Reduction of Latency in Mobile Multi-hop Relay(MMR) Networks

Woon Yong Jo, Ju Wook Jang
Department of Electronics Engineering, Sogang University
wyzo@eeca1.sogang.ac.kr, jjang@sogang.ac.kr

***Abstract* —The frame structure design is more challenging in the new mobile multi-hop relay based (MMR) network architecture, as numerous dimensions of design constraints and challenges have been introduced. Tao et al. propose a simple yet flexible multi-zone framework based upon the current 802.16e OFDMA frame structure design, which enables multi-hop operation while still maintaining the backward compatibility with the legacy mobile stations. However, RS in each tier has different time of receiving data from BS. This time gap is wide and enlarges the ratio of relay zone in frame structure, which decreases system throughput. In addition, this scheme is not considering frequency reuse. In this paper, we propose a MMR frame structure which improves performance while maintaining the backward compatibility. We design the frame structure with frequency reuse. We divide relay zone into several sub relay zones and BS transmits the data starting from the last tier RS to the first tier RS. As a result, we minimize the average time gap of receiving data for RSs. With our proposed frame structure, our simulation shows improvement of MAC efficiency by 30% compared with the scheme byTao et al.**

***Index Terms* — Frame structure, IEEE802.16j, Backward compatibility**

I. Introduction

IEEE 802.16 [1] [2] recently has gained industry wide attention as a potential primary technology for broadband wireless access (BWA). However, due to significant loss of signal strength along the propagation path and the transmit power constraint of IEEE 802.16/16e mobile stations (MSs), the coverage area for a specific high data rate is often of limited geographical size. One known solution to this problem is the use of a relay-based approach, wherein low cost relay stations (RSs) are introduced into the network to help extend the range, improve service, boost network capacity, reduce terminal power consumption and eliminate dead spots, all in a cost effective fashion [6]. In March 2006, a new task group 'j' was officially established within the IEEE 802.16, which attempts to amend current IEEE 802.16e standard [2] in order to support mobile multihop relay (MMR) operation in wireless broadband network. Frame structure is critical to an IEEE 802.16e OFDMA network, as it governs the fundamental channel access in both time and frequency domain. The frame structure design is complicated in the new MMR network architecture, as numerous dimensions of design constraints and challenges have been introduced therein. Tao et al. propose frame structure without compromising with 802.16e MS and backward-compatibility which is based upon the current 802.16e OFDMA system. Frame structure which is proposed by Tao et al. divides relay zone into several sub relay zone. However, they don`t consider maximizing frequency reuse. In this paper, we propose frame structure which is backward compatible with 802.16e OFDMA frame structure and expect performance enhancement compared with Tao et al.`s frame structure. The rest of the paper is organized as follows. Section II first briefly describes the frame structure specified in the current IEEE 802.16e OFDMA standard [2] and explains the requirements and challenges posed by 802.16j MMR operation. In section III, we introduce a simple frame structure which is backward compatible with 802.16e OFDMA frame structure. The proposed generic frame structure design is then elaborated in Section IV. The modeling for proposed frame structure is presented in Section V. The performance evaluation results are presented in Section VI, followed by the conclusion and future work in Section VII.

II. Background

A. Legacy Frame Format for IEEE 802.16e

IEEE 802.16 [3] and 802.16e [4] have adopted orthogonal frequency-division multiple access (OFDMA) as the primary channel access mechanism for non-line-of-sight (NLOS) communications in the frequency bands below 11 GHz. The basic unit of resource for allocation in OFDMA is a slot, which comprises a number of symbols in time domain, and one subchannel in frequency domain. The base station divides the timeline into contiguous frames, each of which further consists of a downlink (*DL*) and an uplink (*UL*) *subframe*. The detail of the frame structure for the access is given in [3] and [4]. Based upon the schedule received from the BS, each MS can determine when (i.e., OFDMA symbols) and where (i.e., subchannels) should it receive from and transmit to BS. Corresponding time gap (e.g., TTG and RTG) is inserted between two consecutive zones, in order to give wireless device sufficient time to switch from the transmission mode to reception mode, or vice versa.

