Isolation Band based Frequency Reuse Scheme for IEEE 802.16j Wireless Relay Networks [*]

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ABSTRACT

In this paper, the throughput performance of the access links (i.e., base station to mobile station and relay station to mobile station) is analyzed for the wireless relay networks based on IEEE 802.16j. An isolation band based frequency reuse scheme (IBFRS) is proposed, which introduces an isolation band around each relay station cluster so that the throughput of the access link can be maximized by allowing frequency reuse between the relay stations and the base station. An analytic method is also proposed to determine the optimal isolation band. A comprehensive simulation shows that by applying the proposed IBFRS, the throughput of the access link can be significantly improved.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communications*

General Terms

Algorithms

Keywords

Frequency reuse, relay network, isolation band

1. INTRODUCTION

With the increasing demand for ubiquitous multimedia data services, the future wireless cellular networks are expected to provide services with wider coverage range and higher data packet throughput. To achieve these goals, wider bandwidth at higher carrier frequency above 2GHz is foreseen to be used. Since the radio propagation in these frequency bands is more vulnerable to non-Line-of-Sight conditions, a new network node, called relay station (RS), is introduced in wireless networks, which could store and forward data packets received from base stations (BSs) to mobile stations (MSs), and vice versa [1, 2, 3]. There are generally two advantages brought by RS: first, instead of increasing the density of BSs, adding RS could overcome the coverage hole of BS and provide ubiquitous wireless services cost-efficiently; second, adding RSs could improve network throughput due to possible reuse of radio resources. As a result, relay networks have driven both industry and academia interests recently.

In industry, relay-related function is being standardized as the extension to the basic standards, such as IEEE 802.16j [4, 5]. Another standard, IEEE802.16m, which is deemed as a potential 4G standard, also support the application of relay stations [6]. In the IST-WINNER project [7], integrating relay function has been considered as an inevitable part of the system design for cellular deployment.

In academia, several studies on relay networks have been performed. One of main focuses is on the resource reuse and scheduling, which could be divided into two categories based on different network topologies under consideration: 1) symmetrical topology where a BS is surrounded by several RSs evenly, and 2) asymmetrical topology where the RSs are established around BS randomly. For the first category, as in Fig.1 (a), two-hop network is considered, where the data could be transmitted to the destination by at most one RS. [8] proposes a frequency partition scheme, which allocates orthogonal frequencies to three kinds of links, i.e., BS to MS, BS to RS and RS to MS; in [9], different fre-

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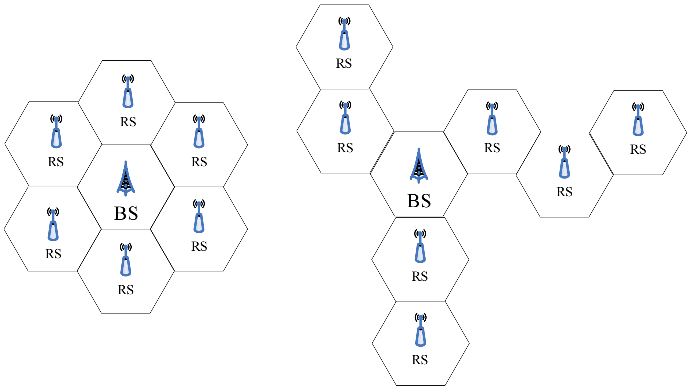


(a) symmetrical topology (b) asymmetrical topology

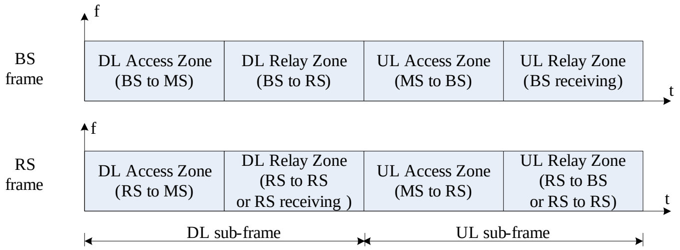
Figure 1: The traditional topology under consideration.

quency reuse factors (FRF), such as 1, 2, 3, 6, are proposed among RSs; similarly, in [10], different FRFs are used for BSs and RSs, respectively. In [11], with FRF=1, frequency hopping scheme among BS and RSs is introduced. For the second category, as in Fig.1 (b), multi-hop network is considered, where the data may be transmitted to the destination through at least two RSs. The area covered by RSs is adjacent to that covered by BS. As a result, the serving area by each RS could be treated as the traditional cell, and the frequency reuse method used in the traditional cellular network could be used in the relay network with minor modifications, as shown in [12], where a soft frequency scheme is proposed with adaptive scheduling among BS and RSs.

