Frequency Reuse During Relay Transmission for Two-hop IEEE 802.16j Relay Networks

Sang Won Kim
Department of Electronic Engineering
Sogang University
Seoul, Korea
signal@eeca1.sogang.ac.kr

Joo Yeon Jung
Cerritos High School
Cerritos, CA90703
U.S.A

Ju Wook Jang
Department of Electronic Engineering
Sogang University
Seoul, Korea
jjang@sogang.ac.kr

Abstract— **Frequency reuse during access zone is widely adopted for throughput enhancement in IEEE 802.16j relay networks. Since areas covered by relay stations (RS) or base Station (BS) may overlap, some Mobile Station (MS)s on the border between two neighboring transmitting stations (RS or BS) using an identical frequency band may suffer severe interference or outage. This co-channel interference within the cell degrades fairness in QoS among MSs as well as system throughput. In this paper, we propose to introduce frequency reuse scheme during relay zone as well as during access zone. Our scheme increases the efficiency of resource without much overhead. The improved efficiency is used to alleviate the above co-channel interference. MSs, which are interference-prone if served during access zone, are now served during relay zone using our proposed frequency reuse scheme to be used along with directional antennae. We show our scheme achieves higher system throughput with higher fairness level in QoS, outperforming previous schemes.**

Keywords- wireless networks; frequency reuse; co-channel interference; frame structure; WiMAX

I. INTRODUCTION

Mobile stations in the cell edge may experience service degradation or even outage due to the path loss. The deployment of fixed relay stations between base station(BS) and MS to alleviate this problem has been actively studied by a task group in IEEE 802.16 [2][3][5][6][7]. Throughput enhancement can be achieved through the frequency reuse capabilities of RS`s. In case that radio resource is fully reused by all RS`s, all sub-cells associated with RS`s are subject to outage due to other cell interference around the sub-cell edges. This co-channel interference not only reduces MCS (Modulation and Coding Scheme) level but also causes service outage in the cell as shown in Table. 1 [3][6]. On the other hand, radio resource can be also orthogonally allocated among all RS`s without any frequency reuse, completely avoiding the co-channel interference in the cell while limiting the co-channel interference from adjacent cells only to some data region. For the orthogonal allocation, however, radio resource efficiency can be significantly reduced.

In this paper, we propose a new frequency reuse scheme based on IEEE 802.16j Draft Standard. The proposed scheme reuse frequency using directional antennas and idle RS in downlink (DL) relay zone. The simulation results show that the system throughput can be dramatically increased by the proposed scheme, as compared to the overlapped allocation scheme for frame structure in IEEE 802.16j Draft Standard. Thus we solved the serious problem of service outage by co-channel interference.

TABLE 1. FREQUENCY REUSE SCHEMES IN ACCESS LINK

Topology	Scheme	throughput (Mbps)	Service Outage (%)
3RS	Overlapped	8.22	24.59
	Orthogonal	3.99	0
6RS	FRF=1	15.24	16.34
	FRF=2	12.42	6.95
	FRF=3	8.84	2.44
	FRF=6	4.57	0

In Section II, We identify the co-channel interference problem along with a brief review of the related work. Then, we present our solution and the corresponding new frame structure to implement our scheme in Section III. Performance evaluation is performed in Section IV and Section V concludes the paper.

II. CURRENT IEEE 802.16J DRAFT STANDARD AND KNOWN SCHEMES

A. Frame Structure and Frequency Reuse Scheme

Depending on the frequency reusability over the access zone, K. Park and Chung G. Kang [6] considered two extreme cases with 3 RSs, no reuse (orthogonal allocation) and full reuse (overlapped allocation) schemes. The orthogonal allocation scheme corresponds to the case for not reusing the same subchannels(frequency band) over the access zone, i.e., no subchannels can be shared by serving stations (a BS and 3 RSs). This scheme can avoid co-channel interference within the cell but it limits resource efficiency and hence results in low system throughput [6]. On the other hand, for the overlapped allocation scheme, all subchannels are fully reused by all serving stations. While allowing for maximizing the bandwidth efficiency, it tends to suffer from co-channel interference, which reduces the overall system throughput and may even induce service outage for a few MSs located on the boundary between neighboring stations (BS or RSs). W-H Park and S. Bahk [3] considered varying the level of reuse in a relay network with 6 RSs surrounding a BS (a 6-RS topology). The frequency reuse factors (FRF), 1, 2, 3 and 6, represent the scenarios where 6, 3, 2, or 1 RS(s) share the same frequency band, respectively. FRF=1 and FRF=6 are similar to overlapped allocation and orthogonal allocation, respectively. They show a trade-off relationship between throughput and service outage with varying FRF as shown in Table 1.