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B. *802.16j Network*

In order to improve capacity and extend coverage range without compromising the backward compatibility with the legacy MSs, IEEE 802.16j task group has been concentrating on designing a minimal set of function enhancement and extension to support mobile multihop relay capability. IEEE 802.16j intends to support multihop relaying function, wherein a BS and multiple RSs can form a multi-level tree topology. A station is called *access station*, if it is at the point of direct access into the network. Note that an access station can be a BS or a RS.

III. A KNOWN BACKWARD COMPATIBLE FRAME STRUCTURE

Similar to the legacy design, the frame structure proposed by Tao et al. in [5] for MMR network is also composed of a DL and an UL portion. However, in order to enable multihop communication, the DL and UL subframe is further divided into multiple zones in the time domain. As depicted in Figure 1, the first zone in both the DL and UL subframe is dedicated for communication that directly engages MSs, and thus is naturally called the access zone. More specifically, MSs receive from or transmit to the BS or RS they are associated with in the access zone of the DL and UL subframe, respectively. The access zone in both DL and UL may be followed by one or multiple relay zones. In each relay zone, BS and RS can stay in the mode of transmission, reception or being idle. However, it is not expected to have BS or RS switch from one mode to the other within the same zone. For the scope of this paper, the case where each DL and UL subframe comprises of more than one relay zones as shown in Figure 1 will be examined.

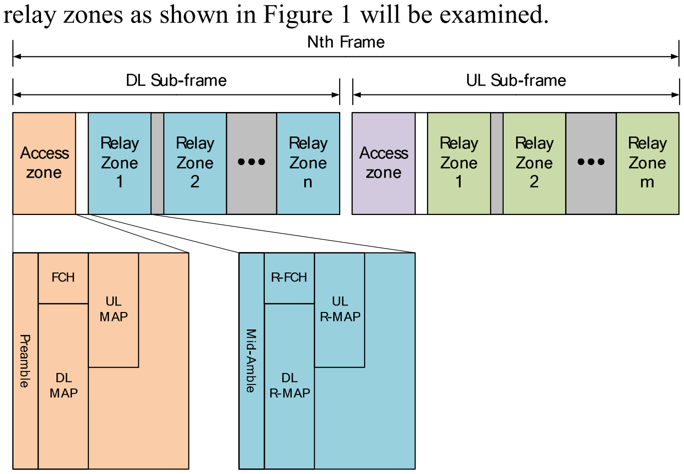

Fig. 1 Simple backward compatibility MMR frame structure which divides relay zone into many sub relay zone

The number of relay zone in the DL sub-frame "n", may or may not be equal to the number of relay zone in the UL subframe "m". Both "n" and "m" can be equal to 1 which implies that there is only one relay zone in the sub-frames. When "n" and "m" equals to zero, it implies that the frame structure becomes the frame structure of the 802.16e standards.

The duration of both the access and relay zone are flexible as long as they are confined within the duration of the sub-frame. Fig.2 shows the frame structure under assumption that each RS receives the same amount of data. BS provides RS1 with the data which should be received by subordinate RSs. RS1 transmits the rest data to RS2 except the data which are supposed to be received. Likewise, RS2 transmits to RS3 and RS3 transmits to RS4. At last, when RS4 transmits to RS5 one frame transmission is completed. In this way, MMR transmission is compatible with 802.16e.

