A Dual Channel Allocation Scheme for WiMedia Networks

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Abstract

In this paper, a Dual Channel Allocation (DCA) Scheme for UWB (Ultra Wide Band) with D-MAC (Distributed Medium Access Control) is proposed. Since distributed characteristic of the WiMedia D-MAC supporting DRP (Distributed Reservation Protocol) scheme may cause lots of conflicts, overall performances of the WiMedia D-MAC can be deteriorated. Such DRP termination and renegotiation time delays due to the DRP conflicts can be a critical problem to the mobile devices transceiving real-time QoS traffic streams. Therefore, we propose a DCA mechanism to avoid DRP conflicts by providing a cooperative relay transmission scheme and demonstrate its performance improvements via simulation results.

Keywords: *WiMedia, Distributed MAC, Relay Transmission*

1. Introduction

A tremendous growth in popularity of wireless personal devices is increasingly requiring efficient communications between those devices. Hence, WPAN technology such as UWB is continuously gaining interest for ubiquitous connections in home entertainment, security, and medical/military applications due to its inexpensive cost, low power consumption, and small size. UWB devices are expected to operate at rates of up to 0.5 Gbps and communicate with other devices within a range of up to 10 m, thus make high-speed WPANs enable. UWB devices are allowed to operate in an unlicensed manner in the 3–10 GHz band, with limited transmit power. Due to the limited transmission power, UWB devices do not make fatal interference, and therefore can coexist with other users and technologies in the same band. The salient features of UWB networks such as high-rate communications, low interference with other radio systems, and low power consumption bring many benefits to users, thus enabling several new applications such as wireless universal serial bus (WUSB) for connecting personal computers (PCs) to their peripherals and the consumer-electronics (CE) in people’s living rooms [1].

The WPAN defines two kinds of MAC scheme, one is centralized approach and the other is distributed one. A representative example of the centralized MAC approach is IEEE 802.15.3 protocol [4]. The IEEE 802.15.3 MAC makes devices form a piconet which consists of a piconet coordinator (PNC) and the rest of piconet member devices. A PNC allocates channel resources to other piconet member devices in its own piconet. However, the current IEEE 802.15.3 based on the centralized architecture has several problems. Firstly, if a PNC device disappears from the piconet *e.g.*, due to movement, dead battery, or channel condition, the member devices of the piconet waste lots of time and energy in order to re-elect a new PNC. As a result, the quality of service (QoS) of all streams cannot be guaranteed during the PNC re-election procedure.

Secondly, when more than two piconets overlap each other, the efficiency of the IEEE 802.15.3 degrades significantly (*i.e.*, SOP (Simultaneous Operating Piconet) problem). For example, if two devices connected to different PNCs are within the range of each other and unfortunately use the same time slots, each device's transmission will collide, and therefore the performance of the piconet operation is deteriorated. In this case, the corresponding PNCs may not be aware of the overlapping piconets since the PNCs are not within the range of each other and not within the range of the interfering device in the other piconet. The last problem of the current IEEE 802.15.3 is a difficulty to extend the coverage of WPANs [1, 4]. Consequently, the centralized MAC approach in WPANs has critical problems in mobility support and QoS provisioning to real-time isochronous streams

On the other hand, the WiMedia Alliance has specified a D-MAC protocol based on UWB for High-Rate WPANs [3]. The WiMedia D-MAC supports a distributed MAC approach. In contrast to the IEEE 802.15.3, the D-MAC UWB supports DRP mechanism which makes all devices be connected using self-organizing approach. In the distributed architecture, by exchanging resource reservation and control information among the devices [1], especially via DRP IE (Information Element) and DRP Availability IE in each device's beacon signal, the WiMedia D-MAC removes the SOP problem in the centralized IEEE 802.15.3 MAC. In the D-MAC, each node broadcasts its own beacon containing IEs per a superframe. The IEs convey certain control and management information. The distributed nature of D-MAC protocol can provide a full mobility support and a scalable and fault tolerant medium access method [3].

However, the conventional WiMedia D-MAC still has hidden node problem, and its distributed characteristic may cause lots of conflicts. Thus, in order to get full benefits of the distributed MAC approach, we should overcome the conflicts among devices. There has been a resolution method for the DRP reservation conflicts [3]. However, the method only focuses on how to resolve conflicts after the conflict occurrence without considering how to avoid the conflicts beforehand. Therefore, in this paper, we propose a mechanism to avoid DRP conflicts by providing a relay transmission scheme [5].

2. WiMedia D-MAC Protocol

As in Figure 1, 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.

