

## Research Article

# A Conflict Avoidance Scheme for WiMedia Wireless Home Networks

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We propose an efficient resource reservation scheme for UWB (Ultrawideband) WPAN (Wireless Personal Area Network) with D-MAC (Distributed Medium Access Control). Since the WiMedia D-MAC supporting DRP (Distributed Reservation Protocol) scheme causes lots of conflicts due to failure of beacon detection in wireless channel environment, overall performances of the WiMedia D-MAC can be deteriorated. Therefore, we propose Relay DRP protocol, which makes a relay path to avoid DRP conflicts or harsh channel conditions through 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 energy consumption.

## 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 efficient communications between those heterogeneous devices. Hence, WPAN technology using UWB is continuously gaining interest for ubiquitous connections in home entertainment and security/medical/military applications due to its high speed data rate, inexpensive cost, low power consumption, and small size.

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 and 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].

The WiMedia Alliance has specified D-MAC protocol based on UWB for high-rate WPANs [4]. In contrast to centralized MAC such as 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, the WiMedia D-MAC removes the SOP (Simultaneous Operating Piconet) problem, that is, packet collisions between overlapped piconets in the centralized IEEE 802.15.3 MAC by exchanging resource reservation and control information among the devices [4], 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 as 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 [4].

However, the conventional WiMedia D-MAC has DRP conflict problem due to failure of beacon detection in wireless channel status and mobile communication environment [4]. Thus, in order to get full benefits of the distributed MAC

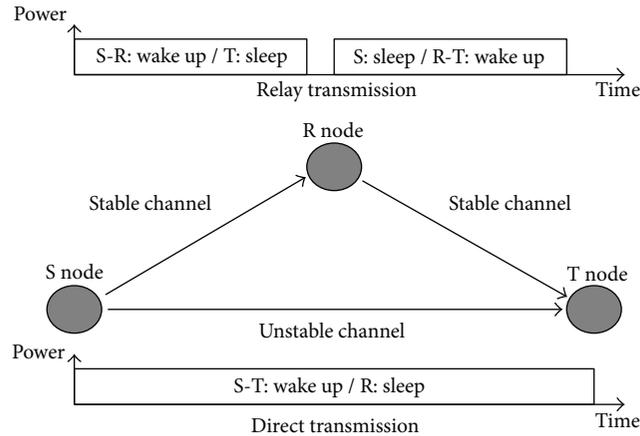


FIGURE 1: Relay-based cooperative communication.

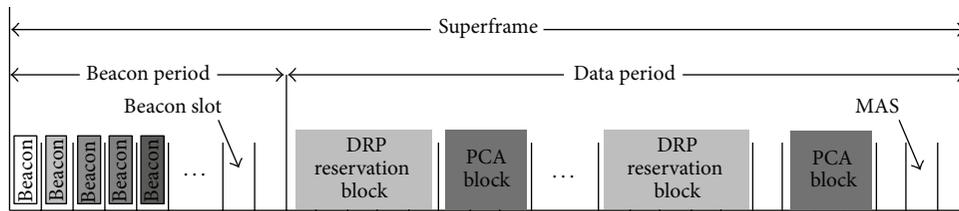


FIGURE 2: Superframe structure in WiMedia D-MAC.

approach, we should 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 [5, 6]. Those schemes consider multihop range DRP conflicts due to mobile hidden node problem and show improvement of throughput performance. However, the methods only focus on how to prevent and/or resolve MAC-level conflicts without considering physical channel status. Therefore, the algorithms in [5, 6] cannot avoid the data transmission errors caused by physical channel distortion on the conflict-resolved link.

There have been previous works to improve system performance by using cooperative communication scheme [7, 8]. As shown in Figure 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 power consumption. Thus, 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 data rate for the link, the corresponding channel resources are wasted even after the link adaptation in physical layer. In this case, we should try to find a detour, for example, the path via the relay node (R node) in Figure 1 as an indirect communication link with good channel status in order to avoid the coarse wireless link. In [7], 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 thus it does not guarantee backward compatibility with legacy devices. In addition, since source device which has relay transmission in mind should overhear data packet transmissions between a pair of other stations to select a relay node, extra energy for overhearing the data packet exchanges is consumed.

