Resource Scheduling with Directional Antennas for Multi-hop Relay Networks in Manhattan-like Environment

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***Abstract*- Multi-hop relay (MR) networks have been proposed for user throughput improvement, coverage extension and/or capacity enhancement to the traditional mobile cellular networks. In particular, an MR network is being standardized by the IEEE 802.16j Task Group as an amendment to the IEEE 802.16e standard. This paper investigates the issue of resource scheduling for the IEEE 802.16j MR network in the Manhattan-like environment. New scheduling methods are proposed for the MR network with directional antennas equipped at both the base station and relay stations. Simulation results show that the system throughput can be dramatically increased by the proposed methods as compared to the system with omni-directional antennas.**

***Keywords*- Multi-hop relay, resource scheduling, directional antenna, Manhattan-like environment.**

I. INTRODUCTION

Next generation mobile cellular systems are envisioned to provide high-data-rate multi-media services to users anytime, anywhere at an affordable cost [1]. With traditional cell architecture, where the base station (BS) is the only serving station in a cell, the cell coverage has to be kept small so as to provide high-data-rate services to users near the cell boundary because of the limited energy available for each transmission bit, and that increases the number of base stations and the system cost. Multi-hop relay (MR) cell architecture is one feasible solution to overcome such a problem [2-13]. It is a concept to set up relay stations (RSs) in a cell to relay information from a BS to mobile stations (MSs), and vise versa. The RS has no direct backhaul connection to the network and hence it is much simpler and easier to deploy than the BS [10, 13]. It has been shown that using RSs can improve cell coverage, user throughput and system capacity [2-13]. Especially, the system capacity can be increased in the Manhattan-like scenario, where an aggressive frequency reuse scheme can be achieved by taking advantage of spatial isolations inherited in the environment [2-5].

In recent years, there have been more and more interests in the design of MR networks [2-12]. In [13], an MR network is being specified as an amendment to the IEEE 802.16e standard [15] with the purpose of cell coverage extension, user throughput improvement and/or system capacity enhancement. In [3], an MR network was proposed for the Manhattan-like environment, where four RSs are deployed outside of the BS's coverage in a cell in order to extend the cell coverage. By utilizing the spatial isolation inherited in the Manhattan-like environment, two relay stations within the same cell can be scheduled to be active simultaneously, and frequency reuse factor of 1 can be achieved in the multi-cell environment [4]. However, since there is a time interval during which the BS is not active, the radio resource is not fully utilized in this design. One other MR network was proposed in [2], where RSs are deployed within the service range of the BS with the purpose of user throughput enhancement. Both the BS and RSs employ omni-directional antennas to serve users and to communicate with each other. As a consequence, the frequency reuse factor has to be at least 2 in order to avoid severe co-channel interference and that reduces the system capacity.

We consider the MR network scenario in [2] for the purpose of user throughput enhancement. New scheduling methods are proposed for the system with directional antennas equipped at both the base station and relay stations. Simulation results show that the system throughput can be dramatically increased by the proposed methods, as compared to the system with omni-directional antennas.

This rest of paper is organized as follows. Section II describes the system setup and the used propagation models. Section III details the proposed scheduling methods. Simulation results are presented in Section IV and finally, conclusions are given in Section V.

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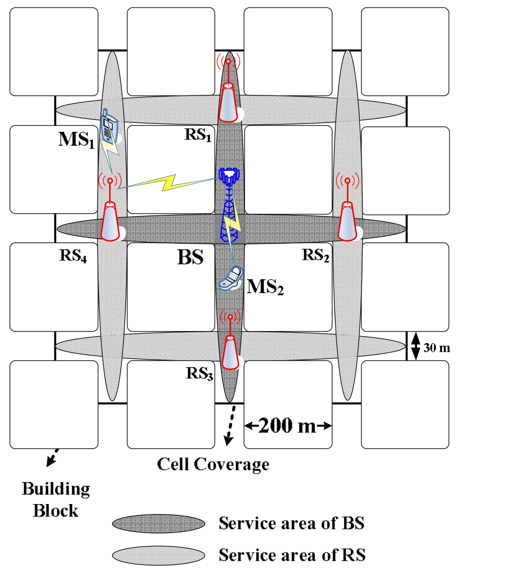

Fig. 1 The deployment of BS and four RSs and their service areas

II. System Setup And Propagation Models

A. System Setup

The MR network in [2] with a MR-cell consisting of one BS and four RSs in the Manhattan-like environment is considered in this paper. As shown in Fig. 1, the BS is located at the main street-crossing with four RSs deployed at the four street corners. The side-length of a street block and the street width are set to be 200 m and 30 m, respectively.

