Inter-Cell Interference Coordination for a Downlink OFDMA Relay Network with Multicells

Junho Eun, Hanmok Shin, and Jae Hong Lee
Department of Electrical Engineering and INMC
Seoul National University
Seoul 151-744, Korea
E-mail: {jheun,hmshin}@snu.ac.kr

***Abstract*—In this paper, an inter-cell interference coordination algorithm is proposed for a downlink OFDMA relay network with multicells. In the proposed algorithm, the resource allocation problem is heuristically divided into subchannel allocation and subchannel restriction for interference coordination. Simulation results show that the proposed algorithm achieves higher cell edge user throughput and cell throughput than the proportional fair algorithm.**

***Index terms* — Cooperative Relaying, Interference Coordination, OFDMA, Relay Network.**

I. Introduction

Cooperative relaying is cost effective technique to overcome multi-path fading through the relay, obtaining spatial diversity (cooperative diversity) without multiple-input multiple-output antennas [1]-[3]. Orthogonal frequency-division multiple-access (OFDMA) is one of the key technologies in future networks such as 3GPP LTE-Advanced and IEEE 802.16m/j. OFDMA is effective to achieve high spectral efficiency by obtaining multiuser diversity through adaptive resource allocation [4]-[6]. Combining OFDMA with cooperative relaying, an OFDMA relay network improves both spectral efficiency and reliability. Most of previous works on OFDMA relay networks have investigated only for single cell environment [7], [8]. In [7] and [8], the resource allocation schemes are proposed to maximize the sum-rate with the fairness constraints for the OFDMA relay network consisting of multiple sources, multiple relays, and a single destination.

In multicell environment, the inter-cell interference significantly degrades the performance of the network, especially for cell edge users. The previous works on the inter-cell interference coordination do not have considered the OFDMA relay network [9], [10].

In this paper, we propose an inter-cell interference coordination algorithm for a downlink OFDMA relay network with multicells to consider the cell edge users. The resource allocation problem is decomposed into two subproblems. subchannels are allocated in each cells. Then, the interference coordination is applied.

This paper is organized as follows. In section II, a system model is described. In section III, optimization problem is formulated and an interference coordination algorithm is proposed. Simulation results are shown in section IV and conclusion is given in section V.

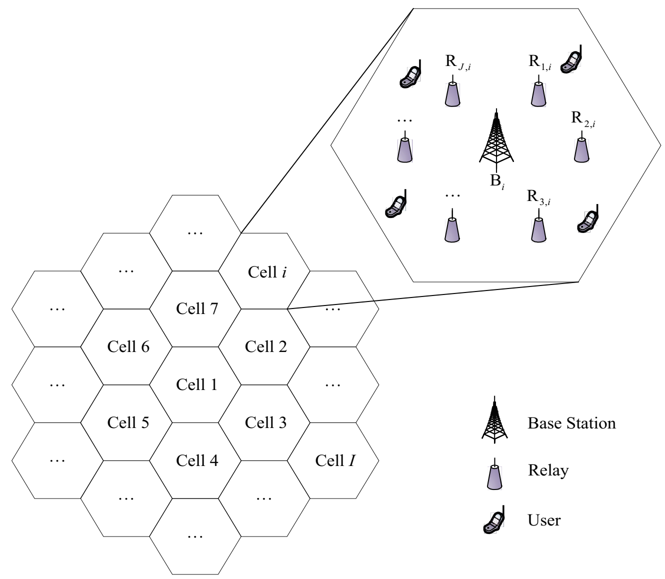

Fig. 1. A Downlink OFDMA relay network.

II. System Model

A. Cellular Architecture

Consider a downlink OFDMA relay network consisting of I hexagonal cells, as shown in Fig. 1. Assume that each cell has a base station (BS) at its center which is connected to the central controller, J relays located symmetrically on a circle, and K users distributed uniformly in it. Assume that the total bandwidth is divided into N subchannels and the frequency reuse factor of the network is one.

Assume that an amplify-and-forward (AF) protocol is employed for cooperative relaying between the base station and the users, in which each base station transmits the signals to the users in two phases [1]. In the first phase, each base station broadcasts signals to the relays and the users. In the second phase, each relay amplifies and forwards the received signals to the users.

