Research Article

Distributed Relay-Assisted Retransmission Scheme for Wireless Home Networks

Seunghyun Park, Hyunhee Park, and Eui-Jik Kim

1 Center for Information Security and Technologies, Korea University, 136-713 Seoul, Republic of Korea
2 Institut National de Recherche en Informatique et en Automatique (INRIA), 35042 Rennes, France
3 Department of Ubiquitous Computing, Hallym University, 39 Hallymdaehak-gil, Chuncheon-si, Gangwon-do 200-702, Republic of Korea

Correspondence should be addressed to Eui-Jik Kim; ejkim32@hallym.ac.kr

Received 28 October 2013; Accepted 30 March 2014; Published 28 April 2014

Copyright © 2014 Seunghyun Park et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A relay transmission is a promising technology to improve network performance in dynamic infrastructure. In this paper, we propose a distributed relay-assisted retransmission (DRR) scheme in multirate wireless home networks. The idea is to exploit overhearing nodes to retransmit on behalf of sender node after receiving the block acknowledgement (B-ACK) from destination node. For the first transmission, a basic relay (BR) node is used by considering the high data rate between source node and BR node. And then, for the retransmission, a retransmission relay (RR) node is used by considering the high data rate between RR node and destination node. The DRR scheme extends a distributed reservation protocol in WiMedia home networks and inquires the candidate relay node as BR nodes and RR nodes during beacon period. In addition, the DRR scheme can minimize control overhead for relay transmission because all nodes should send and listen to the beacon frames of neighbor nodes during beacon period. We also present the relay decision scheme and channel allocation procedure for maximizing the efficiency in the DRR scheme. Extensive simulation results demonstrate that the DRR scheme can improve the overall throughput by 40% and reduce the energy consumption by 47% compared with nonrelay transmission schemes when the number of nodes increases.

1. Introduction

Recently, there has been a growing interest in relay technologies to extend the coverage and improve the reliability of wireless networks by exploiting the spatial diversity gains [1]. In basic relay scheme, packets are transmitted along the relays via a store-and-forward manner, and thus the use of relays does not guarantee perfect transmission (i.e., no error transmission) [2,3]. Dealing with this, diverse retransmission mechanisms are applied at relays to improve the successful transmission rate over wireless networks. In addition, the multirate transmission mechanism is one of the important relay transmissions to improve the system performance. Most of the wireless networks (i.e., IEEE 802.11 series, 802.15.3 series, and WiMedia MAC) can support multiple transmission rate by adaptively choosing the most appropriate modulation under the current channel conditions [4–6]. For instance, IEEE 802.11a/b wireless local area networks (WLANs) provide diverse transmission rates depending on the distance between source and destination nodes (i.e., 1 Mbps at 100 m, 2 Mbps at 74.7 m, and 11 Mbps at 48.2 m) [7]. The rate adaptive mechanisms by diverse PHY modulations have been studied based on request to send (RTS) and clear to send (CTS) for IEEE 802.11 WLANs. In such multirate wireless networks, relay transmission can improve the overall system performance and reduce the energy consumption, since relay transmission supported that the high transmission rate can reduce the transmission time compared with direct transmission over a lower data link.

Relay communications have been investigated and included in long term evolution-advanced (LTE-A) and IEEE 802.16 m candidates for the international mobile telecommunications-advanced (IMT-A fourth generation) standards [8, 9]. Representatively, the automatic repeat request (ARQ) mechanism can deliver reliable transmission over multicast and broadcast networks [10].
However, the retransmission of failed packets using ARQ schemes may cause a significant delay problem since the transmission failed packets are retransmitted individually and the retransmissions have to be repeated until every destination node receives all packets correctly. Furthermore, many studies have been researched to support the relay transmission in various wireless networks. The multihop mechanisms for the relay transmission have been emphasized as the cooperative communications. Liu et al. propose the cooperative MAC by defining the helper ready to send (HTS) using the overheard transmission [11]. Cetinkava and Orsun suggest the cooperative MAC protocol by choosing proper backoff window to be achieved with no compromise in throughput performance for dense wireless networks [12]. Shin et al. provide the use of beacon period to select relay nodes in distributed wireless networks [13]. Wang et al. address the dual communication node considering different transmission paths with peer to peer path and relay path in ultra-wide band (UWB) WPANs [14]. However, there still exists the problem of compatibility between the relay node and the retransmission problem in distributed wireless networks. The previous work has the control overhead problem; if nodes want to relay packets, they should learn the information of neighbor nodes. In addition, the overall throughput and power consumption of the system suffer from sending the packets through the same path between relay node and retransmission node even though the packets are failed by the relay path.

