

A Novel Inter-Cell Interference Coordination Scheme for Relay Enhanced Cellular Networks

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Abstract—Considering the latest development after introducing Relay Nodes (RNs) into the cellular networks and the effect of inter-cell interference coordination in the cellular networks, we propose a novel method of inter-cell interference coordination for relay enhanced cellular networks. Firstly, for each cell, all available frequency resource is divided into two parts. The first part is for the users connected to the BS directly, and the other part is allocated to the users connected indirectly to the BS through Relay Nodes. Furthermore, the second part of frequency resource is divided into three parts which are utilized by cell-edge users. System-level simulation results show that the proposed scheme performs better on system capacity and spectrum efficiency than the Soft Frequency Reuse (SFR) scheme.

Keywords—Relay Nodes; cellular network; inter-cell interference coordination; frequency resource; system capacity; spectrum efficiency

I. INTRODUCTION

Because of the increasing number of mobile subscribers and the growing number of mobile applications, the demands towards improving coverage and the performance of cell-edge users increase. Recently, lots of literatures show that introducing Relay Nodes into conventional cellular networks could improve the coverage of one cell, cover the shadowing area, increase the cell throughput and improve the cell-edge users' Signal to Interference and Noise Ratio (SINR) [1] [2]. However, inter-cell interference maybe a problem in relay based cellular systems as a kind of constraint on system capacity and spectrum efficiency, especially for users at the border of the cells. Therefore, it is essential and necessary to develop an efficient inter-cell interference coordination scheme for Relay Enhanced Cells (RECs) in order to improve the system capacity and spectrum efficiency.

Lots of researches and literatures mainly focus on exploring inter-cell interference mitigation schemes for conventional cellular networks. As a promising approach of the main inter-cell interference mitigation techniques, the interference coordination scheme applies restrictions to the frequency resource management in order to mitigate interference and achieve the optimal performance of the whole network [3]. Furthermore, the SFR scheme is the essential principle for the interference coordination schemes [4]. The main feature of

SFR is dividing the whole frequency resource into two parts, and one part is for cell-center users, and the other part is reserved for cell-edge users with a higher frequency reuse factor. The frequency resource for cell-edge users between adjacent cells is orthogonal, so that inter-cell interference could be mitigated to some extent [5]. A lot of researches and existing schemes are based on the principle of SFR. A dynamic score based scheduling strategy that concerns system throughput and fairness is proposed in [3]. In [6], a modified SFR (MSFR) scheme is proposed. Three frequency reuse schemes with frequency reuse factor of 1 are proposed in [7]. A dynamic inter-cell interference coordination scheme using Hungarian algorithm is described in [8].

Although many researches and schemes focus on inter-cell interference coordination, there are not too many literatures concerning how to mitigate the interference in Relay Enhanced Cells [9]. In order to make a further research on inter-cell interference in RECs, we propose a novel frequency resource allocation scheme for relay based cellular networks. First, the whole frequency resource is divided into two parts: one part is named as major part utilized by cell-center users, and the other part is named as minor part used by cell-edge users. And the frequency resource for cell-edge users between adjacent cells is orthogonal. Furthermore, the minor part of frequency resource is divided into three parts named as minor part subset 1, subset 2 and subset 3. The relay cell-center users could utilize all the minor part of frequency resource. The "relay cell" above refers to the area that a relay covers, distinct from a common cell. The relay cell-edge users could use one of the minor part subset 1, subset 2 or subset 3. In this way, the inter-cell interference is mitigated to some extent. The system capacity and the spectrum efficiency are improved dramatically. In the following system-level simulation, we take the existing SFR scheme as the benchmark. The simulation results show that the strategy proposed in the paper outperforms the SFR scheme remarkably.

The paper continues with Section II where we briefly introduce the system model of the REC network. The proposed scheme and interference analysis are described in Section III. The following Section IV provides simulation environment,

The work in this paper is sponsored by China's National Key Project (2009ZX03003-004-01)

simulation results and analysis in comparison with the SFR scheme. Finally, Section V summarizes our work.