The MR-cell covers nine blocks and thus a cell coverage is about 690 × 690 square meters. According to the technical requirements set forth by IEEE 802.16j [13], BS and RSs are assumed to use the same air interference, and there is no backhaul network connection to RSs. In addition, RSs decode the signal from the source and forward it to the destination (decode and forward).

To improve the system performance, the BS and RSs are equipped with directional antennas to communicate with users and/or each other. The service area of each station is also shown in Fig. 1, where the BS serves RSs and MSs in its line-of-sight (LOS) area with single-hop connections, while RSs serve MSs in the BS's non line-of-sight (NLOS) area through two-hop connections.

B. Propagation Models and Antenna Pattern

In this paper, the propagation loss model proposed in [10] is considered, where the path-loss and shadow fading models for the urban micro-cell environment are adopted. Table 1 summarizes the model parameters for both the LOS and NLOS cases, where f_c is the carrier frequency, d, d_1 and d_2 are the distances indicated in Fig. 2. Note that the probability of having LOS depends on the distance value d.

The antenna pattern proposed in [16] is also adopted here,

Table 1 The propagation loss model for the urban micro-cell environment

Path loss model	
LOS	$PL(d, f_c) = 41 + 22.7\log_{10}(d) + 20\log_{10}(f_c/5.3)$ dB
NLOS	$PL(d_1, d_2, f_c) = 0.096d_1 + (28 - 0.024d_1)\log_{10}(d_2) + 65 + 20\log_{10}(f_c/5.3)$ dB
Standard Deviation of log-normal shadow model	
LOS	2.3 dB
NLOS	3.1 dB
Probability of LOS	
$P_{LOS}(d) = \begin{cases} 1 & , d \le 15\,m \\ 1-(1-(1.56-0.48\log_{10}(d))^3)^{1/3} & , d > 15\,m \end{cases}$ where $d = \sqrt{d_1^2 + d_2^2}$	
Note: f_c is in GHz, d, d_1, d_2 are in meters	

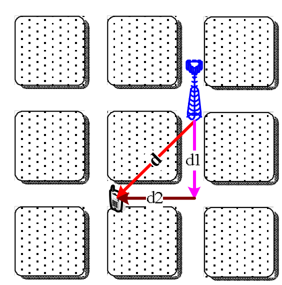

Fig. 2 The relevant distances from BS to determine the path loss and the probability of having LOS

which is

$$A(\theta) = -\min\left[12\cdot\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \text{ dBi} \quad (1)$$

where -180°< θ ≤180°, θ is the angle between the direction of interest and the steering direction of the antenna, θ_{3dB} = 70° is the 3 dB beam width, and A_m = 20 dB is the maximum attenuation.

III. Resource Scheduling Methods

A. Scheduling with Omni-directional Antennas

Since the BS and RSs use the omni-directional antennas, six phases of transmissions are needed of the best design to complete the two-hop connections between the BS and MSs, as shown in Fig. 3. Each phase includes both downlink and uplink transmissions. Here we assume that all the phase transmissions are completed in a frame. The BS takes turns to serve RSs and MSs in its LOS area in the first four phases. To