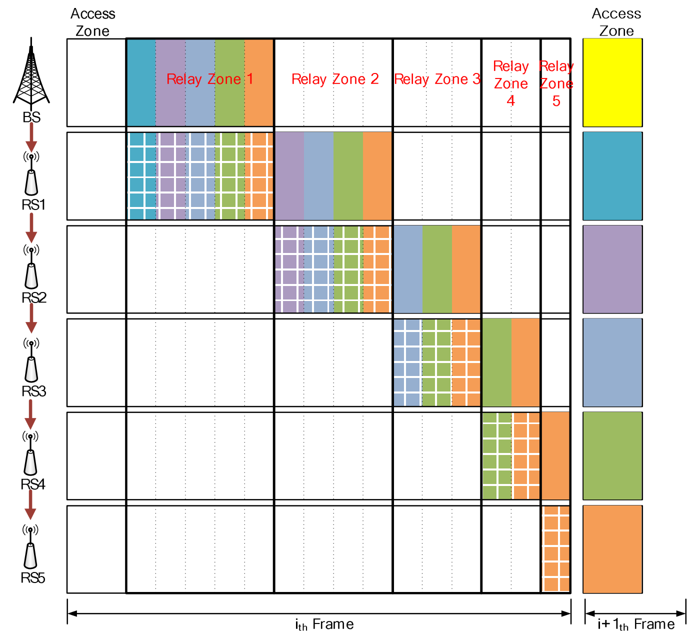

Fig. 2 Example of simple backward compatibility MMR frame structure

IV. PROPOSED FRAME STRUCTURE FOR MMR NETWORKS

This paper proposes a new frame structure to reduce latency for Multi-hop Relay Network. In MMR Network, data are transmitted to final target MS through many relay stations. We divide relay zone into many sub relay zones for backward compatibility. Sub relay zone is used to transmit between stations similar to simple backward compatibility MMR frame structure.

In proposed frame structure, BS schedules the transmission of data in such a way that the data to travel longest is allowed to start first. The data intended for the last RS is scheduled first, the data for the RS which immediately precedes the last RS is scheduled next and so on. We also reuse frequency whenever possible. Figure 3 shows that the same frequency is used simultaneously by every other RS in a relay network stationed in a linear array fashion. Since R-MAP should be transmitted in every sub relay zone, MAC efficiency is expected to be low. However, BS-RS or RS-RS link meets minimum SNR where 64QAM modulation can be used. RS-MAP is given more weight in frame structure since RS-MAP uses QPSK modulation.

