

Hybrid Resource Allocation Scheme in Two-hop Relaying WiMAX Networks

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Abstract—In this paper, we consider resource allocation schemes in two-hop relaying WiMAX networks in order to maximize cell throughput, while serving the subscriber stations (SSs) in a fair manner. First we present two well-known schemes, namely, *orthogonal* and *overlapped*, according to the frequency reuse during the access zone intervals of downlink and uplink subframes. We then propose a hybrid resource allocation scheme to harmonize the orthogonal and overlapped schemes in order to improve the efficiency of resource utilization while minimizing interference. We evaluate the performance of our proposed hybrid scheme by comparing it with the optimal scheduling scheme as well as the orthogonal and overlapped schemes, in terms of cell throughput, outage rate, and computation time. The numerical results show that the proposed hybrid scheme achieves a higher throughput than the overlapped scheme while maintaining as low an outage rate as orthogonal scheme. In addition, the computational time is significantly less than the optimal scheme at the expense of minimal throughput degradation.

I. INTRODUCTION

The addition of relay stations (RSs) to a traditional WiMAX network is seen as an attractive technology for providing throughput enhancement and coverage extension. IEEE 802.16j for WiMAX with RSs was published in 2009 [1]. Furthermore, multihop relaying is considered an essential feature in the IEEE 802.16m standard [2] and 3GPP Long Term-Evolution (LTE) Advanced standard [3]. According to the IEEE 802.16j standard, two kinds of relay operation modes are defined: *transparent* relay mode and *non-transparent* relay mode. The transparent RSs allow only throughput enhancement, whereas non-transparent RSs can extend the coverage and also increase the throughput. In this paper, we focus on deploying non-transparent RSs for the purpose of coverage extension, and a single tier of RSs since additional hops can cause a higher delay and lower bandwidth efficiency. A non-transparent mode frame structure consists of a downlink (DL) and an uplink (UP) subframe, and each subframe includes two zones, namely the *access* and *relay* zones [1]. During the DL access zone period, the base station (BS) and RSs can transmit to the associated SSs simultaneously.

Due to the frequency reuse in non-transparent RS mode, it is more complex and challenging to explore a scheduling scheme that maximizes cell throughput while serving the SSs in a fair manner. In this paper we assume Max-min fairness [6], hence, none of active SSs can achieve more throughput than other SSs without decreasing the throughput of other SSs. Many researchers have recently proposed scheduling

schemes for OFDMA based WiMAX networks. The simplest scheduling scheme is fixed assignment scheduling [4], in which a BS allocates a fixed amount of bandwidth for every RSs. In this simple scheduling scheme the system throughput is significantly degraded due to inefficient resource utilization. To enhance network performance, Park et al. [5] present two scheduling schemes named *orthogonal* and *overlapped* and compare the performance of the two schemes. However the boundary between access and relay zones was not dynamically selected according to the traffic load but statically determined for each scenario. We proposed an optimal scheduling scheme in which the boundary is optimally determined to maximize cell throughput in our previous paper [12]. However, the optimal scheme may not be applicable for the practical system due to the high computational time. In this paper we propose a new scheduling scheme, named hybrid resource allocation scheme that can significantly reduce the computational time while preserving the efficiency of frequency reuse and outage performance. Although we consider only the downlink analysis, our scheme can be easily extended to include the uplink.

The rest of this paper is organized as follows. In the next section, we present the system model. In Section III, we propose a new hybrid resource allocation scheme. Numerical results and analysis are shown in Section IV. Finally, Section V concludes the paper.