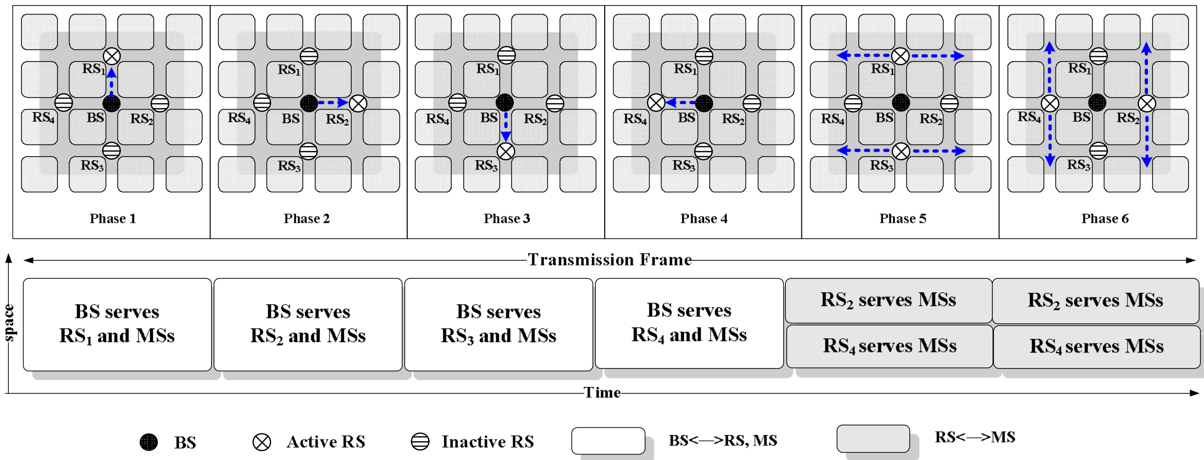

Fig. 3 Resource scheduling with omni-directional antennas

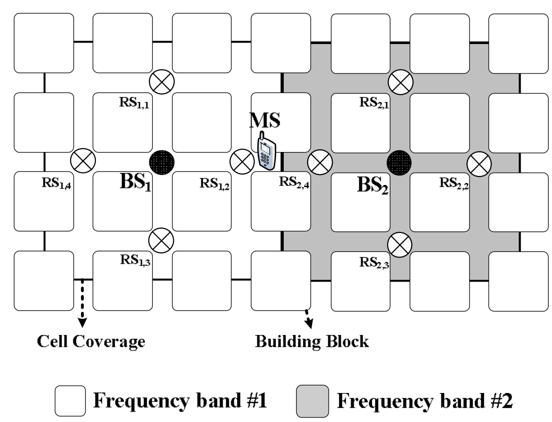

Fig. 4 Frequency reuse pattern in the multi-cell environment with omni-directional antennas

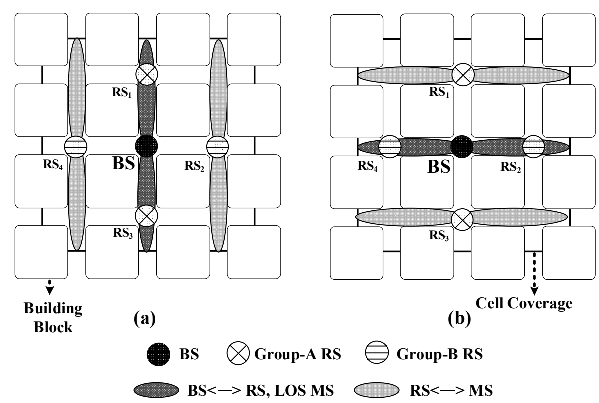

Fig. 5 Two phases of transmission in Method-1, (a) Phase 1 and (b) Phase 2

take advantage of the shadowing effect in the environment, RS_1 and RS_3 serve MSs in their service areas simultaneously in Phase 5, and RS_2 and RS_4 do the same in Phase 6.

Now consider the multi-cell structure. Because of the use of omni-directional antennas, the reuse factor of at least 2 is required to avoid the severe inter-cell interference as clearly shown in Fig. 4, and that decreases the overall system capacity.

B. Scheduling with Directional Antennas

To improve the system performance mentioned in paragraph A, the design of scheduling methods with directional antennas is proposed. In this case, the BS and RSs are equipped with directional antennas to further exploit the advantage of shadowing effect in the Manhattan-like environment. The BS and RSs are equipped with 4 directional antennas pointed to different directions, respectively, as shown in Fig. 5. In different antenna directions, the radio resource can be reused completely. In order to do that, RSs are divided into *groups* according to their mutual interference levels, and those in the same group are scheduled to transmit in the same transmission phase. In Fig. 5, RS_1 and RS_3 are grouped as Group-A, and RS_2 and RS_4 as Group-B. Since there are two groups in a cell, two transmission phases are needed to complete the two-hop transmissions. Again, each phase comprises both downlink and uplink transmissions.

B.1 Method-1

In this design, as shown in Fig. 5(a), the BS serves the Group-A RSs (RS_1 and RS_3) and MSs in its respective LOS area in Phase 1 (both up- and down-link). At the same time, the Group-B RSs (RS_2 and RS_4) serve MSs in their service areas. Alternatively, in Phase 2, illustrated in Fig. 5(b), the BS turns to serve the Group-B RSs and MSs in its respective LOS service areas, while the Group-A RSs serve MSs in their service areas.