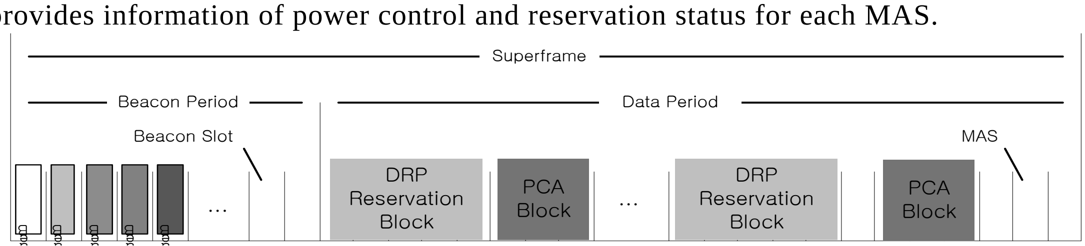

Figure 1. Superframe Structure in WiMedia MAC

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 2 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 2, 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.

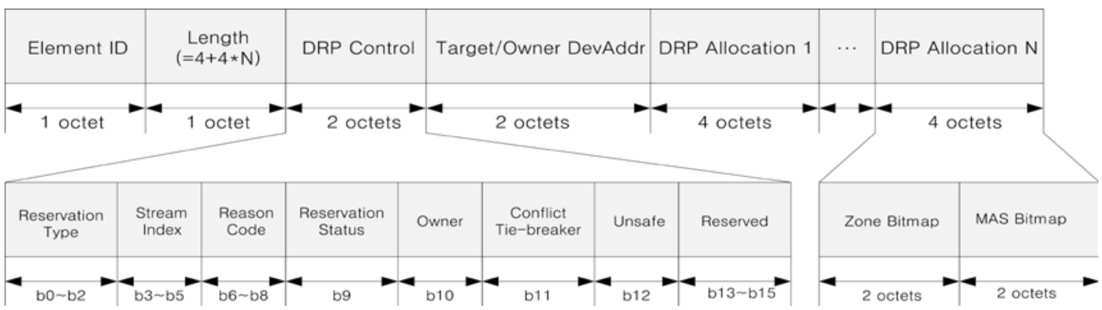

Figure 2. The Format of DRP IE

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

The DRP scheme enables devices to reserve one or more MASs that the device can use to communicate with one or more neighbors. A reservation of MASs guarantees a period of time for transmission during which the reservation owner has exclusive access to the medium. A device that wishes to establish a reservation negotiates the channel time with its communication peer. There is no need for a central entity that controls the reservation process. In DRP, a device can only establish a reservation during the MASs that are not being used by another existing reservations. All devices that use the DRP for transmission or reception shall announce their reservations by including DRP IEs (Information Elements) in their beacons, and DRP IE is illustrated in Figure 2. As mentioned above, DRP IEs are used to negotiate a reservation for certain MASs and to announce the reserved MASs. 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 indicates whether the device sending this DRP IE is the reservation owner or not.

In WiMedia D-MAC, DRP is contention-free channel access scheme since it uses guaranteed slot reservation to provide QoS support and isochronous service. A reservation, defined by a subset of MASs (Medium Access Slots) during the superframe, guarantees a period of time for transmission during which the reservation owner has exclusive access to the medium. A device that needs a reservation starts negotiation to setup the communication channel time with its communication peer. And there is no need of a central entity that controls the reservation process in the WiMedia D-MAC. In the DRP, a device can establish only a reservation of a MAS block among the MASs which are not being used by any other existing reservation.

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’.

3. Dual Channel Allocation (DCA) Scheme for Conflict Avoidance

In this Section, we propose a conflict avoidance algorithm for DRP resource reservation using reservation diversity based on cooperative relay transmission scheme. In order to give the potential loser device (DEV A in Fig. 3) another chance to maintain wireless resources, we propose to request to reserve another link via a relay device (MAS A-C and MAS B-C) as well as the direct link (MAS A-B) as shown in Figure 3.

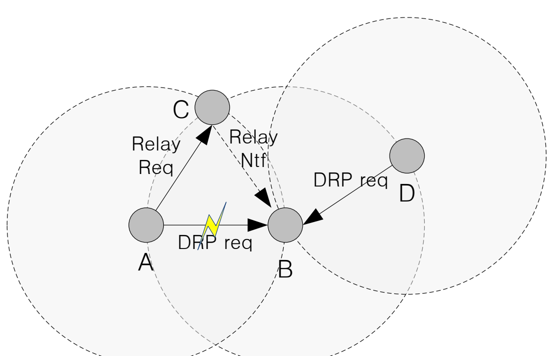

Figure 3. An Example of Dual Channel Allocation

To ensure full compliance with the WiMedia D-MAC and guarantee backward compatibility, our proposed reservation diversity scheme basically follows the DRP standard described above. Our proposal only adds three code-points to the Reason Code as shown in Table 2.

