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# A Cross-layer Link Adaptive HD Video Transmission Scheme in WiMedia D-MAC based UWB Systems

Yang-Ick Joo†

## ABSTRACT

In this paper, we propose a QoS (Quality of Service)-aware and cooperative resource reservation scheme using cross-layer link adaptation for wireless high definition video transmission through UWB (Ultra Wide Band) network with D-MAC (Distributed Medium Access Control). A wireless high definition video transmission system usually requires stable high throughput even without line-of-sight, e.g., a destination device in another room separated by a wall. Since the WiMedia D-MAC supporting DRP (Distributed Reservation Protocol) scheme causes lots of DRP resource reservation conflicts due to failure of beacon detection in wireless channel environment, overall performances of the WiMedia D-MAC can be deteriorated. And the current WiMedia MAC standard has not considered QoS provisioning even though QoS parameters such as a range of service rates are provided to each traffic stream. Therefore, we propose Relay DRP protocol with QoS-based relay node selection criterion, which makes a relay path to avoid DRP resource reservation conflicts and guarantee QoS more stably through cross-layer link adaptation of cooperative relay transmission scheme and is compliant with the current WiMedia D-MAC protocol. Simulation results demonstrate performance improvements of the proposed method for throughput and QoS provisioning.

**Key words:** UWB (Ultra Wide Band), WiMedia, Distributed MAC (D-MAC), Distributed Reservation Protocol (DRP), cooperative communication

## 1. INTRODUCTION

The prosperity of wireless communication technology has been providing various new communication opportunities and services for personal use. A tremendous growth in popularity of wireless personal devices is essentially requiring extremely high rate and short-range wireless networks. Hence, UWB technology is being taken an interest for WPAN (Wireless Personal Area Network) applications such as home entertainment and security/medical/military applications.

UWB is able to support data rates of 0.5 Gbps within a range of up to 10 m and is allowed to operate with limited transmit power in a unlicensed manner in the 3-10 GHz band [1,2]. 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 enable 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 [3, 4].

The WiMedia Alliance has specified D-MAC protocol based on UWB for High-Rate WPANs [5]. In contrast to centralized MAC such as IEEE 802.15.3, the D-MAC UWB supports DRP mecha-

※ Corresponding Author : Yang-Ick Joo, Address : #727 Taejong-ro, Youngdo-gu, Busan, Korea, TEL : +82-51-410-4419, FAX : +82-51-404-3986, E-mail : yijoo@hhu.ac.kr
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† Division of Electrical and Electronics Engineering, Korea Maritime Univ.

nism which makes all devices be connected using self-organizing approach. In the distributed architecture, the WiMedia D-MAC removes the SOP (Simultaneous Operating Piconet) problem, i.e., packet collisions between overlapped piconets in the centralized IEEE 802.15.3 MAC by exchanging resource reservation and control information among the devices [5], especially via DRP IE (Information Element) and DRP Availability IE in each device's beacon signal. In the D-MAC, each node broadcasts its own beacon containing IEs, per periodic interval called superframe. The IEs convey certain control and management information. The distributed nature of the D-MAC protocol can provide a full mobility support with scalable and fault tolerant medium access method [5].

However, the conventional WiMedia D-MAC has DRP conflict problem due to failure of beacon detection in wireless communication environment [5]. Thus, in order to get full benefits of the distributed MAC approach, we have to guarantee the detection of beacon and overcome the resource reservation conflicts among devices. There have been prevention and resolution methods for the DRP reservation conflicts among the WiMedia D-MAC devices in [6,7]. These schemes take multi-hop range DRP conflicts due to mobile hidden node problem into account and show improvement of throughput performance. However, these methods do not consider QoS requirement of each traffic stream and only try to prevent and/or resolve MAC-level conflicts in a fixed link without considering another link which can provide more stable data service. Therefore, the algorithms in [6,7] cannot use wireless resources efficiently and may not meet the QoS requirement even with the conflict-resolved link.