Fig. 1 (a) illustrates a frame structure of DL relay zone. It conforms to the current IEEE 802.16j draft standard [1]. The horizontal axis denotes time while vertical axis denotes frequency. The leftmost part in each frame denotes the overhead used for relay transmission. Note that the relay zone can be divided further for individual receiving RSs along time axis, frequency axis or both as in Fig. 1 (a). Fig. 1 (b) shows a basic frame structure to be used in our scheme, where relay zone is divided among RSs in a time division manner which is compatible with the current draft standard. As BS transmits data to only one RS at once, the other RSs become idle mode. As shown in Fig. 1 (b), the relay zone is divided into three time periods T1, T2 and T3. During Ti, RS i receives data from BS via directional antenna facing RS i. In the current IEEE 802.16j draft standard, there is only one transmitting station, BS, during relay zone, therefore no frequency reuse is used [1]. In Section 3, we propose a new frequency reuse scheme to be used in relay zone.

B. *Directional antennas for Frequency Reuse in Relay Link*

Directional antenna (i.e., beamforming antenna or smart antenna) technology has shown excellent performance in cellular networks. It enjoys the merits of increased signal quality (SNR) through beamforming gain, reduced interference through null steering, spectral reuse through spatial multiple reuse and robustness to multpath fading through spatial diversity (with the combination of space-time codes) [15]. Directional antenna technology is adopted in 3GPP Release 6 version [11], and it is also an optional feature in IEEE 802.16 where it is termed “adaptive antenna system (AAS)” [12]. In this paper we opt to use directional antennae for our proposed frequency reuse during relay transmission in IEEE 802.16j multi-hop relay networks.

One commonly used antenna model is an idealized antenna model [13]. This model has a constant gain within a certain angle width (corresponding to beamwidth), and zero gain outside the beamwidth. The antenna gain pattern is given in (1), where θ_B is the beamwidth, C is the antenna gain within beamwidth and it is independent of beamwidth [13].

$$g(\theta) = \begin{cases} C, & \theta \in [-\theta_B/2, \theta_B/2] \\ 0, & otherwise \end{cases} \qquad (1)$$

III. The Proposed Scheme

A. *The Proposed Frequency Reuse Scheme in Relay zone for a 3-RS topology*

According to the IEEE 802.16j draft standard, the number of RSs in a cell is yet to be determined. It is generally assumed that the number of RSs in a cell is either three or six [3][6], etc. Hence, in our proposed scheme we consider two cases, one with 3 RSs and the other with 6 RSs. For simplicity of presentation, we assume the amount of assigned relay traffic and the wireless environment for all the RSs are identical.

We assume following conditions:

- BS is equipped with three directional antennas to cover 120° range per antenna.
- RS is equipped with one omnidirectional antenna and one directional antenna to cover 60° range.

In time T1 of Fig. 1(b), RS 1 is receiving from BS with directional antenna facing RS 1. When BS uses 120° directional antenna by (1), the coverage of BS in time T1 is shown in Fig. 2(a). At this time RS2 and RS3 are idle mode. Based on this observation our scheme allows RS 2 and RS 3 to provide access service to MSs located in their sub-cell in frequency division manner during T1. RS2 and RS 3 do not interfere with each other’s transmission since they divide the frequency band (orthogonal allocation) and RS1 is not interfered by RS2 or RS3, because RS2 and RS3 use 60° range directional antenna. Since BS uses a directional antenna for transmission to RS 1 as shown in Fig. 2, it does not interfere with MSs which are receiving from RS2 or RS3.Therefore 6 new access zones are formed as shown in Fig. 3.

