and destination node D_1 is good enough, DT is employed. If the link quality between S_1 and D_1 is poor and the link quality of intermediate node, R_1 is good enough, R_1 is selected as relay node and RT is employed. Also, if the link quality between S_1 and D_1 is poor and the link quality of adjacent nodes R_{11} and R_{12} is good enough, R_{11} and R_{12} are selected as relay nodes and they transmit distributed space time coded data frames to destination node D_1 simultaneously.

A new RFID D-MAC Relay (RD-Relay) DRP, proposed in this Section, conforms to WiMedia D-MAC standard for interoperability. To provide cooperative relay transmission, RD-Relay DRP uses newly defined three code-points in the reserved field of Reason Code in Table 1. The newly defined Reason Code Fields are explained in Table 2. The Reason Code of ‘RD-Relay Req’ is sent by a reservation owner to a relay device to request a DRP reservation between the owner and the relay device. The Reason Code of ‘RD-Relay Ntf’ is sent by a reservation owner to a target device to request a DRP reservation between a relay device and the target. These ‘RD-Relay Req’ and ‘RD-Relay Ntf’ Reason Codes ultimately intend to reserve DRP resources for relay transmission to the target node via the RD-Relay node. The Reason Code of ‘RD-Relay Accepted’ denotes that the DRP reservation request via corresponding relay device is granted. Accordingly, if both the Reason Codes from the RD-Relay node and the target node are set to ‘RD-Relay Accepted’, it means the DRP resources from the reservation owner to the target node via the RD-Relay node are successfully reserved.

Table 2. Additional Reason Code Field Encoding for RD-Relay D-MAC

Value	Code	Description
5	Relay Req (=RD-Relay Req)	Sent by a reservation owner to a relay device to request the DRP reservation between the owner and the relay device
6	Relay Ntf (=RD-Relay Ntf)	Sent by a reservation owner to a target device to request the DRP reservation between a relay device and the target
7	Relay Accepted (=RD-Relay Accepted)	The DRP reservation request via corresponding relay device is granted

From Figure 9 to Figure 11, we depict the proposed resource reservation procedures of reservation owner, RD-Relay node, and target node in detail. The reservation owner reserves DRP resources as shown in Figure 9. After reading DRP Availability IEs from other devices' beacons, the reservation owner checks if both MAS S-R and MAS R-T are free to use for the relay transmission. If both resources are available and if the received power level in beacons from the target node is lower than a threshold $Th_{S\text{-}T}$, the reservation owner sends DRP IEs with the same stream index as follows: DRP IE for MAS S-R to the RD-Relay node with the Reason Code of 'RD-Relay Req'; DRP IE for MAS R-T to the target node with the Reason Code of 'RD-Relay Ntf'. After sending the DRP IEs using beacon, the reservation owner waits for the responses from the RD-Relay node and the target node. In case of 'RD-Relay Accepted' Reason Code from both the RD-Relay node and the target node, the reservation owner sends data packets using the Relay transmission. For other Reason Codes, we just follow the legacy DRP standard.

Figure 10 shows the proposed resource reservation procedure for RD-Relay node. When a RD-Relay node has enough energy for relay transmission and receives a DRP IE from the reservation owner with Reason Code of 'RD-Relay Req', the RD-Relay node checks whether the resource request for MAS S-R in the received DRP IE is acceptable. If the resource request is agreeable to the RD-Relay node, the RD-Relay node should read DRP IE to target node which includes Reason Code of 'RD-Relay Ntf' with the same Stream Index and determine whether the requested MAS R-T is also acceptable. If the RD-Relay node agrees the relay transmission using the MAS S-R and the MAS R-T, it stores the MAS R-T information for the relay transmission and sends DRP IE to the reservation owner with Reason Code of 'RD-Relay Accepted'. After sending the DRP IE, the RD-Relay node waits for the responses from the target node. If the Reason Code of the DRP IE from the target node is 'RD-Relay Accepted', the RD-Relay node receives packets at the MAS S-R and relays the received packets to the target node according the stored MAS R-T information. Otherwise, the RD-Relay node frees the MAS S-R and removes the MAS R-T information.