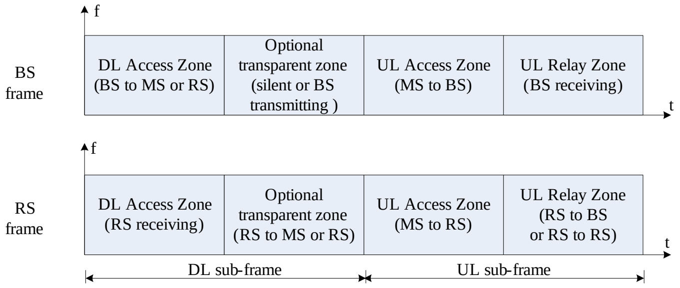
However, in the real world, these regular topologies do not always exist. According to the usage model defined in IEEE 802.16j [13], in order to overcome the coverage hole and the shadowing area of BS, the typical topology is that several RSs are deployed in the BS serving area irregularly, i.e., the areas covered by RSs are often surrounded by rather than adjacent to the area covered by BS.

In order to consider all these new characteristics, in this paper, the frequency reuse among BS and RSs is studied by taking into account a two-hop IEEE 802.16j network with an irregular deployment of RSs. First, the throughput of the access link (i.e., BS to MS, or RS to MS) is analyzed. Then, an isolation band based frequency reuse scheme (IBFRS) is proposed with the aim of enhancing the performance of the access link. In IBFRS, an isolation band is defined around each RS cluster which includes a separate RS or several adjacent RSs in the BS serving area, and each RS cluster could reuse the frequency out of the isolation band. An analytical method is introduced to determine the optimal isolation band for each RS cluster to maximize the throughput of the access link, and the simulation results verify the significant throughput improvement from the proposed IBFRS.

The remainder of this paper is organized as follows. Section 2 provides an overview of IEEE 802.16j. Section 3 gives the throughput analysis of the relay network. Section 4 describes IBFRS and introduces an analytical method to determine the isolation band. Section 5 presents the simulation results, and finally Section 6 concludes the paper.



(a) non-transparent mode



(b) transparent mode

Figure 2: Frame structure.

2. OVERVIEW OF IEEE 802.16J

As the extension of the current standards (IEEE802.16d and IEEE 802.16e), IEEE 802.16j aims at defining the multi-hop relay specification including the MAC and the physical (PHY) layers. According to the newest baseline document [4], two modes, non-transparent mode and transparent mode, are specified to support those usage scenarios. The former indicates that the RS has the scheduling function; while in the latter, the RS just forwards data to and from MSs based on the frequency allocation information obtained from BS.

In Fig.2, the frame structures of BS and RS are depicted for two modes, respectively [4]. For non-transparent mode, as in Fig.2 (a), each frame is divided into downlink (DL) and uplink (UL) sub-frames. Both DL and UL sub-frames consist of one access zone and one relay zone. The access zone is used for the communication between BS (or RS) and the corresponding MSs, while the relay zone is used for the communication between BS and RS or between RS and the subordinate RSs. Both access zones in BS frame and RS frame may share the same resource. For transparent mode, similar BS and RS frame structures are defined as shown in Fig.2 (b). In DL sub-frame, BS transmits data to the corresponding MSs and the subordinate RSs in the access zone. During this period, RSs are in the receiving state. In the optional transparent zone of the DL sub-frame, RS transmits data to the corresponding MSs or the subordinate RSs; while BS could be in silent state or provide the cooperative diversity for RS communicating with its subordinate RSs and MSs. In UL sub-frame, the access zone is used by MSs for transmitting data to the corresponding BS and RSs. However, the zones in BS frame and RS frame should use different frequency bands. In the relay zone, RSs deliver the data to BS or their superordinate RSs.

Through the comparison between the two modes, the main difference lies in that, for non-transparent mode, BS and RSs

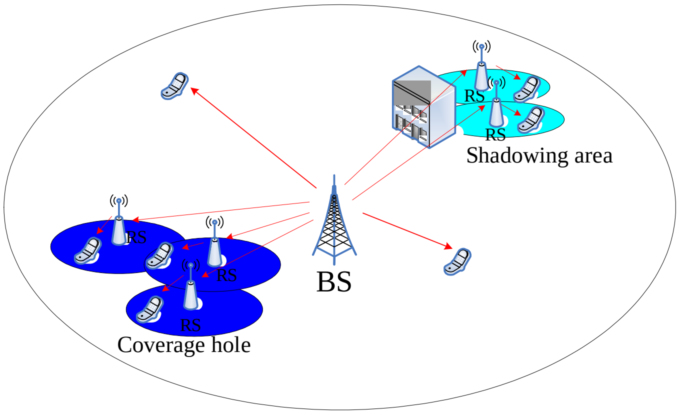


Figure 3: The typical topology of relay network.

may communicate with the corresponding MSs in the access zone using the same frequency bands, while frequency reuse is not allowed in the transparent mode. That is to say, in non-transparent mode, more resource could be used for improving the system performance in the access zone. Therefore, in this paper, we will focus on the resource allocation of the non-transparent mode.