II. SYSTEM MODEL

We consider a WiMAX network enhanced with non-transparent RSs, with each cell consisting of a BS, RSs, and SSs. We assume that every node has a single omni-directional antenna, hence, no terminal can transmit and receive simultaneously. The cell radius, 1200m, is determined by the condition that the cell coverage probability under Rayleigh fading channel is greater than 90% [7], [8]. For the path loss model, we use the Erceg-Greenstein model, which is recommended by the IEEE 802.16 working group [7]. Depending on the link quality, a variety of modulation and coding schemes (MCS) are supported in WiMAX networks. Table I shows the achievable data rates denoted as d_1, d_2, \dots, d_7 and the corresponding MCS; the last column represents the minimum required threshold values of signal to interference and noise ratio (SINR), $\bar{\gamma}_m$, computed by bit error rate expression for M-QAM [9] when bit error rate is 10^{-6} . With the assumption of a Rayleigh fading channel, the received SINR, γ , is an

TABLE I
SINR THRESHOLD SET

MCS	Downlink Data Rate d_m [Mbps]	Spectral Efficiency [bps/Hz]	SINR Threshold $\bar{\gamma}_m$ [dB]
QPSK 1/2	5.25	1.0	9.1
QPSK 3/4	7.87	1.5	11.73
16 QAM 1/2	10.49	2.0	13.87
16 QAM 3/4	15.74	3.0	17.55
64 QAM 2/3	20.99	4.0	20.86
64 QAM 3/4	23.61	4.5	22.45
64 QAM 5/6	26.23	5.0	24.02

exponential random variable [10]. Therefore, the probability that a transmitter can achieve data rate d_m can be expressed as:

$$p(d_m) = \int_{\bar{\gamma}_m}^{\bar{\gamma}_{m+1}} \frac{1}{\gamma^*} \exp\left(-\frac{\gamma}{\gamma^*}\right) d\gamma, \quad (1)$$

where γ^* is the average SINR. Consequently, the average achievable data rate, d_s , can be computed by:

$$d_s = \sum_{m=1}^7 d_m \cdot p(d_m). \quad (2)$$

The relay data rate of an SS via an RS can be influenced by both hops involved. Let d_{BS-RS} and d_{RS-SS} be the average achievable data rate of links from BS to RS and from RS to SS respectively. The relay data rate of an SS will be expressed as:

$$\frac{1}{d_{BS-SS}} = \frac{1}{d_{BS-RS}} + \frac{1}{d_{RS-SS}}. \quad (3)$$

Figure 1 shows a coverage extension scenario with three RSs: the BS is located at the center of the cell and three RSs are deployed at the edge of the BS's transmission range to extend the cell's coverage. All RSs and the BS are referred to as *service nodes* in the rest of this paper. Each contour line in Fig. 1 represents the achievable average data rate of an SS according to its location inside a cell. However, the actual data rate of an SS varies according to its current SINR value.

III. RESOURCE ALLOCATION SCHEMES

In this section we first present two scheduling schemes: orthogonal and overlapped schemes in a two-hop relaying scenario. We then introduce our proposed hybrid scheduling scheme. Due to the fact that the original tile (two-dimensional time \times frequency) scheduling problem is NP-hard [11], we shall not deal with multiuser resource allocation over the frequency domain. In other words, we do not consider frequency selectivity, thus the entire spectrum is allocated to each node whenever they are allowed to transmit, i.e., scheduling is done by assigning time slots to every node.

A. Orthogonal Scheme

The essential consideration in the orthogonal scheduling scheme is to avoid interference by restricting transmission opportunities to one service node at a time during the access zone period [5]. However, by precluding frequency reuse, the radio resource efficiency can be significantly reduced. In the general case, when R RSs are deployed and N SSs are active

