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Reservation Conflict-Free MAC Design for Mobile Wireless USB Devices with Distributed MAC

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ABSTRACT

In this paper, a collision-free resource reservation scheme for WUSB (Wireless Universal Serial Bus) networks with WiMedia D-MAC (Distributed Medium Access Control). Since distributed characteristic of the WiMedia D-MAC supporting DRP (Distributed Reservation Protocol) scheme may cause lots of conflicts, overall performances of the WUSB with WiMedia D-MAC can be deteriorated. In addition, when we consider multi-hop environment, "mobile" hidden node problem due to mobility of WUSB devices can be happened, and it is a critical problem to mobile WUSB devices transceiving real-time QoS (Quality of Service) traffic. To tackle the problem, we propose a new DRP reservation mechanism to prevent DRP conflicts for multi-hop mobility support in WUSB networks with WiMedia D-MAC and show its improved performance via simulation results.

Key words: Wireless USB (WUSB), WiMedia, Distributed MAC (D-MAC), Distributed Reservation Protocol (DRP), wireless resource reservation

1. INTRODUCTION

USB (Universal Serial Bus) technology has been used at an enormous number of USB devices as a universal interface. Technical advances in USB and wireless communication have introduced WUSB standard 1.0 that provides wireless technology's convenience with wired USB's speed and compatibility.

In recent years, efficient and high quality multimedia communications in wireless home networks are increasingly required. Thus, UWB (Ultra Wide Band) of WiMedia Alliance 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. 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 WUSB for connecting personal computers (PCs) to their peripherals and the consumer-electronics (CEs) in people's living rooms [1,2].

A WUSB cluster consists of a WUSB host and several WUSB devices using a "hub and spoke" model [3] as shown in Fig. 1. The WUSB host is the "hub" at the center, and each WUSB device sits at the end of a "spoke". Each spoke of the model represents a point-to-point connection between the host and a device. WUSB basically employs WUSB host driven scheduling scheme, that is, the WUSB host allocates time slots to WUSB devices in its own cluster.

Since WUSB host and devices with WiMedia D-MAC have "distributed" and "wireless" characteristics, we should consider resource reservation

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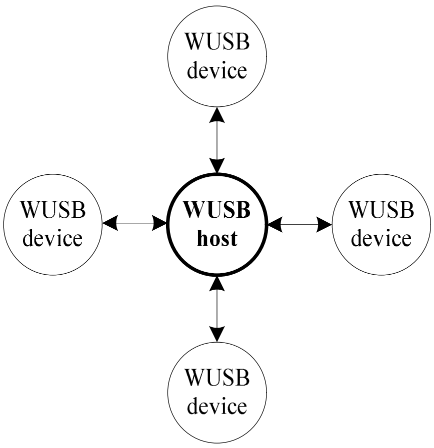

Fig. 1. WUSB cluster.

conflict due to such as hidden node problem and mobility of WUSB host and devices. However, the current WUSB standard has not considered the mobility of the WUSB host and devices [3]. Accordingly, in the WUSB home network environment, the DRP (Distributed Reservation Protocol) reservation conflict can be occurred by the mobility of them. An avoidance method for the DRP reservation conflicts has been proposed in [4]. However, the method has false alarm probability since the proposed signaling message sequence of GetStatus(ExtendedMASAvailability) is made from GetStatus(MASAvailability) information from 1-hop neighbor devices including MAS (Medium Access Slot) availability information of itself as well. Because the false alarm makes both WUSB hosts avoid using the possibly conflicted resources, the radio resources can be wasted. Therefore, in this paper, we propose a new mechanism to avoid WUSB data collision by providing actually overlapped DRP reservation information only.

This paper is organized as follows: In Section 2, we describe the current method for resource reservation in WUSB. 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.

2. Resource Reservation in WUSB

To utilize WiMedia PHY/MAC layer protocol, WUSB defines WUSB Channel which is encapsulated within a WiMedia MAC superframe via private DRP reservation blocks. The WUSB Channel is a continuous sequence of linked application-specific control packets, called MMCs (Micro-scheduled Management Commands), which are transmitted by WUSB host within the private DRP reservation blocks. The MMCs are used for WUSB devices to discover information about a WUSB cluster, to notify their intentions, to manage power, and to schedule data transmissions efficiently [3].