In [13], from the perspective of the infrastructure, especially where the coverage is provided, four usage models are defined as the guideline of drafting IEEE 802.16j. They are fixed infrastructure, in-building coverage, temporary coverage and coverage on mobile vehicle. Therefore, a typical topology will be formed in the real world, as shown in Fig.3, where several RSs are established asymmetrically in each cell to overcome the coverage holes or the shadowing areas where the BS couldn't serve. Obviously, with non-transparent mode, when RSs can use the same resource as the BS in the access zone, they could obtain the whole system bandwidth to serve the users in their coverage area with little interference from the BS. However, they may cause severe interference to the users currently served by BS, especially for the users located close to their coverage area. In order to mitigate such interference from the RSs and improve the performance of the access zone, in this paper, an isolation band based frequency reuse scheme (IBFRS) between BS and RSs is introduced.

3. THROUGHPUT ANALYSIS OF RELAY NETWORK

In this section, throughput analysis of the relay network is carried out for the access zone, as shown in Fig.2 (a). There are two kinds of links, i.e., the access link including BS to MS and RS to MS, and the relay link including BS to RS. Assuming their throughputs are T_{BM}, T_{RM}, and T_{BR}, respectively. Then

$$T_{RM} = \sum_{i=1}^{N} T_{RM}^{(i)} \tag{1}$$

where $T_{RM}^{(i)}$ denotes the throughput achieved between RS i and its corresponding MSs, and N is the number of RSs in the network. In order to utilize the frequency efficiently, the following condition should be satisfied:

$$T_{RM}t_A = T_{BR}t_R. \tag{2}$$

where t_A and t_R are the durations of the access zone and relay zone, respectively. Otherwise, the buffer in RS could be overflowed if $T_{RM}t_A{<}T_{BR}t_R$, or some resource between RS and MS could be wasted if $T_{RM}t_A{>}T_{BR}t_R$.

Thus, by (2), the effective system throughput could be denoted as

$$\begin{aligned} T_{sys} &= \frac{T_{BM}t_A + T_{BR}t_R}{t_A + t_R} \\ &= \frac{T_{BM}t_A + T_{RM}t_A}{t_A + t_R} \\ &= T_{BR}\frac{T_{BM} + T_{RM}}{T_{BR} + T_{RM}}. \end{aligned} \tag{3}$$

Let $T_A{=}T_{BM}{+}T_{RM}$, which means the throughput of the access link, the equation (3) could be rewritten as

$$T_{sys} = \frac{T_{BR}}{1 + \frac{T_{BR} - T_{BM}}{T_A}}. \tag{4}$$

After the deployment of RSs, the relay link is determined; thus, T_{BR} in (4) could be regarded as a constant. Therefore, decreasing $\frac{T_{BR}-T_{BM}}{T_A}$ is the best way to improve the effective system throughput. Assume $\zeta{=}\frac{T_{BR}-T_{BM}}{T_A}$, the following situations should be noticed:

1. T_{BM} is not decreased (fixed or increased)
   Apparently, if T_A could be increased by some schemes, ζ is definitely decreased.

2. T_{BM} is decreased
   Assume T_{BM} is decreased by $\Delta T_{BM}^{-}({>}0)$ and T_A is increased by $\Delta T_A^{+}({>}0)$. Then, the following condition should be satisfied for decreasing ζ

   $$\begin{aligned} &\frac{T_{BR} - (T_{BM} - \Delta T_{BM}^{-})}{T_A + \Delta T_A{}^{+}} - \frac{T_{BR} - T_{BM}}{T_A} < 0. \\ \Rightarrow\ &\frac{T_A \Delta T_{BM}^{-} - \Delta T_A^{+}(T_{BR} - T_{BM})}{T_A(T_A + \Delta T_A^{+})} < 0. \end{aligned} \tag{5}$$

   Therefore,

   $$\frac{\Delta T_{BM}^{-}}{\Delta T_A{}^{+}} < \frac{T_{BR} - T_{BM}}{T_A}. \tag{6}$$

   The above inequality indicates the conditions of decreasing ζ. The right-hand side of (6), as the original ζ, could be regarded as a fixed value; therefore, the left-side of (6) should be as small as possible. In other words, some schemes should be designed to make sure that less decrease on T_{BM} and more increment on T_A would be achieved.