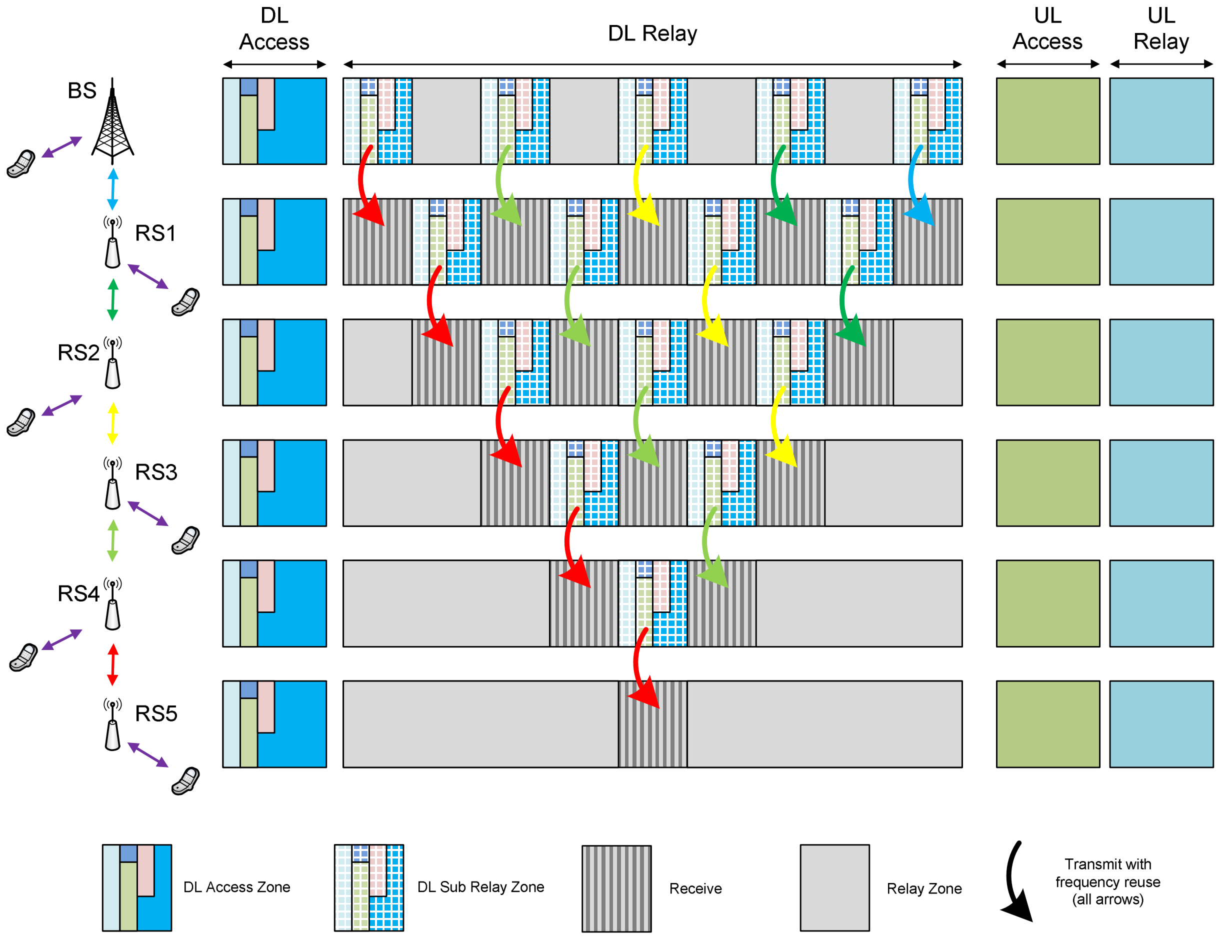

Fig. 3 Process of proposed frame structure transmission

Since QPSK1/2 modulation is used for MAP, the occupying ratio of MAP in access zone is large. R-MAP, however, is the transmission between BS-RS links. Hence, 64QAM modulation is used for transmission. Therefore, the occupying ratio of R-MAP in sub-relay zone is small. For these reasons, overhead transmitted in every sub relay zone is negligible.

In Fig.3, Red-colored arrows denote the data which RS5 is supposed to receive. The data to be received by RS5 located at the last tier is transmitted first. In 3rd sub relay zone where frequency reuse is possible, data which RS4 is supposed to receive are transmitted as denoted by green arrows. In 5th sub relay zone where frequency reuse is possible, data which RS3 is supposed to receive are transmitted as shown by yellow arrow. 7th and 9th sub relay zone also transmit data which RS1 and 2 are supposed to receive. All transmissions are conducted through frequency reuse.

V. Modeling

We define latency as the time elapsed to relay data from BS to the intended RS. Latency for the scheme by Tao et al. can be represented as follows:

$$L_m = \sum_{j=1}^{n} \left(\sum_{k=j}^{n} t_k \right) \quad (1)$$

The t_k denotes the number of data symbols that are allocated to k^{th} RS. If each RS receives different amount of data, we can derive the latency through following metrics.

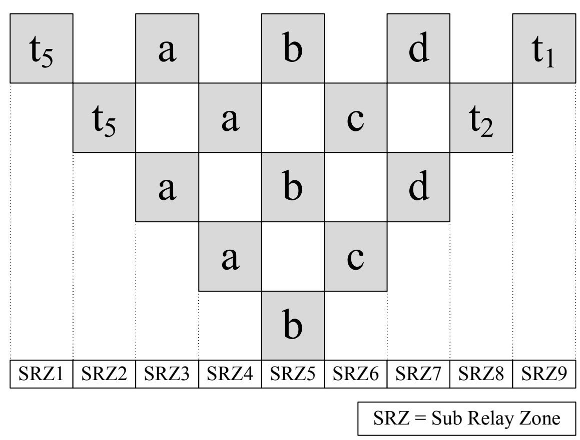

Fig. 4 Sub relay zone

In Fig. 4, the latency for RS1 is $t_5 + 2 \cdot a + b + c + d + t_2 + t_1$. The latency for RS2 is $t_5 + 2 \cdot a + b + c + d + t_2$. The latency of RS3 is $t_5 + 2 \cdot a + b + c + d$. The latency for RS4 is $t_5 + 2 \cdot a + b + c$. The latency of RS5 is $t_5 + 2 \cdot a + b$. Because of difference of allocated data for RSs, we determine the length of sub relay zone with comparing the size of each data symbol.