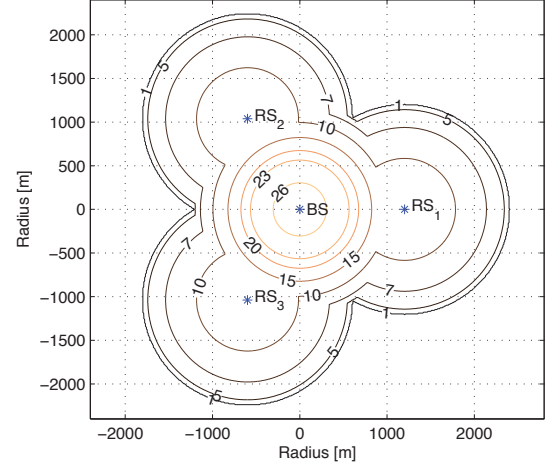


Fig. 1. A coverage extension scenario with three RSs and the achievable data rates in the cell.

in a cell, in the orthogonal scheme each SS will be served only by the service node that has the highest link capacity to the SS. We denote with S_0, S_1, \dots, S_R the set of SSs served by the BS, RS_1, \dots, RS_R respectively. The number of active SSs in the set S_i is denoted by n_i . Although there is no interference between service nodes in the orthogonal scheme, some of the active SSs may encounter outage due to Rayleigh fading channels, hence, the summation of n_i is less than or equal to N :

$$n_0 + n_1 + \dots + n_R \leq N. \quad (4)$$

We also denote with $\lambda_{s_1}, \dots, \lambda_{s_N}$ and $\lambda_{R_1}, \dots, \lambda_{R_R}$ the time fractions allocated to SS_1, \dots, SS_N in the access zone and time fractions allocated to RS_1, \dots, RS_R in the relay zone respectively. Thus, the summation of access and relay zone time fractions should be equal to 1 (for full frame utilization):

$$\sum_{i=1}^N \lambda_{s_i} + \sum_{j=1}^R \lambda_{R_j} = 1. \quad (5)$$

Let us also denote with d_{s_1}, \dots, d_{s_N} and d_{R_1}, \dots, d_{R_R} the achievable data rate of SS_1, \dots, SS_N with its service node and the achievable data rate of RS_1, \dots, RS_R from the BS. The throughput of each node should be equal for fairness and the incoming data from the BS to an RS should be equal to the outgoing data from the RS to the associated SSs as follows:

$$d_{s_1} \lambda_{s_1} = \dots = d_{s_N} \lambda_{s_N} = \frac{d_{R_1} \lambda_{R_1}}{n_1} = \dots = \frac{d_{R_R} \lambda_{R_R}}{n_R}. \quad (6)$$

Using (5) and (6), the time fraction of one of the SSs can be expressed as:

$$\lambda_{s_1} = \frac{1}{1 + \frac{d_{s_1}}{d_{s_2}} + \dots + \frac{d_{s_1}}{d_{s_N}} + \frac{n_1 d_{s_1}}{d_{R_1}} + \dots + \frac{n_R d_{s_1}}{d_{R_R}}}. \quad (7)$$

Once the time fraction for an SS is computed by (7), the rest of the time fractions λ_i can be easily calculated by (6), hence, the cell throughput can be computed by:

$$\text{Cell Throughput} = \sum_{i=1}^N d_{s_i} \lambda_{s_i}. \quad (8)$$

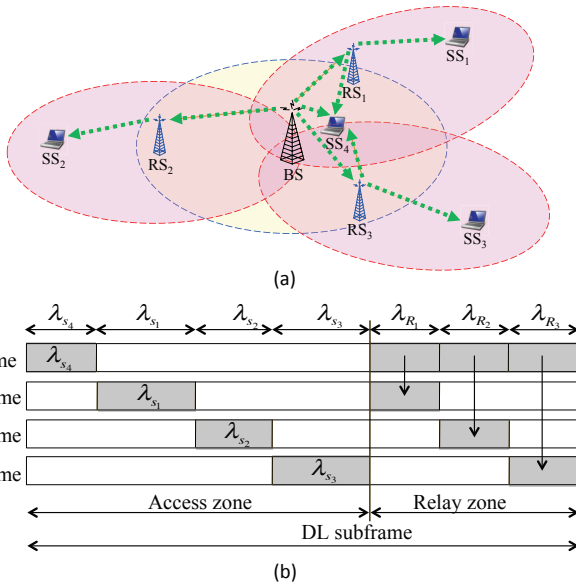


Fig. 2. (a) A sample scenario with three RSs and four SSs. (b) a possible orthogonal resource allocation in the sample scenario (a).