The Reason Code of 'DCA-R Req' is sent by a reservation owner to a relay device to request a DRP reservation between the owner and the relay device. The 'DCA-R Req' Reason Code implicitly notifies the target device of the DRP reservation request between the owner and the DCA-Relay node. The Reason Code of 'DCA-R Ntf' is sent by a reservation owner to a target device to request a DRP reservation between a relay device and the target. The 'DCA-R Ntf' Reason Code implicitly notifies the relay device of the DRP reservation between the DCA-Relay node and the target. These 'DCA-R Req' and 'DCA-R Ntf' Reason Codes ultimately intend to reserve DRP resources for relay transmission to the target node via the DCA-Relay node. The Reason Code of 'DCA-R Accepted' denotes that the DRP reservation request via corresponding relay device is granted. Accordingly, if both the Reason Codes from the DCA-Relay node and the target node are set to 'DCA-R Accepted', it means the DRP resources from the reservation owner to the target node via the DCA-Relay node are successfully reserved.

Table 2. Additional Reason Code Field Encoding for DCA

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

From Figure 4 to Figure 6, we depict the proposed resource reservation procedures of reservation owner, DCA-Relay node, and target node in detail. The reservation owner reserves DRP resources as shown in Figure 4. After reading DRP Availability IEs from other devices' beacons, the reservation owner checks whether MASs between the reservation owner and the target node (MAS S-T) are available.

