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Link Adaptive Cooperative Communication in Wireless USB Networks

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Abstract

In this paper, we propose link-adaptive cooperative communication in wireless USB networks. To select the optimal relay node, we propose the RNS (Relay Node Selection) algorithm considering channel condition. Also, the proposed protocol can be directly applied with small overhead to the current wireless USB standard system. Furthermore, each device independently performs RNS algorithm by using the proposed protocol.

Keywords: *UWB;Wireless USB; Relay Communication; WPAN*

1. Introduction

Ultra wide-band (UWB) technologies are being feverishly developed in the technical community and will enable extremely high rate, short-range wireless networks. UWB devices are expected to operate at rates of up to 480Mbps and communicate with other devices at a range of up to 10 m, thus enabling high-speed wireless personal area Networks (WPANs) [1]. Recently, the rapid growth of demand for multimedia application increases the requirements of high rate network. WiMedia Alliance has specified a Distributed Medium Access Control (D-MAC) protocol based on UWB for High-Rate WPANs [2]. The WiMedia network is suitable for ubiquitous connection in home networks, military/medical applications, etc due to its inexpensive cost, low power consumption, high data rate, and distributed approach.

Wireless USB (Universal Serial Bus) is the USB technology merged with UWB technology, and it can be applied to various applications such as laptop, smart phone, etc. Wireless USB provides high speed connection between host and devices for the compatibility with USB 2.0 specification and removes the cable among devices using the USB protocol. Thus, it can provide the better user convenience than wired USB applications. Wireless USB connects wireless USB devices with the wireless USB host using a ‘hub and spoke’ model [3]. The wireless USB host acts as the ‘hub’, and each wireless USB device sits at the end of a ‘spoke’. Each spoke means a point-to-point connection between the host and device. The network formed by one host and several devices is referred to as a wireless USB cluster.

There is only one host in any wireless USB cluster and wireless USB host performs to transmit/receive a data with wireless USB devices in the wireless USB cluster. Also, it schedules the exchange of data between wireless USB host and wireless USB devices and allocates time slots to wireless USB devices in its own cluster.

In the wireless networks that support the multiple data transfer rate, relay communication can improve the network throughput and reduce the energy consumption and delay. This is because relay communication via the link with high data rate can transmit data frames faster than direct communication via the link with low data rate. Recently, many researches for relay protocol have been carried out. However, the existing researches for cooperative

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communication mainly focused on the physical layer [4, 5]. Also, relay protocols based on the IEEE 802.11 DCF are proposed to reduce the throughput degradation occurred by mobile devices with low data rate [6, 7]. However, they can't select the optimal relay device to forward data frames to destination because their protocol can't rapidly apply new information of link condition to relay communication.

Therefore, we propose link-adaptive cooperative communication of wireless USB network in this paper. To select the optimal relay node we propose link adaptive RNS (Relay Node Selection) algorithm. The proposed link-adaptive cooperative MAC protocol is compatible and can be directly applied with small overhead to the current wireless USB standard system. Also, each device independently performs RNS algorithm by using the proposed protocol, and can transmit data frames via the optimal path.

2. Resource Allocation Scheme in Wireless USB Standard

Figure 1 shows the relationship between WiMedia MAC and wireless USB protocol. In Figure 1, wireless USB defines a wireless USB Channel which is encapsulated within a WiMedia MAC superframe via private DRP (Distributed Reservation Protocol) reservation blocks that enables devices to reserve medium without contention. The wireless USB Channel is a continuous sequence of linked application-specific control packets, called MMCs (Micro-scheduled Management Commands), which are transmitted by the host within the private DRP reservation blocks.