There have been previous works to improve system performance by using cooperative communication scheme [8,9]. As shown in Fig. 1, if the wireless channel status is coarse between Source node (S node) and Target node (T node), the direct communication between S node and T node causes time delay and extra power consumption. In the situation, Adaptive Modulation and Coding (AMC) scheme can be applied in physical layer as a link adaptation solution. However, if the channel status between S node and T node is not good enough to guarantee the minimum required data rate for the link, the corresponding channel resources are wasted even after the link adaptation in physical layer, and QoS requirement of the stream cannot be gratified. In this case, we can try to find a detour e.g., the path via the Relay node (R node) in Fig. 1 as an indirect communication link with good channel status in order to avoid the coarse wireless link. In [8], throughput is increased through an efficient relay communication of the proposed CoopMAC scheme. However, the CoopMAC scheme needs additional CSMA-CA based HTS (Helper ready To Send) signaling overhead for delivering relay confirm/deny messages from a helper station, and QoS of each traffic stream are not guaranteed.

Therefore, in this paper, Relay DRP scheme with QoS-based relay node selection criterion is proposed as a cross-layer link adaptation for the WiMedia D-MAC devices to avoid harsh channel conditions and to meet QoS requirement of traffic stream in non-LOS (non-line of sight) home network environment of wireless High Definition

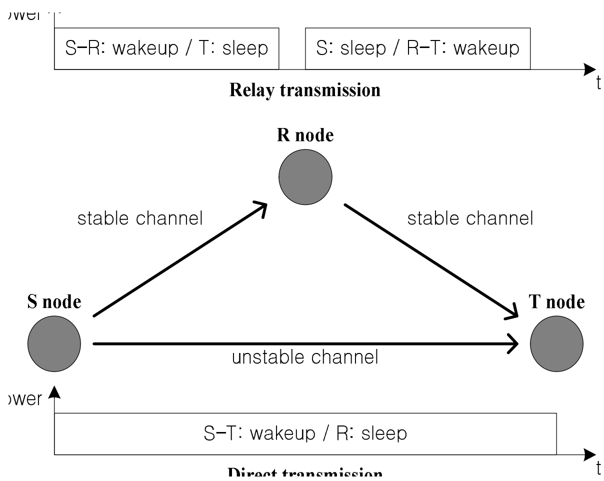


Fig. 1. Relay-based Cooperative Communication.

(HD) video transmissions. For efficient wireless video transmission, several studies have been done in [10-12] in terms of optimal buffering or coded cooperation.In order to improve the quality of the video transmission, some technical challenges such as efficient communication to enhance throughput and buffering to absorb expected delay [11] have to be taken into account. For the technical improvements, we propose and evaluate the Relay DRP algorithm as an efficient transmission scheme to improve throughput performance. In addition, for efficient QoS provisioning, we introduce the Satisfaction ratio of QoS (SoQ) method that was defined in our previous study [13].

This paper is organized as follows: In Section 2, we describe the WiMedia D-MAC protocol. In Section 3, a relay-based cooperative communication protocol is proposed to make a relay path to avoid DRP conflicts and/or bad channel conditions and to guarantee QoS. 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 shown in Fig. 2, WiMedia D-MAC operates with a time unit called superframe. A superframe is divided into a BP (Beacon Period) and a DTP (Data Transfer Period). Unlike other MAC protocols, the 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 synchronize time with other devices. Also, it provides information of power control and reservation status for each MAS (Medium Access Slot).

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. 3 is used to negotiate a reservation for certain MASs and to announce the reserved MASs for a traffic stream. The DRP Availability IE notifies the current status of the MAS utilization of 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 super-

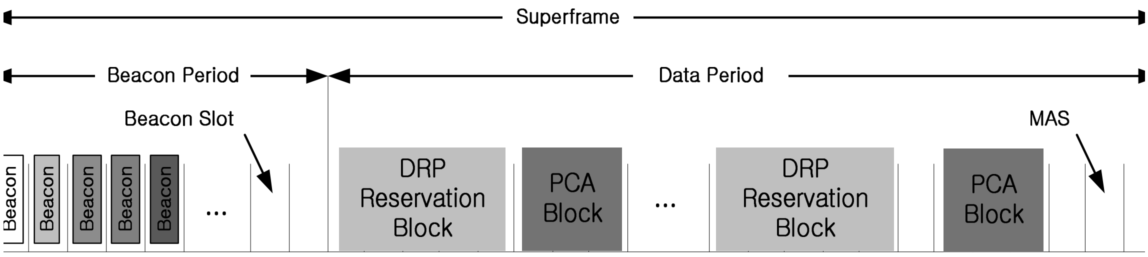


Fig. 2. Superframe structure in WiMedia D-MAC.