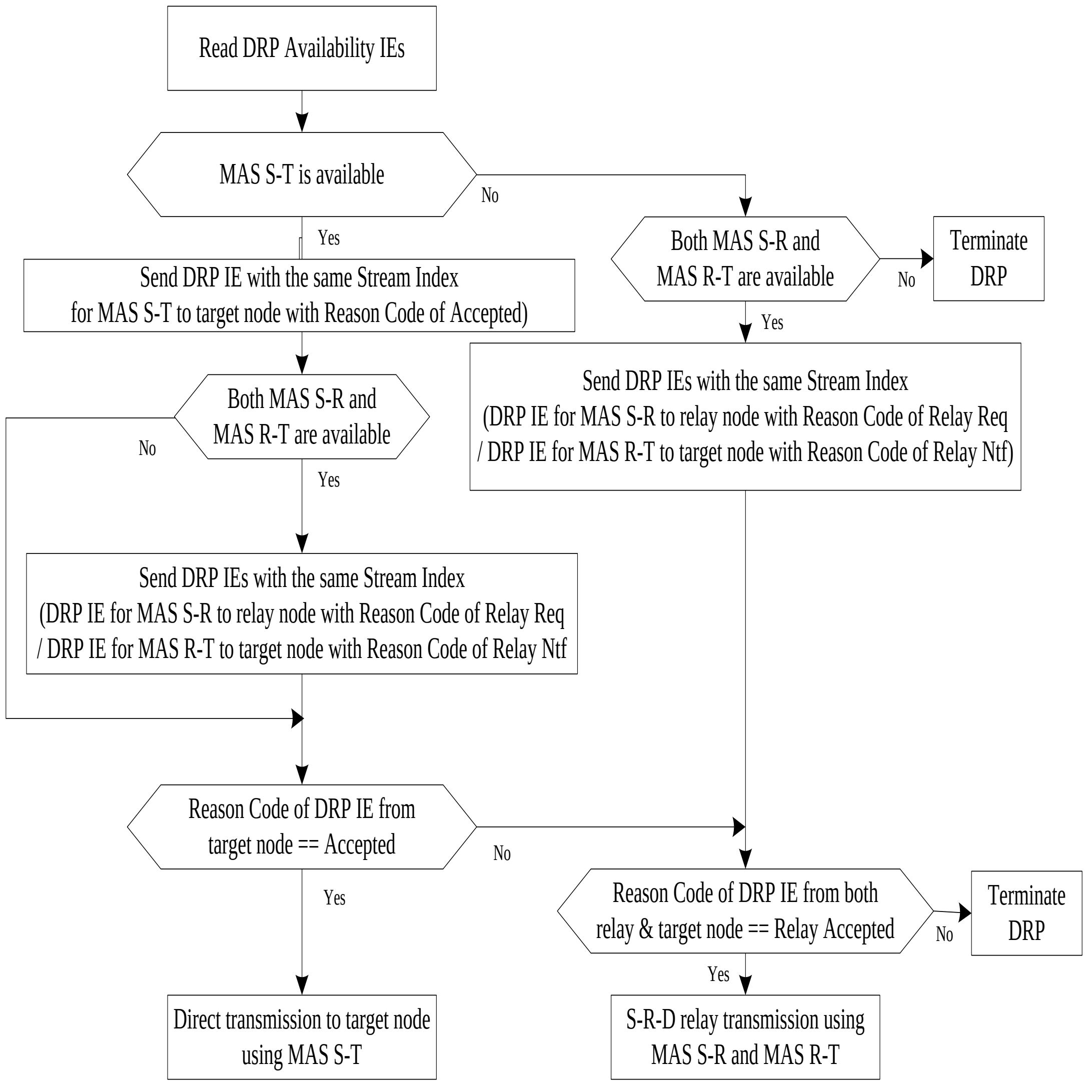

Figure 4. Resource Reservation Procedure of Reservation Owner Device

If there is available MAS S-T, the reservation owner checks if both MAS S-R and MAS R-T are also free to use for the relay transmission. If both resources are available, the reservation owner sends DRP IEs with the same stream index as follows: DRP IE for MAS S-R to the DCA-Relay node with the Reason Code of 'DCA-R Req'; DRP IE for MAS R-T to the target node with the Reason Code of 'DCA-R Ntf'; DRP IE for MAS S-T to the target node with the Reason Code of 'Accepted'. In case of no available MAS S-T, the reservation owner only sends DRP IEs for relay transmission, *i.e.*, MAS S-R and MAS R-T.

After sending the DRP IEs using beacon, the reservation owner waits for the responses from the DCA-Relay node and the target node. If the Reason Code of the DRP IE from the target node is 'Accepted', the reservation owner sends the target node data packets using the direct transmission scheme. In case of 'DCA-R Accepted' Reason Code from both the DCA-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.