From these two situations, we could confidently conclude that increasing T_A has positive effect on improving the effective system throughput. Therefore, the following discussion will focus on improving the throughput of the access link, T_A.

4. ISOLATION BAND BASED FREQUENCY REUSE SCHEME

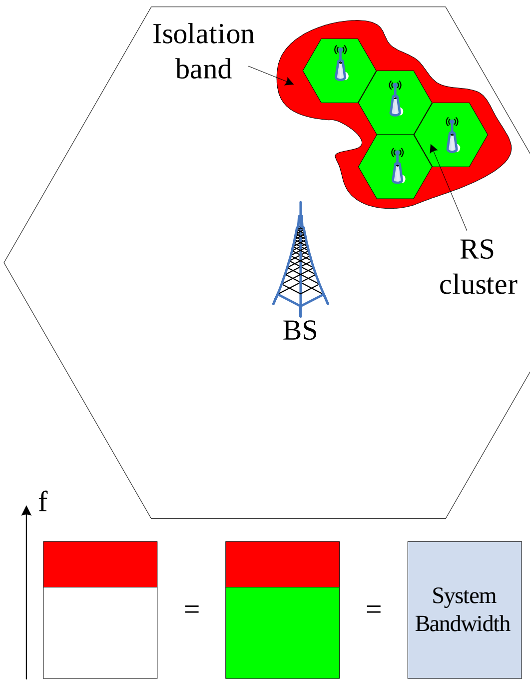


Figure 4: Illustration of IBFRS.

4.1 Introduction of IBFRS

For simplicity, hexagonal cells are used to denote the area covered by BS and RS. The RS cluster in the following denotes a separate RS or several adjacent RSs. Because our focus is on the frequency reuse between BS and RSs, we assume all RSs in a RS cluster serve a same MS simultaneously to provide macro-diversity. The IBFRS is illustrated by considering the DL. However, the similar idea can be applied for UL, as well. As shown in Fig.4, the IBFRS follows three rules:

- Each RS cluster is surrounded by an isolation band;
- The users in the isolation band are served by BS;
- The RSs in the RS cluster can reuse the resource, which is not used by the users in the isolation band.

In Fig.4, the whole coverage of the BS is separated into three subareas, which are the area covered by the RS cluster (RS-area), an isolation band, and the rest area called reuse-area. The RS-area is surrounded by the isolation band. Users locating in both isolation band and the reuse-area can access the whole system bandwidth for transmission, while only the frequency band used in the reuse-area can be exploited in the RS-area. As a result, the users served by BS and close to the edge of RS cluster wouldn't be interfered by the RSs therein, and the interference is mitigated for the users out of the isolation band even RSs reuse their frequency due to the large distance from the RSs.

4.2 Determination of isolation band

Apparently, determining the isolation band of the RS cluster is the key for the performance of the proposed IBFRS. In this subsection, an analytical method is introduced for isolation band determination based on the system model defined in Fig.4.

1) Definition of variables

- S: the total acreage of the cell;
- A_{BS}: the area served by BS with the acreage of S_{BS};
- A_{RSc}: the area served by RS cluster with the acreage of S_{RSc};
- A_{BS}^{nr}: the isolation band with the acreage of S_{BS}^{nr};
- A_{BS}^{r}: the area served by BS but out of the isolation band, which has an acreage of S_{BS}^{r};
- B: system bandwidth;
- C_{BS}(bit/s/Hz): the spectrum efficiency of A_{BS} when no frequency reuse between BS and RS cluster;
- C_{RSc}(bit/s/Hz): the spectrum efficiency of the RS cluster.

According to the variables' definitions, we have

$$S_{BS} + S_{RSc} = S, \tag{7}$$

$$S_{BS}^{r} + S_{BS}^{nr} = S_{BS}. \tag{8}$$

2) Optimal Isolation Band

Assume the users are uniformly distributed in A_{BS}, and the spectrum efficiency of A_{BS}^{r} would be decreased by $\theta(\in [0,1])$ at most after the RSs reuse the frequency from the reuse-area. Thus, from (8), both S_{BS}^{r} and S_{BS}^{nr} are the functions of θ, and can be written as $S_{BS}^{r}(\theta)$ and $S_{BS}^{nr}(\theta)$. The throughput of A_{BS}, denoted as T_{BS}, should be

$$T_{BS} \geq \frac{S_{BS}^{nr}(\theta)}{S_{BS}} \cdot B \cdot C_{BS} + \frac{S_{BS}^{r}(\theta)}{S_{BS}} \cdot B \cdot C_{BS} \cdot (1-\theta) \tag{9}$$