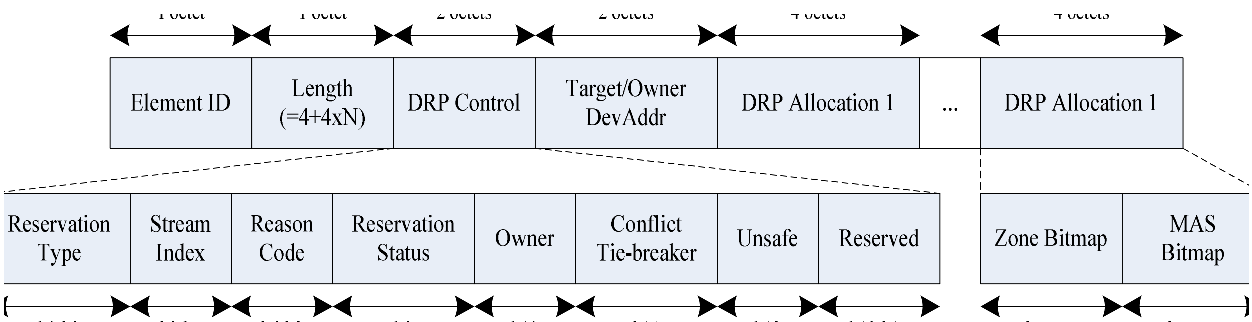


Fig. 3. The format of DRP IE.

frame consists of 256 MASs). It is filled by combining all the DRP IEs transmitted by the 1-hop range neighbor devices.

In Fig. 3, 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 the 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 successfully accepted or not, and it is encoded as described in Table 1.

## 3. RELAY DRP

In this Section, we propose Relay DRP protocol with a policy for suitable relay node selection. The proposed scheme is compatible with the existing WiMedia standard and can be easily applied with small amount of overhead.

### 3.1 QoS-aware relay node selection

To select a suitable relay node for efficient cooperative communication, we need a criterion for the selection. In this paper, SoQ which was defined in our previous study [10] is introduced as the criterion.

The SoQ for traffic stream $j$ at the $n$-th superframe, $SoQ_{j,n}$ is defined as follows:

$$SoQ_{j,n} = \frac{SR_{j,n} - MR_j}{PR_j - MR_j} \tag{1}$$

where $SR_{j,n}$ denotes the service rate allocated to traffic stream $j$ at the $n$-th superframe and is a function of PHY data rate. $MR_j$ and $PR_j$ are the lower and the upper bound of a service rate to guarantee QoS of traffic stream $j$ respectively.

In the WiMedia D-MAC protocol, a device can predict transmission rate and power level for each link by listening Link Feedback IEs from one or more source devices. The IEs contain information of the recommended change to the optimal PHY data rate and transmission power level [5]. Fig. 4 illustrates the Link Feedback IE format. The DevAddr field is set to the device address of the source device for which this feedback is provided. The Transmit Power Level Change field denotes the change in transmit power level that the recipient device sending this IE recommends to the source device, and the Data Rate field is filled with the PHY data rate that the recipient device transmitting this IE recommends to the source device.

After archiving all expected PHY transmission rate information in its beacon group, a source device can get the SoQ of each link and determine if it sends data packets to target device directly or via relay device based on QoS-based relay node

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 |

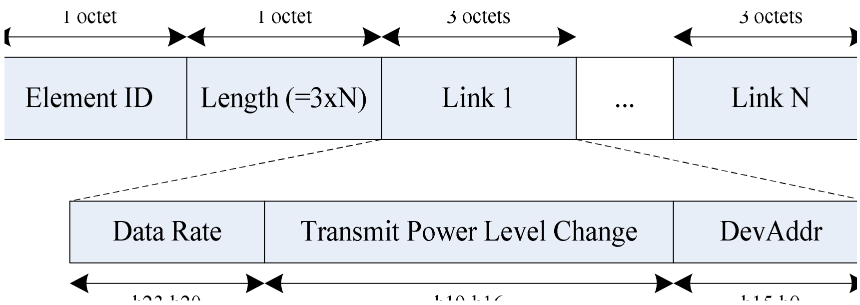


Fig. 4. The format of Link Feedback IE.