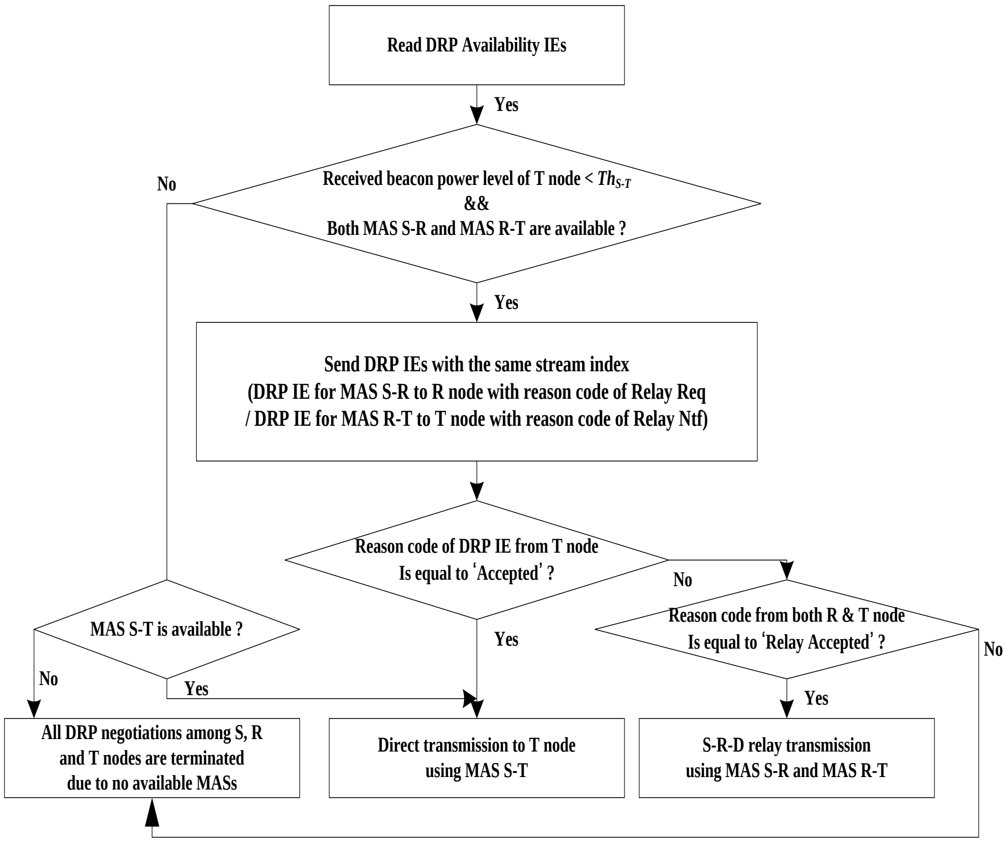


Figure 9. Resource reservation procedure of reservation owner device

The proposed resource reservation procedure of target node is shown in Figure 11. When a target node receives a DRP IE from the reservation owner with Reason Code of 'RD-Relay Ntf', the RD-Relay node checks whether the resource request for MAS R-T in the received DRP IE is acceptable. If the resource request is agreeable to the target node, the target node stores the MAS R-T information for the relay transmission and sends DRP IE to the reservation owner with Reason Code of 'RD-Relay Accepted'. After sending the DRP IE, the target node waits for the responses from the RD-Relay node to the reservation owner. If the Reason Code of the DRP IE from the RD-Relay node to the reservation owner is 'RD-Relay Accepted', the target node receives packets at the MAS R-T. Otherwise, the target node frees the reserved MAS R-T. If the target node receives a DRP IE from the RD-Relay node to the reservation owner with Reason Code which is not equal to 'RD-Relay Accepted' before making decision on the relay transmission, our proposed algorithm makes the target node free the reserved MAS R-T if reserved.