When considering the multi-cell setup, the frequency reuse factor of 1 (universal frequency reuse) can be easily achieved as follows. As represented in Fig. 6 (a), in Phase 1, when BS_1 serves the Group-A RSs and MSs in the respective directions,

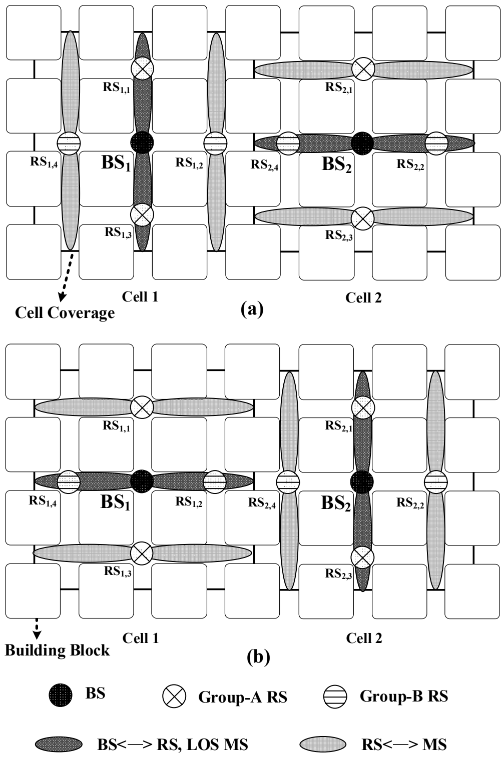

Fig. 6 Two phases of transmission of the neighboring cells in Method-1, (a) Phase 1 and (b) Phase 2

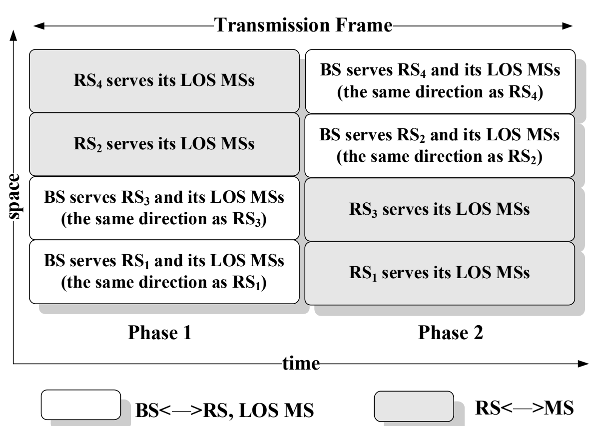

Fig. 7 The frame structure of Method-1

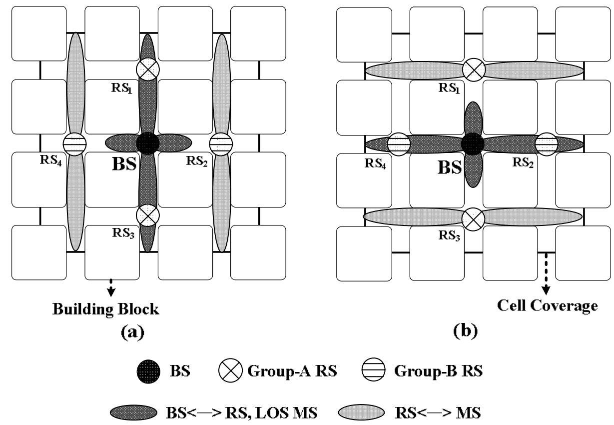

Fig. 8 Two phases of transmissions in Method-2, (a) Phase 1 and (b) Phase 2

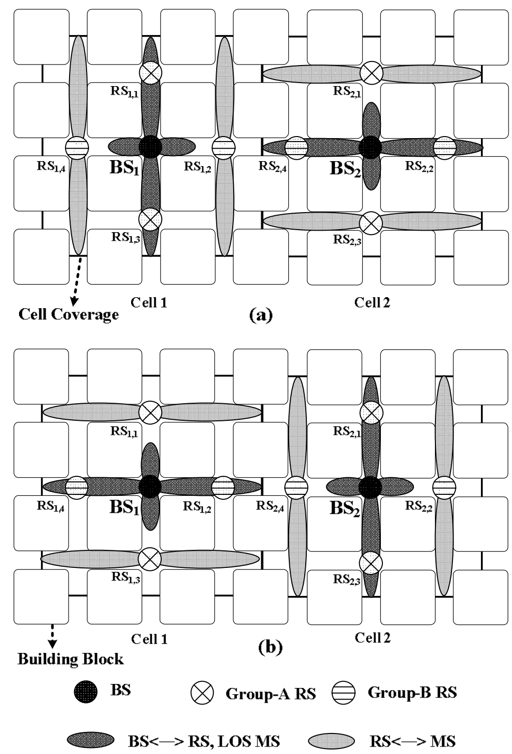

Fig. 9 Two phases of the transmission of the neighboring cells in Method-2, (a) Phase 1 and (b) Phase 2