B. Channel Model and Received Signal

In this paper, the subchannel is the group of contiguous OFDM subcarriers over a time period [11]. Assume that a wireless channel is frequency-selective and the bandwidth of

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a subchannel is much smaller than the coherence bandwidth of the wireless channel so that each subchannel appears frequency-flat [12].

Let $H_{\mathrm{U}_{k,i}}^{\mathrm{B}_i,(n)}$, $H_{\mathrm{R}_{j,i}}^{\mathrm{B}_i,(n)}$, and $H_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}$ denote the channel coefficients on the subchannel n from the base station (B_i) to the user k in the cell i ($\mathrm{U}_{k,i}$), from B_i to the relay j in the cell i ($\mathrm{R}_{j,i}$), and from $\mathrm{R}_{j,i}$ to $\mathrm{U}_{k,i}$, respectively.

In the first phase, each base station transmits the signals to the relays and the users, the received signal at $\mathrm{R}_{j,i}$ on the subchannel n is given by

$$y_{1,\mathrm{R}_{j,i}}^{(n)} = H_{\mathrm{R}_{j,i}}^{\mathrm{B}_i,(n)} \sqrt{P_{\mathrm{B}_i}^{(n)}} x_{\mathrm{B}_i}^{(n)} + \Gamma_{1,\mathrm{R}_{j,i}}^{(n)} + n_{1,\mathrm{R}_{j,i}}^{(n)} \tag{1}$$

where $P_{\mathrm{B}_i}^{(n)}$ is the transmit power of B_i, $x_{\mathrm{B}_i}^{(n)}$ is the transmit signal from B_i, $\Gamma_{1,\mathrm{R}_{j,i}}^{(n)}$ is the interference at $\mathrm{R}_{j,i}$, and $n_{1,\mathrm{R}_{j,i}}^{(n)}$ is the complex Gaussian noise at $\mathrm{R}_{j,i}$ on the subchannel n. The received signal at $\mathrm{U}_{k,i}$ on the subchannel n is given by

$$y_{1,\mathrm{U}_{k,i}}^{(n)} = H_{\mathrm{U}_{k,i}}^{\mathrm{B}_i,(n)} \sqrt{P_{\mathrm{B}_i}^{(n)}} x_{\mathrm{B}_i}^{(n)} + \Gamma_{1,\mathrm{U}_{k,i}}^{(n)} + n_{1,\mathrm{U}_{k,i}}^{(n)} \tag{2}$$

where $\Gamma_{1,\mathrm{U}_{k,i}}^{(n)}$ is the interference at $\mathrm{U}_{k,i}$ and $n_{1,\mathrm{U}_{k,i}}^{(n)}$ is the complex Gaussian noise at $\mathrm{U}_{k,i}$ on the subchannel n.

In the second phase, the relays amplify and forward the received signal to the users, the received signal at $\mathrm{U}_{k,i}$ on the subchannel n is given by

$$y_{2,\mathrm{U}_{k,i}}^{(n)} = H_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} \beta_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} y_{1,\mathrm{R}_{j,i}}^{(n)} + \Gamma_{2,\mathrm{U}_{k,i}}^{(n)} + n_{2,\mathrm{U}_{k,i}}^{(n)} \tag{3}$$

where $\beta_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} = \sqrt{P_{\mathrm{R}_{j,i}}^{(n)} / |y_{1,\mathrm{R}_{j,i}}^{(n)}|^2}$, $\Gamma_{2,\mathrm{U}_{k,i}}^{(n)}$ is the interference at $\mathrm{U}_{k,i}$, and $n_{2,\mathrm{U}_{k,i}}^{(n)}$ is the complex Gaussian noise at $\mathrm{U}_{k,i}$ on the subchannel n. $P_{\mathrm{R}_{j,i}}^{(n)}$ is the transmit power of $\mathrm{R}_{j,i}$ on the subchannel n. Suppose that the inter-cell interference is measured in the previous transmission.