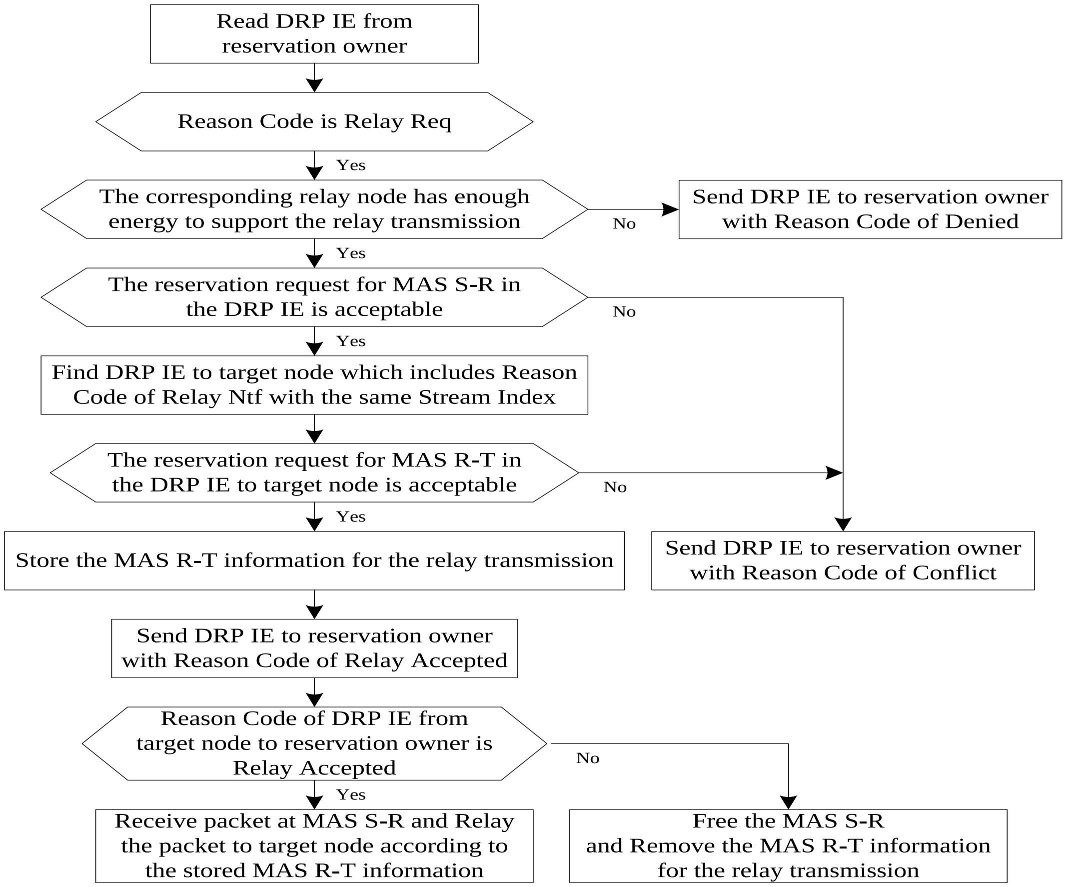

Figure 5. Resource Reservation Procedure of DCA-Relay Node

Figure 5 shows the proposed resource reservation procedure for DCA-Relay node. When a DCA-Relay node supporting relay diversity has enough energy for relay transmission and receives a DRP IE from the reservation owner with Reason Code of ‘DCA-R Req’, the DCA-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 DCA-Relay node, the DCA-Relay node should read DRP IE to target node which includes Reason Code of ‘DCA-R Ntf’ with the same Stream Index and determine whether the requested MAS R-T is also acceptable. If the DCA-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 ‘DCA-R Accepted’.

After sending the DRP IE, the DCA-Relay node waits for the responses from the target node. If the Reason Code of the DRP IE from the target node is ‘DCA-R Accepted’, the DCA-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 DCA-Relay node frees the MAS S-R and removes the MAS R-T information. If the DCA-Relay node receives a DRP IE from the target node with Reason Code which is not equal to ‘DCA-R Accepted’ before making decision on the relay transmission, our proposed algorithm makes the DCA-Relay node free the MAS S-R and remove the MAS R-T information.

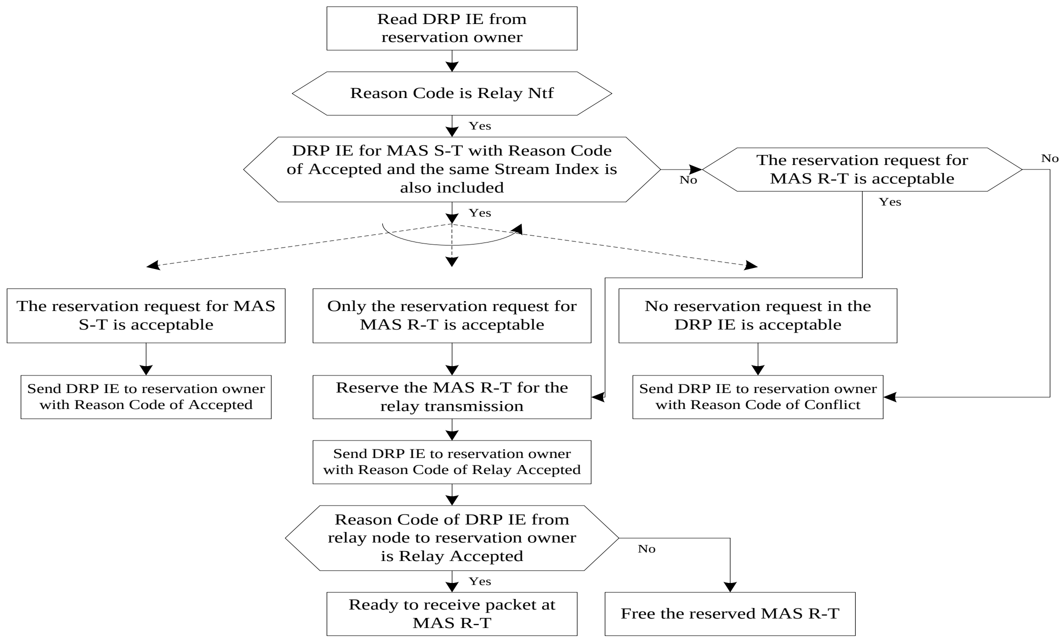

Figure 6. Resource Reservation Procedure of the Target Node

The proposed resource reservation procedure of target node is shown in Figure 6. If a DRP IE for MAS S-T with the same Stream Index is not included in the same beacon from the reservation owner and the reservation request for the 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 ‘DCA-R Accepted’ since no MAS S-T is available.

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 ‘DCA-R 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’.