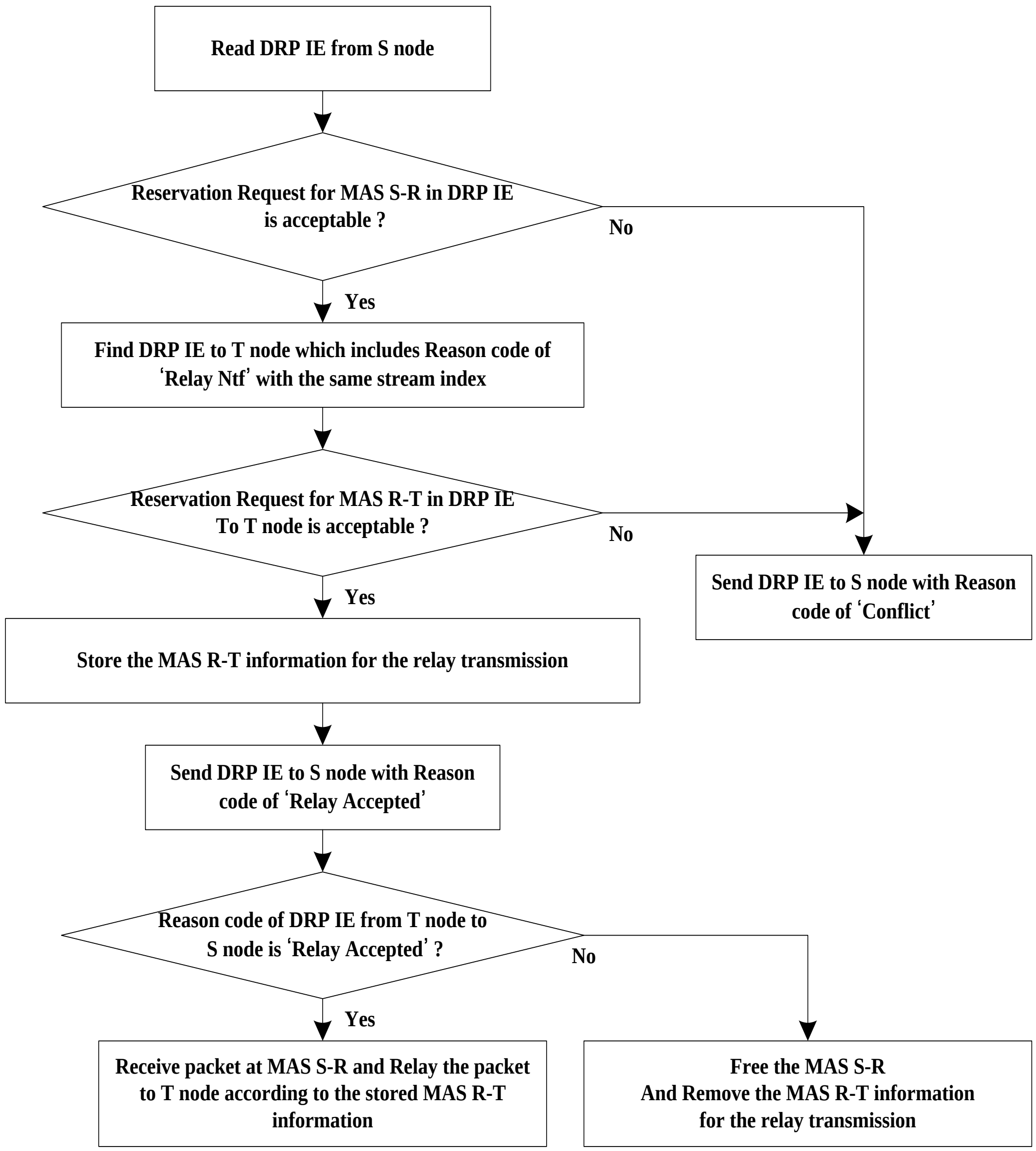


Figure 10. Resource reservation procedure of RD-Relay node

When a DRP IE for MAS S-T with the same Stream Index is included in the same beacon from the reservation owner: 1) when the reservation requests for MAS S-T is agreeable, it sends a DRP IE to the reservation owner with Reason Code of 'Accepted'; 2) if only the reservation request for MAS R-T is acceptable, the target node reserves the MAS R-T for the relay transmission and sends a DRP IE to the reservation owner with Reason Code of 'RD-Relay Accepted'; 3) if no reservation request in the DRP IE is acceptable, the target node sends a DRP IE to the reservation owner with Reason Code of 'Conflict'.