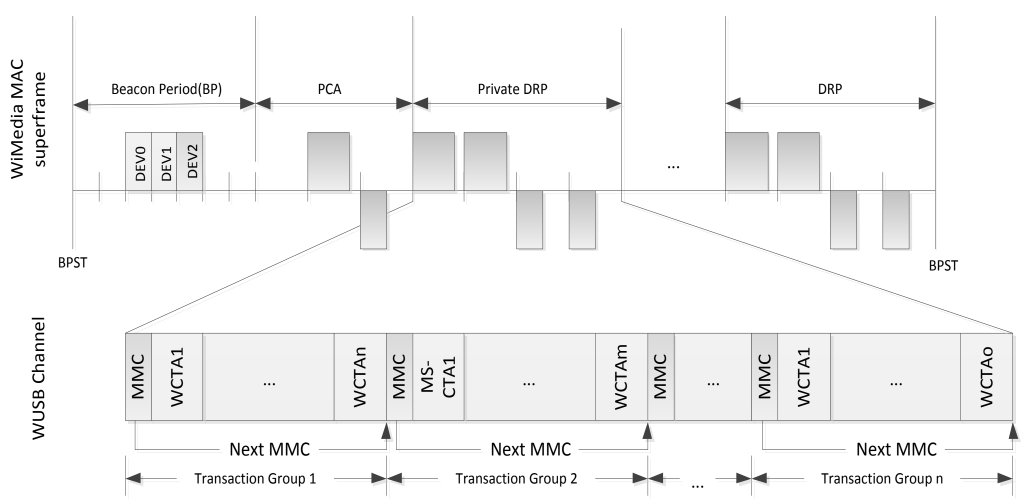

Figure 1. Example of a Data Exchange Between Wireless Usb Devices Through Wimedia Mac

Within wireless USB protocol, the Micro-scheduled sequence consists of a MMC and the subsequent time slot which is described in the MMC and is called a Transaction Group. As shown in Figure 1, A Wireless USB Channel consists of a continuous sequence of MMC (Micro-scheduled Management Commands) transmissions from the host. The linked stream of MMCs is used primarily to dynamically schedule channel time for data communications between host applications and Wireless USB Endpoints. An MMC contains WCTA (wireless USB channel time allocation) IE (Information Element) to indicate the information of wireless USB Channel utilization in wireless

USB Transaction. The MMC payload must be encapsulated within a WiMedia MAC secure packet; however its data payload is transmitted in plain text, thus using the security encapsulation for authentication purpose only.

As mentioned above, a wireless USB host and wireless USB devices must include a DRP IE in their beacon frames to establish and protect the wireless USB Channel. Once the host is beaconing it then establishes a wireless USB Channel by private DRP reservation for wireless USB transaction group. Also, wireless USB device must be able to inform which MASs are available for wireless USB Channel.

To reserve private DRP duration, a wireless USB host transmits the GetStatus(MAS Availability) request. The GetStatus(MAS Availability) request is used to retrieve a device's MAS Availability information. A wireless USB device that receives the GetStatus(MAS Availability) request from the wireless USB host accumulate the information from its neighbors' beacon about available MASs. Then, the wireless USB device responds to the GetStatus(MAS Availability) request through the bmMASAvailability field in GetSatus request. Figure 2 illustrates the format of the GetStatus request.

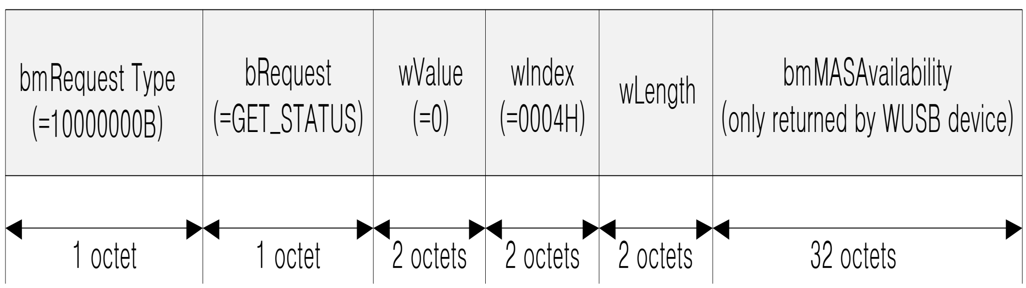

Figure 2. The Format of GetStatus(MAS Availability)

In Figure 2, bmMASAvailability field is a 256-bit map, where each bit location corresponds to a MAS slot in the WiMedia MAC superframe. A 1B in a bit location means that the device is available for a reservation in the corresponding MAS slot. A 0B indicates the device is not available.