The frame structure which contains 6 new access zones by proposed scheme is shown in Fig. 3. We call the new zone as *relay_access zone* since it is both a relay zone for BS and an access zone for RSs except the one RS involved in relay communication. The RS cover half of own sub-cell in one *relay_access zone* using 60° directional antenna as show in Fig.

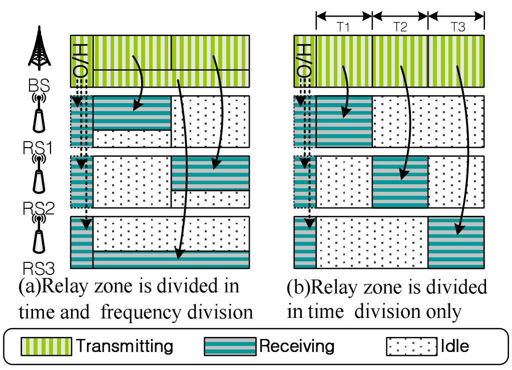


Fig. 1. Resource allocation of downlink relay zone in confirming to IEEE 802.16j Draft standard

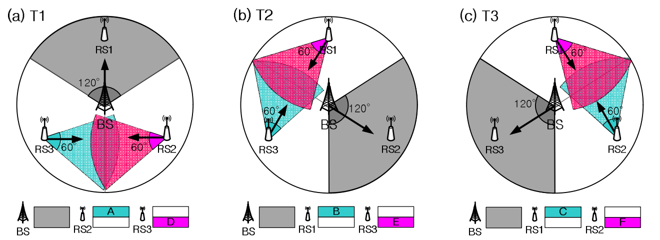


Fig. 2. Frequency reuse using directional antennas in relay zone for a 3-RSs topology.

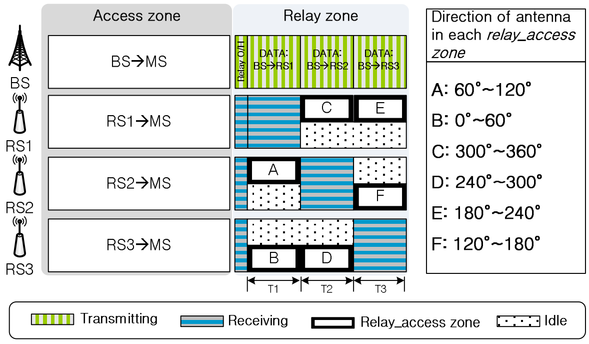


Fig. 3. Proposed frequency reuse scheme for a 3-RSs topology

2. As there is two *relay_access zone* in a frame, the RS can cover whole sub-cell. The proposed reuse scheme is independent of frequency reuse scheme in access zone. In case of that the proposed scheme applies to orthogonal allocation scheme, the throughput is improved by resource increment. The other side when proposed scheme applies to overlapped allocation scheme, it improves not only throughput but also service outage problem because *relay_access zone* adopts orthogonal allocation.

We assume PUSC subchannelization mode, and a DL:UL ratio of 2:1. These are the default values recommended by WiMAX forum system evaluation methodology and are also common values used in practice. In PUSC mode, the slot is defined as one subchannel by two OFDMA symbols [1]. We may roughly estimate the number of slots gained through our scheme of frequency reuse in relay with some simplifying assumptions. For example, if we assume T1=T2=T3 in Figure 4, the number of slots gained by our scheme can be estimated as in (2).

$$(\#symbol_{relay\_access\ zone} / 2\times\#subchannel_{relay\_access\ zone})\times 6 \qquad (2)$$

where $\#symbol_{relay\_access\ zone}$ and $\#subchannel_{relay\_access\ zone}$ denote the numbers of symbols and the numbers of subchannels of one *relay_access zone*, respectively. In each frame, there are 47 data symbols and 30 subchannels in total. [1]. Since one *relay_access zone* uses half of total bandwidth, $\#subchannel_{relay\_access\ zone}$ becomes 15. When one *relay_access zone* uses two data symbols, the increment of used slot for access transmission becomes $(2/2\times15)\times6=90$ slots.