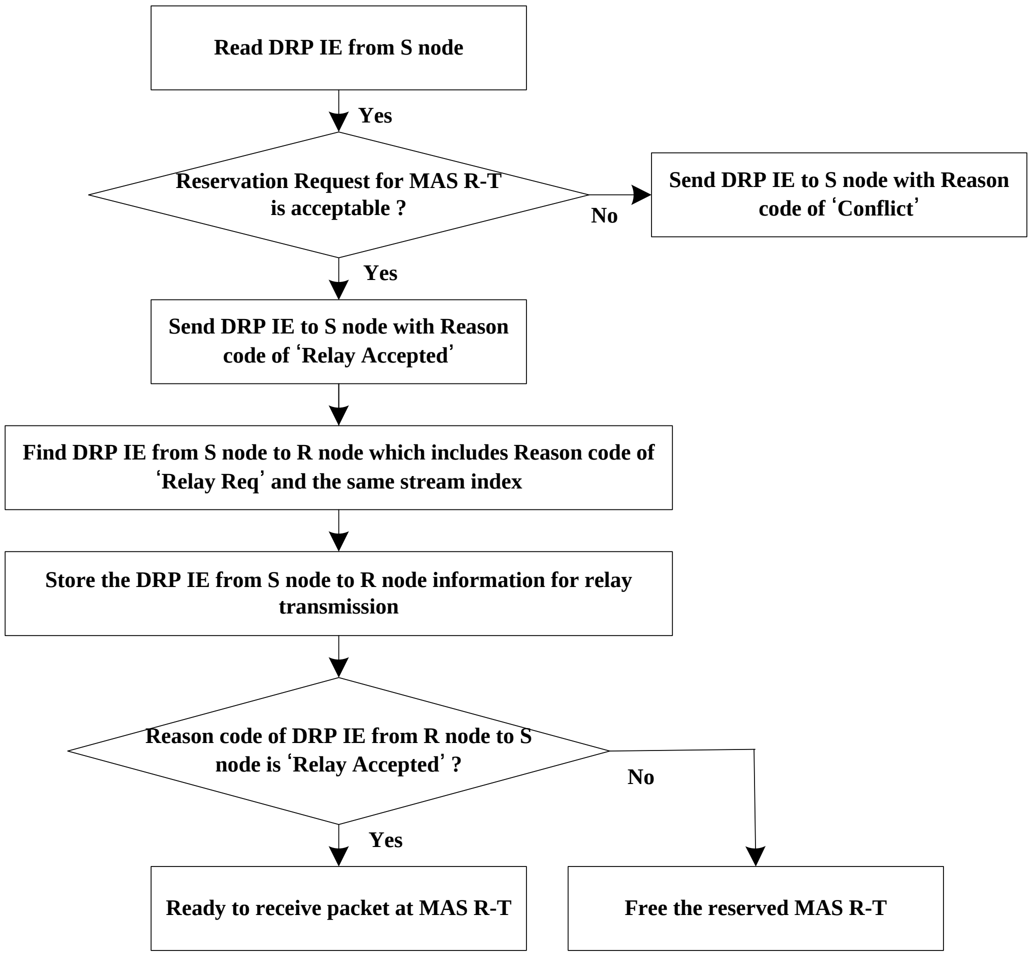