II. RELAY-ENABLED SYSTEM MODEL

A. Relay Enhanced Cell Model

In this paper, we consider the downlink of two-hop fixed relay based cellular network with Orthogonal Frequency Division Multiplexing Access (OFDMA) physical-layer. There are 6 position fixed RNs deployed symmetrically around the cell center at the position of $2/3$ of the cell radius in each cell, as illustrated in Fig. 1. Additional RNs can be added if needed. All BSs are deployed in the cell center. The radius of the cell is R , and the distance from the cell center to the RN equals R_f . All the RNs are equipped with directional antennas. The BS communicates with a MS directly or indirectly through a relay, which depends on a routing algorithm, e.g. SINR-based routing algorithm.

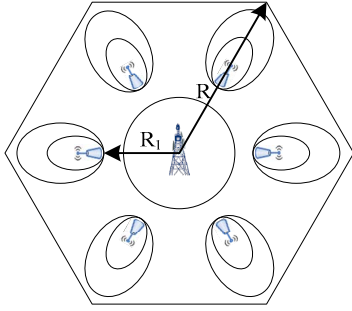


Figure 1. Basic model of relay enhanced cellular network

B. Calculations of Basic Parameters

In the following system level simulation, some equations and parameters are needed. The power of transmission node is denoted by P_t . The received signal power P_r is

$$P_r = G_{ij} \cdot P_t \quad (1)$$

where G_{ij} is the signal attenuation from the transmission node i to the receiving node j .

The propagation environment between BS, RN and MS is different, so three different pathloss equations are considered throughout the paper. The value of pathloss can be calculated by

Distance-dependent path loss for BS to MS:

$$L_{BM} = 128.1 + 37.6 \lg(R), R \text{ in kilometers} \quad (2)$$

Distance-dependent path loss for BS to RN:

$$L_{BR} = 124.5 + 37.6 \lg(R), R \text{ in kilometers} \quad (3)$$

Distance-dependent path loss for RN to MS:

$$L_{RM} = 140.7 + 36.7 \lg(R), R \text{ in kilometers} \quad (4)$$

where L is the average pathloss, and R is the distance between the transmitter and the receiver.

In this paper, the value of $SINR$ can be calculated by

$$SINR = \frac{G_{ij} \cdot P_t}{I_{intra} + I_{inter} + P_{noise}} \quad (5)$$

where I_{intra} is the intra-cell interference, I_{inter} is the inter-cell interference, and P_{noise} is the Additive White Gaussian Noise(AWGN).

The throughput of the system, denoted by T , can be calculated by

$$T = B \cdot \log_2(1 + SINR) \quad (6)$$

where B is the frequency bandwidth.

III. INTERFERENCE COORDINATION SCHEMES AND INTERFERENCE ANALYSIS

A. The Novel Frequency Resource Partitioning

The total available frequency resource is divided into N sub-channels which are orthogonal between each other. The group of $2/3$ of the total sub-channels is named as major part just as described in Section 1, and the major part is allocated to cell-center users. The group of the rest of the sub-channels is named as minor part, which is utilized by cell-edge users. Furthermore, the frequency resource for cell-edge users between adjacent cells is orthogonal. The minor part is needed to be divided into three parts again named as minor part subset 1, subset 2 and subset 3. And all the minor part of the frequency resource can be utilized by the relay cell-center users. However, the relay cell-edge users can only use one of minor part subset 1, subset 2 or subset 3. A specific scheme of frequency resource partitioning is illustrated in Fig. 2 and Fig. 3.