B. Overlapped Scheme

In contrast to the orthogonal scheme, the focus of the overlapped scheme is to fully reuse radio resources during the access zone interval [5]. On one hand, the cell throughput is likely to be increased, but, on the other hand, outage events are also increased due to significant interference. The cell throughput and outage probability for the overlapped scheme vary according to the selection of the active service nodes, as not every service node has to be active during the access zone. We assume that the set of active service nodes is selected to maximize the number of served SSs. Three different objectives of determining the set of active service nodes are introduced in [12]. By using the same example scenario shown in Fig. 2(a) with an assumption that every SS has different achievable data rates from its service node ($d_{s_3} > d_{s_1} > d_{s_2}$), one possible resource allocation for the overlapped scheme is shown in Fig. 3. Every RS can be active simultaneously to serve associated SSs during the access zone period, however the SS₄ can not be served due to strong interference. Another unique aspect of the overlapped scheme is that there may be wasted resources due to fairness. If we denote with λ_0 the fraction time allocated to the entire access zone, (5) will be rewritten as:

$$\lambda_0 + \lambda_{R_1} + \dots + \lambda_{R_R} = 1. \quad (9)$$

Let us also denote with d_j^i and λ_j^i the achievable data rate of the j^{th} active SS ($j = 1, \dots, n_i$) with its service node and the time fraction allocated to the j^{th} active SS in the set S_i ($i = 0, \dots, R$) respectively. The SSs in the same set S_i have to share the access zone, i.e., $\lambda_0 \geq \lambda_1^i + \lambda_2^i + \dots + \lambda_{n_i}^i$. In each set S_i , the throughput of each node should be equal for fairness:

$$d_1^i \lambda_1^i = d_2^i \lambda_2^i = \dots = d_{n_i}^i \lambda_{n_i}^i, \quad i \in \{0, 1, \dots, R\}. \quad (10)$$

We define the average data rate (H_i) of each set S_i as the

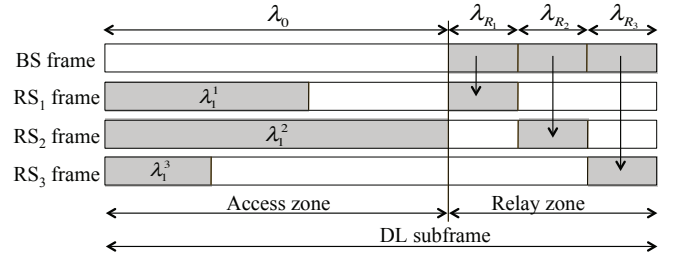


Fig. 3. Overlapped resource allocation example for the sample scenario in Fig. 2(a).

sum of the throughput of active nodes in S_i divided by the total time duration of the access zone:

$$H_i = \frac{n_i d_1^i \lambda_1^i}{\lambda_1^i + \lambda_2^i + \dots + \lambda_{n_i}^i}, \quad i \in \{0, 1, \dots, R\}. \quad (11)$$

Using (10), we can eliminate times λ_j^i in (11):

$$H_i = \frac{n_i}{\frac{1}{d_1^i} + \frac{1}{d_2^i} + \dots + \frac{1}{d_{n_i}^i}}, \quad i \in \{0, 1, \dots, R\}. \quad (12)$$