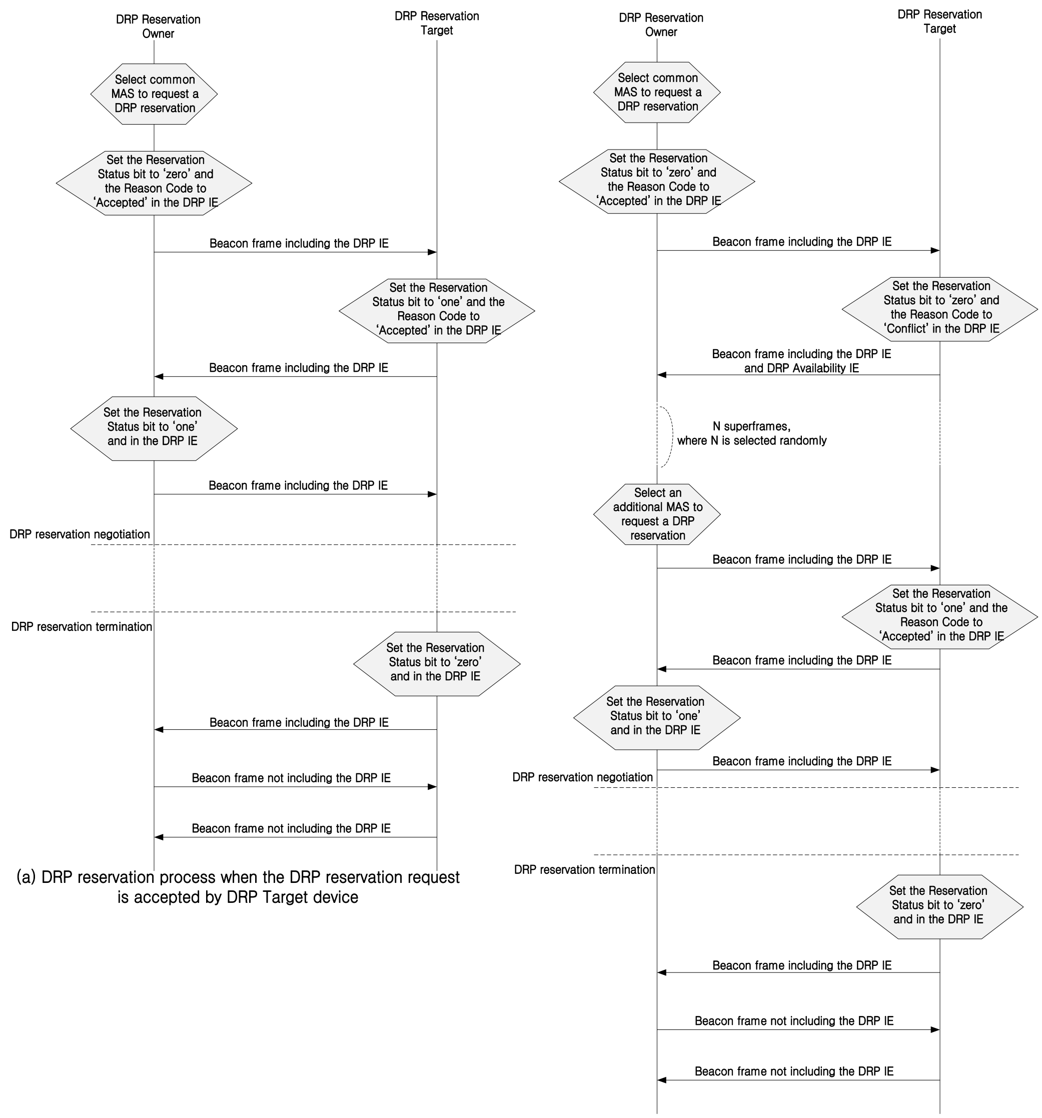