The co-channel interference problem with a relay network with 3 RSs is illustrated in Fig. 4. In overlapped allocation, we identify 6 *interference area*s during access zone. We call some areas as *interference area* if we expect the nodes in the areas to suffer much interference considering their relative distances to BS and RSs. It is not our assumption that only the nodes residing in *interference area* suffer interference. It is not on-off situation. We just estimate CINR for every when we choose MCS level. Clearly, MSs located in *interference areas* are expected to suffer severe interference and even service outage. In relay zone (*relay_access zone*) these 6 *interference areas* are not interference area anymore. 3 RSs can cover 6 *interference areas* in 6 *relay_access zone* without intra cell interference. For example The A and D in Fig. 3 represent the slots in which RS

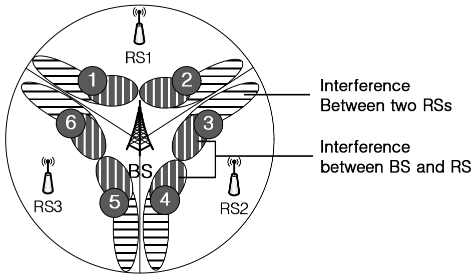


Fig. 4. Interference problem in overlapped allocation scheme

TABLE 2. Mapping *Relay_access zone* to Interference Areas For a 3-RS Topology

Relay_access zone	Transmitting RSs	Interference area
A	RS2	4
B	RS3	5
C	RS1	1
D	RS3	6
E	RS1	2
F	RS2	3

2 and RS 3 provide access to MSs located in *interference area* 4 and 5, respectively, as dictated in Table 2.

Table 2 summarizes the *relay_access zone* assigned to provide access service to corresponding *interference areas*. In this way the MSs located in *interference areas* can be provided access services with much reduced interference. Since those MSs would have been provided access service with poor QoS levels in overlapped allocation [6], our scheme allows us to obtain improved fairness. Since our scheme virtually increases the access zone of each RS, it also greatly improves the system throughput.

B. The Proposed Frequency Reuse Scheme in Relay zone for a 6-RS topology

For a 6-RS topology, the angle covered at a time by the directional antenna from BS is reduced to 60 degrees and RS has only one omni-directional antenna. Fig. 5 shows a frame structure where relay zone is divided into 6 time periods T1 through T6 for 6 RSs in a time division manner, which is compatible with the current IEEE draft standard [1]. During Ti, RS i receives data from BS via directional antenna facing RS i. In time T1, 5 RSs except RS1 can serve subordinate MSs while BS transmits to RS 1. However, RS 1 is expected to suffer severe interference if the rest 5 RSs simultaneously transmit.

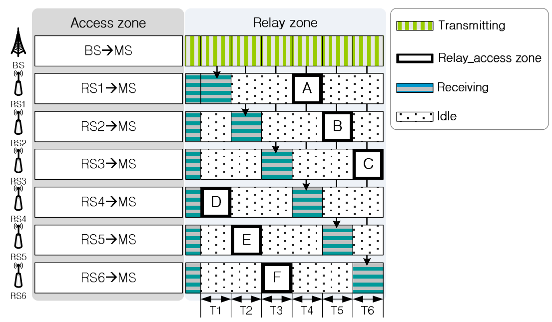


Fig. 5. Proposed frequency reuse scheme for a 6-RSs topology.

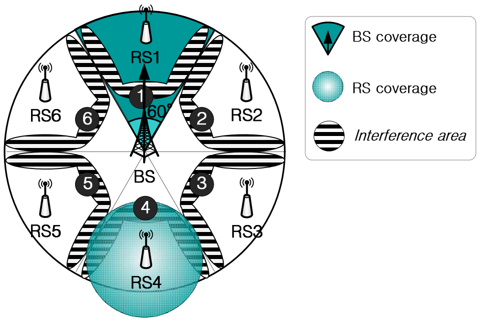


Fig. 7. Frequency reuse using directional antennas in relay zone for a 6-RSs topology.