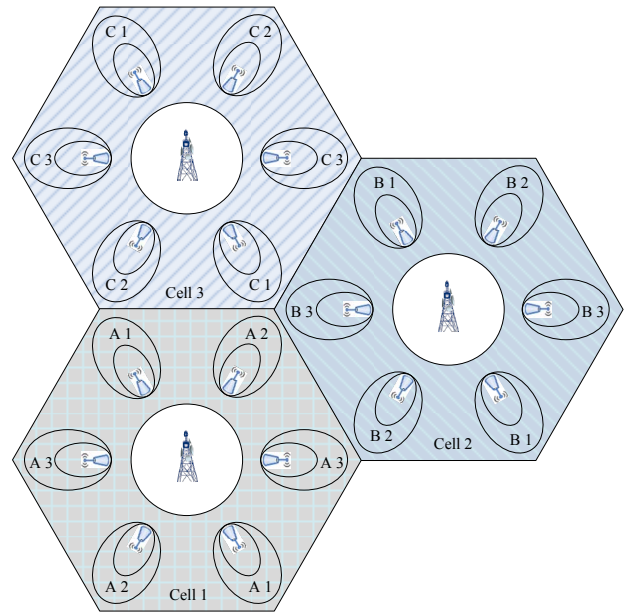


Figure 2. The novel frequency reuse scheme

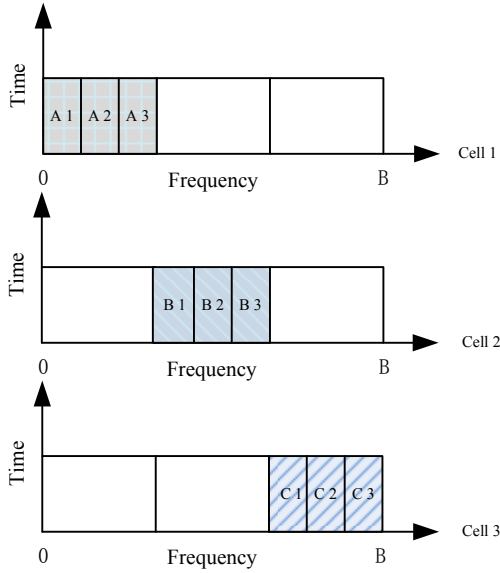


Figure 3. The frequency allocation scheme for each cell

As illustrated in Fig. 2, the shaded parts of the cells represent the edge of the cells, named as outer zone, which use the minor part of the frequency resource. The circular area of each cell represents the center of the cells, named as inner zone, which utilizes the major part of the frequency resource. For each cell, the corresponding frequency allocation scheme is illustrated in Fig. 3. For example, in the first graph of Fig. 3, the shaded parts, such as A1, A2 and A3, represent the frequency resource used by the outer zone of Cell 1 and the rest of the resource is allocated to the cell-center users in the inner zone of Cell 1. In the center of every relay cell of Cell 1, the total shaded parts, i.e. any of A1, A2 or A3, can be used. However, on the edge of any relay cell of Cell 1, only one of A1, A2, or A3 can be utilized and the three parts are deployed in rotation, as illustrated in Fig. 2. The frequency allocation scheme in other cells is similar to Cell 1. As is shown in Fig. 3, the shaded parts of the three graphs are not overlapped, so that the frequency resource for cell-edge users between adjacent cells is orthogonal.

B. Scheduling Scheme and Interference Analysis

In this paper, the BS classifies all the users into cell-center users and cell-edge users. The classification principle is as follows: if the distance from the user to the center of the cell is greater than a threshold G_{SNR} , the user is marked as cell-edge user, otherwise it is marked as cell-center user. The threshold G_{SNR} can be modified adaptively with respect to the specific circumstances. And G_{SNR} is set to be $2/3 R$ where R is the radius of the cell.

One of six available RNs can be selected for cell-edge users. The problem of the relay selection is a hot topic, which is beyond the scope of this paper. In order to simplify implementation, the principle of the relay selection is based on minimum distance which means that the RN closest to the cell-edge user will be selected as the server for the user. And other

criteria such as maximum receiving power and minimum path loss can also be used in the scheme.

First, the cell-center user is considered. We assume the user, denoted by the phone in Fig. 4, is served by the BS using the major part of the frequency resource. However, the interference analysis of the cell-center user in this scheme is different from the SFR scheme. As illustrated in Fig. 4, the cell-center user may be interfered by two neighboring BSs and four surrounding RNs in the novel scheme, while the cell-center user is interfered by two neighboring BSs in the SFR scheme.