In this paper, we propose a distributed relay-assisted retransmission (DRR) scheme based on the WiMedia home network standard by using the distributed beacon period. As our knowledge of prior studies, any significant relay mechanism for distributed network to minimize the overheads due to control frames has not been proposed before. Consequently, we focus on the considerations of how to avoid additional control frames when neighbor nodes are collecting information of neighbors and how to maximize the successful transmission rate with the efficient retransmission assisted relay nodes. As a 1st step, we define a distributed relay decision procedure to determine a basic relay (BR) node. Each node manages the modulation support to neighbor (MSN) table which includes the modulations between a node and neighbors. To acquire modulation information of neighbors, we define a new information element for relay decision (RD IE) which includes the request and response frames according to modification of the beacon frame. After all, since all the exchange process of beacon frames is executed during beacon period while RD IE is attached to the default beacon frame, there are no more header frames added except for the minute size of RD IE. Through the MSN table and RD IE, the BR node is selected, then the source node can transmit the packets to the BR node, and the BR node also can transmit the packets to the destination node, respectively. However, this process does not guarantee perfect packet transmission, because the packet error or transmission fail can occur during the source to BR node path or BR node to destination path. Therefore, we also define a relay-assisted retransmission to support the retransmission for the reliable communication as a 2nd step. Specifically, if the intended destination node does not receive the transmitted packets, a retransmission relay (RR) node is elected by investigating the channel condition between the candidate relay node and the destination node. Extensive simulation results demonstrate that the DRR scheme can improve the overall throughput by 47% compared with direct transmission and can reduce the energy consumption up to 40% according to the number of nodes.

The remaining of this paper is organized as follows. In Section 2, we introduce the system model and background of this work. In Section 3, we describe the proposed relay-assisted retransmission scheme. In Section 4, we perform extensive simulations to evaluate the performance of our scheme. Section 5 concludes this paper.

2. System Description

2.1. WiMedia MAC. In the WiMedia MAC, the channel time is divided into fixed-length superframes and each superframe consists of discrete media access slots (MAs), as depicted in Figure 1 [6]. In addition, the superframe consists of a beacon period (BP) and a data transfer period (DTP). During the BP, each node should choose an empty beacon slot in order to transmit its own beacon frame. To occupy an empty beacon slot, all nodes must execute beacon hearing process, in which a new node waits and listens to beacon frames during few superframes. From the received beacon frames, the node can determine an idle beacon slot and transmit its own beacon frame with beacon transmitting rate of 53.3 Mbps during the beacon slot. Furthermore, the DTP defies two distributed channel access mechanisms: a contention-free channel access mechanism as a distributed reservation protocol (DRP) and a contention-based channel access mechanism as a prioritized channel access (PCA). The DRP is a kind of time division multiple access (TDMA) protocol, in which nodes have the exclusive right of transmission during their reserved time slots [15]. On the other hand, the PCA is generally used to send control frames and excessive data of the reservation block as well as to transmit asynchronous traffic with a variable bit rate (VBR) in unreserved periods [16].

WiMedia MAC supports the high speed, short range communications in order to support multimedia transmissions in distributed home networks [17]. Eight traffic classes and four access categories are defined, which can be applied to different QoS and supports both isochronous and asynchronous data types with DRP and PCA. In the proposed DRR scheme, we utilize DRP because it provides robust operations compared with the centralized scheme. In addition, in WiMedia MAC standard supporting UWB PHY, eight kinds of transmission rates are introduced in Table 1. According to the channel condition, PHY modulation algorithm is selected to satisfy the current condition such as bit error rate (BER), signal to noise ratio (SNR), and received signal strength indicator (RSSI). Although the source node should transmit the beacon at the lowest rate (i.e., 53.3 Mbps), the packets are sent at the supported rate as Table 1 received in the PHY capability information element (IE) [6]. The source node may send the data rate information through the link feedback IE attached to the beacon frame. The optimal decision of data
rate affects the performance of networks and the acceptable BER. Therefore, the source node should consider the recommended rate from the target or should find the optimal rate.