TABLE 3. MAPPING *RELAY_ACCESS ZONE* TO INTERFERENCE AREAS FOR A 6-RS TOPOLOGY

Relay_access zone	Interference area	*Relay_access zone*	Interference area
A	1	D	4
B	2	E	5
C	3	F	6

So, we choose only one RS which is farthest from RS 1 and allow it to transmit. For example, RS 4 is chosen when BS transmits to RS 1 as illustrated in Fig. 6. Therefore each RS has only one *relay_access zone* in a frame, and can cover whole sub-cell in a *relay_access zone* using omnidirectional antenna.

We identify 6 *interference areas* when 6 RSs are used. For example, MSs in *interference area* 1 are covered by RS 1 and interfered by BS and RS 6 or RS2. Table 3 summarizes the mapping of *relay_access zone* to *interference areas*.

In 6-RS topology, the increased amount of the resources for access transmission by proposed scheme can be written as (2), but one *relay_access zone* uses total bandwidth differently from 3-RS topology, therefore $\#subchannel_{relay\_access\ zone}$ is 30. If we substitute 2 and 30 for $\#symbol_{relay\_access\ zone}$ and $\#subchannel_{relay\_access\ zone}$, respectively, 180 slots are increased.

IV. PERFORMANCE EVALUATION

We perform simulation of our scheme as well as known schemes [3][6] to evaluate the efficiency of our approach using C++. The simulation environment is set up according to a procedure generally accepted in the literature. Due to space limitation we provide detailed description only about a 3-RS topology while brief description is provided to a 6-RS topology. 3 RSs in the cell are located 120 degrees apart, creating three sub-cells each of which is covered by an RS. The cell radius is 1km. Each RS is assumed to be located at 3/4 position in a line from BS to the cell boundary. Transmit power, antenna gain, antenna height, transmit frequency and system bandwidth assumed in the simulation are summarized in Table 4. We consider a full buffer traffic model and applied the PUSC subchannelization scheme [1]. Table 5 is the MCS level table of IEEE 802.16e system used in simulation [4]. For the IEEE 802.16j system, we consider the performance of our scheme and conventional frequency reuse schemes. We allow MSs to move according to a random walk model [10] and investigate the system throughput, fairness and service outage for DL.

TABLE 4. SETUP FOR SIMULATION ENVIRONMENT

	BS	RS	MS
Transmit power	20W	10W	30mW
Antenna gain	14dB	12 dB	0 dB
Antenna height	32m	15m	1.5m
Transmit frequency	2.3GHz	2.3GHz	2.3GHz
System bandwidth	10MHz		

TABLE 5. MCS TABLE FOR ADAPTIVE MODULATION AND CODING

MCS level		Required CINR(dB)	Bits/slot
BPSK	1/2	3.0	24
QPSK	1/2	6.0	48
QPSK	3/4	8.5	72
16-QAM	1/2	11.5	96
16-QAM	3/4	15.0	144
64-QAM	1/2	19.0	144
64-QAM	3/4	21.0	216

We obtain MCS levels for all individual MSs using (3) and Table 5.