Fig. 2. shows the relationship between WiMedia

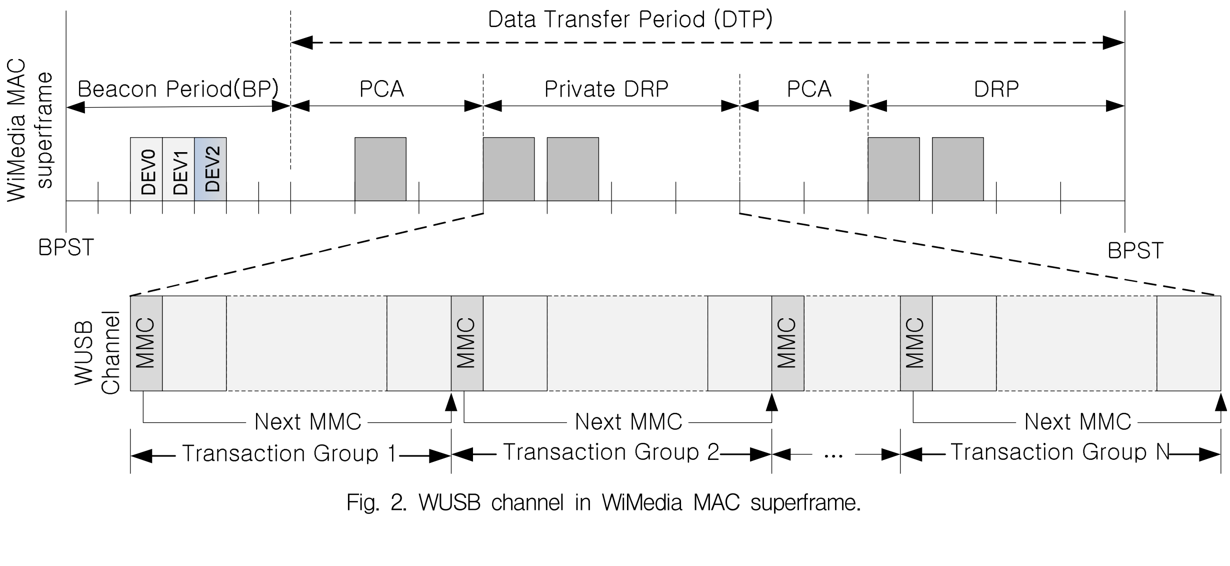

Fig. 2. WUSB channel in WiMedia MAC superframe.

MAC and WUSB protocol. When a WUSB host becomes active, it reserves MASs where to operate WUSB Channel for WUSB data communications by sending DRP IE (Information Element). In this case, the WUSB host is the DRP reservation owner, and WUSB devices are the DRP reservation targets.

The current DRP reservation procedure in WUSB is depicted in Fig. 3. In order to retrieve a WUSB device's MAS availability information, a WUSB host uses a GetStatus(MASAvailability) request. A WUSB device that has received the GetStatus(MASAvailability) request from the WUSB host gathers the MAS availability information from its neighbors' beacons and responds to the GetStatus(MASAvailability) request using a GetStatus(MASAvailability) response message.

When the WUSB host receives the WUSB device's GetStatus(MASAvailability) response, it chooses available MASs according to the response and provides the WUSB device with an appropriate DRP IE (Information Element) via SetWUSBData (DRPIEInfo) request.

When a WUSB device receives SetFeature (TX_DRPIE) request, it starts including the DRP IE provided by the SetWUSBData(DRPIEInfo) request in its beacon. To terminate the DRP reservation, a WUSB host uses a ClearFeature(TX_DRPIE) request to instruct a device to cease transmitting the DRP IE in its beacon.

