A Conflict-Avoided Resource Reservation using Reservation Diversity for UWB WPAN with Distributed MAC Protocol

Yang-Ick Joo, Kyeong Hur, *Member, KIMICS*

***Abstract*—In this paper, a conflict-avoided resource reservation scheme for UWB (Ultra Wide Band) WPAN (Wireless Personal Area Network) 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. In addition, once a DRP conflict occurs, only one of the DRP reservations involved in that DRP conflict maintains the reserved MASs, while the other DRP reservation must be terminated and DRP negotiations for them have to be re-started. 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 mechanism to avoid DRP conflicts by providing a kind of path diversity using relay transmission scheme and demonstrate its performance improvements via simulation results.**

***Index Terms*— WiMedia, Distributed MAC, WPAN, UWB, Distributed Reservation Protocol (DRP), Relay.**

I. 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

Manuscript received July 11, 2011; revised July 15, 2011; accepted July 29, 2011.

Yang-Ick Joo is with the Department of Electronics Engineering, Korea University, Seoul, Korea (e-mail: yangick.joo@gmail.com).

Kyeong Hur is the corresponding author with the Department of Computer Education. Gyeongin National University of Education, Incheon, Korea(e-mail: khur@ginue.ac.kr).

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] [5], [6]. 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 kind of path diversity using relay transmission scheme.

This paper is organized as follows: In Section 2, we describe the current method for DRP reservation and the associated conflict resolution scheme in WiMedia D-MAC. Our proposed DRP conflict avoidance algorithm among devices is explained in Section 3. In Section 4, a simulation model for the proposed scheme is presented and its performances are demonstrated. Finally, in Section 5, concluding remarks are presented.

II. THE CURRENT DRP RESERVATION AND CONFLICT RESOLUTION SCHEME

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 Fig. 1 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 Fig. 1, 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 Reservation Type field indicates the type of the reservation and the Stream Index field identifies the stream of data to be sent in this reservation. 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. This Reason Code is set to 'zero' (i.e., 'Accepted'), in a DRP IE sent by a reservation owner during negotiation or by a device maintaining an established reservation. The Reservation Status bit shows the status of the DRP negotiation process. The Reservation Status bit is set to 'zero' in a DRP IE for a reservation that is under negotiation or in conflict, while it is set to 'one' by a device granting or maintaining a reservation referred to as an established reservation. The Owner bit is set to 'one' if the device transmitting the DRP IE is a reservation owner, or to 'zero' if the device transmitting the DRP IE is a reservation target. The Conflict Tie-breaker bit is set to a random value of zero or one when the reservation request is made. For all DRP IEs that represent the same reservation, the Conflict Tie-breaker bit is set to the same value. The Unsafe bit is set to 'one' if any MASs identified in the DRP Allocation fields are considered in excess of reservation limits.

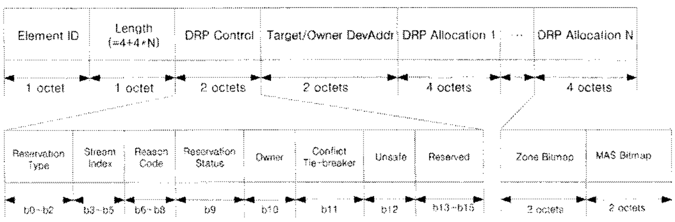


Fig. 1. The format of DRP IE.

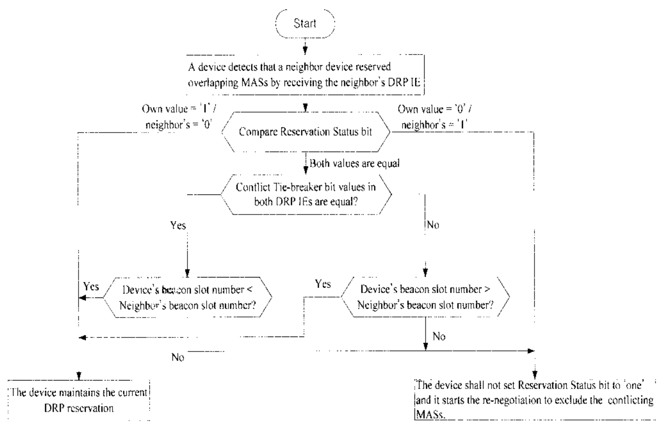


Fig. 2. The DRP reservation conflict resolution scheme.