Table 1. Key PHY and MAC Simulation Parameters

FFT Size	1024	Number of Symbols in a Frame	47
Sampling Frequency	10MHz	TTG(Transmit/receive Transition Gap)	121.2us
(MCS) for data	64QAM with 3/4 coding rate	RTG(Receive/transmit Transition Gap)	40.4us
MCS for preamble and MAP	64QAM with 3/4 coding rate	Number of Hops for MMR	5
Preamble	1 symbol	Number of Subchannels (DL)	30
OFDMA symbol time	102.9us	Number of data subcarriers per subchannel (DL)	24

In our proposed frame structure, latency of RS1 equals to the time that relay zone occupies in each frame. The ratio of relay zone is decreased as much as latency of RS1, which means the ratio of access zone is increased. The following pseudo code is for obtaining the length of sub relay zone.

Pseudo Code for Adaptive Subrelayzone

```
INPUT : Symbol_time_RS[j]
OUTPUT : SubRelayzone[i]
for i = 1 to n do
  if SubRelayzone[i] ⊃ Symbol_time_RS[j] then
    select max Symbol_time_RS[j] then
    SubRelayzone[i] = max Symbol_time_RS[j]
  end if
end for

SubRelayzone[i] : the length of i-th Sub Relay zone
Symbol_time_RS[j] : allocated symbol of j-th RS
tier of RSs
select max Y[m] : choose the max value of finite set Y[m]
```

With the metrics, length of sub relay zone can be determined and we can derive the latency by equation (2)

$$L_p = \sum_{i=1}^{2n-1} T_i \quad (2),$$

where Ti denotes the length of i^{th} sub relay zone. For n-hop relay networks, we have 2n-1 sub relay zones. T_i can be represented below:

$$T_i = \begin{cases} \max\left(t_{n-\left\lfloor \frac{i-1}{2} \right\rfloor}, \ldots, t_n\right), & (1 \le i \le n) \\ \max\left(t_{\left\lfloor \frac{2n-i+2}{2} \right\rfloor}, \ldots, t_{2n-i}\right), & (n+1 \le i \le 2n-1) \end{cases}$$

The t_k denotes the number of data symbols that are allocated to k^{th} RS.

VI. Performance Evaluation

Performance of proposed frame structure is evaluated in 2 ways. We compare general backward compatibility with proposed frame structure in latency and throughput aspect. At this time, we assume that 64QAM 3/4 are used for BS-RS link and RS-RS link. Some other key PHY and MAC parameters used in the simulation are summarized in Table 1.

A. Latency

We define latency as the time elapsed to relay data from BS to the intended RS. In order to evaluate performance, we transmit same amount of data to two each frame structure. Since we assume that 64QAM 3/4 is used for BS-RS link and RS-RS link, the same amount of data is carried in one symbol. At this time, the amount of data which is supposed to receive from each RS is randomly allocated from 1 to 3 symbols. We put the amount of data in ascending order from 1 to 3 symbols. We define cases up to case243 with increasing symbols. When one symbol is assigned to RS1, RS2, RS3, RS4 and RS5, it is defined as Case 1. When 3 symbols are assigned to every RS, it is defined as case243. It is transmitted by each case through frame structures. We estimate the performance how long it takes to communicate by all cases.

Fig. 5 shows the average latency of each station. In proposed scheme, data which are supposed to receive from RS1 transmit last. We then define the size of relay zone. In the scheme by Tao et al, latency of RS5 determines the size of relay zone. When the hops are increased, the latency is increased abruptly compared with proposed scheme. Since the latency of proposed scheme is less by 30% than previous scheme, the size of relay zone of proposed scheme is less by 30% than previous scheme.