Therefore, in this paper, Relay DRP scheme is proposed as an efficient relay-based cooperative communication protocol for the WiMedia D-MAC devices to avoid DRP conflicts and/or harsh channel conditions. 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 avoid DRP conflicts and bad channel conditions. 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 Figure 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 nonoverlapping beacon slot. This feature of the BP helps to

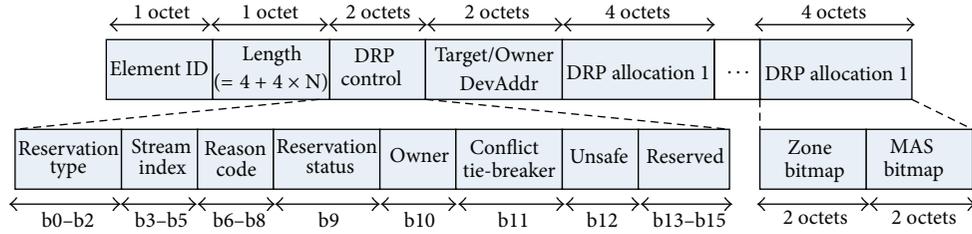


FIGURE 3: The format of DRP IE.

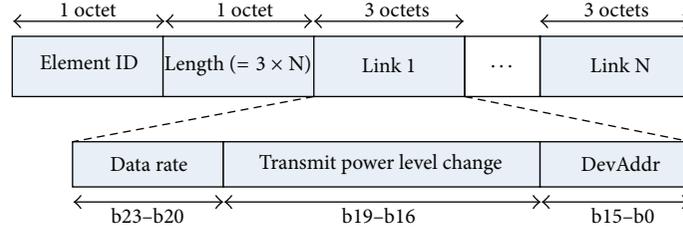


FIGURE 4: The format of Link Feedback IE.

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 Figure 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 indicates a corresponding MAS in a superframe because a superframe consists of 256 MASs. It is filled by combining all the DRP IEs transmitted by the 1-hop range neighbor devices.

In Figure 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; that is, 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 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 [4]. Figure 4 illustrates the Link Feedback IE format. The DevAddr field is set to the DevAddr 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.

In this paper, a new Relay DRP is proposed for the WiMedia D-MAC. To provide cooperative relay transmission, Relay DRP uses newly defined three code points in the reserved field of the Reason Code explained in Table 2. “Relay Req” and “Relay Ntf” Reason Codes ultimately intend to reserve DRP resources for relay transmission to the target node via the relay node. If both 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 Figures 5, 6, and 7, we depict the proposed Relay DRP resource reservation procedures of reservation owner (transmitting device), relay node, and target node in detail.

After reading DRP Availability IEs from other devices’ beacons, the reservation owner checks if both MAS S-R (medium access slots between sender and relay infra-nodes or RFID readers) and MAS R-T (medium access slots between target and relay infra-nodes) are free to be used for the relay transmission. If both resources are available and if the received power level in beacons from the target node is lower than a threshold  $Th_{S-T}$  (a bad channel condition), the reservation owner starts the proposed Relay DRP.

### 4. Performance Analyses

Performance of the Relay DRP scheme is evaluated through NS-2 simulations. The network size covered by randomly distributed WiMedia D-MAC devices is 10 m \* 10 m. And we assume multiple WiMedia D-MAC application clusters