where $\frac{S_{BS}^{nr}(\theta)}{S_{BS}}B$ is the frequency used in the isolation band and $\frac{S_{BS}^{r}(\theta)}{S_{BS}}B$ is the potential frequency band, which could be reused by RS cluster. For the worse-case scenario, where all potential frequency bands are applied by the RS cluster, the throughput of the RS cluster after the frequency reuse can be calculated as

$$T_{RSc} = \frac{S_{BS}^{r}(\theta)}{S_{BS}} \cdot B \cdot C_{RSc}. \tag{10}$$

Therefore, the system throughput of the DL access zone is

$$\begin{aligned} T \geq T_{RSc} + T_{BS} &= \frac{S_{BS}^{r}(\theta)}{S_{BS}}B \cdot C_{RSc} + \frac{S_{BS}^{nr}(\theta)}{S_{BS}}B \cdot C_{BS} \\ &+ \frac{S_{BS}^{r}(\theta)}{S_{BS}} \cdot B \cdot C_{BS} \cdot (1-\theta) \qquad (11) \\ &= C_{BS}B + \frac{S_{BS}^{r}(\theta)}{S_{BS}}B(C_{RSc} - C_{BS}\theta). \end{aligned}$$

Obviously, maximizing the right-side of (11) could improve the throughput of the access link. Therefore, the optimal value of θ should satisfy

$$\theta_{opt} = \underset{\theta \in [0,1]}{\operatorname{argmax}} \{C_{BS}B + \frac{S_{BS}^{r}(\theta)}{S_{BS}}B(C_{RSc} - C_{BS}\theta)\}. \tag{12}$$

Obtaining C_{BS}, C_{RSc} and $S_{BS}^{r}(\theta)$ is the key for solving (12).

In order to consider the possible inter-cell interference, consider a cellular system with 19 cells and let the central one is the home cell. First, we calculate C_{BS} in (12). Assume a location of $x_{BS}^{(0)}$ in A_{BS} of the home cell. The signal to interference plus noise ratio (SINR) at $x_{BS}^{(0)}$ could be written as:

$$\gamma_{x_{BS}^{(0)}} = \frac{P_{BS}^{(0)} L_{BS}^{(0)} \chi_{BS}^{(0)}}{\sum\limits_{m \in I_{BS}} P_{BS}^{(m)} L_{BS}^{(m)} \chi_{BS}^{(m)} + \eta_{BS}^{(0)}}, (x_{BS}^{(0)} \in A_{BS}) \quad (13)$$

where I_{BS} is the set of the interference sources to $x_{BS}^{(0)}$ in two-tier cells. In both numerator and denominator of (13), $P_{BS}^{(d)}$ is the transmitting power of BS in cell d, $L_{BS}^{(d)}$ and $\chi_{BS}^{(d)}$ are the path loss and shadowing from BS in cell d to $x_{BS}^{(0)}$, respectively. In general, the latter one in dB is modeled as a lognormal variable. $\eta_{BS}^{(0)}$ means the noise which is ignored in the following analysis due to its smaller value compared to the interference. According to [14], $\gamma_{x_{BS}^{(0)}}$ in (13) can be approximated by a lognormal variable with mean $\mu(x_{BS}^{(0)})$ and standard variance $\sigma(x_{BS}^{(0)})$ in dB. Therefore, the cumulative density function (CDF) of $\gamma_{x_{BS}^{(0)}}$ can be calculated as

$$\begin{aligned} F_{x_{BS}^{(0)}}(\gamma) &= P(\gamma_{x_{BS}^{(0)}} < \gamma) \\ &= 1 - Q(\frac{10\log_{10}(\gamma) - \mu(x_{BS}^{(0)})}{\sigma(x_{BS}^{(0)})}) \end{aligned} \quad (14)$$

where $Q(x)$=$\int_x^{\infty} \frac{1}{\sqrt{2\pi}} exp(-\frac{Z^2}{2}) dZ$. Given CDF, the probability density function (PDF) of SINR, $f_{x_{BS}^{(0)}}(\gamma)$, can be obtained by differentiating $F_{x_{BS}^{(0)}}(\gamma)$. Let the relationship between the SINR and the throughput in unit bandwidth be $\nu = g(\gamma), (\nu \in V)$, where V is the set of possible values of ν. Then, the PDF of the throughput in unit bandwidth at $x_{BS}^{(0)}$ equals

$$T_{x_{BS}^{(0)}}(\nu) = \int\limits_{\gamma \in \Phi} f_{x_{BS}^{(0)}}(\gamma) d\gamma, (\nu \in V, \Phi = \{\gamma | \nu = g(\gamma)\}). \quad (15)$$

From (15), the average throughput in unit bandwidth at $x_{BS}^{(0)}$ equals

$$\overline{T_{x_{BS}^{(0)}}} = \sum_{\nu \in V} \nu T_{x_{BS}^{(0)}}(\nu). \quad (16)$$

Finally, C_{BS} could be obtained as

$$C_{BS} = \oint\limits_{A_{BS}} \overline{T_{x_{BS}^{(0)}}} P(x_{BS}^{(0)}) dx_{BS}^{(0)} \quad (17)$$

where $P(x_{BS}^{(0)})$ is the probability that the user is located at $x_{BS}^{(0)}$.