B. Throughput

We compare each frame structure in terms of throughput which is the transmitted data amount per unit time.

Note that m_k is the symbol for transmitting to k^{th} RS. R is the allocable bits in one symbol when the link (BS-RS or RS-RS link) is set to 64QAM 3/4. We assume that data can be transmitted in 64QAM3/4 in relay link, since relay link is the transmission between BS and RS or RS and RS. The transmittable data amount is as follows in current frame structure.

If we transmit data through proposed frame structure, we transmit same amount of data with consuming less symbol time than Tao et al. Hence, more data can be transmitted in one frame compared with Tao et al. Fig. 7 shows the

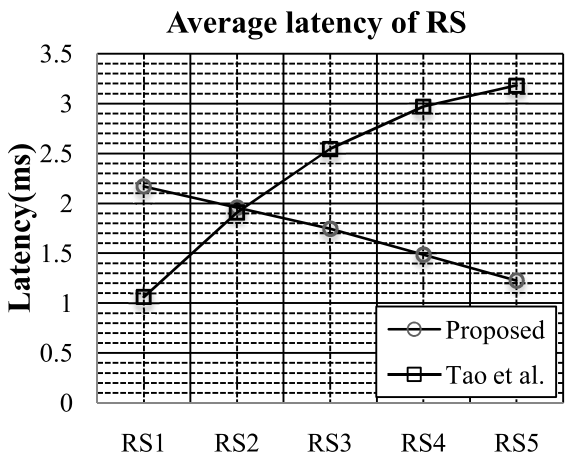

Fig. 5 Average latency of RS

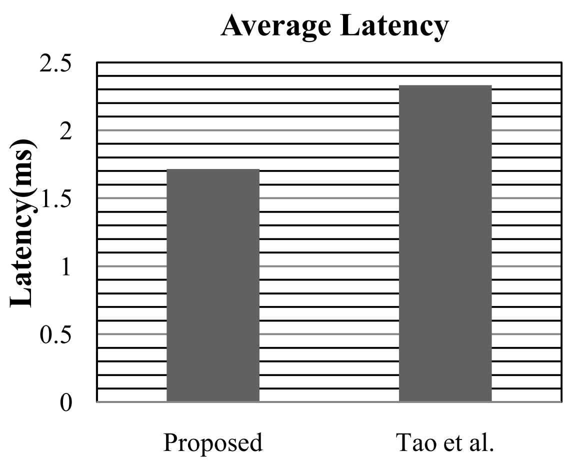

Fig. 6 Average Latency

throughput of two frame structures. The efficiency is more improved about 30% than simple backward compatibility frame structure in throughput side.

VII. CONCLUSION

This paper introduces a generic frame structure to support the mobile multihop relay (MMR) operation of IEEE 802.16j, while maintaining the backward compatibility with the legacy 802.16e mobile stations. This paper doesn't propose only frame structure for backward compatibility, but frame structure to derive maximum performance with assuming backward compatibility. Since we introduce relay in 802.16e, more researches are needed about frequency interference and enhancing end-to-end capacity.

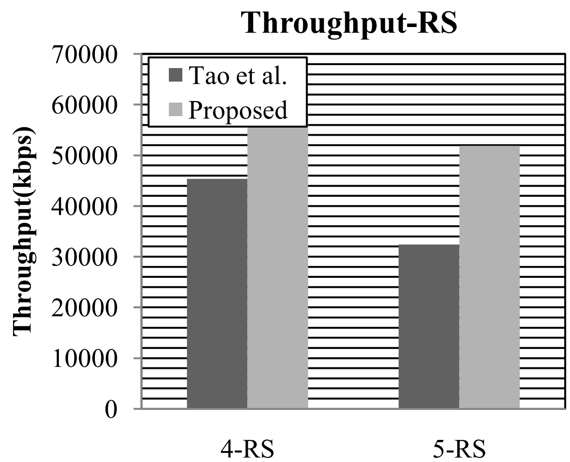

Fig. 7 Throughput-RS

VIII. ACKNOWLEDGMENT

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