If the subchannel n is allocated to $\mathrm{R}_{j,i}$ and $\mathrm{U}_{k,i}$, the achievable rate on the subchannel n is given by (4) , shown at the top of next page [2], where N_0 is the noise power spectral density and $\alpha_i^{(n)}$ is the subchannel restriction indicator for the interference coordination. The indicator $\alpha_i^{(n)}$ is 1 if the subchannel n is restricted to use within the cell i in the second phase and 0 otherwise. Let $\rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}$ denote the subchannel assignment indicator which is 1 if the subchannel n is assigned to $\mathrm{R}_{j,i}$ and $\mathrm{U}_{k,i}$, and 0 otherwise. Then, the achievable rate of $\mathrm{U}_{k,i}$ is given by

$$R_{\mathrm{U}_{k,i}} = \sum_{j=1}^{J} \sum_{n=1}^{N} \rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}. \tag{5}$$

The sum achievable rate of the network is given by

$$R = \sum_{i=1}^{I} \sum_{k=1}^{K} R_{\mathrm{U}_{k,i}}. \tag{6}$$

III. Proposed Algorithm

A. Problem Formulation

The resource allocation in this paper is based on the proportional fair algorithm [13]. Maximizing the sum log-rate of the network, the optimization problem is formulated as

$$U^* = \max_{\boldsymbol{\rho},\boldsymbol{\alpha}} \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} \log\left(R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}\right) \tag{7}$$

$$\text{subject to:} \quad \rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} \in \{0,1\}, \forall i,j,k,n \tag{8a}$$

$$\sum_{j=1}^{J} \sum_{k=1}^{K} \rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} = 1, \forall i,n \tag{8b}$$

$$\alpha_i^{(n)} \in \{0,1\}, \forall i,n \tag{8c}$$

where $\boldsymbol{\rho}$ is the subchannel assignment indicator vector with the elements $\rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}$ and $\boldsymbol{\alpha}$ is the subchannel restriction indicator vector with the elements $\alpha_i^{(n)}$.

(8a) and (8b) guarantee that a subchannel is exclusively allocated to one relay and one user in a cell. (8c) is about the subchannel restriction for interference coordination.

B. Proposed Interference Coordination Algorithm

In (7), the subchannel allocation and subchannel restriction are jointly considered. Due to prohibitive computational complexity to find an optimal solution for the problem, it is heuristically divided into two subproblems: the subchannel allocation for each cell and the subchannel restriction for the central controller [9]. Assume that the equal power is allocated to each subchannel.

The proposed algorithm consists of four steps as shown in Algorithm 1 in which $\mathcal{I}$ is the set of cells, and $\mathcal{J}_i$, $\mathcal{K}_i$, and $\mathcal{N}_i$ are the sets of relays, users, and subchannels in the cell i, respectively. In the first step, all sets and variables are initialized. Each base station receives the channel state information, including the information from the first and second dominant interfering cells, from the users. In the second step, subchannels in $\mathcal{N}_i$ are allocated to relays in $\mathcal{J}_i$ and users in $\mathcal{K}_i$ in the cell i, $i = 1, \cdots, I$, based on the proportional fair algorithm. The subchannel n is allocated to the relay and user such that $(j^*, k^*) = \arg\max_{j,k} R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} / \bar{R}_{\mathrm{U}_{k,i}}$ where $\overline{R}_{\mathrm{U}_{k,i}}$ is the average rate for $\mathrm{U}_{k,i}$ which is updated at time t as [14]

$$\overline{R}_{\mathrm{U}_{k,i}}(t) = \left(1 - \frac{1}{T_p}\right) \overline{R}_{\mathrm{U}_{k,i}}(t-1) + \frac{1}{T_p} \sum_{n=1}^{N} \rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{k,i}} R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} \tag{9}$$

where T_p is the averaging window size.