For C_{RSc} in (12), let a location of $x_{RSc}^{(0)}$ in A_{RSc} of the home cell. Then, its SINR could be written as

$$\gamma_{x_{RSc}^{(0)}} = \frac{\sum\limits_{n \in \Omega} P_{RSc}^{(n)} L_{RSc}^{(n)} \chi_{RSc}^{(n)}}{\sum\limits_{m \in I_{RSc}} P_{RSc}^{(m)} L_{RSc}^{(m)} \chi_{RSc}^{(m)} + \eta_{RSc}^{(0)}}, (x_{RSc}^{(0)} \in A_{RSc}) \quad (18)$$

where Ω is the set of RSs in the RS cluster, and I_{RSc} is the set of the interference sources to $x_{RSc}^{(0)}$. Due to the frequency reuse between the BS and the RS cluster, I_{RSc} should include the BS which covers the RS cluster and BSs in two-tier cells. Here, the interference from the RS cluster in other cells is ignored due to the relatively small transmitting power of the RS. By the similar method used for C_{BS}, we could derive C_{RSc} as

$$C_{RSc} = \oint\limits_{A_{RSc}} \overline{T_{x_{RSc}^{(0)}}} P(x_{RSc}^{(0)}) dx_{RSc}^{(0)} \quad (19)$$

where $\overline{T_{x_{RSc}^{(0)}}}$ is the average throughput in unit bandwidth at $x_{RSc}^{(0)}$ and $P(x_{RSc}^{(0)})$ is the probability that the user is located at $x_{RSc}^{(0)}$.

Similarly, for $S_{BS}^{r}(\theta)$ in (12), consider a location of $x_{BS}^{(0),r}$ in A_{BS}^{r} of the home cell. Since the resource used by users located at $x_{BS}^{(0),r}$ is reused by the RS cluster, its SINR becomes

$$\gamma_{x_{BS}^{(0),r}} = \frac{P_{BS}^{(0),r} L_{BS}^{(0),r} \chi_{BS}^{(n),r}}{\sum\limits_{m \in I_{BS}^{r}} P_{BS}^{(m),r} L_{BS}^{(m),r} \chi_{BS}^{(m),r} + \eta_{BS}^{(0),r}}, (x_{BS}^{(0),r} \in A_{BS}^{r}) \quad (20)$$

where I_{BS}^{r} is the set of interference sources to $x_{BS}^{(0),r}$, which includes BSs in two tiers and the RSs in the RS cluster which is within the same BS coverage. The interference from the RSs in the other cells is ignored. Likewise, the average throughput in unit bandwidth at $x_{BS}^{(0),r}$ could be obtained by

$$\overline{T_{x_{BS}^{(0),r}}} = \sum_{\nu \in V} \nu T_{x_{BS}^{(0),r}}(\nu) \quad (21)$$

where $T_{x_{BS}^{(0),r}}$ is the PDF of the throughput in unit bandwidth at $x_{BS}^{(0),r}$ after the resource is reused by RS cluster. Therefore, A_{BS}^{r} could be derived by

$$\begin{aligned} &A_{BS}^{r} = \\ &\{x_{BS}^{(0),r} | x_{BS}^{(0),r} \in A_{BS}, x_{BS}^{(0),r} = x_{BS}^{(0)}, \frac{\overline{T_{x_{BS}^{(0)}}} - \overline{T_{x_{BS}^{(0),r}}}}{\overline{T_{x_{BS}^{(0)}}}} < \theta\}. \quad (22) \end{aligned}$$

Equation (22) indicates that at any location in A_{BS}^{r}, the average throughput in unit bandwidth is decreased by no more than θ after the frequency reuse between the BS and the RS cluster. Combing (12), (17), (19) and (22), the optimal θ and the corresponding isolation band can be obtained.