When the wireless USB host receives the GetStatus(MAS Availability) response, it selects non-overlapped MASs. It transmits a SetWUSBData(DRP Info) request including wireless USB Channel information. The SetWUSBData(DRP Info) is used to construct the DRP IE that the wireless USB device transmits in its beacon. If the wireless USB device does not have an existing DRP IE for this Wireless USB Channel, it simply adds the received DRP IE to its beacon. If the device has an existing DRP IE for this Wireless USB Channel, then it must replace the existing DRP IE with the new DRP IE provided in this command payload.

To start wireless USB network, the wireless USB host transmits the SetFeature(TX_DRPIE) request to the wireless USB device. The wireless USB device that receives the SetFeature(TX_DRPIE) request starts the transmission of its beacon including DRP IE set to the values in DRP IE Information field.

To terminate the private DRP reservations with the wireless USB devices, wireless USB host transmits the ClearFeature(TX_DRPIE) request. On receipt of this request from the wireless USB host, the wireless USB device removes the associated DRP IE from its own beacon.

3. Proposed Link-adaptive MAC Protocol

In this Section, we propose a new link adaptive cooperative MAC protocol in wireless USB network. The proposed scheme establish relay path using a DRD (Dual Role Devices). Wireless USB allows a DRD to operate separately in time as a wireless USB host and as a wireless USB device on a single transceiver. A number of scenarios are possible for DRD devices including ‘combination’ and ‘point-to-point’ scenarios [3]. In the combination scenario, the DRD operates as a wireless USB device connected to a wireless USB host. Separately in time, the same DRD also operates as a wireless USB host that manages other wireless USB devices. On the other hand, in the point-to-point scenario, two DRDs connect themselves with each other as both a wireless USB host and a wireless USB device. In the wireless USB specification [3], the wireless USB host operating mode in a DRD is denoted as DRD-host, and the wireless USB device operating mode in a DRD is denoted as DRD-device.

3.1. RNS (Relay Node Selection) Algorithm

The WiMedia MAC protocol used by wireless USB host and devices provides the Link Feedback IE that can be interpreted as the optimal data rate that the source device can use for each particular link according to channel condition. Figure 4 shows the format of the Link Feedback IE.

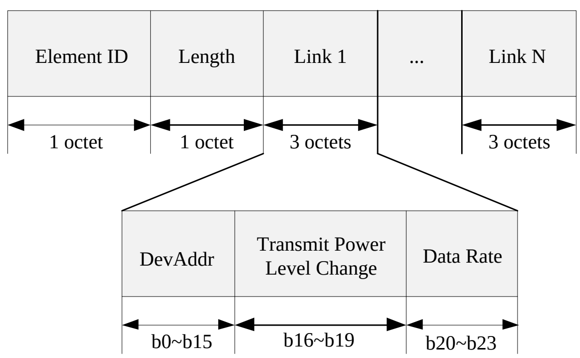

Figure 4. The format of Link Feedback IE

In Figure 4, DevAddr field indicates the address of source device that provides feedback. All wireless USB devices can construct and maintain a RNT (Relay Node Table) to select a potential relay device that can relay data transmissions through the Link Feedback IE. The formation and updating of RNT is accomplished by listening beacon frame of neighbor devices during the beacon period in superframe. As the Link Feedback IE in device’s WiMedia MAC beacon includes the optimal data transmission rate that can successfully receive the data frame from source, additional hardware is not required for the creation or updating of the RNT. The beacon frame and header of WiMedia MAC frame is always transmitted at 48.5Mbps, the lowest data rate supported by WiMedia PHY. The neighbor’s data rate in the received Link Feedback IE is stored in RNT. As shown Table 1, RNT consists of Source DEV Addr, Data rate, and Dest DEV Addr field. Source DEV Addr field indicates neighbor device’s address, and Data rate field indicates the data rate between source and destination. Dest DEV Addr field indicates destination device’s address. The information of RNT created or updated is forwarded into wireless USB protocol layer. When wireless USB host or device has data to transmit, it first checks the RNT.