Fig. 4 shows an example of DRP reservation conflict resolution operation between 2-hop range devices based on the current DRP protocol. In Fig. 4, a DRP reservation DRP_{H1} has been established between WUSB host H1 and WUSB device D1. H1 transmits data frames to D1 during the DRP_{H1} period. If some of the reserved MASs between WUSB host H2 and WUSB device D2 are overlapped with DRP_{H1}, DRP conflicts happen between

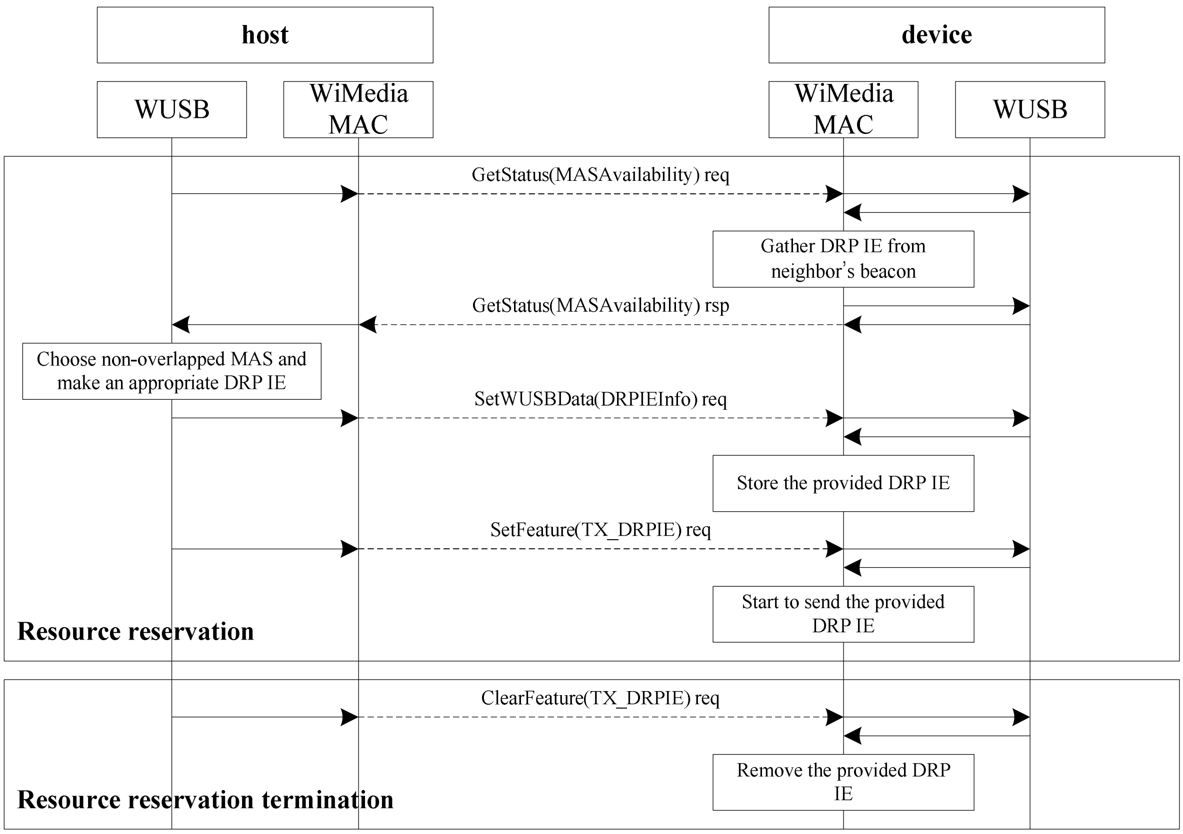

Fig. 3. The current DRP reservation in WUSB.