The throughput per node (H_i/n_i) in each set S_i varies since each set has a different number of SSs and different link capacities. Therefore, it is necessary to control the throughput per node in each set for global fairness. Let H_x and n_x be the average data rate and the number of active SSs of the set that has minimum throughput per node. Only this set can fully use resources during the access zone λ_0 , while the rest of the sets excluding S_0 are constrained by the data transferred from the BS to RSs, $d_{R_i} \lambda_{R_i}$ ($i = 1, \dots, R$):

$$\frac{H_x \lambda_0}{n_x} = \frac{d_{R_1} \lambda_{R_1}}{n_1} = \frac{d_{R_2} \lambda_{R_2}}{n_2} = \dots = \frac{d_{R_R} \lambda_{R_R}}{n_R}. \quad (13)$$

Only S_0 is not constrained by the relay zone transmissions since every SS in S_0 is directly connected with the BS. Therefore, unless S_0 has a minimum throughput per node, the active SSs in S_0 can achieve higher throughputs since they can fully use resources during λ_0 . If we use (13) to substitute for λ_{R_i} in (9), λ_0 can be expressed as:

$$\lambda_0 = \frac{1}{\frac{n_1}{n_x} \frac{H_x}{d_{R_1}} + \frac{n_2}{n_x} \frac{H_x}{d_{R_2}} + \dots + \frac{n_R}{n_x} \frac{H_x}{d_{R_R}} + 1}. \quad (14)$$

After determining λ_0 from (14), the time fractions $\lambda_{R_1}, \dots, \lambda_{R_R}$ can be easily computed using (13). Consequently, the cell throughput can be computed by:

$$\text{Cell Throughput} = H_0 \lambda_0 + \sum_{i=1}^R d_{R_i} \lambda_{R_i}. \quad (15)$$

C. Hybrid Scheme

The main goal of the proposed hybrid scheme is to combine the orthogonal and overlapped schemes in order to improve performance in terms of the cell throughput and outage rate, while preserving a low computational complexity. To achieve more throughput than the orthogonal scheme, the resources should be utilized by allowing the service nodes to be active simultaneously, but at the same time, the outage events due

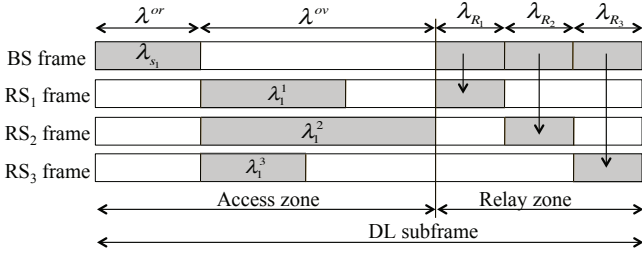


Fig. 4. Hybrid resource allocation example for the sample scenario in Fig. 2(a).

to interference should be avoided. In other words, the hybrid scheme performs like an overlapped scheme when there are no active SSs affected by interference, however, when outage events occur, the resources are orthogonally allocated to those SSs. Therefore, the number of active SSs in each set S_i are divided into two groups denoted as S_i^{or} and S_i^{ov} : one is served as in the orthogonal scheme, and the other is served as in the overlapped scheme. Let n_i^{or} and n_i^{ov} be the number of active SSs that are served orthogonally, and overlapped respectively, i.e., $n_i = n_i^{or} + n_i^{ov}$. If we denote with K the total number of SSs that are served orthogonally, (4) can be rewritten as:

$$K + n_0^{ov} + n_1^{ov} + \dots + n_R^{ov} \leq N. \quad (16)$$

By using the same example scenario in Fig. 2(a), one possible resource allocation for the hybrid scheme is depicted in Fig. 4. The access zone time fraction is divided into two subsections: the orthogonal and overlapped subsections are denoted by λ^{or} and λ^{ov} . The summation of time fractions allocated to the active SSs that are served orthogonally is equal to λ^{or} , i.e., $\lambda^{or} = \lambda_{s_1} + \dots + \lambda_{s_K}$. To ensure fairness, the orthogonally served SSs should also achieve equal throughput as minimum per node throughput and the service nodes have to relay more data to support them, thus (13) can be modified as:

$$\begin{aligned} \frac{H_x^{ov} \lambda^{ov}}{n_x^{ov}} &= \frac{d_{R_1} \lambda_{R_1}}{n_1^{or} + n_1^{ov}} = \frac{d_{R_2} \lambda_{R_2}}{n_2^{or} + n_2^{ov}} = \dots = \frac{d_{R_R} \lambda_{R_R}}{n_R^{or} + n_R^{ov}} \\ &= d_{s_1} \lambda_{s_1} = d_{s_2} \lambda_{s_2} = \dots = d_{s_K} \lambda_{s_K}, \end{aligned} \quad (17)$$

where H_x^{ov} and n_x^{ov} be the average data rate and the number of active SSs of the set that has minimum throughput per node among the set S_i^{ov} . In a manner similar to that of the overlapped scheme, the time fraction allocated to the overlapped section can be expressed as:

$$\lambda^{ov} = \frac{1}{\frac{n_1^{or} + n_1^{ov}}{n_x^{ov}} \frac{H_x}{d_{R_1}} + \dots + \frac{n_R^{or} + n_R^{ov}}{n_x^{ov}} \frac{H_x}{d_{R_R}} + 1 + \frac{H_x}{n_x^{ov} d_{s_1}} + \dots + \frac{H_x}{n_x^{ov} d_{s_K}}}. \quad (18)$$

Consequently, the cell throughput from the hybrid scheme can be computed by:

$$Cell \text{ Throughput} = H_0^{ov} \lambda^{ov} + \frac{H_x^{ov} \lambda^{ov}}{n_x^{ov}} \left(\sum_{i=1}^R n_i - n_0^{ov} \right). \quad (19)$$

D. Optimal Scheme

Optimal scheduling scheme determines the time duration of the transmissions for each SS and RS in the access and relay zones in order to maximize cell throughput under the max-min fairness constraint. It is neither wasting resources nor allowing for outage due to interference. To determine the optimal schedule, all the possible combinations of active service nodes should be considered. The detail formulation can be found in [12].

IV. NUMERICAL RESULTS AND ANALYSIS

In this section we evaluate the performance of the proposed hybrid scheme by comparing it with the orthogonal, overlapped, and optimal schemes. Fig. 5 shows all performance results for the four different scheduling schemes. The upper three graphs are the cell throughput, outage, and computation time results as a function of the number of active SSs in a cell when three RSs are deployed, and the lower three graphs are the results when the number of RSs vary from one to six when there are 25 active SSs in a cell. To obtain the average cell throughput value, the simulation is repeated 10,000 times for each scenario with N active SSs randomly placed within a cell. We computed the 95% confidence intervals, but do not show them as they are very small and would clutter the graphs.

As shown in Fig. 5(a), when the number of active SSs increases, the cell throughput achieved by orthogonal scheme decreases because it is more likely to have SSs with low link capacities consuming large fractions of the time in order to preserve fairness. In contrast, the cell throughput for an optimal scheme grows as the number of active SSs increases, since the optimal scheme maximizes frequency reuse, while minimizing co-channel interference in order to avoid outage. The cell throughput of our proposed hybrid scheme is only 4 to 7% lower than that of the optimal case (the higher the number of SSs, the lower the difference.) Fig. 5(b) shows that the outage rate from proposed hybrid scheme is identical to the results from the optimal and orthogonal schemes, whereas the outage rate for the overlapped case continues to rise significantly as more SSs join the cell because the number of active service nodes also increases leading to an insufficient SINR for many SSs. Although there is no interference between service nodes for the rest of the schemes, about 6% of active SSs still encounter outage due to the Rayleigh fading channels. This result shows that the cell coverage probability under Rayleigh fading channel was improved from 90% without RSs to 94% with three RSs in addition to coverage extension.