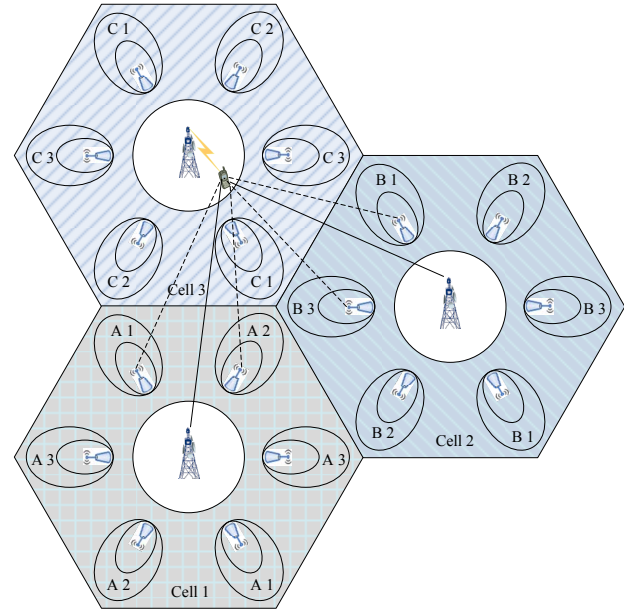


Figure 4. Interference analysis of the cell-center user

The $SINR$ of the cell-center user can be calculated by

$$\begin{aligned}
 SINR_{cell-center} &= \frac{P_{BS} / L_{BM}(R_{BM})}{\sum_{b=1}^2 \sum_r (P_{RN} / L_{RM}(R_{br})) + \sum_{b=1}^2 (P_{BS} / L_{BM}(R_{b0}))} \\
 &= \frac{L_{BM}^{-1}(R_{BM})}{(L_{RM}^{-1}(R_{11}) + L_{RM}^{-1}(R_{12}) + L_{RM}^{-1}(R_{21}) + L_{RM}^{-1}(R_{23})) P_{RN} / P_{BS} + \sum_{b=1}^2 L_{BM}^{-1}(R_{b0})}
 \end{aligned} \quad (7)$$

where P_{BS} is the transmission power of BS, P_{RN} is the transmission power of RN, R_{BM} is the distance from the server BS to the considered user, R_{br} is the distance from the main interference sources to the considered cell-center user, b represents the number of the cells, r is the number of the main interference sources in the cells. For the r , it represents the BS when r is 0, and represents the corresponding RN when r is 1 to 6. In fact, the number of the main interference sources considered in (7) is a maximum case. When the cell-center user utilizes one sub-channel of the major part, the main interference sources are one interference BS and two interference RNs. In general, the transmission power of the RN is much less than the BS. The number of the interference BSs which are the main interference sources in the SFR scheme is twice of that in the novel scheme.

Second, the interference case of the cell-edge user is shown in Fig. 5. We assume the user, denoted by the phone in Fig. 5, is served by the RN using the frequency band A2. However, the interference analysis of the cell-edge user in this scheme is different from the SFR scheme. As illustrated in Fig. 5, the cell-edge user is interfered by two neighboring BSs and three surrounding RNs in the novel scheme, while the cell-edge user is interfered by two neighboring BSs in the SFR scheme. Although there are three more interference RNs in the proposed scheme than the SFR scheme, the capacity of the cell and spectrum efficiency in the novel scheme can be increased dramatically.

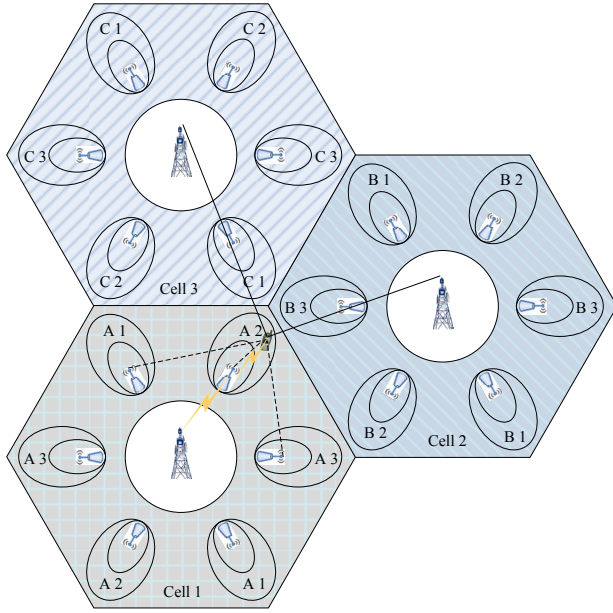


Figure 5. Interference analysis of the cell-edge user

The SINR of the cell-edge user can be expressed by

$$SINR_{cell-edge} = \frac{P_{RN} / L_{RM}(R_{RM})}{\sum_{r=1}^3 (P_{RN} / L_{RM}(R_{1r})) + \sum_{b=2}^3 (P_{BS} / L_{BM}(R_{b0}))} \quad (8)$$

where R_{RM} is the distance from the server RN to the considered user and the other parameters of (8) have the same meanings as those in (7).

IV. SIMULATION RESULTS

In this section, the performance of the proposed inter-cell interference coordination scheme is evaluated by the system level simulation. We adopt the snapshot and time-driven method in the simulation platform. In this simulation, the channel undergoes fast fading according to the motion of the MS during each “drop”. At the beginning of each “drop”, the locations of the MSs are randomly varied. The Spatial Channel Model (SCM) and log normal distribution are used as the model of fast fading and slow fading respectively [10]. The main simulation parameters are shown in Table 1.