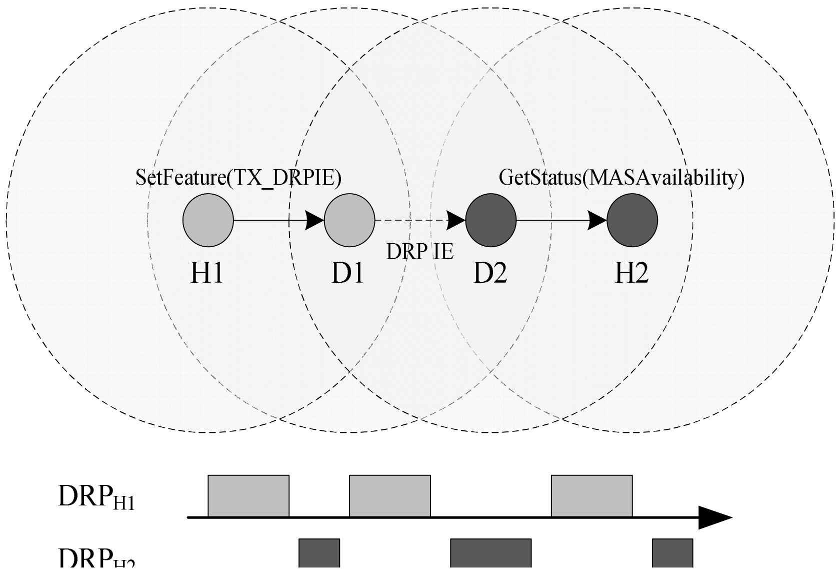

Fig. 4. Example of DRP reservation conflict resolution operation between 2-hop range devices based on the current DRP protocol.

DRP_{H1} and DRP_{H2}. In the WUSB standard [3], such a collision is prevented by using a bmMASAvailability field in GetStatus(MASAvailability) in Fig. 5. The bmMASAvailability field is used by a device to indicate its view of the current utilization of MASs by 1-hop neighbors in the current superframe [4]. A device's bmMASAvailability field is made by receiving and combining the WiMedia DRP IEs from its 1-hop range neighbor devices. From the MAS information of the received D1's WiMedia DRP IE, D2 marks DRP_{H1} period as unavailable in its bmMASAvailability field. When H2 receives the GetStatus(MASAvailability) response from D2, H2 gets to know that the DRP_{H1} period is unavailable for D2. And in reserving DRP_{H2} period, it excludes those MASs belonging to the DRP_{H1} period. Therefore, DRP reservation conflicts between the 2-hop range hidden devices (i.e., D1 and H2 in Fig. 4) can be avoided by transmitting the GetStatus(MASAvailability).

Now we consider another scenario taking "mobile" hidden node into consideration. In Fig. 6, data can be exchanged without interference in each WUSB cluster when WUSB device D3 is at the initial location of D3. However, if WUSB device D3 moves to the new location of D3', i.e., within 1-hop range of D1, the reserved MASs of the D3 (DRP_{H3}) can be overlapped with the reserved ones of D1 (DRP_{H1}), and it will introduce interference between their reserved MAS resources.

To resolve DRP reservation conflict between more than 2-hop range WUSB devices, a 3-hop range DRP reservation conflict prevention method using GetStatus(ExtendedMASAvailability) was proposed in [4]. However, since the GetStatus (ExtendedMASAvailability) responses received from WUSB devices are made by simply accumulating WiMedia MAC DRP Availability IEs which

bmRequest Type (=10000000B)	bRequest (=GET_STATUS)	wValue (=0)	wIndex (=0004H)	wLength	bmMASAvailability (only returned by WUSB device)
1 octet	1 octet	2 octets	2 octets	2 octets	32 octets

Fig. 5. The format of the GetStatus(MASAvailability).

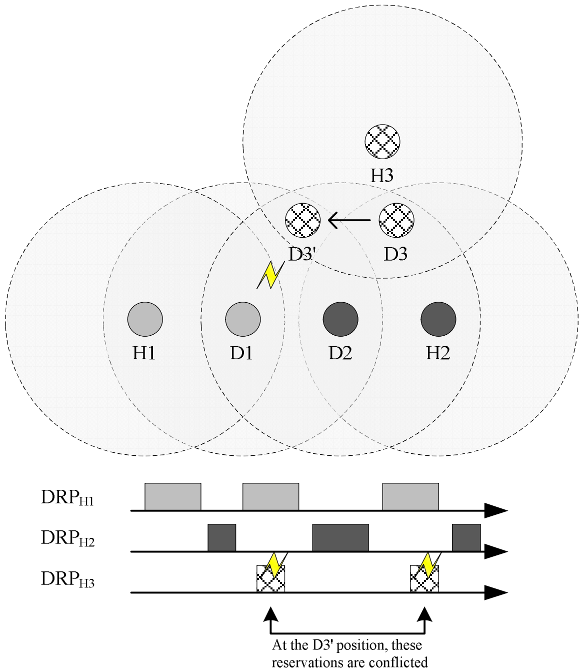

Fig. 6. Example of DRP reservation conflict due to mobile hidden node.

includes the WUSB host's own MAS reservation information as well, the method has false alarm problem on overlapped MAS. That is, the false alarm can be happened since D2 marks the corresponding resources as unavailable in its bmExtendedMASAvailability field of GetStatus (ExtendedMASAvailability) even when D2 only receives GetStatus(MASAvailability) of D1 without that of D3 or when D2 receives GetStatus (MASAvailability)s of both D1 and D3 without overlapped MASs between them.