BS_2 in the neighboring cell serves the Group-B RSs and the MSs in the indicated directions. Of course, at the same time, the Group-B RSs in the cell 1, and the Group-A RSs in the cell 2 provide services to MSs in their service areas. In Phase 2, shown in Fig. 6 (b), the operation is the same by changing the role of Group-A and Group-B in each respective cell. As clearly seen, with directional antennas along with the proposed scheduling, the universal frequency reuse is achieved very easily. The corresponding frame structure for Method-1 is shown in Fig. 7.

B.2 Method-2

In Method-1, only two antennas at the base station are activated in each transmission phase. Obviously, the two idle antennas can also be activated to better use the radio resource. However, the transmit power of these two antennas needs be controlled so that it will not cause too much interference to

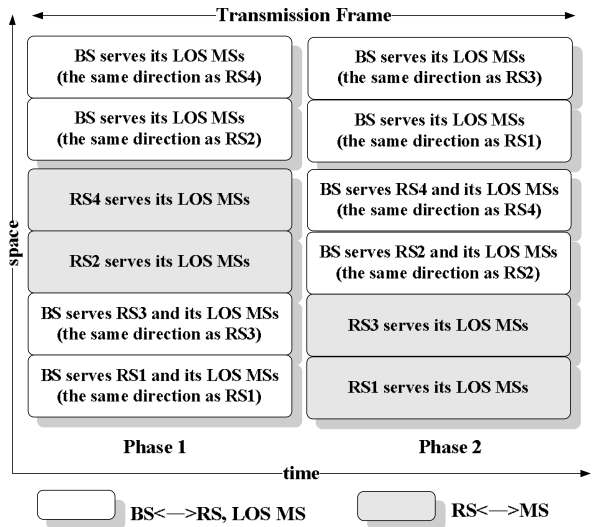

Fig. 10 The frame structure of Method-2

Table 2 OFDMA parameters for system-level simulation

Parameters	Value
Carrier frequency	3.5 GHz
Bandwidth	6 MHz
Duplexing/ Frame duration	TDD/ 20 ms
Permutation mode of each sector	FUSC (full usage of sub-channels)
Total number of sub-carriers	2048
Number of sub-channels per sector	32
Number of sub-carriers per sub-channel	48
Max. transmit power of BS	100 mW
Max. transmit power of RS	100 mW
BS-to-BS distance	690 m
Number of MR-cells (two-tier interfering cells)	25

other ongoing transmissions. Except for this new feature, Method-2 is the same as Method-1. Each phase of transmissions in a cell is shown in Fig. 8, and the scheduling for the multi-cell setup to achieve frequency reuse of 1 is shown in Fig. 9.

The frame structure of Methos-2 is shown in Fig. 10. We can see that since four directional antennas of the base station are all active, the number of BS's transmissions in each phase is four. The spectrum efficiency of Method-2 is twice of Method-1 ideally. Note that the data from/to the BS constitutes the effective throughput of the MR-cell; RSs only relay data between the BS and MSs.

V. Numerical Results

The key parameters of the simulated system are set according to the OFDMA mode in the IEEE 802.16 standard [14-15], which are summarized in Table 2. The required signal to noise plus interference ratio (SINRs) to achieve 10^{-6} Bit-Error-Rate (BER) for the considered modulation and coding schemes (MCSs) are given in Table 3 [14]. The scheduling method for the system with omni-directional antennas is also simulated to serve as the base-line scheme for the performance comparisons. The multi-cell setup with two-tier interfering cells is considered. The locations of BS and RSs are fixed, while users are uniformly distributed within the cell. The traffic model of each user is full buffered. A fixed transmission power is used in the downlink and adaptive rate control is performed every frame to adjust the modulation and coding scheme based on the perfect channel state information.