Figures 5(d) and (e) show the throughput and outage results as a function of the number of RSs. When more RSs are deployed at the edge of the transmission range of the BS in a circular manner, the outage probability of the overlapped scheme gradually deteriorates, whereas the outage rates from the rest of the schemes decrease as the addition of relays increases the chance of at least one good link to one of them. The difference between optimal and hybrid throughput results is less than 4% in the case of up to three RSs, and then the gap increases as the number of RSs increases since more

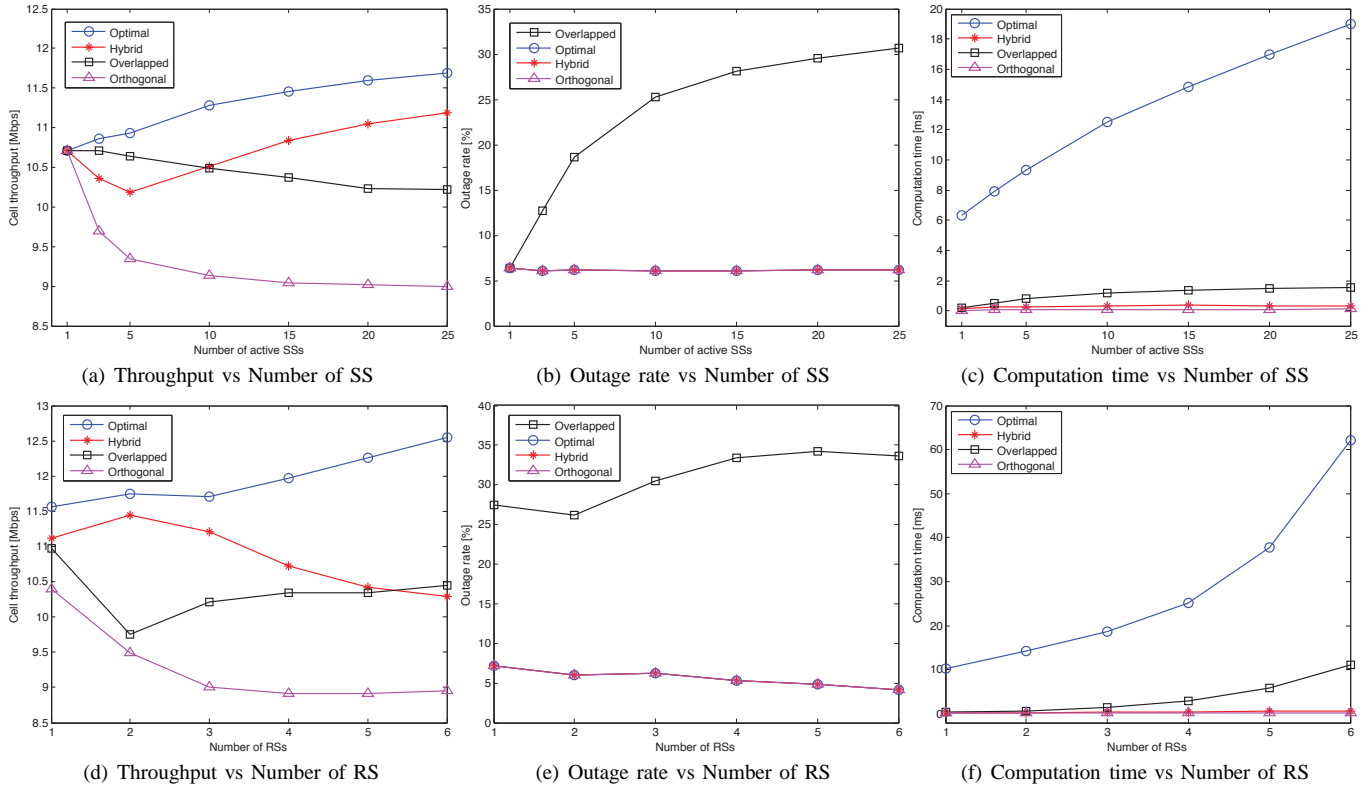


Fig. 5. Cell throughput, outage rate, and computation time results as a function of the number of active SSs and RSs respectively for different scheduling schemes.

resources are used orthogonally to avoid outage events. In general, however, deploying more than four RSs having the same transmission power and antenna gain as the BS is not a desirable scenario from the cost effective perspective.