4.3 Implementation of IBFRS

In each BS cell, when a RS cluster is established, the corresponding isolation band can be determined through the method defined in section 4.2 and could be maintained for a long period unless the RS cluster is changed. After that, the IBFRS could be implemented frame by frame. Through the frame structure in Fig.2, since BS and RS work at the same time in the DL access zone, in each frame, the BS should schedule the frequency of the next BS frame and inform the RS in the relay zone of the current frame what the reusable resource is in the next RS frame. In summary, the implementation at each frame follows three steps:

1. BS schedules the resource of the next BS frame;
2. BS finds out the users in the isolation band of the RS cluster by the location technology, such as GPS (Global Position System), and then fixes the reusable resource of the RS cluster in the next BS frame, which is used by the users out of the isolation band;

Table 1: Simulation Parameters

Carrier frequency	2.5GHz
System bandwidth	10MHz
Number of sub-channels	30
Number of sub-carriers in a sub-channel	24
BS cell radius	1Km
BS TX power	38dBm
BS pathloss	$138.6 + 34.79 \log_{10}(d)$ d is the distance in Km
RS cell radius	0.1Km
RS TX power	5dBm
RS pathloss	$143.69 + 37.2 \log_{10}(d)$ d is the distance in Km
Shadowing	Lognormal variable with mean 0 dB and standard variance 8 dB
Modulation and coding scheme	See IEEE 802.16e[17]

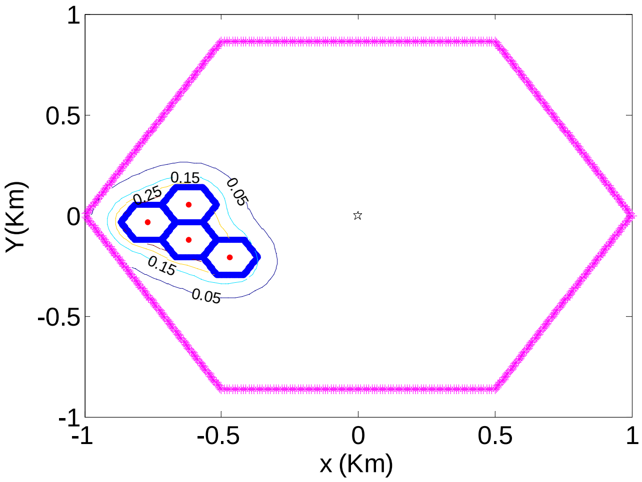


Figure 5: An example of the isolation band.

3. BS informs the RSs in the RS cluster the reusable resource of the next RS frame through the message in the relay zone.

Compared to the existed schemes, the additional implementations of IBFRS are fixing the isolation band by a long period and pre-scheduling the resource of the next frame. Thus, the complexity of the proposed scheme is acceptable.

5. SIMULATION AND DISCUSSIONS

In this section, an OFDM cellular network with 19 BS cells is considered in both numerical analysis and simulation. Soft frequency reuse scheme [15, 16] is used among BS cells. The related simulation parameters are listed in Table 1.

According to (22), we first study the isolation band of the RS cluster. RSs are placed in the BS cell randomly and at most 10 RSs are included in a RS cluster. Fig.5 shows an example of the isolation band (A_{BS}^{nr}) of a RS cluster and its corresponding θ. The area enclosed by the contour except the coverage area of the RS cluster is the isolation band and the number on the contour denotes the corresponding θ. Obviously, with the decrease of the area of the isolation band, θ is increased since the RS cluster will interfere with the users out of the isolation band more severely. In Fig.6, the average ratio of S_{BS}^{r} to S_{BS} (y-axis) is shown with respect to the number of RSs in the RS cluster (x-axis). It can be seen that the acreage ratio is decreased with the increase of the number of RSs. That is because the interference to the users served by BS would be increased as the number of RSs increases. Nevertheless, the ratio is still above 80% which means most frequency could be reused by the RS cluster.

We then apply the system-level simulation to study the IBFRS by Matlab. Since no specific studies on the topology considered in this paper are found yet, the scheme without frequency reuse, i.e., the BS and the RSs in the RS cluster use different frequency bands to serve the respective users [8], is simulated for the comparison purpose and we call this scheme as the traditional scheme in the following. For simplicity, each user is allocated one sub-channel, so that both BS and RS cluster could serve 30 users at most. During the simulation, 20 kinds of topology are emulated. For each topology, the RS clusters are deployed randomly. The number of RS clusters in each BS cell and the number of RSs in each RS cluster are uniformly distributed in [1, 3] and [1, 5], respectively. 100 samples are simulated for each topology, and the steps for user generation in each sample are as follows:

1. Generating 30 users distributed randomly in the BS cell (including RS-areas) for the traditional scheme;

2. Based on the users in step 1, for IBFRS, increase the number of users in the BS serving area (except RS-areas) to 30, while the number of users in each RS-area is uniformly distributed in [1,30].