In the third step, each cell obtains the subchannel restriction indicator for inter-cell interference coordination. Let λ_i denote the i-th dominant interfering cell which is determined by the interference power. Then, if

$$\frac{R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1\}}^{\mathrm{R}_{j,i},(n)}}{R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}} > R_{\mathrm{TH},1} \tag{10}$$

$$R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}=\frac{1}{2}\log_2\left\{1+\frac{|H_{\mathrm{U}_{k,i}}^{\mathrm{B}_i,(n)}|^2P_{\mathrm{B}_i}^{(n)}}{|\Gamma_{1,\mathrm{U}_{k,i}}^{(n)}|^2+N_0}+\left(1-\alpha_i^{(n)}\right)\times\frac{\frac{|H_{\mathrm{R}_{j,i}}^{\mathrm{B}_i,(n)}|^2P_{\mathrm{B}_i}^{(n)}}{|\Gamma_{1,\mathrm{R}_{j,i}}^{(n)}|^2+N_0}\times\frac{|H_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}|^2P_{\mathrm{R}_{j,i}}^{(n)}}{|\Gamma_{2,\mathrm{U}_{k,i}}^{(n)}|^2+N_0}}{1+\frac{|H_{\mathrm{R}_{j,i}}^{\mathrm{B}_i,(n)}|^2P_{\mathrm{B}_i}^{(n)}}{|\Gamma_{1,\mathrm{R}_{j,i}}^{(n)}|^2+N_0}+\frac{|H_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}|^2P_{\mathrm{R}_{j,i}}^{(n)}}{|\Gamma_{2,\mathrm{U}_{k,i}}^{(n)}|^2+N_0}}\right\} \tag{4}$$

Algorithm 1: Proposed interference coordination algorithm

Step 1

$\mathcal{I}=\{1,\ldots,I\}$, $\mathcal{J}_i=\{1,\ldots,J\}$, $\mathcal{K}_i=\{1,\ldots,K\}$, $\mathcal{N}_i=\{1,\ldots,N\}$, $\rho_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}=0$, $\alpha_i^{(n)}=0$, $\forall i,j,k,n$;

Step 2

for $i=1:I$ **do**

  while $\mathcal{N}_i\neq\emptyset$ **do**

    $(j^*,k^*,n^*)=\arg\max_{j,k,n}\frac{R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}}{\bar{R}_{\mathrm{U}_{k,i}}}$, $j\in\mathcal{J}_i$, $k\in\mathcal{K}_i, n\in\mathcal{N}_i$;

    $\rho_{\mathrm{U}_{k^*,i}}^{\mathrm{R}_{j^*,i},(n^*)}=1$, $\mathcal{N}_i=\mathcal{N}_i-\{n^*\}$;

Step 3

for $i=1:I$ **do**

  for $k=1:K$ **do**

    if $\frac{R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1\}}^{\mathrm{R}_{j,i},(n)}}{R_{\mathrm{U}_{k,i}|\Lambda=\phi}^{\mathrm{R}_{j,i},(n)}}>R_{\mathrm{TH},1}$ **then** $\alpha_{\lambda_1}^{(n)}=1$;

    if $\frac{R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1,\lambda_2\}}^{\mathrm{R}_{j,i},(n)}}{R_{\mathrm{U}_{k,i}|\Lambda=\phi}^{\mathrm{R}_{j,i},(n)}}>R_{\mathrm{TH},2}$ **then** $\alpha_{\lambda_1}^{(n)}=1$, $\alpha_{\lambda_2}^{(n)}=1$;

Step 4

for $n=1:N$ **do**

  for $i,i'\in\Phi$ **do**

    $Z^*=\max\left\{\frac{R_{\mathrm{U}_{k(i,n),i}|\Lambda=\{i'\}}^{\mathrm{R}_{j(i,n),i},(n)}}{\bar{R}_{\mathrm{U}_{k(i,n),i}}}+\frac{R_{\mathrm{U}_{k(i',n),i'}|\Lambda=\{i\}}^{\mathrm{R}_{j(i',n),i'},(n)}}{\bar{R}_{\mathrm{U}_{k(i',n),i'}}}\right\}$;

update $\overline{R}_{\mathrm{U}_{k,i}}$ $\forall i,k$;

where $R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1\}}^{\mathrm{R}_{j,i},(n)}$ is the achievable rate given that the subchannel n is not used within λ_1 in the second phase and $R_{\mathrm{TH},1}$ is the predetermined threshold, then the restriction on the subchannel n is requested to λ_1 so that $\alpha_{\lambda_1}^{(n)}=1$. Similarly, if

$$\frac{R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1,\lambda_2\}}^{\mathrm{R}_{j,i},(n)}}{R_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}}>R_{\mathrm{TH},2} \tag{11}$$