selection criterion as defined in (2).

$$path\,l = \underset{1 \le m \le M}{\arg\max}\, SoQ_m \qquad (2)$$

where $SoQ_m$ is the SoQ value of path $m$. When comparing $SoQ_m$ using (2), if the path $m$ includes a relay node, the SoQ is calculated by using (3).

$$SoQ_m = \min(SoQ_{S-R}, SoQ_{R-T}) \qquad (3)$$

After selecting a suitable relay node using the criterion in (2), DRP resource reservation considering cooperative relay transmission can be done according to the Relay DRP procedure explained in the next subsection.

### 3.2 Resource reservation procedure using Relay DRP

Since a wireless HD video transmission system usually requires stable high throughput, the system is generally defined in higher carrier frequency to guarantee wider spectrum bandwidth. Although it can achieve a high transmission rate, it has many technical problems such as signal attenuation with increasing propagation distance and LOS dependency of signal quality [12]. Therefore, we need to consider a cooperative communication scheme for efficient HD video transmission. To provide cooperative relay transmission, Relay DRP, proposed in this subsection, uses newly defined three codepoints in the reserved field of Reason Code in Table 1. Thus, the Relay DRP conforms to WiMedia D-MAC standard for interoperability. The newly defined Reason Code Fields are explained 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 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. 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 that the DRP resources from the reservation owner to the target node via the relay node are successfully reserved.