Table 1. RNT Table

Source DEV Addr	PHY Data rate	Dest DEV Addr

After obtaining the information of potential relay node or neighbor nodes, source device determines relay node that provides minimum relay transmission time through RNT table. To do this, source device must calculate transmission time on the available path (direct path and relay path). Table 2 lists the notations used in the proposed adaptive RNS algorithm. ACK frame and MAC header are transmitted at a basic data rate of 53.3Mbps. In direct transmission, T_{direct} is transmission time between source device and destination device, and PHY data transfer rate between source device and destination device is used to calculate T_{direct}. On the other hand, transmission time by relay communication is the sum of $T_{S\text{-}R}$ and $T_{R\text{-}D}$. If relay transmission time (T_{relay}) is shorter than the direct transmission time (T_{direct}), source device transmits data frames to destination device via relay device.

Table 2. Parameter Notations in the Proposed RNS Algorithms

Variables	Description
T_{direct}	Direct transmission time between source device and destination device
T_{relay}	Relay transmission time between source device and destination device
$T_{S\text{-}R}$	Transmission time between source device and relay device
$T_{R\text{-}D}$	Transmission time between relay device and destination device
$R_{S\text{-}R}$	Data transfer rate between source device and relay device
$R_{R\text{-}D}$	Data transfer rate between relay device and destination device
$R_{S\text{-}D}$	Data transfer rate between source device and destination device
T_{MISF}	Time length of MISF
T_{SISF}	Time length of SISF
R_{min}	Basic Data rate defined in wireless USB standard
N_f	The number of the transmitted data frame
L_h	The length of frame header
L_p	The length of frame payload

The transmission time for direct and cooperative communication can be expressed as

$$T_{direct} = \frac{(N_f \cdot L_h)}{R_{\min}} + \frac{N_f \cdot L_p}{R_{S0D}} + (N_f - 1) \cdot T_{MIFS} + 2 \cdot T_{SIFS} \qquad (1)$$

$$T_{relay} = 2 \cdot \frac{N_f \cdot L_h}{R_{\min}} + \frac{N_f \cdot L_P}{R_{S-R}} + \frac{N_f \cdot L_P}{R_{R-D}} + 2 \cdot (N_f - 1) \cdot T_{MISF} + 2 \cdot T_{SIFS} \quad (2)$$

$$T_{direct} = T_{S-D},\ T_{relay} = T_{S-R} + T_{R-D}, \quad T_{relay} < T_{direct} \quad (3)$$

If the equation (3) is summarized to satisfy the condition for relay transmission, the RNS (Relay Node Selection) condition to decide relay node is derived as equation (4).

$$\text{Relay Node Selection (RNS) Criterion} \quad (R_{S-D} \cdot R_{R-D} + R_{S-R} \cdot R_{S-D}) < R_{S-R} \cdot R_{R-T} \quad (4)$$

3.2. Link-Adaptive MAC Design Using DRD

Source device decides a device with the highest data rate among devices that satisfy the RNS condition in equation (4), it performs the private DRP reservation for relay transmission. Figure 5 shows the format of SetWUSBData(DRPIE Info) request. In proposed protocol, Operation Info subfield is used to inform the type of DRD, and it is included in DRP IE Information field of SetWUSBData(DRPIE Info) request. DRP IE Information field is transmitted by wireless USB host. After DRP IE Information field including Operation Info bits is transmitted via beacon from wireless USB host, wireless USB devices that have received wireless USB host's beacon knows type of the indicated wireless USB device and its DRP reservation information. Figure 6 shows proposed DRP IE Information field.

bmRequest Type (=00000000B)	bRequest (=SET_WUSB_DATA)	wValue (=0001H)	wIndex (=0)	wLength	DRP IE Information
1 octet	1 octet	2 octets	2 octets	2 octets	variable

Figure 5. The Format of The Setwusbdata(Drp Info) Request

bmAttributes			DRPIEData
Reserved	Operation Info	Conflict Tie-Breaker bit	
b3-b7	b1~b2	b0	4*N octets

Figure 6. The Format of Proposed DRP IE Information Field

In Figure 6, bmAttributes field is used to construct the DRP Control field of a DRP IE in the WiMedia MAC layer. The Conflict Tie-breaker bit is set to a random value of zero or one when a reservation request is made, and it is used for DRP conflict resolution. DRP IE Data field is the DRP Allocation blocks that must be included in the DRP IE [2].