In case of sending DRP IE with Reason Code of ‘DCA-R Accepted’, the target node waits for the responses from the DCA-Relay node to the reservation owner after sending the DRP IE. If the Reason Code of the DRP IE from the DCA-Relay node is ‘DCA-R Accepted’, the target node prepares to receive 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 DCA-Relay node to the reservation owner with Reason Code which is not equal to ‘DCA-R Accepted’ before making decision on the relay transmission, our proposed algorithm makes the target node free the reserved MAS R-T if reserved.

4. Performance Evaluation

Performance of the proposed scheme is evaluated through NS-2 simulations [6-13]. Table 3 shows WiMedia PHY/MAC simulation parameters used in this paper. And Table 4 shows the DRP simulation parameters used in this paper; the network size, covered by two-hop range of a reference device, is 10m*10m; the total 30 devices are randomly deployed into this area. For this simulation, we denote a number of MASs in own DRP reservations of the reference device during 30 seconds per one minute as DRP_{own}. And a number of MASs in DRP periods reserved during 30 seconds per one minute by a 1-hop neighbor device of the reference device is denoted as $R_{1\text{-}hop}$. Also, a number of 2-hop distant devices from the reference device is denoted as $N_{2\text{-}hop}$. On the other hand, each device has two kinds of mobility with each corresponding probability such as m_{in} and m_{out}. The m_{in} means a probability during one minute with which a device moves into a 1-hop closer range of the reference device, such as it moves from 2-hop to 1-hop range. And m_{out} means a probability during one minute with which a device moves into a 1-hop outer range of the reference device, such as it moves from 1-hop to 2-hop range.

Table 3. WiMedia PHY/MAC Parameters

Parameter	Value
T_{SYM}	312.5ns
T_{sync}	Standard Preamble: 9.375 μs
pMIFS	1.875 μs
pSIFS	10 μs
mMAXFramePayloadSize	4,095 octets
mMAXBPLength	96 beacon slots
mBeaconSlotLength	85 μs
mSuperframeLength	256*mMASLength
mMASLength	256 μs
mBPExtension	8 beacon slots
mTotalMASLimit	112 MASs

Table 4. DRP Simulation Parameters

Parameter	Value
Total number of devices	30
Total Simulation Time	10 minutes
$R_{1\text{-}hop}$	30MASs/30secs/minute
$N_{2\text{-}hop}$	20
DRP_{own}	30MASs/30secs/minute
m_{out}	0.2/minute

To analyze the WiMedia D-MAC efficiency, we adopted the Theoretical Maximum Throughput (TMT) concept used in [2] and assume that (1) Bit error rate (BER) is zero (2) There are no losses due to collisions (3) No packet loss occurs due to buffer overflow at the receiving node (4) Sending node always has sufficient packets to send (5) The MAC layer does not use fragmentation (6) Management frames such as beacon and association frames are not considered.

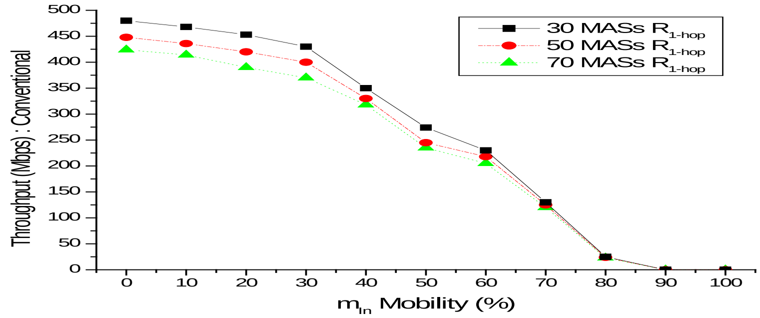

Figure 7. Throughput of a WiMedia D-MAC Device according to each m_{In} Probability

Figure 7 shows throughput of the D-MAC reference device according to min value of a device. In Figure 7, we assume that the UWB PHY data rate of the reference device is fixed to 480 Mbps and the frame size transmitted in a beacon group is fixed to 4095 bytes. As shown in Figure 7, the throughput of D-MAC device doesn't depend largely on the $R_{1\text{-}hop}$ value especially at high m_{In} robability over 70%, but it varies according to m_{In} probability of devices. This result may affect the QoS throughput performance and degrade the energy efficiency of the WiMedia D-MAC devices. Therefore, such DRP reservation conflicts should be considered seriously when designing the WiMedia D-MAC technology.