Figure 11. Resource reservation procedure of target node

The inter-operation of DRP negotiation in the RFID D-MAC is explained in Figure 12. The DRP reservation process is always initiated by the device that will initiate frame transactions in the reservation, referred to as the reservation owner. The device requested the reservation negotiation is referred to as the reservation target. When negotiating a reservation, the reservation owner sets the Target/Owner DevAddr field of the DRP IE to the DevAddr of the reservation target. It sets the Reservation Status bit to zero and the Reason Code to Accepted in the DRP IE. When receiving the beacon frame included DRP IE that the Target/Owner DevAddr field sets to the own DevAddr, a reservation target set the the Target/Owner DevAddr field of DRP IE to the DevAddr of the reservation owner. If the reservation is granted, the reservation target shall set the Reservation Status bit to one and the Reason Code bit to 'Accepted'. If the reservation is not granted, it shall set the Reservation Status bit to zero. If the reservation can't be granted due to a conflict with its own or its neighbors' reservations, the reservation target shall set the Reason Code to 'Conflict'.



(a) DRP reservation process when the DRP reservation request is accepted by DRP Target device

(b) DRP reservation process when the DRP reservation request is rejected by DRP Target device due to DRP reservation conflict

Figure 12. The inter-operation of RFID DRP negotiation

4. Performance Evaluation

Performance of the proposed RD-Relay DRP scheme is evaluated through NS-2 simulations. The network size of WiMedia D-MAC based WMS (Warehouse Management System), covered by RFID readers distributed randomly, is 10m*10m. The transmission power of a device is fixed to -41.25dBm/MHz and the packet size transmitted in a beacon group is fixed to 2048 bytes [1, 2]. To analyze WiMedia D-MAC performance, the WiMedia PHY/MAC parameters in the WiMedia specification [3], [6-12] are considered and are found in Table 3.

Table 3. WiMedia PHY/MAC Parameters

Parameter	Value
LPreamble	64 bits
LPHY_Hdr	15 bits
LMAC_Hdr	56 bits
LFCS	16 bits
pMIFS	20 μs
pSIFS	75 μs
pAllocationSlotMin	16 μs
pAllocationSlotResolution	16 μs
pAllocationSlotLength	32 μs
mSuperframeLength	256
pSuperframeLength	mSuperframeLength*pAllocationSlotLength
mBeaconSlotLength	96 μs
mBPExtention	24 μs
mBeacon2SlotLength	80 μs
mB2PExtention	24 μs

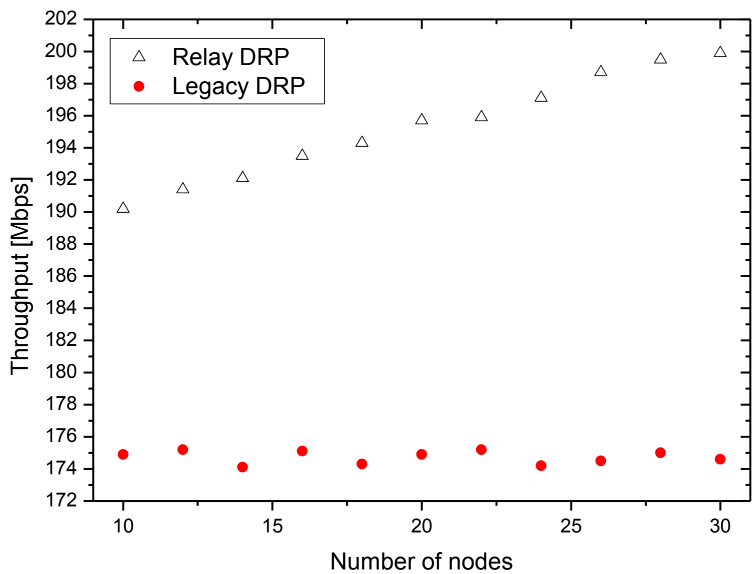


Figure 13. Throughput according to the number of RFID reader nodes

Figure 13 shows throughput of the D-MAC reference device according to the number of RFID reader nodes in the warehouse. Throughput of the proposed RD-Relay DRP scheme is superior to the throughput of the Legacy DRP scheme, and it increases in proportion to the number of RFID reader nodes. This result can be explained as follows. As the number of RFID reader nodes or infra-nodes increases in the warehouse, the more clusters of WiMedia D-MAC beacon groups having overlapping regions with others are generated. Therefore, there occur the more obstacles during communications between the nodes. In these cases, by performing cooperative relay transmissions through RD-Relay DRP scheme, throughput at each node is increased the more.