In addition, block-acknowledgement (B-ACK) mode was examined because it helps to save wasteful control space because duration of minimum interframe space (MIFS) between data transmissions is much shorter than short interframe space (SIFS). The superiority of B-ACK has been studied to prove its high throughput achievement [18, 19]. However, if the retransmission policy is used together or the channel condition is bad, B-ACK can deteriorate the performance of networks. In the DRR scheme, as the BER is considered to be up to $10^{-3}$, that is, BER is not severe, B-ACK mode is adopted to show the improved throughput.

### Table 1: Data rate-dependent modulation scheme.

| Data rate (Mb/s) | Modulation | Coding rate ($R$) |
|------------------|------------|------------------|
| 53.5             | QPSK       | 1/3              |
| 80               | QPSK       | 1/2              |
| 106.7            | QPSK       | 1/3              |
| 160              | QPSK       | 1/2              |
| 200              | QPSK       | 5/8              |
| 320              | DCM        | 1/2              |
| 400              | DCM        | 5/8              |
| 480              | DCM        | 3/4              |

2.2. Channel Model. In wireless systems, there exist much complicated propagation characteristics of radio waves. Therefore, various channel models were studied to describe the property of wireless channel [20, 21]. Let $G_T(i), G_R(i)$, and $\delta_{ij}$ be the antenna gains of the transmitter and the receiver of stream $i$ and the distance between the transmitter of stream $i$ and the receiver of stream $j$, $j \neq i$, respectively. Then the average received signal power of stream $i$ is given by [22]

$$P_R(i) = \kappa_1 G_T(i) G_R(i) P_T(i) \delta_{ij}^{-\alpha},$$

where $\alpha$ and $P_T(i)$ are the path loss exponent and the transmission power of stream $i$, respectively, and $\kappa_1$ is a constant depending on wavelength. To obtain $P_T(i), P_R(i)$ is set to the receiver sensitivity as specified in [21]. The receiver sensitivity indicates the threshold of the received power for successful transmission. If the stream $i$ experiences interference by the stream $j$, then the interference power between them, $I_{jj}$, is given by

$$I_{jj} = \kappa_2 G_0 G_T(i) G_R(j) P_T(i) \delta_{ij}^{-\alpha},$$

where $G_0$ is the cross correlation which is assumed to be a constant. The cross correlation is the impact incurred between any two streams caused by using spreading code. Assuming that the CDMA achieves a higher channel capacity than the TDMA, the interference power should be less than the background noise, that is, $I_{jj} \leq N_0 W$, where $N_0$ and $W$ are the one-sided spectral density of white Gaussian noise and the channel bandwidth, respectively. If only one
flow is allowed to transmit at a time the achievable data rate of the ith flow, $R_i$ [23], can be obtained as

$$R_i = W \log_2 \left( \frac{k_1 G_0 G_T(j) G_R(i) P_T(j) \delta_{i,j}^{\alpha}}{N_0 W} + 1 \right). \quad (3)$$

In WiMedia system, data rate determined by PHY modulation is limited to eight discrete values. When a distance $\delta_{i,j}$ between nodes is given, we can calculate the data rate $R_i(\delta_{i,j})$ and then it can be mapped to a discrete rate in the WiMedia standard using the mapping table in Table 2. However, Table 2 does not consider the real world conditions such as BER and SNR conditions. When the source node finds the appropriate data rate that can improve the throughput at the best, it should consider many channel characteristics such as PHY modulation, coding rate, frame size, and acknowledgement mechanism. The coding rate is one of the most important factors to contribute for higher throughput as it determines the data rate. The selection of data rate affects the throughput as well as the BER [24]. As the higher coding rate generally implies the bigger BER, it is a tradeoff to improve the performance of the networks. Therefore, with the desirable BER requirement, the most appropriate coding rate should be found. Therefore, we find the coding rate; we can derive SNR as

$$\text{SNR}_i = \frac{P_R(i)}{N_0 W}. \quad (4)$$

After all, we can find the best coding rate after the calculation of the current SNR in Table 2. When the desirable BER condition is given, that is, BER is $10^{-3}$, the coding rate value becomes lower as SNR is the worst. Low coding rate means that many redundant bits are added to the original packet. For example, 1/10 indicates that the source sends the identical ten bits to transmit one bit. In order to decide the appropriate coding rate, the intersection of current SNR and BER is considered. After all, the data rate is calculated according to the PHY modulation. When the PHY operates as BPSK, which sends one bit per one Hertz, data rate can be calculated from the coding rate by multiplying bandwidth.

### 3. Distributed Relay-Assisted Retransmission Scheme

In this section, we first introduce the distributed relay decision procedure as the 1st step. Then, the relay-assisted retransmission will be followed. In addition, we provide a distributed channel allocation procedure for each path of relay.