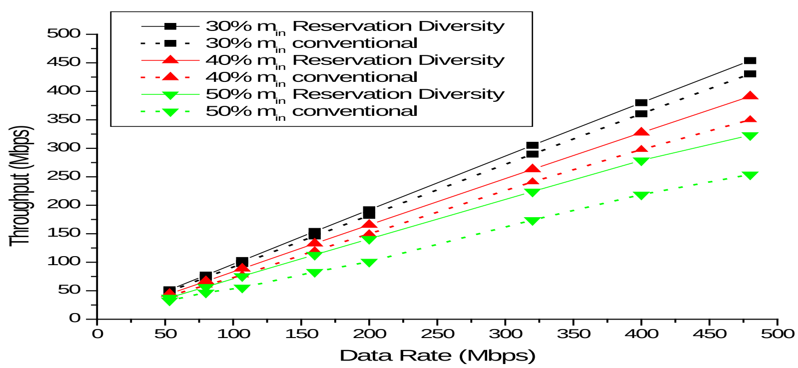

Figure 8. Conflict-avoided throughput of a D-MAC Stream according to UWB PHY Data Rate

Figure 8 shows conflict-avoided throughput QoS performance of a WiMedia D-MAC stream according to the PHY data rate of UWB for each m_{In} probability. As shown in this simulation result, the conflict-avoided throughput of a stream decreases according to the probability of m_{In} of a 2-hop distant device. This is because the increment of the m_{In} probability causes more DRP reservation conflicts. From another point of view, this result shows that how much the proposed DRP DCA scheme based on cooperative relay transmission scheme improves throughput QoS performance for a traffic stream from a WiMedia device, through the conflict avoidance.

To analyze the efficiency of proposed scheme, we introduce the Theoretical Maximum Throughput (TMT) concept used in [2]. The TMT of private DRP mode is presented as in Eq. (1) where NMSDU is the total number of MSDUs that can be completely transmitted in private DRP reservation blocks, L_{MSDU} is the length of MSDU (MAC Service Data Unit) up to 4096 bytes, T_{DRP} denotes the actual time required to successfully transmit those MSDUs, L_{DTP} is the length of a DTP (Data Transmission Period) and mSuperframeLength is the length of a superframe which is defined in the WiMedia Specification [3].

$$TMT_{DRP} = \frac{8 \times N_{MSDU} \times L_{MSDU}}{T_{DRP}} \times \frac{L_{DTP}}{mSuperframeLength} \quad (1)$$

In Eq. (1), L_{DTP} can't exceed mTotalMASLimit MASs. Because data frames cannot be transmitted during BP (Beacon Period) in a superframe, we must consider the ratio of the length of BP in a superframe. The length of a BP is decided by the number of devices in a beacon group. Therefore, L_{DTP} is calculated as in Eq. (2) where mBeaconSlotLength is the length of each beacon slot.

$$L_{DTP} = mSuperframeLength - mBeaconSlotLength \times (2 + N_{devices} + mBPExtension) \quad (2)$$

In Eq. (2), $N_{devices}$ is the number of devices in a beacon group, and mBPExtension is the number of surplus beacon slots prepared for beacon group extensions. Since the length of BP doesn't exceed mMaxBPLength, L_{DTP} may include more than 224 MASs. In the WiMedia D-MAC, unlike the conventional PPDU (PLCP Protocol Data Unit) structure, an MSDU becomes the payload in a PPDU. The length of PLCP (Physical Layer Convergence Protocol) Header including WiMedia D-MAC header can be ignored since it is very short compared with the length of PSDU (PHY Service Data Unit). Thus, N_{MSDU} is equal to the number of PPDUs in private DRP reservation blocks.

$$N_{MSDU} = N_{PSDU} = N_{PPDU} \quad (3)$$

Figure 9 shows some frame transactions according to each acknowledgement (ACK) policy. As shown in Figure 9, the number of MSDUs within a private DRP reservation block is determined by an ACK policy. With No-ACK or B-ACK (Block-ACK) policy, there are MIFS (Minimum Interframe Spacing) durations between frames in the burst except the last frame, as shown in Figure 9. Also, all the frames are separated by an SIFS (Short Interframe Spacing) interval. The length of SIFS and MIFS is given by the pSIFS and pMIFS parameters and their values are defined in the WiMedia specification [3]. Therefore, N_{MSDU} is differently calculated according to ACK policy as follows.