From Fig. 5 to Fig. 7, we depict the proposed

Table 2. Additional Reason Code Fields Encoding for Relay DRP

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

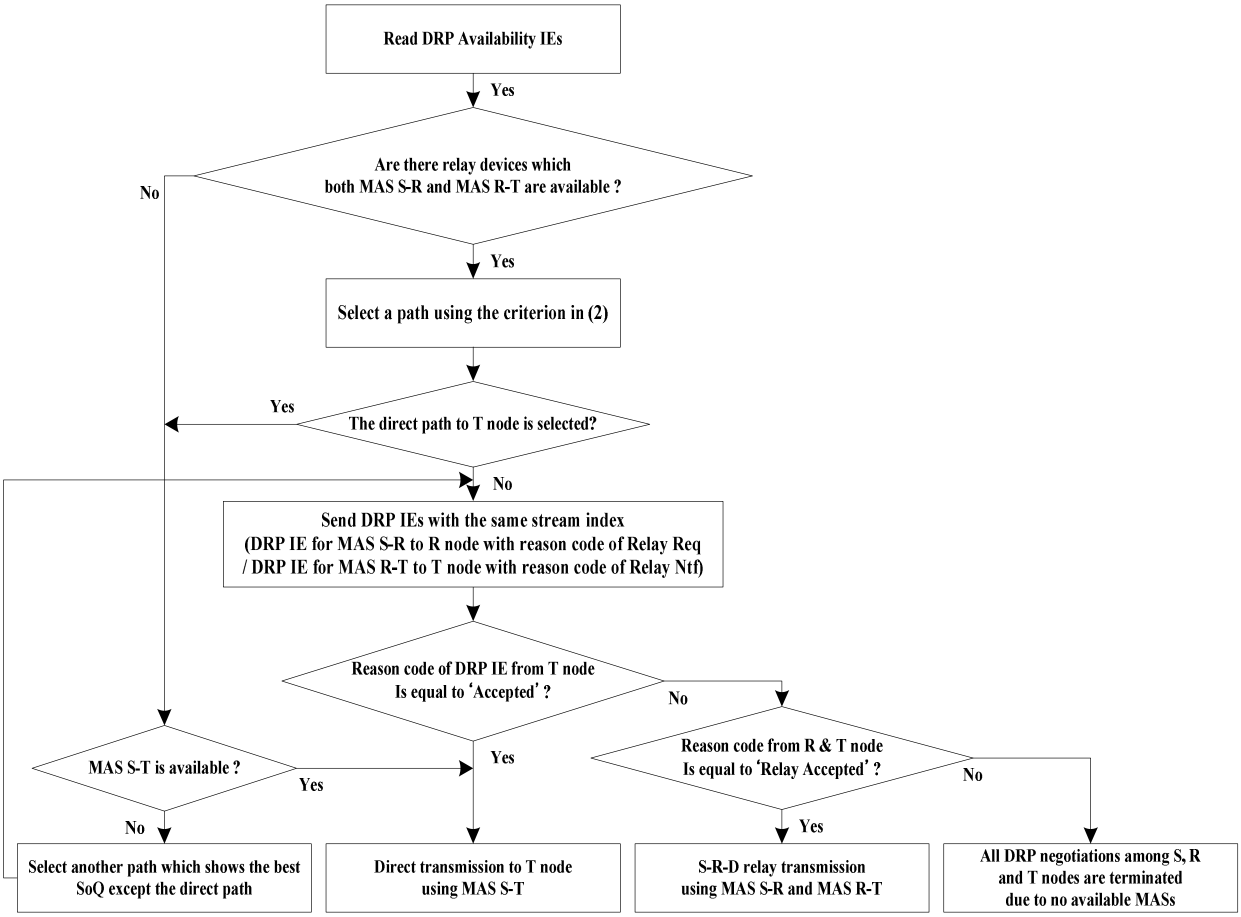

Fig. 5. Relay DRP procedure of reservation owner device.

Relay DRP procedures of reservation owner node, relay node, and target node in detail.

The reservation owner reserves DRP resources as shown in Fig. 5. After archiving expected PHY transmission rate information and reading DRP Availability IEs from other devices' beacons in its beacon group, the reservation owner checks if there exists at least one relay device which both MAS S-R and MAS R-T for the relay device are free to use for the relay transmission. If there are several suitable relay nodes meeting the condition, the reservation owner selects a communication path using the criterion in (2). In case that the direct path to the target node is not selected, it sends DRP IEs for the relay transmission with the same stream index. In this case, the DRP IE for MAS S-R sent to the relay node includes the Reason Code of 'Relay Req', and the DRP IE for MAS R-T with the Reason Code of 'Relay Ntf' is delivered to the target node.

After sending the DRP IEs using beacon, the reservation owner waits for the responses from the relay node and the target node. In case of 'Relay Accepted' Reason Code from both the relay node and the target node, the reservation owner sends data packets using the resources for the relay transmission. For other Reason Codes, we just follow the legacy DRP standard.

Fig. 6 shows the Relay DRP procedure for relay node. When a relay node 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 or not. If the resource request is agreeable to the relay node, the relay node should read