The basic idea of distributed relay-assisted retransmission is to have intermediate nodes that overhear a failed packet to retransmit the packet on behalf of the source node. We provide the intuition into the potential benefits of relay-assisted retransmission using the four-node network in Figure 2. We denote $P_{xy}$ as the packet delivery path from $x$ to $y$. Let us look for the best strategy to deliver a packet from source ($S$) to destination ($D$). The simplest strategy is to transmit the packet directly from $S$ to $D$ as $P_{SD}$. The average of direct communication, $P_{SD}$, takes

$$T_{SD} = \frac{1}{\lambda_{SD}}. \quad (5)$$

transmission to deliver a packet, where $\lambda_{xy}$ means the packet delivery rate from $x$ to $y$. On the contrary, an alternative is to exploit relay transmission in this topology for time benefit. The relay strategy is to transmit a packet through two paths such as $P_{SR}$ and $P_{RD}$, in which $P_{RD}$ means the path of relay and destination. Here, the important assumption is that $\lambda_{SR}$ has the higher transmission rate than the transmission rate of $\lambda_{SD}$. Therefore, in this topology, there are two approaches: $S$ sends a packet to $D$ directly or $S$ sends a packet to $R_1$, where $R_1$ then forwards it to $D$. $S$ uses the approach that requires the fewest transmissions. After that, the average time of relay transmission is given by

$$T_{\text{topology}} = \min \left( \frac{1}{\lambda_{SR}}, \frac{1}{\lambda_{RD}}, \frac{1}{\lambda_{SD}} \right). \quad (6)$$

where $T_{\text{topology}}$ should choose the minimum transmission rate between the relay path and direct path. In case, if the transmission of relay path is failed from $P_{SR}$ or $P_{RD}$, then another device, that is, $R_2$, can be joined to retransmit a packet. In order to support relay based retransmission, $P_{RTD}$ is defined as the path of retransmission and destination in Figure 2. Based on the distributed relay assisted retransmission, we can derive the expected number of transmission as

$$T_{RTD} = \sum_{k=1}^{\infty} k \lambda(k), \quad (7)$$

where $\lambda(k)$ is the probability of taking $k$ transmission to deliver a packet.

**Table 2: Relation table between the distance and the data rate.**

| Distance (m) | Rate (Mb/s) |
|-------------|-------------|
| 2.8         | 480         |
| 3.2         | 400         |
| 3.7         | 320         |
| 4.9         | 200         |
| 5.5         | 160         |
| 6.9         | 106.7       |
| 8.0         | 80          |
| 10          | 53.3        |
3.1. Distributed Relay Decision. A beacon frame consists of a MAC header and a payload. The MAC header follows the WiMedia standard and the payload includes one beacon parameter and several IEs [6]. Every IE has a unique identifier (ID) and is attached to the beacon frame payload in an increasing ID value order. After all, by listening to beacon frames from neighbors, every node can obtain communication types and the neighbor information. Specifically, the beacon frame includes several IEs to configure various functions such as beacon period occupancy IE (BPOIE), DRP IE, and identification of IE. In order to support relay based transmission, we define a new relay communication information element (RC IE) as shown in Figure 3. It shows the elements of RC IE and RC IE command value. The relay node address field notifies the selected relay node to relay communication during the relay DRP allocation. The data rate to destination field is filled with the enumerated values (i.e., 0–7) as mark of data rate, modulation, and coding rate defined in the WiMedia standard to prevent consuming large bits [6].

A node needs to listen to beacon frames from other nodes during a number of superframes. In so doing, the node can reduce the possibility that multiple nodes use the same beacon slots in the current beacon period. Thus, the collision problem of beacon slots can be mitigated. Moreover, by collecting beacon frames during multiple superframes, it is possible to detect the existence of hidden node problems because a beacon frame of neighbor node includes the information of the neighbor’s neighbor nodes [25]. Furthermore, during BP, each node listens to the beacon frames of neighbors and then estimates the transmission rate to each neighbor device from the signal strength by channel model.