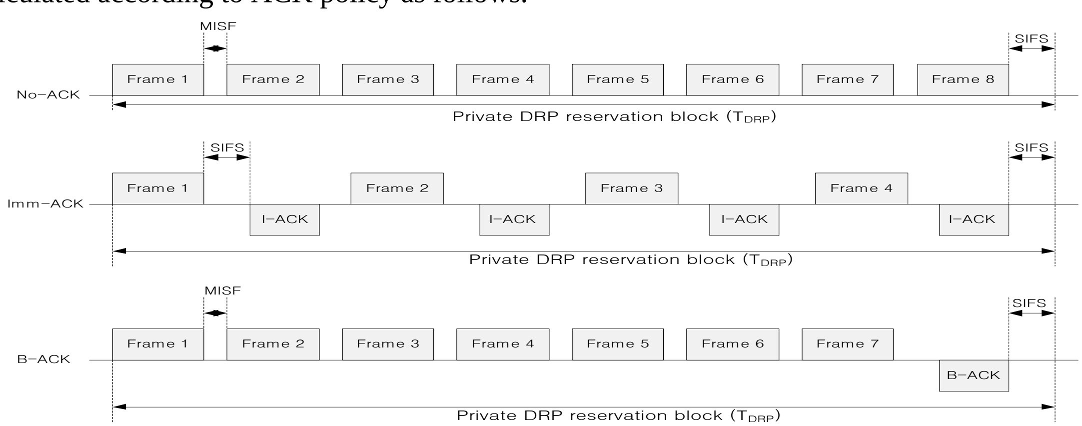

Figure 9. Example of some Frame Transactions according to each ACK Policy

With the No-ACK policy, the number of MSDUs within a private DRP reservation block is calculated by Eq. (4) where Tframe is the duration of a PSDU and can it be derived from Eq. (5). The T_{SYM} is defined in the WiMedia specification.

$$N_{MSDU} = \frac{T_{DRP} + pMIFS - pSIFS}{T_{frame}} \quad (4)$$

$$T_{frame} = 6 \times \left\lceil \frac{8 \times L_{MSDU} + 38}{N_{IBP6S}} \right\rceil \times T_{SYM} \quad (5)$$

With the Imm-ACK (Immediate-ACK) policy, the number of MSDUs within a private DRP reservation block is calculated by Eq. (6) where $T_{Imm\text{-}ACK}$ is the duration for the Imm-ACK frame.

$$N_{MSDU} = \frac{T_{DRP}}{T_{frame} + T_{\mathrm{Im}m-ACK} - 2\,pSIFS} \quad (6)$$

According to the WiMedia specification, Imm-ACK frame has no payload with only a MAC header. Therefore, TImm-ACK can be derived from Eq. (7) where T_{sync} is the duration of the PLCP preamble and T_{hdr} is the length PLCP header.

$$T_{\mathrm{Im}m-ACK} = T_{sync} + T_{hdr} \quad (7)$$

With the B-ACK policy, the number of MSDUs within a DRP reservation block is calculated by Eq. (8) where $T_{B\text{-}ACK}$ is the duration of the B-ACK frame and can be derived from Eq. (9).

$$N_{MSDU} = \frac{T_{DRP} - T_{B-ACK} + pMIFS - 2\,pSIFS}{T_{frame} + pMIFS} \quad (8)$$

$$T_{B-ACK} = T_{sync} + T_{hdr} + T_{frame} \quad (9)$$

The PSDU data rate-dependant modulation parameters in the WiMedia specification can be found in Table 5.

Table 5. PSDU Data Rate-Dependant Parameters

Data Rate (Mbps)	Info Bits / 6 OFDM Symbol (NIBP6S)
53.3	100
80	150
106.7	200
160	300
200	375
320	600
400	750
480	900

5. Conclusion

In this paper, a new Dual Channel Allocation (DCA) to avoid DRP reservation conflicts has been proposed. The proposed algorithm prominently improves throughput and guarantees seamless QoS performance for real-time traffic streams by using the cooperative relay transmission scheme with small amount of overhead. Therefore, it will play a key role in a typical personal/mobile WiMedia D-MAC communication environment and in a wireless USB communication environment.

Acknowledgements

This work was supported in part by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (MEST) (2010-0002366) and in part by Mid-career Researcher Program through NRF grant funded by the MEST (2011-0016145).

This paper is a revised and expanded version of a paper entitled Mobility and QoS support Mechanism for WiMedia Home Networks presented at Computer and Applications, Seoul, Korea, 3.30-31, 2012.

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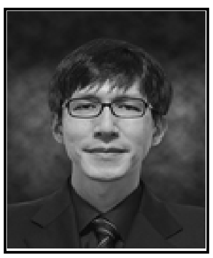

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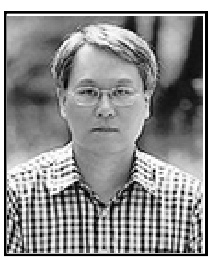

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