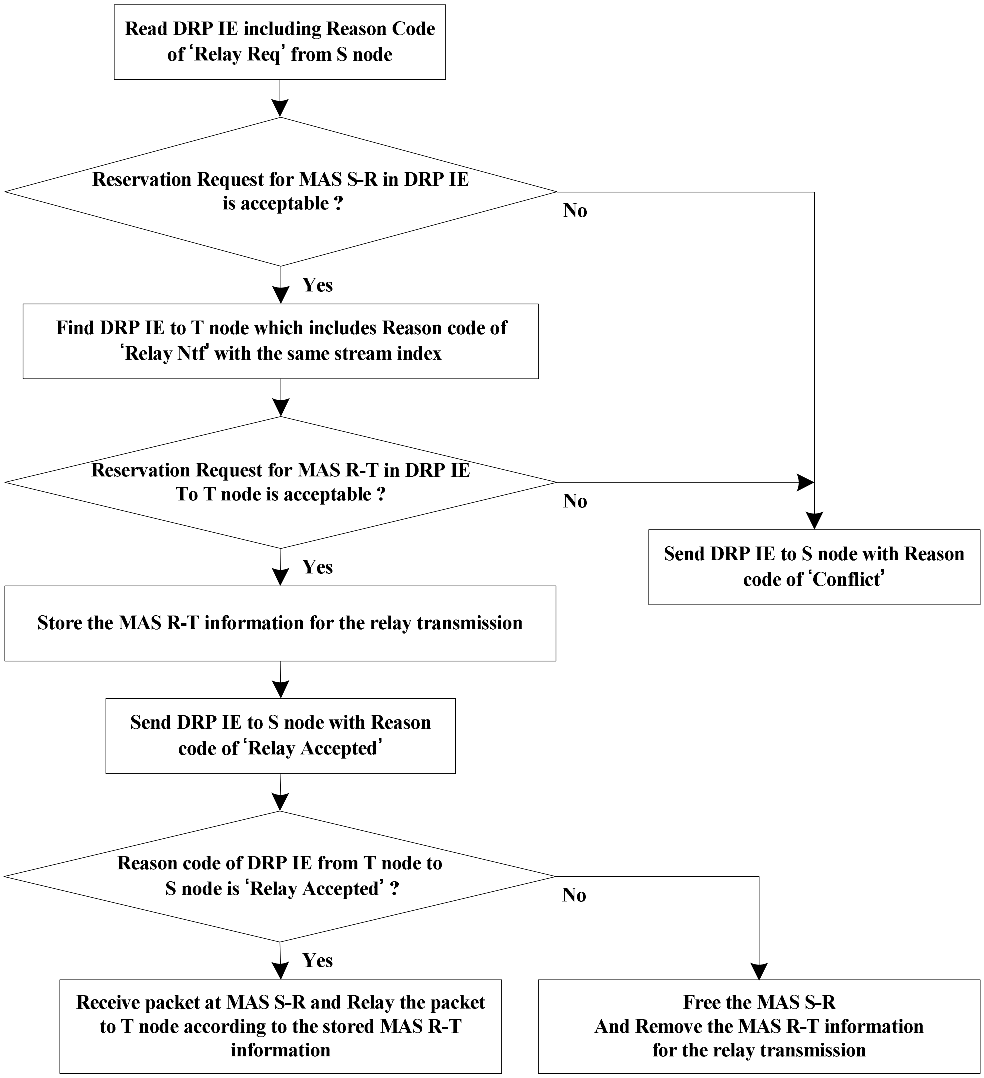


Fig. 6. Relay DRP procedure of relay node.

DRP IE to target node which includes Reason Code of 'Relay Ntf' with the same Stream Index and checks whether the requested MAS R-T is also acceptable or not. 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 response 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.

The Relay DRP procedure of target node is shown in Fig. 7. When a target node receives a DRP IE from the reservation owner with Reason Code of 'Relay Ntf', the target node checks whether the resource request for MAS R-T in the received DRP IE is acceptable or not. 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 'Relay Accepted'. After sending the DRP IE, the target node waits for the