Through the listening and the exchanging of beacon frames, we prepare the relay decision procedure for $P_{SR}$ and $P_{RD}$. For better understanding, we describe an example of the relay decision procedure. Let the four nodes be located randomly in the network and assume that they can reach each other. In Figure 4, $S$ forms the MSN table from listening to beacon frames of neighbors during several superframes, as shown in Figure 5. It is noted that the MSN table is controlled between $S$ and $R$, which means $S$ cannot recognize the transmission rate between $R$ and $D$. Therefore, the relay node is selected by comparing only the transmission rates of $P_{SD}$ and $P_{SR}$ by exchanging RC IE. Following the gathering of the data rate information from RC IE commands of all candidate relay nodes, $S$ can calculate the smallest relay
transmission time ($T_{SR}$). Firstly, when B-ACK mode is used, direct transmission time, $T_{SD}$, is given by

$$T_{SD} = \frac{N_{pk} \cdot l_{MH}}{R_b} + \frac{l_{back} + l_{MH}}{R_b} + \frac{N_{pk} \cdot l_{pl}}{R_r} + T_M \cdot (N_{pk} - 1) + T_S. \tag{8}$$

where $N_{pk}$ is the number of packets, and $l_{MH}$, $l_{back}$, and $l_{pl}$ denote the size of general MAC header, the payload size of the B-ACK, and the size of packets (bits), respectively. Also, $T_M$ and $T_S$ denote the time of MIFS and SIFS. In general, the MAC headers and control frames are delivered at the base data rate, $R_b$. On the contrary, the payload of packets is transmitted with supported data rate, $R_r$ by the flow. In addition, we can derive the time of relay transmission. $T_{SRD}$ can be acquired from the repetition of (8) by summation of $T_{SR}$ and $T_{RD}$, which is given by

$$T_{SRD} = 2 \cdot \left(\frac{N_{pk} \cdot l_{MH}}{R_b} + \frac{l_{back} + l_{MH}}{R_b} + \frac{N_{pk} \cdot l_{pl}}{R_r} + T_M \cdot (N_{pk} - 1)\right) + 2T_S. \tag{9}$$

From the example topology in Figure 4, the relay node is determined $R1$ by exchanging the RC IE command such as data rate request and data rate response, because the transmission rate of $P_{SR1}$ is large among the transmission rates of $P_{SR1}$ and $P_{SR2}$. And then, $S$ delivers the RC IE with relay response of RC IE command to $R1$ in order to decide the appropriate relay node.

3.2. Relay-Assisted Retransmission. When the channel between $S$ and $D$ is very poor, frequent relaying of ACKs may occur. In that case, it may be more efficient to employ a mesh network based approach (i.e., $S$ sends packets to a relay which forwards them to $D$) as almost all packets will be relayed anyway. However, relays detect failed transmission through the overheard of B-ACK. Eligible relay nodes which have the packet by overhearing the transmission transmit own RC IE (i.e., relay retransmission and supported data rate). If there are several eligible relay nodes in the topology, $R$ should compare the supported data rate of eligible nodes; then $R$ determines the relay node for retransmission by considering the largest transmission rate among $P_{RD}$'s. In Figure 6, through the MSN table for retransmission, the best transmission rate between $R$ and $D$ is $R2$ as 320 Mbps. Because the relay node, which has the largest transmission rate, has also the stronger connectivity to the destination node since it has a higher chance of successfully transmitting the packet, if a retransmission is failed with $R2$ (i.e., the highest RSSI), all neighbor nodes can hear the B-ACK frame, and only $R2$ prepares the retransmission again after $T_S$. That is, non-relay nodes ignore the B-ACK frames, even though they could hear that the retransmission is failed.

3.3. Medium Access Slot Allocation Procedure. In order to consider the medium access slot (MAS) allocation for relay transmission, the distributed reservation period is used by attaching DRP IE to a beacon frame. We should consider two reserved periods: $S$ to $R$ and $R$ to $D$, respectively. The DRP is based on a TDMA style reservation [6]. That is, each node reserves its transmission time slots; it needs to reserve the time slots by sending DRP IE. When $S$ broadcasts the beacon frame with the DRP allocation field in DRP IE during BP, all nodes should be aware of the relay node that is selected by receiving DRP IE. And then, the relay node figures out the information of data transfer period. During the reserved MAS block, only the reservation owner can access the channel to deliver packets; that is, DRP will not bring about any channel collisions. First, $S$ should send relay request in RC IE attached to the beacon frame.

4. Performance Evaluation

In this section, the overall throughput and the energy efficiency have been measured when the number of nodes is increasing in order to evaluate the performance improvement of the DRR scheme. The overall throughput means the transmission rate to deliver the packets successfully between $S$ and $D$ considering delay, control space, and frames. Both with no BER and with BER have been evaluated to find the effect of BER on the DRR scheme while the retransmission policy with B-ACK mode is implemented.

