A Novel User Pairing Algorithm for LTE Femtocell Uplink

Jie Wang, Chen Xu
National Mobile Communications Research Laboratory, Southeast University, China
Email: wangjie@seu.edu.cn

***Abstract*—This paper considers the user pairing algorithm for LTE (Long Term Evolution) femtocell uplink V-MIMO (Virtual Multiple Input Multiple Output) Systems, and propose a new simulated annealing based bit error rate pairing scheduling (SA-BPS) algorithm. The SA-BPS uses Round Robin (RR) criterion to decide the first user, and simulated annealing (SA) algorithm with objective function of bit error rate (BER) is suggested to decide the pairing users. Simulation results show that the proposed SA-BPS algorithm outperforms the conventional SA algorithm in terms of BER performance. Moreover, as a growth control coefficient is used to control the growth of average BER of users in the pairing group, rapid user BER deterioration can be prevented by adopting a proper coefficient .**

***Index Terms*– User Pairing; Femtocell; Simulated Annealing; V-MIMO; Bit Error Rate**

I. INTRODUCTION

As the performance of V-MIMO (Virtual Multiple Input Multiple Output) system is constrained by the presence of inter-user interference, it can be enhanced by user pairing so that minimal inter-user interference can be achieved. Several user pairing strategies have been declared in [1]-[6], such as Random Pairing Scheduling (RPS), Determinant Pairing Scheduling (DPS) and Capacity Pairing Scheduling (CPS). RPS achieves low computation complexity while inter-user interference can hardly be cancelled. DPS selects pairing users according to their channel conditions, while satisfying performance can only be achieved under ideal uplink power control assumption. CPS achieves better system performs, yet its complexity rises rapidly with the increase of the number of users.

A promising user pairing strategy based on simulated annealing (SA) has been proposed in [7]. With the memory of the last transmit antenna selection step, this SA pairing algorithm can easily find the asymptotical optimal pairing user group, which achieves almost the same system performance as the greedy algorithm. However, when used in LTE femtocell, the bit error rate (BER) performance of SA pairing algorithm becomes to deteriorate, since the distance of receive antenna is limited by the mechanical size of femtocell, which raises channel correlation. As far as concerned, literatures specifically concerning user pairing algorithms of femtocell case has been rarely reported.

In this paper, a SA based BER pairing scheduling (SA-BPS) algorithm is proposed. This SA-BPS algorithm combines SA algorithm with objective function of BER. Simulation results show that, in LTE femtocell case, the proposed SA-BPS algorithm outperforms the conventional SA algorithm in terms of BER performance. Moreover, as a growth control coefficient is used to control the growth of average BER of users in the pairing group, rapid user BER deterioration can be prevented by adopting a proper coefficient .

The rest of the paper is organized as follows. In Section II, the system model is considered. Section III describes the SA-BPS algorithm. Simulation results are presented in Section IV. Finally, Section V concludes the paper.

II. SYSTEM MODEL

The LTE femtocell uplink V-MIMO system has N_R receive antennas at HeNB (Home eNodeB or femtocell) and a single transmit antenna at each UE, We consider the $N_T \times N_R$ MIMO case, where N_T stands for the number of users in the pairing group, while the pairing strategy will be discussed in the next Section. The transmitter and receiver models of the femtocell system under consideration are shown in Fig. 1 and Fig. 2, respectively.

On the transmitter side, the data block of each UE containing M symbols is transformed by an M point Fast Fourier Transform (FFT) to a frequency domain form before mapping to N (N>M) orthogonal subcarriers. Then the outputs are put to an N point Inverse FFT (IFFT) module to transform to time domain complex signal sequences.

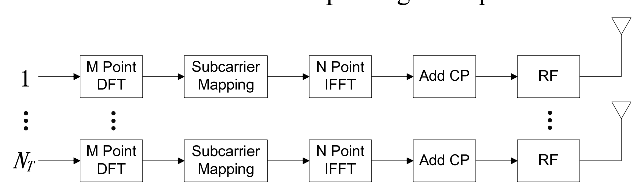

Fig. 1 MIMO transmitter on UE side

Two different approaches are available for mapping subcarriers, namely localized mapping and distributed mapping. In this paper, only the localized FDMA transmission is considered. After Circle Prefix (CP) insertion, the signal sequences are directed to the Radio Frequency (RF) module. In the channel, noise and interference are attached to the signals. On the receiver side, after signal sequences are get from the RF module, the CP will be removed first. Then an N FFT will be applied to transform the signal sequences into frequency domain sequences. After subcarrier demapping, M symbols will be send to the MMSE Detector[8]. The symbol on the mth ($m \in \{1, \cdots M\}$) subcarriers can be expressed as

$$\boldsymbol{r}[m] = \boldsymbol{H}[m]\boldsymbol{s}[m] + \boldsymbol{w}[m] \tag{1}$$