Figure 14 shows throughput according to BER (Bit Error Rate) indicating current wireless channel status in case that there exist twenty RFID reader nodes or infra-nodes. As the channel status becomes worse, throughput is decreased. But, when using the RD-Relay DRP, throughput decreases less than the Legacy DRP. In the result of RD-Relay DRP, the throughput decreases more than others at the period from BER 10^{-4} to BER 10^{-3} . This result shows that there exist a threshold value where the RD-Relay DRP cannot compensate the throughput decrease due to the deteriorated wireless channel status even though it performs cooperative relay transmissions to find stable channels. Therefore, we can determine the Th_{S-T} value in Fig. 9 for the values of received beacon power levels from target node.

Equation (1) explains the energy consumption required for data transmissions within a superframe in WiMedia D-MAC system with No-Ack policy [6]. P_{tx}, P_{rx}, and P_{idle} are the power consumed at data transmissions, at data receptions, and at idle states within a superframe, respectively. N_{tx} and N_{rx} denote the number of transmitted PSDUs (PHY Service Data Unit) and that of received PSDUs in a DRP reservation block. T_{PSDU} denotes the required time delay during transmitting or receiving a PSDU. T_{MIFS} and T_{SIFS} are time length of MIFS (Minimum Inter-Frame Spacing) and SIFS (Short Inter-Frame Spacing) defined in the WiMedia D-MAC Standard [3], respectively. N_{DRP} denotes the number of DRP reservation blocks in a superframe.

$$E_{Superframe} = [P_{tx} \cdot T_{PSDU} \cdot N_{tx} + P_{rx} \cdot T_{PSDU} \cdot N_{rx} + P_{idle} \cdot T_{MIFS} \cdot (N_{tx} + N_{rx}) + P_{idle} \cdot T_{SIFS}] \cdot N_{DRP} \quad (1)$$

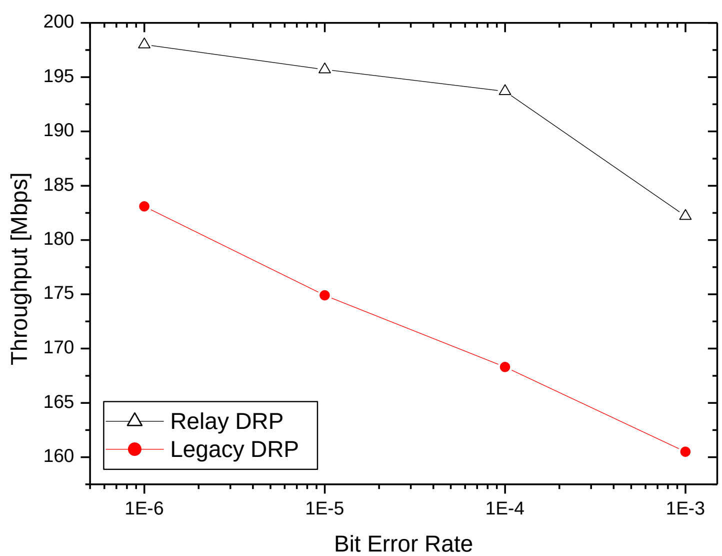


Figure 14. Throughput according to wireless channel status (BER)

5. Conclusion

In this paper, a novel wireless MAC protocol for RFID networks is proposed. To solve the interoperating problem due to the absence of a unified standard between RFID nodes, and to guarantee mobility of RFID reader node, the Distributed MAC-based communication scheme is applied between RFID reader nodes. Especially, a Relay DRP algorithm for the cooperative relay transmissions is proposed to realize the reliable and stable information delivery in RFID networks. From the simulation results, the proposed relay DRP scheme is superior to the Legacy DRP scheme in throughput and energy consumption performances. And the RD-Relay DRP scheme can be directly applied with small overhead to current WiMedia D-MAC standard systems

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