4.1. Simulation Parameters. To validate performance of WiMedia MAC and DRR scheme, we develop simulators using Matlab (R2008b) [26, 27]. In order to validate the performance of the DRR scheme, we adopted retransmission policy and B-ACK filling the sending buffer similar to the actual environment. Parameter used in this simulation is shown in Table 3. The PHY model is BPSK described in the channel model. The bandwidth size is set to the closest value

| Neighbor node ID | Data rate between R and D (Mb/s) |
|------------------|----------------------------------|
| R1               | 160                              |
| R2               | 320                              |
| R3               | 200                              |
Table 3: Simulation parameters.

| Parameter          | Value                          |
|--------------------|-------------------------------|
| Max. beacon length | 96 slots                      |
| Superframe size    | 65,536 μs                     |
| MAS size           | 256 μs                        |
| Beacon slot size   | 85 μs                         |
| Space size         | 10 m by 10 m                  |
| Packet size        | 512, 1024, 2048, 4096 bytes   |
| PHY header size    | 5 bytes                       |
| MAC header size    | 10 bytes                      |
| B-ACK payload size | 7 bytes                       |
| MIFS time          | 1.875 μs                      |
| SIFS time          | 10 μs                         |
| Beacon transmission rate | 54 Mb/s                   |
| Maximum bandwidth  | 540 MHz                       |
| Transmission power | −41.25 dBm/MHz                |
| Receive power      | −63 dBm/MHz                   |

Figure 7: Overall throughput as direct transmission, relay-based transmission, and relay-assisted retransmission with no BER.

Figure 8: Overall throughput as direct transmission, relay-based transmission, and relay-assisted retransmission with $10^{-5}$ BER.

4.2. Simulation Results

4.2.1. Overall Throughput. Although the networks support high bandwidth and data rate, transmission rate cannot be equal to them. This is because the transmission rate depends on the control frames, queuing delays, packet losses, and other error environment. Therefore, the overall throughput, $S_o$, can be obtained as the number of successfully received packets, which is given by

$$S_o = \frac{N_{suc} \cdot l_p}{\sum T_{tr}}$$

(10)

where $N_{suc}$ is the number of successfully received packets. In addition, the sum of $T_{tr}$ is the total transmission time. This is the equation for overall throughput without any retransmission. When the failed packets occur, the latency per a packet should be considered due to the retransmission

$$S_{o \text{r}} = \frac{\sum_{k=1}^{N_o} S_{tr,k}}{N_{tr}}$$

(11)

where $S_{tr,k}$ is the throughput for the $k$th packets and $N_o$ is the number of all sent packets.

The packets are retransmitted up to three times, BER is set to $10^{-5}$, and the packet size is 2048 bytes in Figure 8. On the other hand, Figure 7 shows the overall throughput without BER while Figure 8 represents the overall throughput considering BER. We can discover that the more nodes are deployed, the higher overall throughput can be obtained in both Figures 7 and 8. That is practicable because relay candidates are increasing, that is, better choices for the higher throughput. In both Figures 7 and 8, with an adoption of DRR scheme, the throughput improves 26% and 45% with no BER and 27% and 47% with $10^{-5}$ BER compared to the direct transmission and relay-based transmission, when the
number of nodes is 20. In other words, the consideration of BER does not affect (or barely affects) the improvement by relay. When the packets are relayed, the distance between the source node and the relay node and the distance between the relay node and the destination node become shorter. Because the short distance makes SNR condition higher, the data rate becomes higher than direct transmission.

In addition, BER is the important factor to influence the overall throughput. Also, packet error rate (PER) can be calculated with BER as PER = 1 – (1 – BER)^pk. Figure 9 shows the overall throughput increase as BER is smaller. The effect of the DRR scheme can be notable in Figure 9.

We compute the overall throughput per various packet sizes. Figure 10 shows that the bigger the packet size, the more improved the overall throughput. This is because the overheads by control frames are decreased with the bigger packet size. However, when we add BER into overall throughput, packet size directly influences the throughput and deteriorates the performance. The reason that the overall throughput decreases after 1024 bytes packet size proves the tradeoff between the burst transmission and the packet error rate. Despite of the tradeoff, the relay-assisted retransmission shows higher overall throughput when the packet size is large. This is because the overhead by control frames influence on the throughput remarkably. In addition, we devise the improvement ratio by

$$
\tau(\%) = \left(\frac{S_{\text{relay}} - S_{\text{DRR}}}{S_{\text{relay}}} \times 100\right),
$$

(12)

where $S_{\text{relay}}$ and $S_{\text{DRR}}$ mean the overall throughput in case of relay-based transmission and relay-assisted retransmission, respectively. When the packet sizes of $S_{\text{relay}}$ and $S_{\text{DRR}}$ are 512 bytes, 1024 bytes, 2048 bytes, and 4096 bytes, each $\tau$ as improvement ratio shows 7.7%, 9.2%, 10%, and 12%, respectively.