Because the false alarm makes both WUSB hosts avoid using the possibly conflicted resources, the radio resources are wasted. Therefore, in this paper, we propose a new mechanism to avoid WUSB data collision by providing actually overlapped DRP reservation information only.

3. Resource Reservation Conflict Avoidance Scheme for WUSB Devices

Once a DRP conflict occurs due to the mobile hidden node problem, only one of the DRP reservations involved in that DRP conflict maintains the reserved MASs, while the other DRP reservations must be terminated and DRP negotiations for them have to be re-started although only a few MASs are overlapped. Such DRP termination and re-negotiation time delays due to the DRP conflicts can be a critical problem to the mobile devices transceiving real-time QoS traffic streams. However, if a WUSB host can know the information of multi-hop range hidden private DRP reservation status, it can avoid use of overlapped MASs. Therefore, in this Section, we propose a conflict avoidance algorithm for WUSB resource reservation using a newly defined GetStatus(OverlappedMAS). The GetStatus(OverlappedMAS) only provides actually overlapped MAS reservation information which is made by combining the received WiMedia MAC DRP Availability IEs.

The format of the GetStatus(OverlappedMAS) is shown in Fig. 7. In Fig. 7, the bmOverlappedMAS bitmap field is up to 256-bit long, where each bit location corresponds to a MAS slot in the WiMedia D-MAC layer superframe. Using overlapped MAS detector, each bit is set to 'one' if the corresponding MAS is reserved by at least two devices in the same superframe, or each bit is set to 'zero' otherwise.

The proposed DRP reservation procedure in WUSB is depicted in Fig. 8. To start a new private DRP reservation process, a WUSB host uses the GetStatus(MASAvailability) request to retrieve a

bmRequest Type (=10000000B)	bRequest (=GET_STATUS)	wValue (=0)	wIndex	wLength	bmOverlappedMAS
1 octet	1 octet	2 octets	2 octets	2 octets	32 octets

Fig. 7. The format of the GetStatus(OverlappedMAS).