where $R_{\mathrm{U}_{k,i}|\Lambda=\{\lambda_1,\lambda_2\}}^{\mathrm{R}_{j,i},(n)}$ is the achievable rate given that the subchannel n is not used within λ_1 and λ_2 in the second phase and $R_{\mathrm{TH},2}$ is the other predetermined threshold, then the restrictions on the subchannel n are requested to λ_1 and λ_2 so that $\alpha_{\lambda_1}^{(n)}=1$ and $\alpha_{\lambda_2}^{(n)}=1$. Each base station forwards its results to the central controller.

In the fourth step, the problem of collision between restriction requests from multiple cells is managed by the central controller. Let Φ denote the set of the cells which bring the problems of collision between restriction requests. Then, the optimization problem to avoid collision is formulated as

$$Z^*=\sum_{i,i'\in\Phi}\max\left\{\frac{R_{\mathrm{U}_{k(i,n),i}|\Lambda=\{i'\}}^{\mathrm{R}_{j(i,n),i},(n)}}{\bar{R}_{\mathrm{U}_{k(i,n),i}}}+\frac{R_{\mathrm{U}_{k(i',n),i'}|\Lambda=\{i\}}^{\mathrm{R}_{j(i',n),i'},(n)}}{\bar{R}_{\mathrm{U}_{k(i',n),i'}}}\right\} \tag{12}$$

$$\text{subject to:}\quad \alpha_i^{(n)}+\alpha_{i'}^{(n)}\leq 1,\forall n \tag{13a}$$

$$\alpha_i^{(n)}\in\{0,1\},\forall i,n \tag{13b}$$

where $j(i,n)$ and $k(i,n)$ are the relay and user which are assigned to the subchannel n in the cell i.

After the optimization problem is solved for each subchannel, its results are forwarded to all base stations.

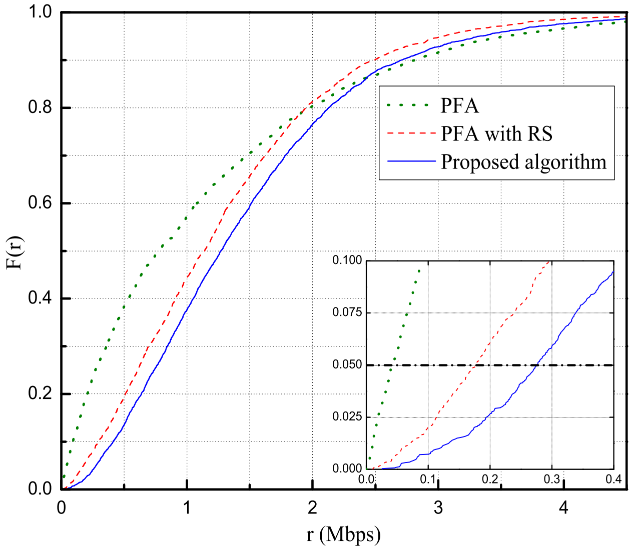
TABLE I
SIMULATION PARAMETERS

Inter-site distance	500 m
BS-relay distance	0.65×cell radius
Minimum distance between BS and user	30 m
BS transmit antenna gain	15 dB
Relay transmit antenna gain	10 dB
Receive antenna gain	0 dB
Shadowing σ for LOS	4 dB
Shadowing σ for NLOS	8 dB
Rician factor	10 dB
Carrier frequency	2 GHz
Total bandwidth	10 MHz
Number of subchannels	64
User mobility	30 km/hr
LOS link maximum Doppler spread	4 Hz
OFDM symbol duration	102.86 μs
Noise power spectral density	-174 dBm/Hz
BS total transmit power	46 dBm
Relay total transmit power	37 dBm
PF averaging window size	5
Traffic model	Full buffer