If the wireless USB host transmits the SetFeature(TX DRP IE) request to the wireless USB device, the wireless USB device starts the transmission of its beacon including the DRP IE set according to SetWUSBData command. To terminate the DRP reservation, wireless USB host transmits a ClearFeature(TX DRP IE) request. It instructs a wireless USB device to cease transmitting the corresponding DRP IE in its beacon. Figure 7 shows the operation flow of private DRP reservation for wireless USB channel setup/release.

All wireless USB devices can receive data frames from its wireless USB host at the reserved private DRPs in WiMedia MAC, according to private DRP reservation information in the received beacon from its wireless USB host. All wireless USB command frames such as GetStatus request/response, SetWUSBData request, SetFeature request, and ClreaFeature request are conveyed into WiMedia beacons.

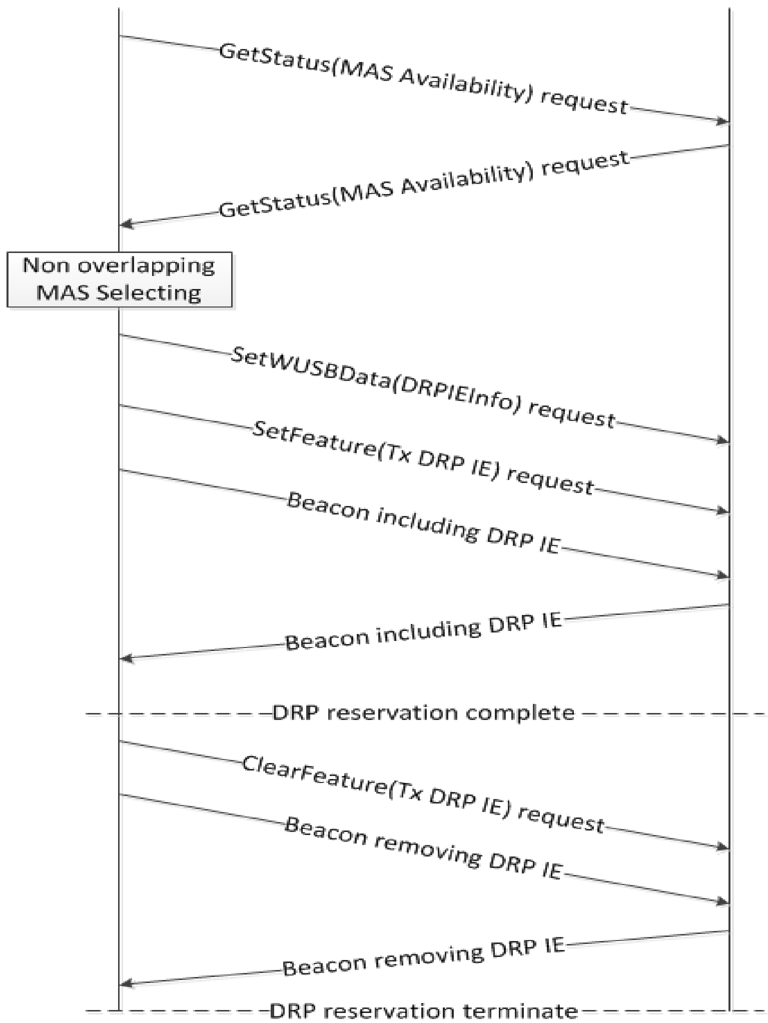

Figure 7. The Operation Flow of Private DRP Reservation

4. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme through NS-2 simulations. Table 4 shows the simulation parameters used in this paper; the network size is 20m*20m; the maximum 40 devices are randomly deployed into this area.

Table 4 Simulation Parameters

Parameter	Value
Network Size	20m x 20m
Frame Size	512, 1024, 2049, 4096 Bytes
Basic Data Rate	53.3Mbps
Bandwidth	528Mhz
Symbol Length	312.5ns
Preamble Length	9.375us
Header Length	3.75us
SIFS	10us
MISF	1.875us
Transmission Power	-41.3dB/Mhz