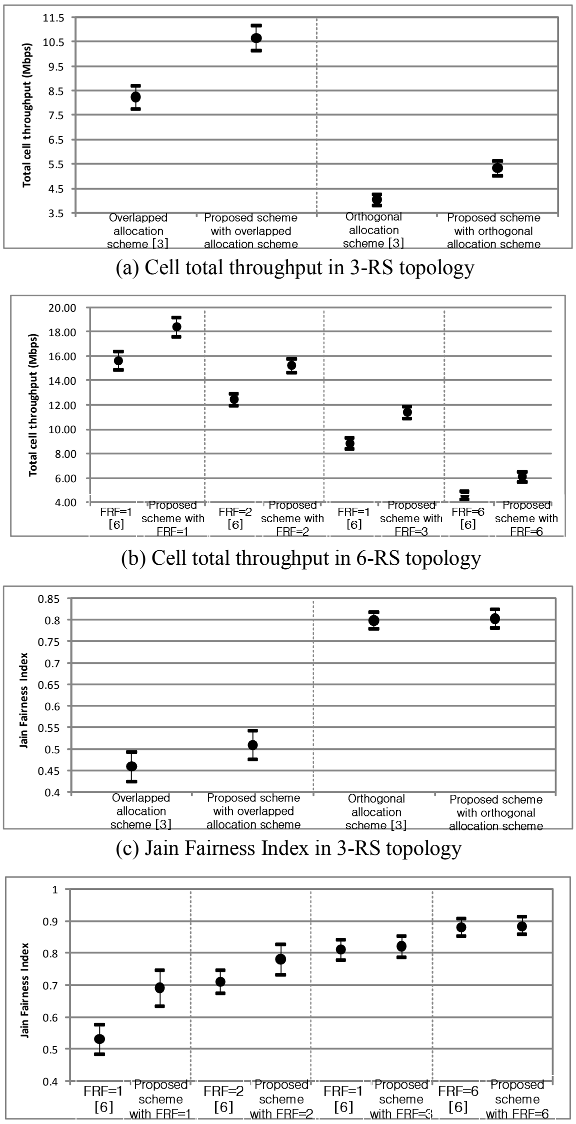
$$\frac{C}{I} = \frac{1}{N_{used}} \sum_{k=1}^{N_{used}} \frac{C_k}{I_k + N_0 \times NF} \tag{3}$$

In (3), C_k, where k denotes one of the slots assigned to an MS, denote the received signal power in slot k from the serving station. Similarly, I_k denote the corresponding interference signal power received from interfering stations. N_0 and NF denote thermal noise power and noise figure, respectively and N_{used} denotes the number of slots used by the MS. Then, the average CINR for each MS is obtained by taking the average of all slots used by itself as in [6]. MCS level and bits/slot equivalent for the obtained CINR is determined from Table 5. Then we employ round-robin packet scheduling algorithm [14] which allocates the equal amount of resources to each MS.

As show in Fig. 7, when the proposed scheme is used along with known schemes [3][6], the total cell throughput is improved as 18~33%. Through numerous simulation runs, we also estimated include the 95 percent confidence interval as well as the estimated average in Fig. 7. We use the Jain's fairness index which is generally accepted [8][9] for measure of fairness. The fairness index gets closer to 1 as the fairness is increased or to 0 as the fairness is decreased [9]. In case of that the proposed scheme applies to the conventional schemes, the system throughput and fairness is expected to improve due to reduction of service outage for nodes residing in interference area.

V. CONCLUSION

In IEEE 802.16j relay networks, the frequency reuse method in access link has been studied a lot recently [3][6]. However, frequency reuse scheme in relay link has not been widely addressed and the frequency reuse method in access link has the problem of service outage or low throughput. This paper proposes the frequency reuse scheme in relay zone and



(a) Cell total throughput in 3-RS topology

(b) Cell total throughput in 6-RS topology

(c) Jain Fairness Index in 3-RS topology

(d) Jain Fairness Index in 6-RS topology

Fig. 7. Simulation Results: Total cell throughput, Jain fairness index (Average with 95% confidence interval)

solves these problems. New methods are proposed with directional antennas equipped at both the BS and RSs. By taking advantage of the directional antenna, the total cell throughput can be increased by nearly 18~33%, by the proposed scheme, as compared to the conventional frequency reuse schemes.

VI. ACKNOWLEDGMENT

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TABLE 6. SIMULATION RESULTS

Topology	Scheme	throughput (Mbps)	Service Outage (%)	Jain Fairness Index
3RS	Overlapped [3]	8.22	24.59	0.48
	Proposed scheme with overlapped	10.64	0	0.62
	Orthogonal [3]	3.99	0	0.80
	Proposed scheme with orthogonal	5.31	0	0.80
6RS	FRF=1 [6]	15.24	16.34	0.53
	Proposed scheme with FRF=1	18.38	0	0.69
	FRF=2 [6]	12.42	6.95	0.71
	Proposed scheme with FRF=2	15.22	0	0.78
	FRF=3 [6]	8.84	2.44	0.81
	Proposed scheme with FRF=3	11.37	0	0.82
	FRF=6 [6]	4.57	0	0.88
	Proposed scheme with FRF=6	6.09	0	0.88

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