4.2.2. Energy Consumption. The energy consumption per bit, $E_b$, between two nodes, can be computed as

$$
E_b = \frac{T_{pk} \cdot (\omega_{tx} + \omega_{rx}) + \omega_{idle} \cdot T_S}{N_{pk} \cdot l_{pl}},
$$

(13)

where $\omega_{tx}$ and $\omega_{rx}$ mean the power of transmitting and receiving, respectively. Also, $T_{pk}$ is the time to transmit packets except for the control frames. We assume that nodes enter to sleep period during data transfer period for other nodes and there is no energy consumption during the sleep period. The power consumed in idle state $\omega_{idle}$ is zero. Despite the activity of the relay, the relay-assisted retransmission time can be shorter than the relay-based transmission as shown in Figure 11. Due to the two separate periods, end node can go to sleep period, which helps to save the energy as well.

We define the energy saving as $\omega_{\text{DRR}} / \omega_{\text{relay}}$ for a conspicuous contrast of DRR scheme with the relay-based transmission. Figure 11 describes that the DDR scheme can reduce the energy consumption by 40%–47% according to the number of nodes. This appearance is related to Figure 9. Because the overall throughput improves by increasing nodes, it means that the transmission time becomes short. When the overall throughput improvement ratio is 80% that means the DDR scheme consumes 80% energy comparing that the relay-based transmission consumes 100%. In that case, 40% energy consumption is saved with the DRR scheme.

5. Conclusion Remarks

In this paper, we propose a distributed relay-assisted retransmission scheme that employs a distributed relay path and relay-assisted retransmission to efficient system performance in distributed wireless home networks. The DRR scheme outperforms the direct transmission and relay transmission by examining the appropriate data rate for each path and separating each path for relay transmission and retransmission. In addition, the DRR scheme can shorten the transmission.
time comparing to the direct transmission and the relay transmission, respectively. The extensive simulation results demonstrate that the performance gain of the DRR scheme is significant when the number of nodes is large. Consequently, it leads to the overall throughput improvement and the energy efficiency. Furthermore, the DRR scheme supports compatibility with the WiMedia standard by keeping the rule of beacon period.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This research was supported by Hallym University Research Fund, 2014 (HRF-201402-009).