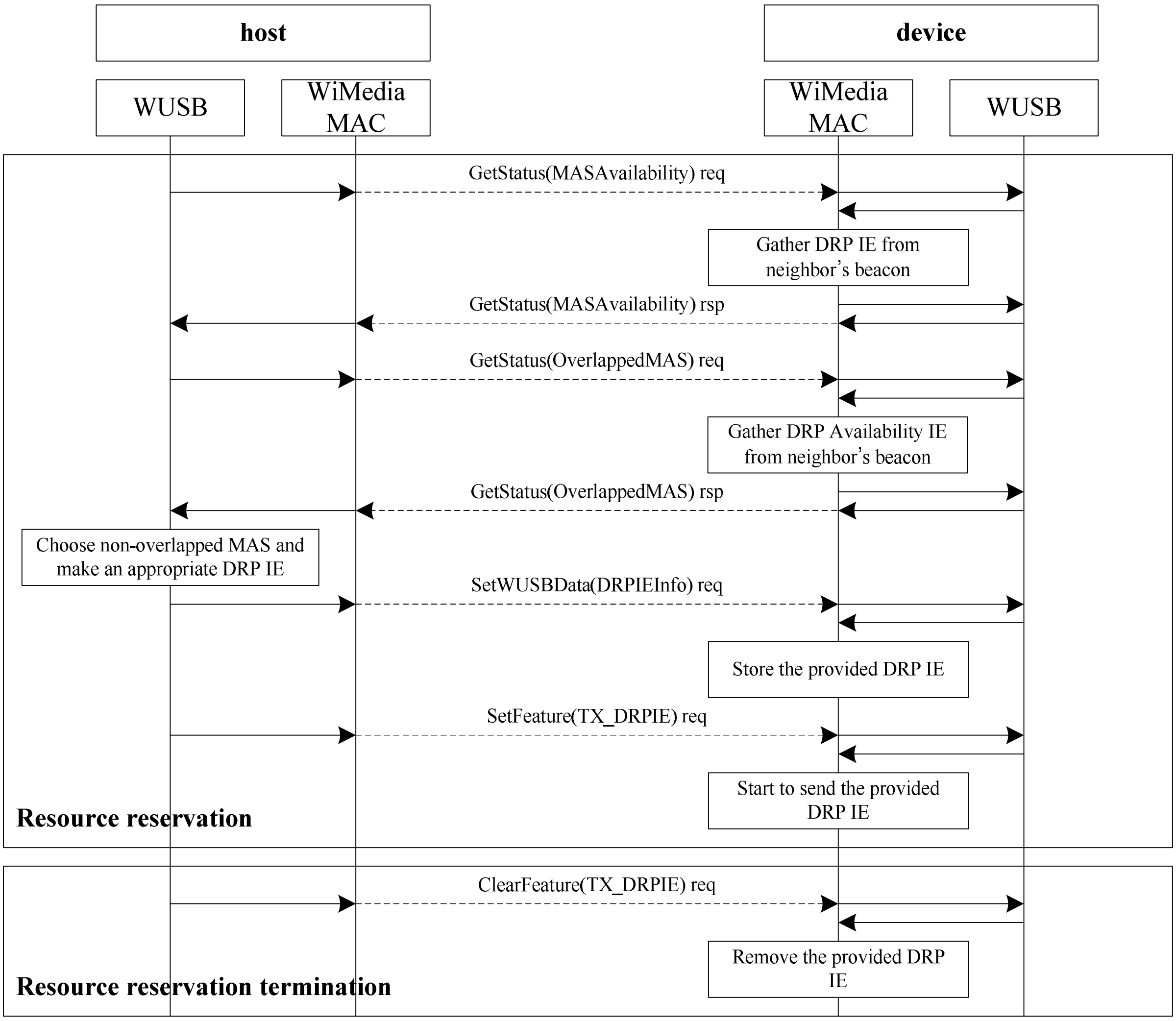

Fig. 8. The proposed DRP reservation in WUSB.

WUSB device's MAS availability information. A WUSB device that has received the GetStatus (MASAvailability) request from the WUSB host gathers the MAS availability information from its neighbors' beacons and responds to the GetStatus (MASAvailability) request using GetStatus (MASAvailability) response message.

A WUSB host that has received the GetStatus (MASAvailability) responses from WUSB devices transmits the GetStatus(OverlappedMAS) request to get the overlapped MAS reservation information within its multi-hop range private DRP reservation. A WUSB device that has received the GetStatus (OverlappedMAS) request from the WUSB host listens the WiMedia MAC DRP Availability IEs of neighbor devices and sends GetStatus(OverlappedMAS) response. The WUSB host that has received the WUSB devices' responses for GetStatus (OverlappedMAS) chooses non-overlapped MASs based on the MAS reservation information provided by GetStatus(MASAvailability) and GetStatus (OverlappedMAS) responses and provides the WUSB device with an appropriate DRP IE via SetWUSBData(DRPIEInfo) request.

When a WUSB device receives SetFeature (TX_DRPIE) request, it starts including the DRP IE provided by the SetWUSBData(DRPIEInfo) request in its beacon. To terminate the DRP reservation, a WUSB host uses a ClearFeature(TX_DRPIE) request to instruct a device to cease transmitting the DRP IE in its beacon.

4. Performance Evaluation

Performance of the proposed scheme is evaluated through NS-2 simulations. In the simulation, we assume that the network size is 10m*10m and the total 30 devices are randomly deployed into this area. The number of MASs in own DRP reservations of the reference WUSB device during 30 seconds denoted as DRP_{own} is set to 20 MASs. And the number of MASs in private DRP periods reserved by 1-hop neighbor devices, 2-hop distance devices and 3-hop distance hidden devices of the reference device denoted as $N_{1\text{-hop}}$, $N_{2\text{-hop}}$, and $N_{3\text{-hop}}$ respectively are set to 30 MASs, 30 MASs, and 20 MASs. Each node has two kinds of mobility with corresponding probability of m_{in} and m_{out}. The m_{in} and m_{out} are a probability with which a device moves into a 1-hop closer range of the reference device (from (n+1)-hop to n-hop range) and a probability with which a device moves far a 1-hop range of the reference device (from n-hop to (n+1)-hop range) respectively. The m_{out} is set to 0.2 in the simulation. The size of a frame transmitted by devices in a beacon group is fixed to 4095 bytes.