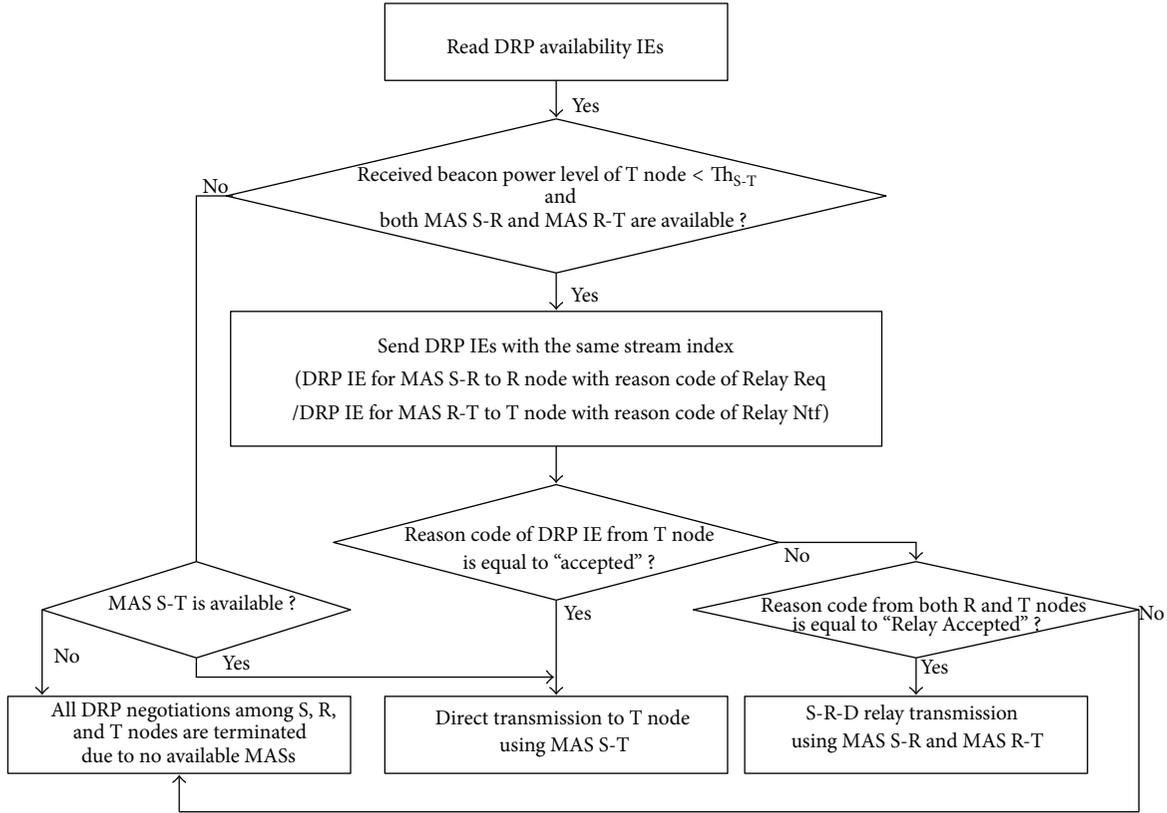


FIGURE 5: Resource reservation procedure of reservation owner device.

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

TABLE 2: Additional reason code field encoding for relay DRP.

Value	Code	Description
5	Relay Req	Sent by a reservation owner (a transmitting device) for a relay device to request the DRP reservation between the owner and the relay device
6	Relay Ntf	Sent by a reservation owner for a target device to request the DRP reservation between a relay device and the target
7	Relay Accepted	A DRP reservation request via corresponding relay device is granted

for home network or warehouse application composed of 10~30 devices in the network area (1 to 3 devices per 10 m<sup>2</sup>) [5, 6]. The transmission power of a device is fixed to -41.25 dBm/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, 4] are considered and are found in Table 3.

Figure 8 shows throughput performance of the WiMedia D-MAC devices according to the number of devices in the

network with the maximum PER (Packet Error Rate) of 8% which is the defined value of WiMedia test specification [9]. The throughput of the proposed Relay DRP scheme is superior to that of the legacy DRP scheme, and it increases in proportion to the number of nodes. Since the Relay DRP scheme avoids DRP conflicts or bad links by performing cooperative relay transmission, the throughput of each node can be increased. However, the throughput performances are degraded when the number of devices increases over some threshold number of nodes in the given environment of simulation, because more MASs are overlapped with other WiMedia D-MAC devices' clusters as the number of devices increases. The threshold number of the legacy DRP is somewhat larger than that of the Relay DRP since neighbor