Fig. 2 summarizes the conventional conflict resolution scheme using the IEs described above. When a device detects that a device reserved overlapped MASs by receiving the neighbor device's DRP IE, the device should resolve the reservation conflict using the values of Reservation Status bit and Conflict Tie-breaker bit as shown in Fig. 2. Once a DRP conflict occurs, only one of the DRP reservations involved in that DRP conflict maintains the reserved MASs. On the other hand, the other DRP reservation must be terminated and DRP negotiations for them have to be re-started, although only a few MASs are overlapped. Consequently, the conventional WiMedia D-MAC protocol can waste channel time slots and consume additional TX/RX power during the renegotiation processes due to the DRP reservation conflicts. However, any conflict avoidance method against the DRP conflict has not been defined in the WiMedia D-MAC protocol.

TABLE I
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

III. CONFLICT AVOIDANCE SCHEME FOR DRP RESOURCE RESERVATION

In this Section, we propose a conflict avoidance algorithm for DRP resource reservation using reservation diversity based on 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 Fig. 3.

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

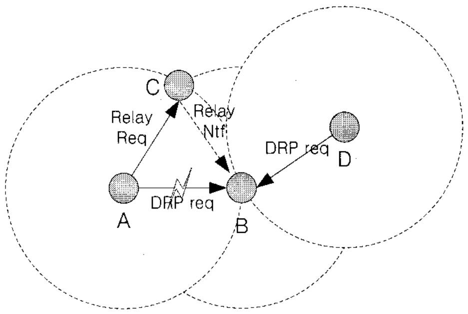


Fig. 3. An example of reservation diversity.

TABLE II
ADDITIONAL REASON CODE FIELDS ENCODING FOR RESERVATION DIVERSITY.

Value	Code	Description
5	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	Sent by a reservation owner to a target device to request the DRP reservation between a relay device and the target
7	Relay Accepted	The DRP reservation request via corresponding relay device is granted

From Fig. 4 to Fig. 6, we depict the proposed resource reservation procedures of reservation owner, relay node, and target node in detail. The reservation owner reserves DRP resources as shown in Fig. 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.

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 relay node with the Reason Code of 'Relay Req'; DRP IE for MAS R-T to the target node with the Reason Code of 'Relay 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.

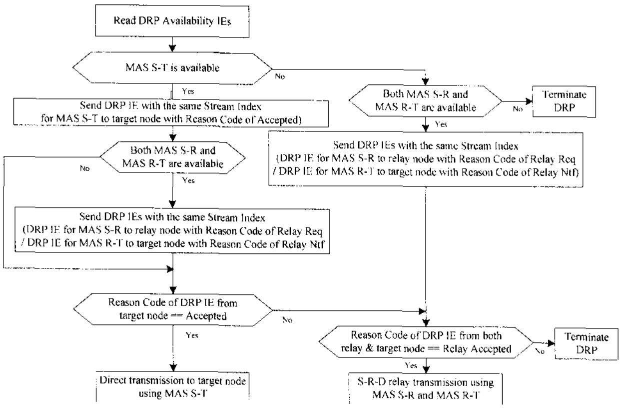


Fig. 4. The proposed resource reservation procedure of reservation owner device.

After sending the DRP IEs using beacon, the reservation owner waits for the responses from the 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 'Relay Accepted' Reason Code from both the 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.

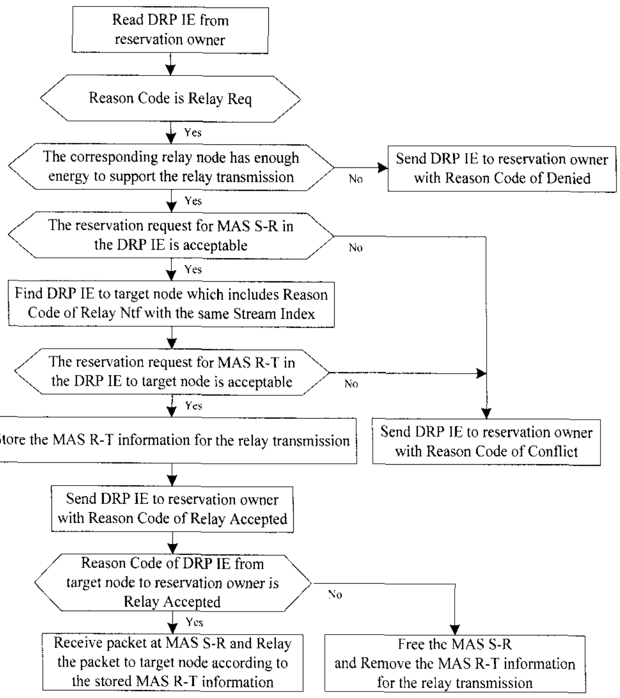


Fig. 5. The proposed resource reservation procedure of relay node.