Figures 5(c) and (f) show that the computational time of an optimal scheme is substantially higher than the rest of the schemes and increases exponentially with the number of RSs, while the three suboptimal schemes have relatively low computation times. The computational times of the orthogonal and hybrid schemes are always less than 1ms regardless of the increase in the number of SSs and RSs in a cell; however the computation time of the overlapped scheme increases with the number of RSs since it has to go through the process of determining the set of service node before allocating resources. The reported times are based on Matlab computations, not a particularly fast language.

V. CONCLUSION

In this paper we studied the resource allocation problem in 802.16j based two-hop relaying networks. We proposed a hybrid resource allocation scheme that combines advantages from both the orthogonal and overlapped schemes in order to improve the efficiency of resource utilization, while minimizing the interference. The outage rate of the proposed hybrid scheme is always as good as the orthogonal scheme, but a higher cell throughput can be achieved with a hybrid scheme than in the overlapped case. We also compared our proposed scheme with the optimal scheduling scheme, which can optimally allocate resources by using linear programming.

Our numerical results show that the computational time of hybrid scheme is significantly lower than the optimal scheme at the expense of the small amount of throughput degradation.

REFERENCES

- [1] "Air interface for broadband wireless access systems: Multihop relay specification," IEEE Standard 802.16j, Jun 2009.
- [2] "Part 16: Air interface for fixed and mobile broadband wireless access systems - DRAFT amendment to ieee standard for local and metropolitan area networks," IEEE 802.16m/D10, Nov 2010.
- [3] 3GPP, "Relay advancements for E-UTRA (LTE-Advanced)," 3rd Generation Partnership Project (3GPP), TR 36.806, Sep 2009.
- [4] M. Kaneko and P. Popovski, "Adaptive resource allocation in cellular OFDMA system with multiple relay stations," in *Vehicular Technology Conference*. IEEE, 2007, pp. 3026–3030.
- [5] K. Park, H. S. Ryu, C. G. Kang, D. Chang, S. Song, J. Ahn, and J. Ihm, "The performance of relay-enhanced cellular OFDMA-TDD network for mobile broadband wireless services," *EURASIP J. Wirel. Commun. Netw.*, vol. 2009, pp. 1–10, 2009.
- [6] L. Tassiulas and S. Sarkar, "Max-min fair scheduling in wireless networks," in *INFOCOM*, vol. 2, 2002, pp. 763–772.
- [7] V. Erceg and K. V. S. Hari, "Channel models for fixed wireless applications," in *IEEE 802.16 Broadband Wireless Access Working Group*. Technical Report, 2001.
- [8] "WiMAX's technology for LOS and NLOS environments." WiMAX Forum white paper, Aug 2004.
- [9] G. J. Foschini and J. Salz, "Digital communications over fading radio channels," *Bell System Tech. J.*, pp. 429–456, Feb 1983.
- [10] Q. Zhang and S. Kassam, "Finite-state Markov model for Rayleigh fading channels," *Communications, IEEE Transactions on*, vol. 47, no. 11, pp. 1688–1692, Nov 1999.
- [11] S. Deb, V. Mhatre, and V. Ramaiyan, "WiMAX relay networks: opportunistic scheduling to exploit multiuser diversity and frequency selectivity," in *MOBICOM*. ACM, Sep 2008, pp. 163–174.
- [12] Y. Kim and M. L. Sichitiu, "Optimal resource allocation in multihop relay-enhanced WiMAX networks," in *WCNC*. IEEE, Mar 2011, pp. 737–742.