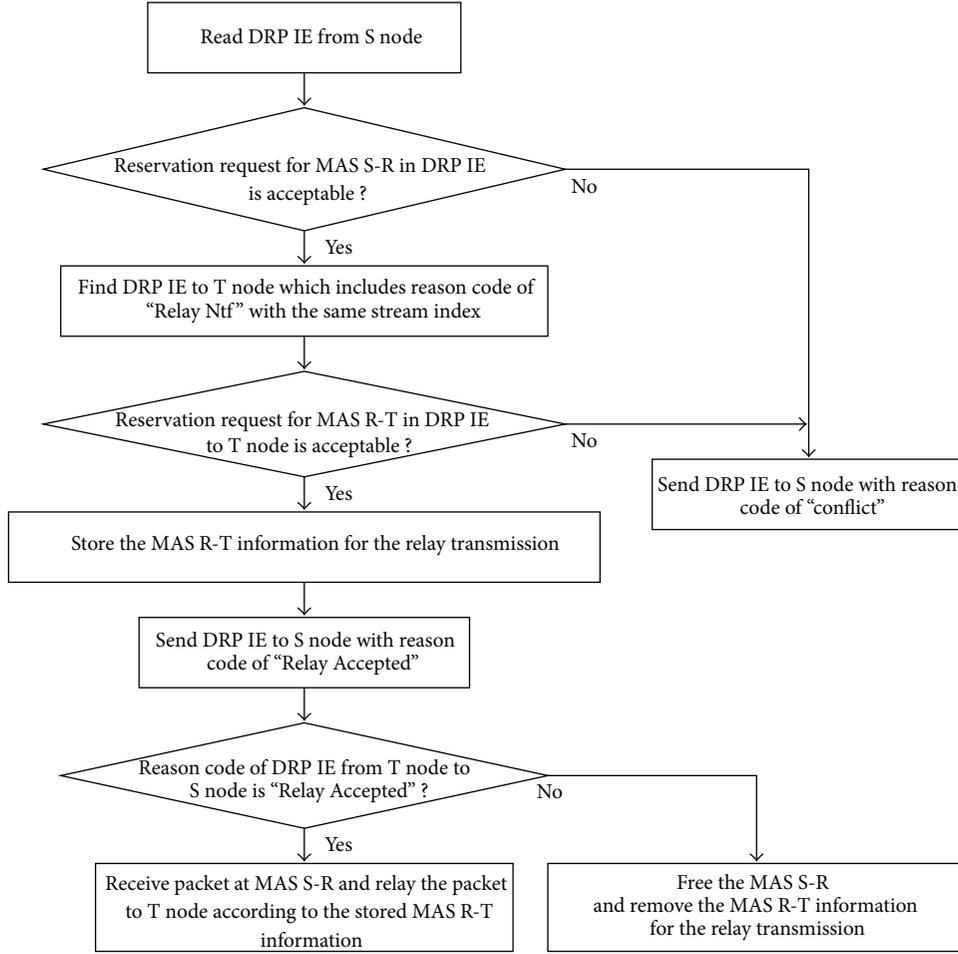


FIGURE 6: Resource reservation procedure of relay node.

TABLE 3: WiMedia PHY/MAC simulation parameters.

Parameter	Value
$T_{\text{SYM}}$	312.5 ns
$T_{\text{sync}}$	Standard preamble: 9.375 $\mu\text{s}$
$p_{\text{MIFS}}$	1.875 $\mu\text{s}$
$p_{\text{SIFS}}$	10 $\mu\text{s}$
$m_{\text{MAXFramePayloadSize}}$	4,095 octets
$m_{\text{MAXBPLength}}$	96 beacon slots
$m_{\text{BeaconSlotLength}}$	85 $\mu\text{s}$
$m_{\text{SuperframeLength}}$	$256 * m_{\text{MASLength}}$
$m_{\text{MASLength}}$	256 $\mu\text{s}$
$m_{\text{BPExtension}}$	8 beacon slots
$m_{\text{TotalMASLimit}}$	112 MASs

devices in case of the legacy DRP have less amount of traffic as much as the relayed packet transfer than the case of the Relay DRP.