The throughput is defined as the number of bits of data frames per unit time. Therefore, it can be computed as the whole delivered data by dividing the total transmission time. The payload size is fixed at 2048 bytes. Figure 8 compares the saturation throughput achieved by both legacy wireless USB standard and proposed wireless USB protocol. As shown in Figure 8, the cooperative communication can improve the throughput compared with the direct transmission. It can also found that the throughput improvement increases as the number of devices deployed increases. This is because more devices can act as a helper device with the increase in the number of devices. Meanwhile the simulation results demonstrate that the throughput for both MAC protocols are significantly lower than maximum data rate 480 Mbps supported by wireless USB standard, because only a portion of the wireless USB devices are able to transmit at 480 Mbps. Moreover, PHY/MAC layer overhead among transmissions also contribute to the reduced throughput. This highly desirable feature of proposed protocol is attributed to the fact that as the number of stations increases, the likelihood of a low rate station finding a high rate two-hop path also increases. The growing availability of helping stations not only cancels the throughput degradation caused by increasing collisions, but also results in a substantial net increase in the aggregate network throughput.

Throughput performance in the wireless USB network environment where twenty devices operate according to BER (Bit Error Rate) indicating current wireless channel status is shown in Figure 9. As the channel status becomes worse, throughput is decreased. However, when using the proposed protocol, the throughput decline is less than the legacy wireless USB standard. In the result of proposed protocol, the throughput is more degraded than others at the period from BER 10-4 to BER 10-3. This result shows that there exists a threshold value where the proposed protocol cannot compensate the throughput decrement due to the harsh wireless channel status even though it performs relay transmissions to find stable channels.

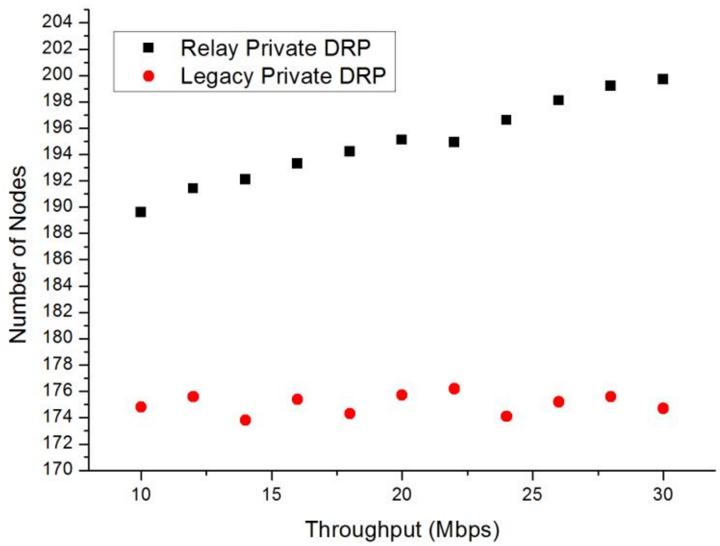

Figure 8. Throughput Comparison

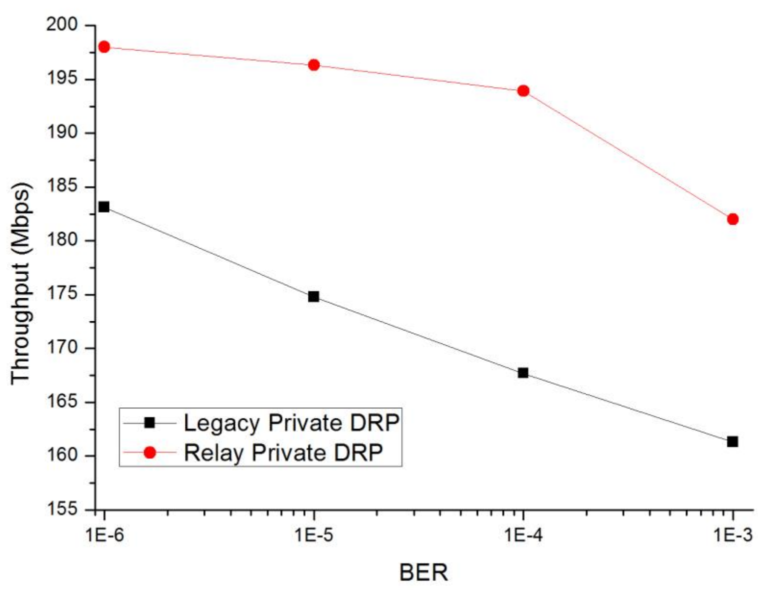

Figure 9. Throughput According To Wireless Channel Status (BER)