To analyze the designed MAC efficiency for WUSB device, we 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. The WiMedia PHY/MAC parameters and the PSDU data rate-dependant modulation parameters in the WiMedia standard [5] are found in Table 1 and Table 2, respectively.

Fig. 9 shows the probability of a 1-hop range private DRP conflict according to the $L_{1\text{-hop}}$ value which is the number of MASs reserved by a 1-hop neighbor device. As shown in Fig. 9, the probability of a private DRP reservation conflict increases rapidly along with $L_{1\text{-hop}}$ 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. 10 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

Table 1. WiMedia PHY/MAC simulation parameters

Parameter	Value
T_{SYM}	312.5 ns
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 2. PSDU data rate-dependant simulation parameters

Data rate (Mbps)	Modulation	Info bits/6 OFDM symbols (N_{IBP6S})
53.3	QPSK	100
80	QPSK	150
106.7	QPSK	200
160	QPSK	300
200	QPSK	375
320	DCM	600
400	DCM	750
480	DCM	900

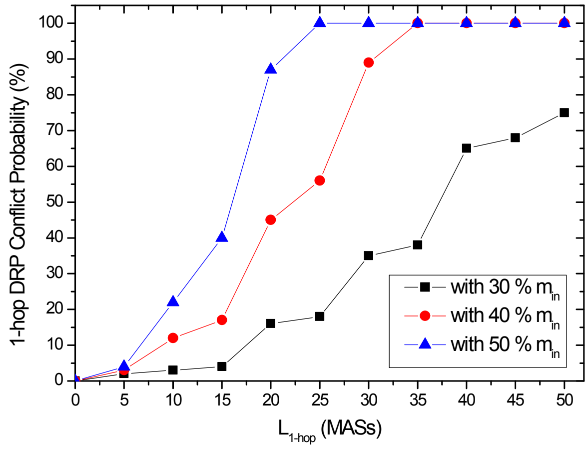

Fig. 9. 1-hop DRP conflict probabilities.

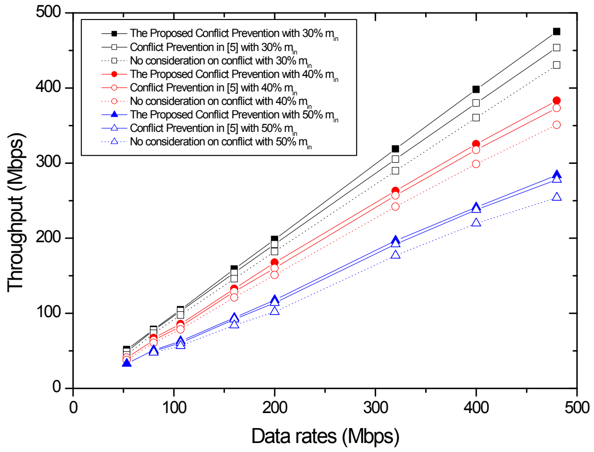

Fig. 10. Conflict-avoided throughput of a D-MAC stream according to PHY data rate.

m_{in} probability causes more DRP reservation conflicts. Both our proposed scheme and the previous one in [4] show performance improvement through their own conflict prevention methods. And the proposed algorithm using the newly defined GetStatus(OverlappedMAS) shows the best performance especially with 30% of m_{in} case. This is because the case of lower m_{in} value has higher false alarm probability on the MAS overlap. And since the proposed mechanism reduces the false alarm problem of the method in [4] and avoids WUSB data collision by providing actually overlapped DRP reservation information only, it prevents the private DRP reservation conflicts effectively.

5. CONCLUSION

In this paper, a new method to avoid private DRP reservation conflicts for WUSB device has been proposed. The proposed algorithm effectively avoids the resource conflicts and prominently improves throughput performance with reasonable amount of overhead. Therefore, it can be easily applied to applications for a personal/mobile WiMedia D-MAC communication environment adopting wireless USB communication technology.

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