Figure 9 compares the average delay performance between the legacy WiMedia D-MAC standard and the proposed Relay DRP scheme according to the number of

devices in the same simulation environment with Figure 8. The delay of each packet transfer was measured considering both queuing delay and transmission delay of head-of-line packet in the queue. The delay for the Relay DRP is much shorter than that for the legacy scheme and decreases in proportion to the node density. The reason of the delay performance improvement of the Relay DRP is that the proposed scheme can detect channel status and find a stable detour if necessary. However, just like the throughput performance, the delay performance in Figure 9 also shows the performance degradation due to the MAS-overlap among different WiMedia D-MAC devices' clusters after a threshold number of devices in the given environment of simulation.

Figure 10 shows the ratio of  $E_{\text{Relay DRP}}/E_{\text{Legacy DRP}}$  according to the number of WiMedia D-MAC devices.  $E_{\text{Relay DRP}}$  is the  $E_{\text{Superframe}}$  value of the Relay DRP scheme and  $E_{\text{Legacy DRP}}$  denotes the value of the legacy DRP scheme [10]. As shown in Figure 10, the proposed Relay DRP scheme shows the superior energy saving performance to the legacy DRP scheme. Furthermore, the ratio of the energy consumption decreases as the number of WiMedia D-MAC devices increases up to a threshold number of nodes. This result can be explained that there are more DRP conflicts causing retransmissions

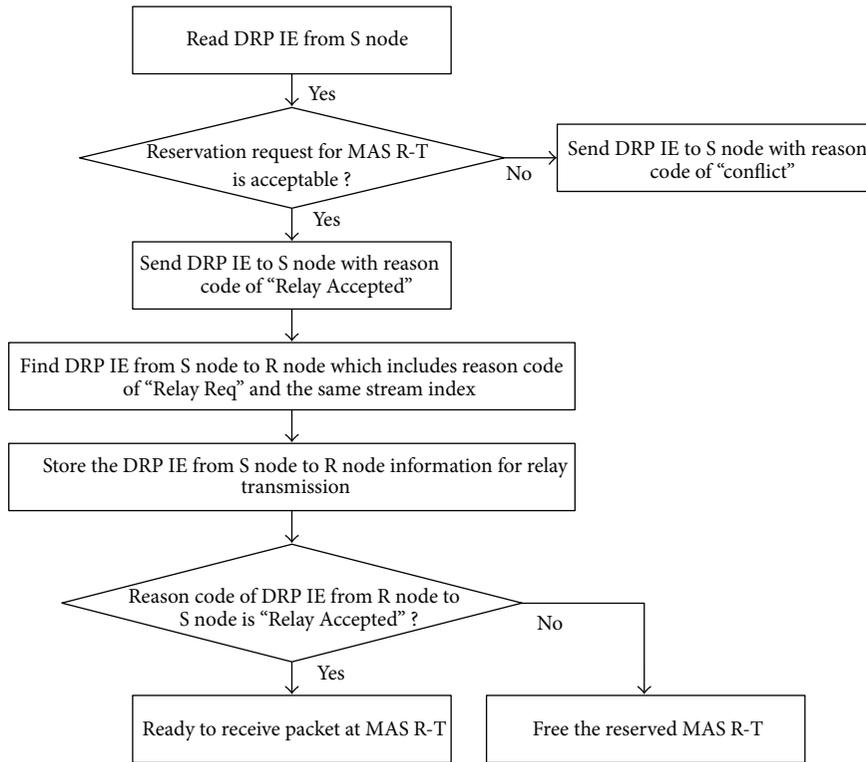


FIGURE 7: Resource reservation procedure of target node.