References

[1] H. Wang, S. Ma, and T.-S. Ng, “On performance of cooperative communication systems with spatial random relays,” IEEE Transactions on Communications, vol. 59, no. 4, pp. 1190–1199, 2011.
[2] P. Kolios, V. Friderikos, and K. Papadaki, “Load balancing via store-carry and forward relaying in cellular networks,” in Proceedings of the 53rd IEEE Global Communications Conference (GLOBECOM ’10), pp. 1–6, December 2010.
[3] L. Yang and G. B. Giannakis, “Ultra-wideband communications,” IEEE Signal Processing Magazine, vol. 21, no. 6, pp. 26–54, 2004.
[4] IEEE Standard for Information Technology-Local and Metropolitan Area Networks-Specific Requirements Part II: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 2003.
[5] IEEE Standard for IEEE Amendment to Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPAN): Amendment to MAC Sublayer, 2006.
[6] WiMedia Alliance, ECMA-368 High Rate Ultra Wide Band PHY and MAC Standard, ECMA, 3rd edition, 2008.
[7] H. Park, W. Kim, and S. Pack, “A deterministic channel access scheme for multimedia streaming in WiMedia networks,” Wireless Networks, vol. 18, no. 7, pp. 771–785, 2012.
[8] W. Chung, C. Chang, and L. Wang, “An intelligent priority resource allocation scheme for LTE-A downlink systems,” IEEE Wireless Communications Letters, vol. 1, no. 3, pp. 241–244, 2012.
[9] IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems Amendment 3: Advanced Air Interface, IEEE Std 802.16m, 2011.
[10] J. Kao and F. Chen, “On RANCArQ for wireless relay networks: from the transmission perspective,” IEEE Transactions on Wireless Communications, vol. 12, no. 6, pp. 2962–2976, 2013.
[11] P. Liu, Z. Tao, S. Narayanan, T. Korakis, and S. S. Panwar, “CoopMAC: a cooperative MAC for wireless LANs,” IEEE Journal on Selected Areas in Communications, vol. 25, no. 2, pp. 340–354, 2007.
[12] C. Cetinkaya and F. Orsun, “Cooperative medium access protocol for dense wireless networks,” in Proceedings of the 3rd Annual Mediterranean Ad Hoc Networking Workshop, June 2004.
[13] H. Shin, Y. Kim, S. Pack, and C.-H. Kang, “A distributed relay MAC protocol in WiMedia wireless personal area networks,” in Proceedings of the International Symposium on Parallel and Distributed Processing with Applications (ISPA ’08), pp. 784–789, Sydney, Australia, December 2008.
[14] X. Wang, Y. Ren, J. Zhao, Z. Guo, and R. Yao, “Energy efficient transmission protocol for UWB WPAN,” in Proceedings of the IEEE 60th Vehicular Technology Conference, VTC2004-Fall: Wireless Technologies for Global Security, pp. 5292–5296, September 2004.
[15] Z.-N. Kong, D. H. K. Tsang, B. Bensou, and D. Gao, “Performance analysis of IEEE 802.11e contention-based channel access,” IEEE Journal on Selected Areas in Communications, vol. 22, no. 10, pp. 2095–2106, 2004.
[16] X. Shen, W. Zhuang, H. Jiang, and J. Cai, “Medium access control in ultra-wideband wireless networks,” IEEE Transactions on Vehicular Technology, vol. 54, no. 5, pp. 1663–1677, 2005.
[17] H. Park, S. Pack, and C.-H. Kang, “Dynamic adaptation of contention window for consumer devices in WiMedia home networks,” IEEE Transactions on Consumer Electronics, vol. 57, no. 1, pp. 28–34, 2011.
[18] T. Li, Q. Ni, T. Turleiti, and Y. Xiao, “Performance analysis of the IEEE 802.11e block ACK scheme in a noisy channel,” in Proceedings of the 2nd International Conference on Broadband Networks (BROADNETS’05), pp. 551–557, October 2005.
[19] H. Chen, Z. Guo, R. Yao, and L. I. Yanda, “Improved performance with adaptive Dly-ACK for IEEE 802.15.3 WPAN over UWB PHY,” IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, vol. E88-A, no. 9, pp. 2364–2372, 2005.
[20] H. Park and C.-H. Kang, “A group-aware multicast scheme in 60GHz WLANs,” KSII Transactions on Internet and Information Systems, vol. 5, no. 5, pp. 1028–1048, 2011.
[21] H. Park, S. Park, T. Song, and S. Pack, “An incremental multicast grouping scheme for mmWave networks with directional antennas,” IEEE Communications Letter, vol. 17, no. 1, pp. 616–619, 2013.
[22] H. Park and C.-H. Kang, “Dynamic beam steering using directional antennas in mmwave wireless networks,” IEICE Electronics Express, vol. 8, no. 6, pp. 378–384, 2011.
[23] L. X. Cai, L. Caai, X. Shen, and J. W. Mark, “Rex: a randomized Exclusive region based scheduling scheme for mmWave WPANs with directional antenna,” IEEE Transactions on Wireless Communications, vol. 9, no. 1, pp. 113–121, 2010.

[24] F. A. Onat, A. Adinoyi, Y. Fan, H. Yanikomeroglu, J. S. Thompson, and I. D. Marsland, “Threshold selection for SNR-based selective digital relaying in cooperative wireless networks,” IEEE Transactions on Wireless Communications, vol. 7, no. 11, pp. 4226–4237, 2008.

[25] V. M. Vishnevsky, A. I. Lyakhov, A. A. Safonov, S. S. Mo, and A. D. Gelman, “Study of beaconing in multihop wireless PAN with distributed control,” IEEE Transactions on Mobile Computing, vol. 7, no. 1, pp. 113–126, 2008.

[26] Software Package, MATLAB R2008b, The Mathworks Inc., Natick, Mass, USA, 2008, http://www.mathworks.com.

[27] M. Clark, M. Mulligan, D. Jackson, and D. Linebarger, “Fixed-Point Modeling in an Ultra Wideband (UWB) Wireless Communication System,” Matlab Digest, 2004, http://www.mathworks.co.uk/company/newsletters/digest/may04/uwb.html.