In step 1, due to no frequency reuse in the traditional scheme, 30 users means the system is fully loaded. However, actually, the reason of the deployment of RS is that more users can be supported in the RS-areas; thus, in step 2, by considering the frequency reuse in IBFRS, 30 users could be served by BS and more users should be generated for each RS-area.

Figs.7 (a)-(d) give the average throughput of the system, BS serving area, RS serving area and the isolation band, respectively, in the access zone. For the traditional scheme, since only 30 users could be supported in the whole BS cell, there is only one point in Fig.7 (a), and in Figs.7 (b) and (c), the number of users in the BS and RS serving areas wouldn't exceed 30, respectively. From Fig.7 (a) and (c), due to frequency reuse between BS and RS clusters in IBFRS, more users could be served with the increment of the number of RSs in the RS clusters, and the throughput is improved greatly with the increase of the number of users. In Fig. 7 (b), only one point corresponding 30 users is illustrated for IBFRS because the number of users served by the BS has reached the maximum of the system. Obviously, the throughput in BS served area in IBFRS is decreased a little because of the frequency reuse by the users in the RS cluster. In Fig.7 (d), the throughput of the isolation band in IBFRS is also decreased a little. As mentioned before, in the simulation, each BS cell may include several RS clusters. Since the frequency used by one isolation band may be

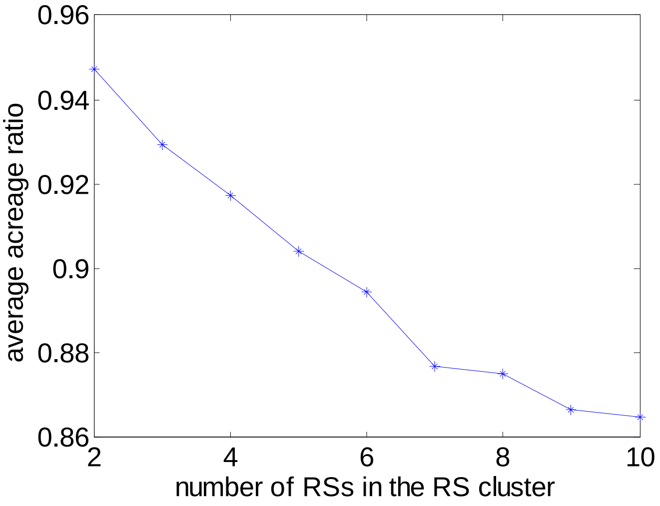


Figure 6: The average acreage ratio of S_{BS}^{r} to S_{BS}.

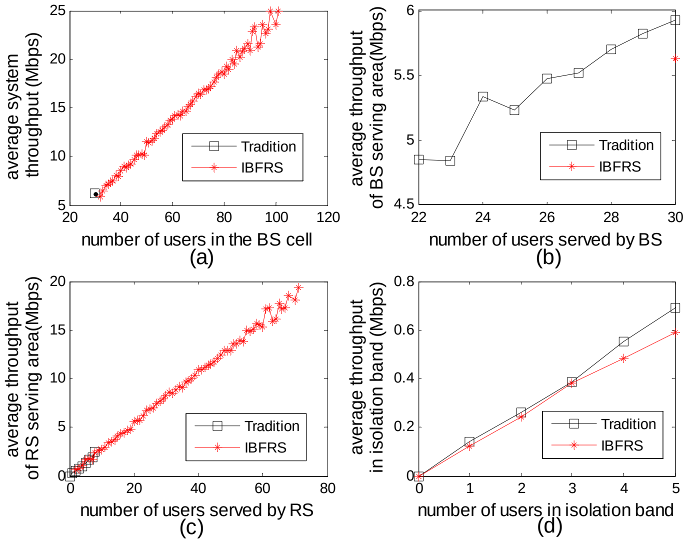


Figure 7: Throughput comparison.

reused by other RS clusters, the throughput of the isolation band is lower than that in the traditional scheme. In summary, through IBFRS, the throughput of the access link is improved largely with little negative influence to the users served by the link of BS to MS. Therefore, based on the analysis in section 3, we could conclude that IBFRS could improve the effective system capacity significantly.

6. CONCLUSIONS

In this paper, a new frequency reuse scheme for the two-hop relay network based on IEEE 802.16j has been proposed. By introducing an isolation band for each RS cluster, the proposed isolation band based frequency reuse (IBFRS) scheme allows each RS cluster reuses all frequency resources out of the isolation band. The determination of the optimal isolation band is derived analytically. Simulation results indicate that the proposed IBFRS scheme can significantly improve the throughput of the access links with little negative influence to other users served by the BS. In the future, our work will focus on the extension of the IBFRS on the multi-hop relay network and consider more complex scenarios, such as networks with directional antennas.

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