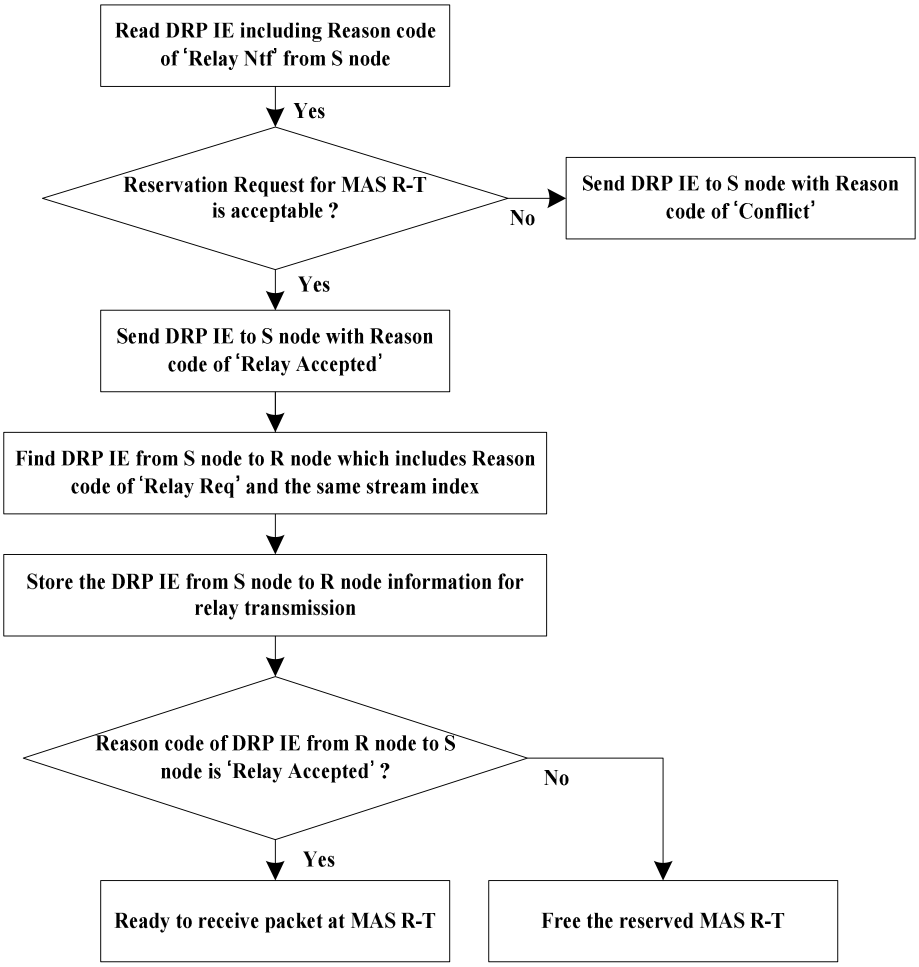


Fig. 7. Relay DRP procedure of target node.

response from the relay node to the reservation owner. If the Reason Code of the DRP IE from the relay node to the reservation owner is 'Relay Accepted', the target node receives packets at the MAS R-T. Otherwise, the target node frees the reserved MAS R-T.

## 4. PERFORMANCE EVALUATION

Performance of the proposed Relay DRP scheme with the QoS-based relay node selection criterion is evaluated through NS-2 simulations. The network size covered by randomly distributed WiMedia D-MAC devices is 10m*10m. And we assume multiple WiMedia D-MAC application clusters for home network composed of 30 devices randomly distributed in the network area [6,7]. Each device has two kinds of mobility with each corresponding probability of $m_{IN}$ and $m_{OUT}$. The $m_{IN}$ is a probability that a device gets 1-hop near to the reference device, e.g., that device moves from 2-hop to 1-hop distance range, and the $m_{OUT}$ is a probability that a device goes 1-hop away from the reference device, e.g., that device moves from 1-hop to 2-hop distance range. 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]. In the WiMedia D-MAC performance analysis, the WiMedia PHY/MAC parameters in the WiMedia specifications [1,5] are considered and are found in Table 3.

Fig. 8 shows average throughput performance of the WiMedia D-MAC devices in the simulated network according to $m_{IN}$ value of neighbor

Table 3. 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 |

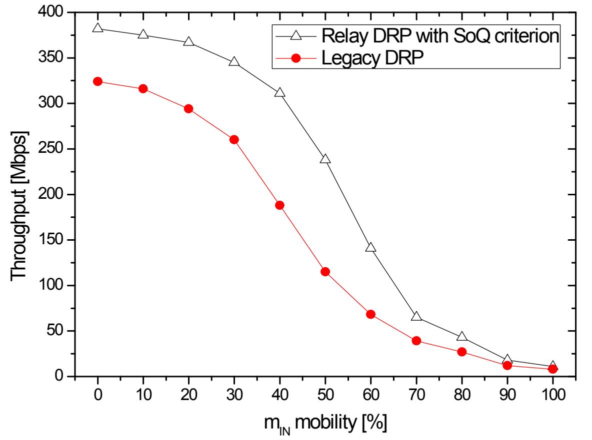


Fig. 8. Throughput performance according to mIN mobility.

devices. The throughput of the proposed scheme is superior to that of the legacy DRP scheme, and it decreases in proportion to the $m_{IN}$ probability. Since the proposed scheme avoids bad links or DRP conflicts by performing cooperative relay transmission, throughput of each node can be better even if more MASs are overlapped with other WiMedia D-MAC devices' clusters as the number of devices increases.