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

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

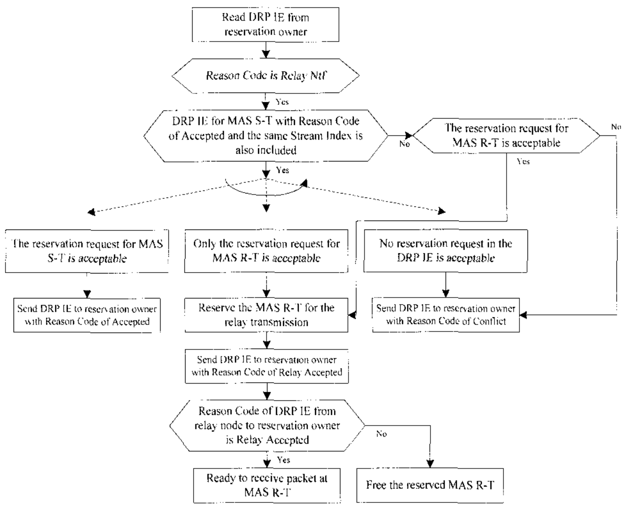


Fig. 6. The proposed resource reservation procedure of target node.

The proposed resource reservation procedure of target node is shown in Fig. 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 'Relay 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 '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'.

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

IV. PERFORMANCE ANALYSES

TABLE III
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

Performance of the proposed scheme is evaluated through NS-2 simulations. Table 3 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. The WiMedia PHY/MAC parameters in the WiMedia specification [3] are found in Table 4.

TABLE IV
WIMEDIA PHY/MAC SIMULATION PARAMETERS.

Parameter	Value
T_{SYM}	312.5ns
T_{sync}	Standard Preamble: 9.375μs
pMIFS	1.875μs
pSIFS	10μs
mMAXFramePayloadSize	4,095 octets
mMAXBPLength	96 beacon slots
mBeaconSlotLength	85μs
mSuperframeLength	256*mMASLength
mMASLength	256μs
mBPExtension	8 beacon slots
mTotalMASLimit	112 MASs
Data rate (Mbps)	53.3, 80, 106.7, 160, 200, 320, 400, 480

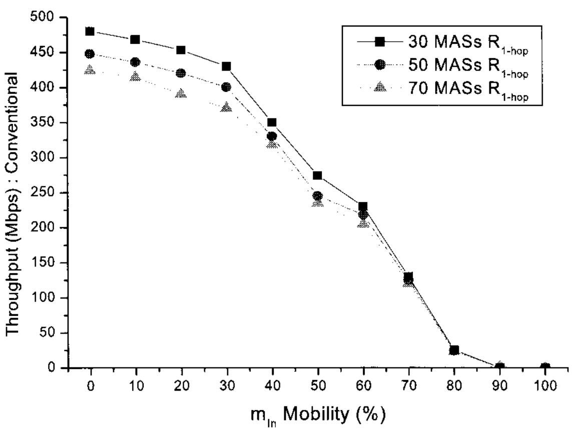


Fig. 7. Throughput of a WiMedia D-MAC device according to each m_{in} probability.

Fig. 7 shows throughput of the D-MAC reference device according to m_{in} value of a device. In Fig. 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 Fig. 7, the throughput of D-MAC device doesn't depend largely on the $R_{1\text{-}hop}$ value especially at high m_{in} probability over 70%, but it varies according to m_{in} probability of devices. Fig. 8 shows the probability of a 1-hop range DRP conflict according to the $R_{1\text{-}hop}$ value which is the number of MASs in the DTP period reserved by a 1-hop neighbor device. As shown in Fig. 8, the probability of a DRP reservation conflict increases rapidly along with $R_{1\text{-}hop}$ and m_{in} values. 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.

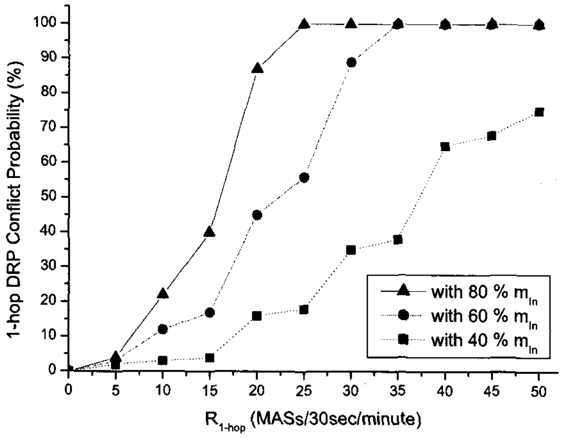


Fig. 8. 1-hop DRP conflict probabilities.