where

$$\boldsymbol{H}[m] = \begin{bmatrix} H_{11}[m] & H_{21}[m] & \cdots & H_{N_T1}[m] \\ H_{12}[m] & H_{22}[m] & \cdots & H_{N_T2}[m] \\ \cdots & \cdots & \cdots & \cdots \\ H_{1N_R}[m] & H_{2N_R}[m] & \cdots & H_{N_TN_R}[m] \end{bmatrix} \quad (2)$$

is the frequency domain channel matrix on the mth subcarrier, where $H_{tr}[m]\ (1 \le t \le N_T, 1 \le r \le N_R)$ donates the frequency domain channel gain between the tth UE antenna in the pairing group and the rth receive antenna on the mth subcarrier; $\boldsymbol{s}[m] = [s_1[m] s_2[m] \cdots s_{N_T}[m]]^{\mathcal{T}}$ donates the frequency domain data, on the mth subcarrier, of the N_T users in the pairing group; $\boldsymbol{w}[m] = [w_1[m]\, w_2[m] \cdots w_{N_R}[m]]^{\mathcal{T}} \in \mathbb{C}^{N_R \times 1}$ is a complex Gaussian noise vector with zero mean and covariance matrix $N_0\boldsymbol{I} \in \mathbb{R}^{N_R \times N_R}$, i.e., $\boldsymbol{w}[m] \sim \mathcal{CN}(0, N_0\boldsymbol{I})$; $\boldsymbol{r}[m] = [r_1[m]\, r_2[m] \cdots r_{N_R}[m]]^{\mathcal{T}}$ donates the frequency domain received symbol on the mth subcarrier on the N_R receive antennas.

After frequency domain received data sequences pass through the MMSE detector, the estimated frequency domain data sequence of the N_T users in the pairing group can be obtained. According to MMSE criterion [9], the estimated frequency domain data sequence of on the mth subcarrier $\hat{\boldsymbol{s}}[m]$ is given by

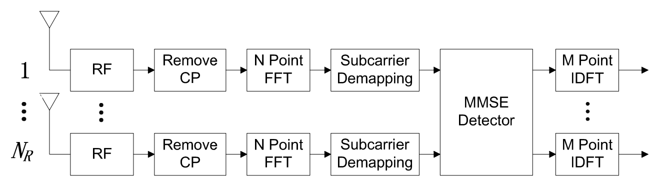

Fig. 2 MIMO receiver on HeNB side

$$\hat{\boldsymbol{s}}[m] = \boldsymbol{A}[m]\boldsymbol{r}[m] \quad (3)$$

where

$$\boldsymbol{A}[m] = \boldsymbol{H}^{\mathcal{H}}[m]\left(\boldsymbol{H}[m]\boldsymbol{H}^{\mathcal{H}}[m] + N_0\boldsymbol{I}\right)^{-1} \quad (4)$$

is the equalization matrix on the mth subcarrier.

III. SA-BPS ALGORITHM

To study the pairing algorithm, we consider the femtocell uplink V-MIMO system, where HeNB, configured N_R receive antennas, serves N_0 users, each equipped with a single transmit antenna. N_T ($N_T \le N_0$) transmit antennas are selected to form a pairing group, where N_T is defined by the pairing strategy. All the N_T transmit antennas transmit independent signals on the same time-frequency blocks.

In this section we concentrate on the proposed SA-BPS algorithm. This pairing algorithm combines SA algorithm with objective function of BER. The method to select the optimal antennas to form the pairing group can be formulated as

$$\boldsymbol{Q} = \arg \min_{\boldsymbol{Q} \in \mathfrak{B}_{N_0}} \Delta\overline{BER} = \arg \min_{\boldsymbol{Q} \in \mathfrak{B}_{N_0}} \sum_{n=1}^{N_0} q_n \Delta\overline{BER_n} \quad (5)$$

on condition that

$$\sum_{n=1}^{N_0} q_n \le N_R\,, q_n \in \{0,1\} \quad (6)$$

and

$$\eta(i) \le \eta_c \quad (7)$$

where, $\boldsymbol{Q}$ donates a $N \times 1$ pairing indication vector with the nth element q_n defined as: $q_n = 1$ if the nth antenna is selected to join in the pairing group, otherwise, $q_n = 0$; $\mathfrak{B}_{N_0}$ donates the set of all possible pairing indication vector; η_c, the growth control coefficient of BER, is constant that can adopt different value so as to restrict the growth rate of average BER of users in the pairing group properly; $\Delta\overline{BER}$ is the variation of average BER during the whole pairing procedure, which can be expressed as

$$\Delta\overline{BER} = \sum_{i=2}^{N_T} \Delta\overline{BER(i)} \quad (8)$$

where, N_T is the number of antennas in the pairing group after the pairing procedure is done; $\Delta\overline{BER(i)}$ donates the variation of the average BER of the users in the pairing group after the ith pairing step, as is described is equation (9); $\eta(i)$ donates the growth rate of the average BER of the users in the pairing group after the ith pairing step, in respect to the average BER in the i-1th pairing step, as is given by equation (10).