The SoQ variation of a HD video traffic stream with the TSPEC of 25 Mbps *MR* and 50Mbps *PR* according to available radio resources is shown in Fig. 9. During the simulation, available resources are increased by releasing DRP resources reserved

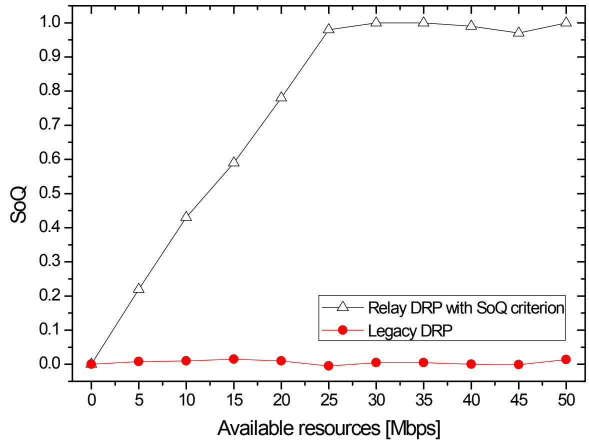


Fig. 9. SoQ variation.

by the neighbor devices. Assuming that the DRP resources are reserved as much as the *MR* at the beginning of the simulation, the SoQ of the legacy DRP scheme is almost constant with '0' value, since the legacy DRP does not consider other routes to transmit the video stream and QoS aspect in DRP resource reservation.

Throughput performance in the same home network environment with fixed 20% of $m_{IN}$ according to average BER (Bit Error Rate) indicating current wireless channel status is shown in Fig. 10. As the channel status becomes worse, throughput is decreased. However, when using the proposed algorithm, the throughput decline is less than the legacy DRP. In the result of the proposed scheme, the throughput is slightly more degraded than oth-

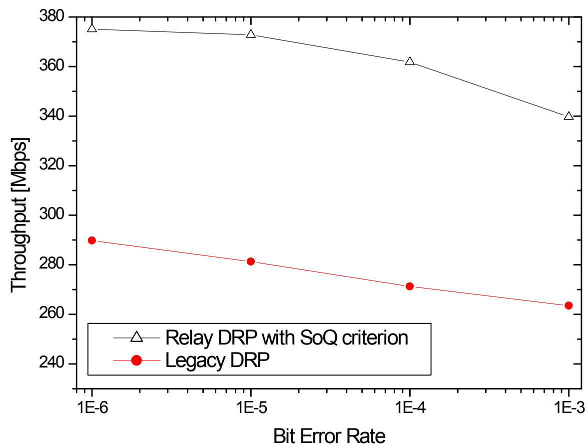


Fig. 10. Throughput according to wireless channel status (BER).

ers at the period from BER $10^{-4}$ to BER $10^{-3}$. This result shows that there exists a threshold value where the Relay DRP with SoQ criterion cannot compensate the throughput decrement due to the harsh wireless channel status even though it performs cooperative relay transmissions to find stable channels.

## 5. CONCLUSION

In this paper, a cooperative relay transmission scheme with QoS-aware relay node selection criterion for wireless HD video transmission system adopting WiMedia DRP protocol-based WPAN devices has been proposed to enhance throughput performance by avoiding bad channel conditions and resource reservation conflicts through the cross-layer link adaptation and considering QoS requirement of traffic stream. From the simulation results for throughput and SoQ, it is shown that the performances of the proposed Relay DRP scheme with the QoS-based relay node selection criterion are superior to those of the legacy DRP scheme. And the proposed scheme is compatible and can be directly applied with small overhead to the current WiMedia D-MAC standard system.

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Yang-Ick Joo

Feb. 1998: Bachelor in Dept. of Electronics Engineering, Korea University, Korea

Aug. 2000 : Master in Dept. of Electronics Engineering, Korea University, Korea

Aug. 2004 : Ph.D. in Dept. of Electronics Engineering, Korea University, Korea

~Feb. 2012: Senior Engineer at Division of Telecommunication Networks, Samsung Electronics

~Current: Assistant Professor with Division of Electrical and Electronics Engineering, Korea Maritime University, Korea