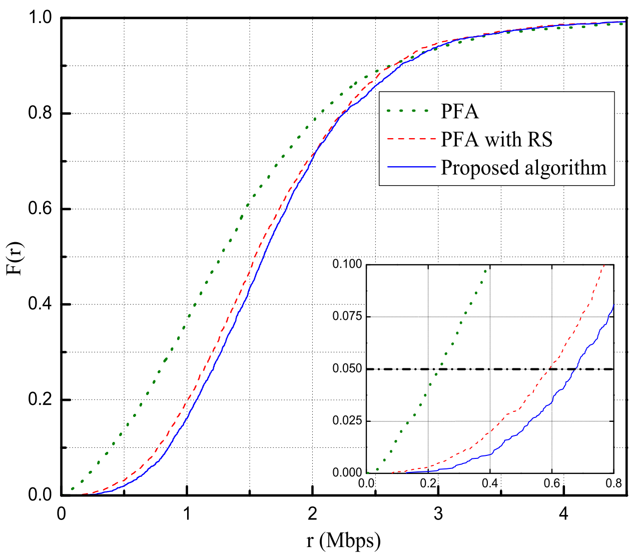
IV. SIMULATION RESULTS

Consider a downlink OFDMA relay network consisting of 19 hexagonal cells. Assume that the base station is located at the center and J relays are symmetrically located on a circle and K users are uniformly distributed in each cell.

Suppose that the path-loss of the COST 231 Walfisch-Ikegami model is adopted for (BS-relay) LOS links and the path-loss of the modified COST 231 Hata urban propagation model is adopted for other links. Suppose that the fading



(a) $J = 3$ and $K = 15$



(b) $J = 6$ and $K = 15$

Fig. 2. CDF of average user throughput and its lower tail.

channel of the 3GPP urban macro spatial channel model is adopted [15]. The simulation parameters are shown in Table I. The 5th percentile user throughput is used as the performance metric of the cell edge user as in LTE performance evaluation [16]. The performance of the proposed algorithm is compared with those of the proportional fair algorithm (PFA) and the PFA with relay selection (RS).

A. Cell Edge User Throughput

Fig. 2 shows the CDF of average user throughput. Fig. 2 (a) illustrates the CDF and its lower tail for $J = 3$ and $K = 15$. It is shown that the proposed algorithm achieves higher 5th percentile user throughput than both of the PFA and the PFA with RS. Fig. 2 (b) illustrates the CDF and its lower tail for $J = 6$ and $K = 15$. It is shown that the proposed algorithm achieves higher 5th percentile user throughput than both of the PFA and the PFA with RS.

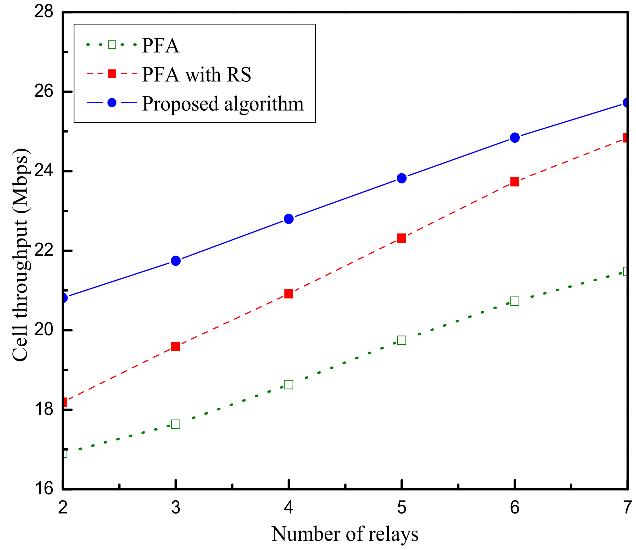


Fig. 3. Cell throughput versus number of relays per cell. $K = 15$.

B. Cell Throughput

Fig. 3 shows the cell throughput versus the number of relays per cell for $K = 15$. It is shown that the cell throughput of the proposed algorithm increases as the number of relays increases. The resource allocation problem is divided into subchannel allocation and subchannel restriction for inter-cell interference coordination. It is also shown that the proposed algorithm achieves higher cell throughput than both of the PFA and the PFA with RS.

V. Conclusion

In this paper, we propose an inter-cell interference coordination algorithm for a downlink OFDMA relay network with multicells. By computer simulation, it is shown that the proposed algorithm achieves higher cell edge user throughput and cell throughput than proportional fair algorithm with and without relay selection.

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