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

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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) 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 antenna. 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-channels 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.

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

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TABLE 1. FREQUENCY REUSE SCHEMES IN ACCESS LINK

<table>
<thead>
<tr>
<th>Topology</th>
<th>Scheme</th>
<th>Throughput (Mbps)</th>
<th>Service Outage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3RS</td>
<td>Overlapped</td>
<td>8.22</td>
<td>24.59</td>
</tr>
<tr>
<td></td>
<td>Orthogonal</td>
<td>3.99</td>
<td>0</td>
</tr>
<tr>
<td>6RS</td>
<td>FRF=1</td>
<td>15.24</td>
<td>16.34</td>
</tr>
<tr>
<td></td>
<td>FRF=2</td>
<td>12.42</td>
<td>6.95</td>
</tr>
<tr>
<td></td>
<td>FRF=3</td>
<td>8.84</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td>FRF=6</td>
<td>4.57</td>
<td>0</td>
</tr>
</tbody>
</table>

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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 T1, RS 1 receives data from BS via directional antenna facing RS 1. 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 multipath 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 \( \theta_g \) is the beamwidth, C is the antenna gain within beamwidth and it is independent of beamwidth [13].

\[
g(\theta) = \begin{cases} C, & \theta \in [-\theta_g / 2, \theta_g / 2] \\ 0, & \text{otherwise} \end{cases}
\]  

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.
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 by 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).

\[(\frac{\text{symbol}_{\text{relay access zone}}}{2\times\text{subchannel}_{\text{relay access zone}}}) \times 6 \tag{2}\]

where \(\text{symbol}_{\text{relay access zone}}\) and \(\text{subchannel}_{\text{relay access zone}}\) 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, \(\text{subchannel}_{\text{relay access zone}}\) 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 areas in a relay 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 an-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

<table>
<thead>
<tr>
<th>Relay access zone</th>
<th>Transmitting RSs</th>
<th>Interference area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>RS2</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>RS3</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>RS1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>RS3</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>RS1</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>RS2</td>
<td>3</td>
</tr>
</tbody>
</table>

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 omnidirectional 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.
from 3-RS topology, therefore access transmission by proposed scheme can be written as (2), sub-cell in a mapping of interfered by BS and RS 6 or RS 2. Table 3 summarizes the example, MSs in If we substitute 2 and 30 for allow it to transmit. For example, RS 4 is chosen when BS 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 RS 2. 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.

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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 measurement 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
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.

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