Eq. (5) explains the energy consumption required for data transmissions within a superframe in wireless USB system. P_{tx}, P_{rx}, and P_{idle} are the power consumed at data transmissions, at data receptions, and at idle states within a superframe, respectively. N_{tx} and N_{rx} denote the number of transmitted PSDUs (PHY Service Data Unit) and that of received

PSDUs in a DRP reservation block. T_{PSDU} denotes the required time delay during transmitting or receiving a PSDU. T_{MIFS} and T_{SIFS} are time length of MIFS and SIFS defined in the WiMedia MAC Standard [2], respectively. NDRP denotes the number of DRP reservation blocks in a superframe.

$$E_{Superframe} = [P_{tx} \cdot T_{PSDU} \cdot N_{tx} + P_{rx} \cdot T_{PSDU} \cdot N_{rx} + P_{idle} \cdot T_{MISF} \cdot (N_{tx} + N_{rx}) + P_{idle} \cdot T_{SIFS}] \cdot N_{DRP} \quad (5)$$

Fig. 10 shows the ratio of $E_{Proposed\_scheme}$ / $E_{Legacy\_standard}$ according to the number of wireless USB devices. $E_{Proposed\_scheme}$ is the $E_{Superframe}$ value of the proposed scheme and $E_{Legacy\ standard}$ denotes that value of the legacy wireless USB standard. As shown in Fig. 10, the proposed protocol shows the superior energy saving performance to the legacy wireless USB standard. Furthermore, the ratio of the energy consumption decreases as the number of wireless USB devices increases. This result can be explained that there occur more interference causing retransmissions during communications between the nodes as the number of nodes increases in the network. In this case, by performing cooperative relay transmissions via stable channels through the proposed scheme, energy consumption at each node decreases. Furthermore, because multiple relay nodes share the role of relay transmission, the entire energy consumption is reduced more.

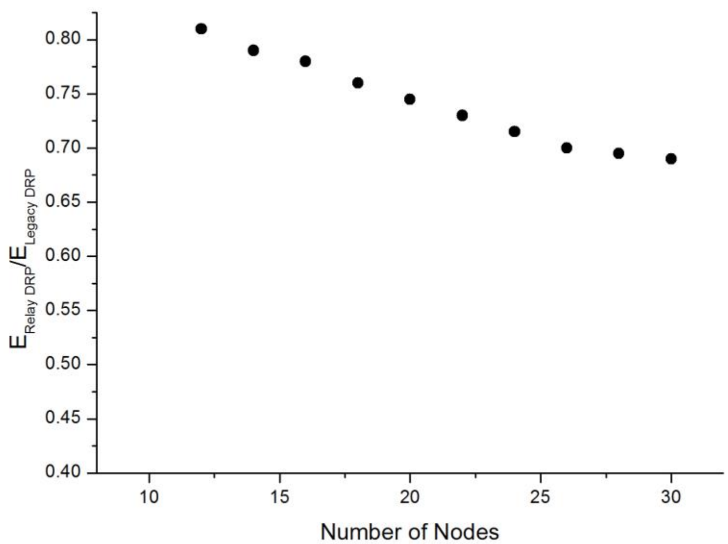

Figure 10. Energy Consumption Comparison according to the Number of Devices

5. Conclusion

In this paper, we propose the cooperative MAC protocol for cross-layer link adaptation of wireless USB cluster. To do this, we propose the RNS (Relay Node Selection) algorithm considering UWB link state. The proposed cooperative MAC protocol is compatible and can be directly applied with small overhead to the current WUSB standard system. Also, in the proposed protocol, each device independently performs RNS algorithm. From the simulation results, it is shown that the performance of the proposed protocol is superior to that of the legacy wireless USB standard. Since the relay device simply forwards the packet without looking into the contents of the MSDU, the confidentiality of the MSDU can be maintained by encrypting the content.

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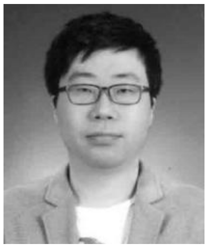

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