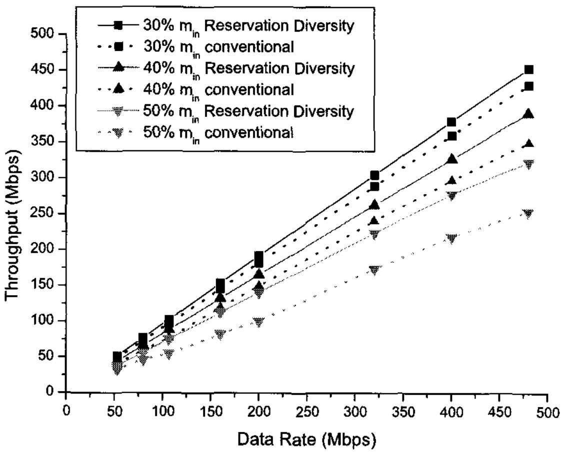


Fig. 9. Conflict-avoided throughput of a D-MAC stream according to UWB PHY data rate.

Fig. 9 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 reservation diversity based on relay transmission scheme improves throughput QoS performance for a traffic stream from a WiMedia device, through the conflict avoidance.

IV. CONCLUSIONS

In this paper, a new method 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 reservation diversity based on 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.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0002366).

REFERENCES

[1] del Prado Pavon, J. Sai Shankar N Gaddam, V. Challapali, K. Chun-Ting Chou, "The MBOA-WiMedia specification for ultra wideband distributed networks," IEEE Communications Magazine, Vol. 44, no. 6, pp. 128-134, June. 2006.

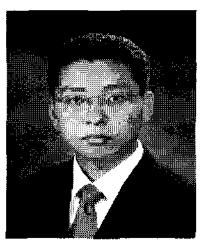
[2] Yunpeng Zang, Guido R. Hiertz, Jörg Habetha, Begonya Otal, Hamza Sirin and Hans-J Reumerman, "Towards High Speed Wireless Personal Area Network – Efficiency Analysis of MBOA MAC," International Workshop on Wireless Ad-hoc Network 2005, pp.10-20, 23-26 May 2005.

[3] WiMedia Alliance, "Distributed Medium Access Control (MAC) for Wireless Networks," WiMedia MAC Release Spec. 1.5, December, 2009, http://www.wimedia.org/en/index.asp.

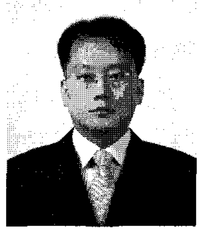
[4] IEEE 802.15.3, "Wireless Medium Access Control and Physical Layer Specification for High Rate Wireless Personal Area Networks," 2003.

[5] J.-W. Kim, K. Hur, J. Park, and D.-S. Eom, "A Distributed MAC Design for Data Collision-Free Wireless USB Home Networks," IEEE Transactions on Consumer Electronics, vol. 55, no. 3, pp. 1337-1343, Aug. 2009.

[6] J.-W. Kim, K. Hur, J.-O. Kim, D.-S. Eom, and Y. Lee, "A Distributed Resource Reservation Structure for Mobility and QoS Support in WiMedia Networks," IEEE Transactions on Consumer Electronics, vol. 56, no. 2, pp. 547-553, May 2010



Yang-Ick Joo received the M.S. and Ph.D. degrees in Department of Electronics Engineering from Korea University, Seoul, Korea in 2000 and 2004, respectively. Since 2004, he has been worked at Division of Telecommunication Networks, Samsung Electronics Suwon. His research interests include PHY and MAC layer solutions for wireless system, Bluetooth, wireless PAN, and ubiquitous networking.



Kyeong Hur (corresponding author) is currently an Assistant Professor in the Department of Computer Education at Gyeongin National University of Education, Republic of Korea. He was senior researcher with Samsung Advanced Institute of Technology (SAIT), Korea from September 2004 to August 2005. He received a M.S. and Ph.D. in Department of Electronics and Computer Engineering from Korea University, Seoul, Korea, in 2000 and 2004, respectively. His research interests include; computer network designs, next generation Internet, Internet QoS, and future All-IP networks.