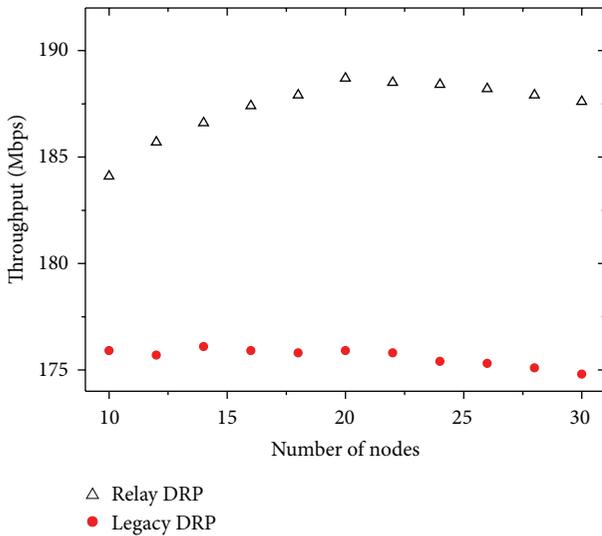


FIGURE 8: Throughput according to the number of devices.

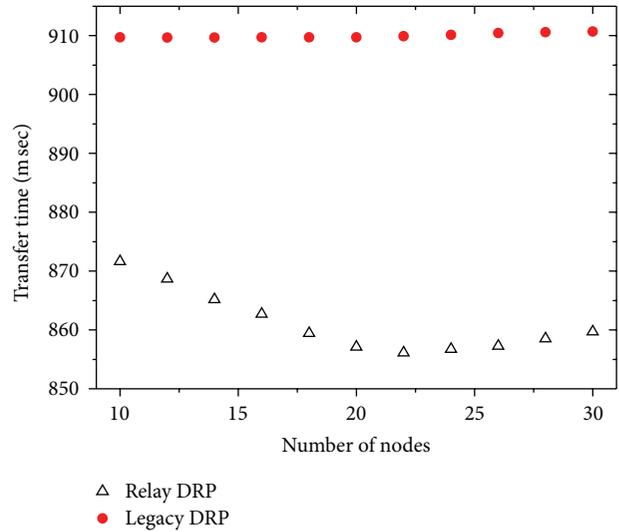


FIGURE 9: File transfer time according to the number of devices.

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 Relay DRP scheme, energy consumption at each node decreases. In addition, because multiple neighbor devices can share the role of relay transmission, the entire energy consumption can be reduced as the number of devices increases. However, since the relayed packets also introduces

additional interferences, that is, DRP conflicts after the threshold number of nodes, the energy consumption of the Relay DRP increases.

### 5. Conclusions

In this paper, a cooperative relay transmission scheme for WiMedia DRP protocol-based WPAN devices has been

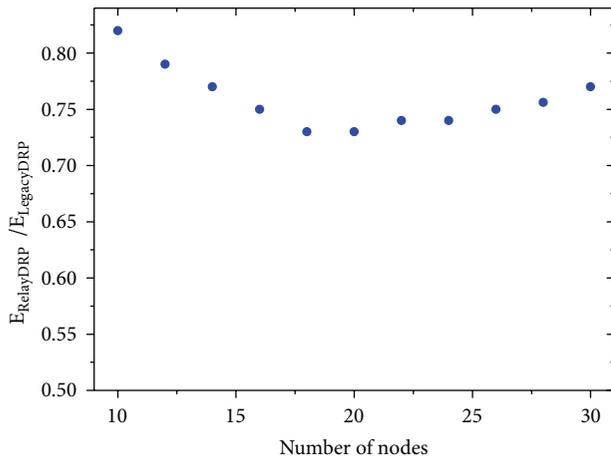


FIGURE 10: Energy consumption comparison according to the number of devices.

proposed to enhance throughput performance and to improve energy efficiency by avoiding resource reservation conflicts and bad channel conditions through the cross-layer link adaptation. From the simulation results for throughput and energy consumption, it is shown that the performance of the proposed Relay DRP scheme is superior to that of the legacy DRP scheme. And the Relay DRP scheme is compatible and can be directly applied with small overhead to the current WiMedia D-MAC standard system.

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