TABLE I. THE MAIN SIMULATION PARAMETERS

Parameter	Values
Carrier frequency	2GHz
System bandwidth	10MHz
Inter-site distance	1732m
Standard deviation of slow fading	8 dB
Number of antennas	2×2
BS total transmission power	12 W
RN total transmission power	8 W
Traffic model	Full buffer
Link Adaptation	Perfect
Thermal noise power spectral density	-174 dBm/Hz
Scheduling algorithm	Proportional fair
MS speed	3 Km/h
Channel estimation	Ideal
HARQ scheme	Chase combine

In the system level simulation, the system is full load. In the proposed scheme, the MS transceivers and the BS transceivers are equipped with omnidirectional antennas, while the RN transceivers are equipped with directional antennas. And all transceivers in the SFR scheme are equipped with omnidirectional antennas [11].

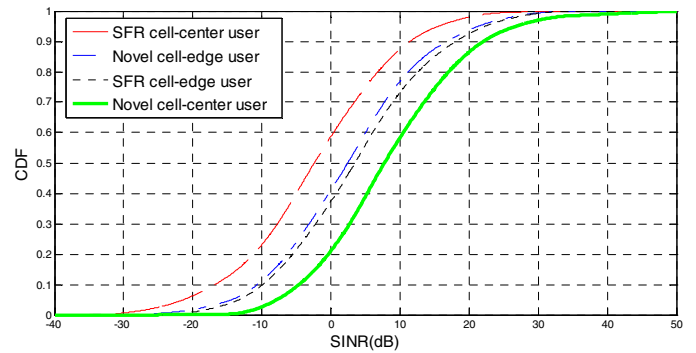


Figure 6. CDF of SINR received by cell-center user and cell-edge user

The Cumulative Distribution Function (CDF) of SINR received by cell-center user and cell-edge user is shown in Fig 6. As can be observed that the cell-center user in the novel scheme has the best SINR condition because the interference RN has less transmission power than the interference BS, moreover, there are fewest interference BSs for the cell-center user in the novel scheme. Fig 6 shows that the cell-edge user in the novel scheme has only a little SINR performance degradation compared with the cell-edge user in the SFR scheme, but has a better SINR condition than the cell-center user in the SFR scheme.

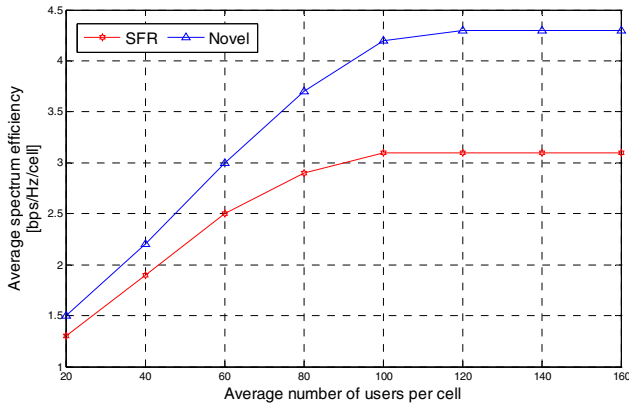


Figure 7. Average spectrum efficiency vs. MS number per cell

Fig. 7 shows the average spectrum efficiency under different MS numbers in a cell. As can be observed, the novel inter-cell interference coordination scheme has higher spectrum efficiency than the SFR scheme. It can be concluded through Fig. 6 and Fig. 7 that the novel scheme has gotten better spectrum efficiency and larger system capacity with a little SINR degradation of the cell-edge user in the proposed scheme. And the average spectrum efficiency of both schemes increases when the MS number per cell increases. Fig. 7 shows that when the number of MS in a cell increases, the proposed inter-cell interference coordination scheme has an increasing performance gain than the SFR scheme.

V. CONCLUSIONS

A novel inter-cell interference coordination scheme for relay enhanced cellular networks is proposed in this paper. The content of the novel scheme is specifically described in Section III. As can be observed in the system level simulation, the performance of the proposed novel scheme is better than the SFR scheme in terms of the average spectrum efficiency, the SINR conditions of the cell-center users and the system capacity. In a word, the novel inter-cell interference coordination scheme has obvious superior performance compared with the SFR scheme.

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