Fig. 11 shows the simulated CDFs of SINR for different scheduling methods. To emphasize the capacity gain obtained from the scheduling, the transmission power in the simulation of onmi-directional case is increased to offset the antenna gain

Table 3 The used MCS

Modulation	Coding rate	Receiver SINR (dB) to achieve 10^{-6} BER
BPSK	1/2	6.4
QPSK	1/2	9.4
	3/4	11.2
16-QAM	1/2	16.4
	3/4	18.2
64-QAM	2/3	22.7
	3/4	24.4

obtained with the directional antennas. Clearly, the scheduling with omni-directional antennas has performance, while the Method-2 has the worst because Method-2 reuses the frequency most aggressively.

The capacity simulation result is shown in Fig. 12. The cell capacity is increased largely with the proposed methods. The capacity gain is approximately 6 and 12 times for Method-1 and Method-2, respectively, as compared to the system with the omni-directional antennas. The reason of the capacity gain can be simply analyzed as follows. Firstly, as shown in Fig. 6 and Fig. 9, Method-1 and Method-2 can achieve frequency reuse factor of 1, while in Fig. 4, the reuse factor of at least 2 (here the case of 2 is simulated) is required for the system with omni-directional antennas. Hence, at least 2 times (here is 2) of capacity gain is obtained as compared to the omni-directional antenna case. Secondly, from Fig. 3 only 2/3 of the transmission phases in a frame are used for the BS's transmission. On the other hand, 2 and 4 BS's transmissions in each phase are possible for Method-1 and Method-2, respectively as shown in Fig. 7 and Fig. 10. That results in another 3 and 6 times of capacity gain over the case of the

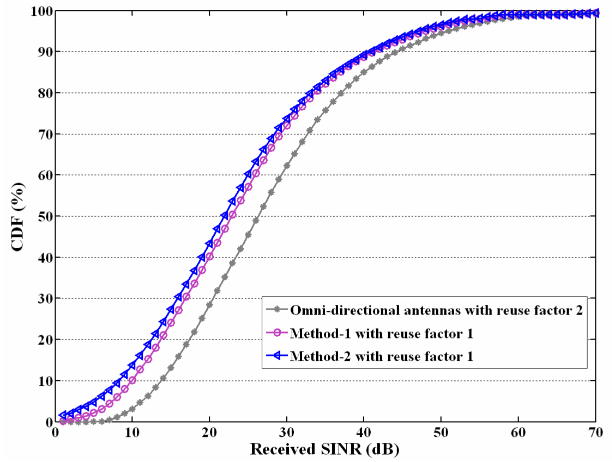

Fig. 11 The CDF of SINR for different scheduling methods

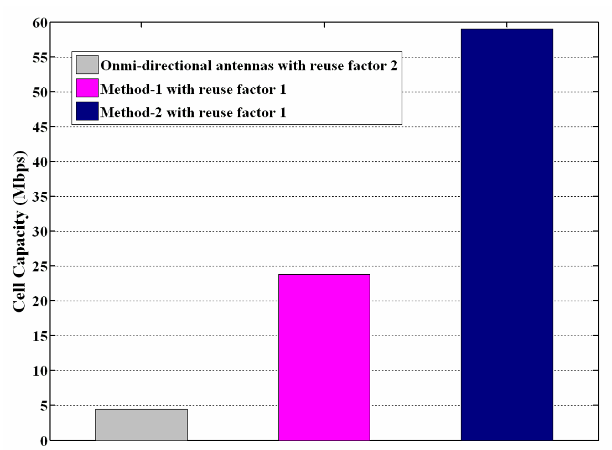

Fig. 12 Comparisons of cell capacity between different scheduling methods

omni-directional antennas. However, due to the higher interference level observed in Fig. 11, the simulated capacity gain of Method-1 over the system with omni-directional antennas is slightly less than 6 times, which our simplified analysis predicts. On the other hand, the simulated capacity gain of Method-2 over Method-1 is larger than 2 because the former provides more higher-data-rate connections.

V. Conclusions

This paper investigates the issue of resource scheduling for MR networks in the Manhattan-like environment. New methods are proposed for the MR networks with directional antennas equipped at both the base station and relay stations. By taking advantage of the effect of high degree shadowing in the Manhattan-like environment, the system throughput can be increased by nearly 6 and 12 times, respectively, by the proposed methods, as compared to the system with omni-directional antennas.

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