$$\Delta\overline{BER(i)} = \overline{BER(i)} - \overline{BER(i-1)} \quad (9)$$

$$\eta(i) = \frac{\Delta\overline{BER(i)}}{\overline{BER(i-1)}} \quad (10)$$

where, $\overline{BER(i)}$ is the average BER of the users in the pairing group after the ith pairing step, given by

$$\overline{BER(i)} = \frac{1}{i}\sum_{j=1}^{i} BER_{n_j}(i) \quad (11)$$

where, $BER_{n_j}(i)$ donates the BER ofthe jth user from the i users in the pairing group after the ith pairing step [10], which can be expressed as

$$BER_{n_j}(i) = \frac{N_{min}}{\log_2 M_0} \mathcal{Q}\left(\sqrt{\xi \cdot SINR_{\mathrm{n}_j} \cdot G_c}\right) \quad (12)$$

where N_{min} donates the average number of nearest neighbors of a constellation point of the modulation alphabet; M_0 donates the size of the modulation alphabet; $\mathcal{Q}()$ donates Q function, which is defined as $\mathcal{Q}(\alpha) = \int_\alpha^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz$; the coefficient ξ is defined as $\xi = 3/[R(M_0 - 1)]$, where R is the channel coding rate; G_c is the gain of channel code. $SINR_{\mathrm{n}_j}$, the unbiased SINR (Signal to interference plus Noise Ratio) of the jth pairing user, is obtained by

$$SINR_{\mathrm{n}_j} = \frac{\sigma^2_{a_{n_j}}}{\sigma^2_{e_{n_j}}} - 1 \quad (13)$$

where $\sigma^2_{a_{n_j}}$ is the variance of the signal of the jth pairing user; $\sigma^2_{e_{n_j}}$, the error variance of the detected signal of the jth pairing user, is defined as

$$\sigma_{e_{n_j}}^2 = \frac{1}{M}\sum_{m=0}^{M-1} \Sigma_{n_j n_j}^2[m] \tag{14}$$

where M is the number of subcarriers; the intermedium variable $\Sigma_{n_j n_j}^2[m]\ (1 \le j \le i)$ is constrained by the following equation [11]:

$$\begin{bmatrix} \Sigma_{n_1 n_1}^2[m] & \Sigma_{n_1 n_2}^2[m] & \cdots & \Sigma_{n_1 n_i}^2[m] \\ \Sigma_{n_2 n_1}^2[m] & \Sigma_{n_2 n_2}^2[m] & \cdots & \Sigma_{n_2 n_i}^2[m] \\ \cdots & \cdots & \cdots & \cdots \\ \Sigma_{n_i n_1}^2[m] & \Sigma_{n_i n_2}^2[m] & \cdots & \Sigma_{n_i n_i}^2[m] \end{bmatrix} = \sigma_n^2 \left(\boldsymbol{H}^{\mathcal{H}}[m]\boldsymbol{H}[m] + \frac{\sigma_n^2}{\sigma_{a_{n_j}}^2}\boldsymbol{I}_i \right)^{-1} \tag{15}$$

where superscript $(\cdot)^{\mathcal{H}}$ denotes Hermitian transpose; σ_n^2 is the variance of noise; $\boldsymbol{I}_i$ donates the i dimension identity matrix; $\boldsymbol{H}[m]$, the frequency domain channel equation on *m*th subcarrier of the users in the pairing group after the *i*th pairing step, is written as

$$\boldsymbol{H}[m] = \begin{bmatrix} H_{n_1 1}[m] & H_{n_2 1}[m] & \cdots & H_{n_i 1}[m] \\ H_{n_1 2}[m] & H_{n_2 2}[m] & \cdots & H_{n_i 2}[m] \\ \cdots & \cdots & \cdots & \cdots \\ H_{n_1 N_R}[m] & H_{n_2 N_R}[m] & \cdots & H_{n_i N_R}[m] \end{bmatrix} \tag{16}$$

where $H_{n_j r}[m]\ (1 \le j \le i, 1 \le r \le N_R)$ donates the frequency domain channel gain between the *j*th pairing antenna and the *r*th receive antenna on the *m*th subcarrier.

The procedure of the proposed SA-BPS algorithm can be summarized as follow:

① The 1st pairing step: Choose the first transmit antenna to join in the pairing group, based on RR, from all N_0 users served by femtocell, by setting $q_{n_1} = 1$, where q_{n_1} is an element of the pairing indication vector $\boldsymbol{Q}(1)$ and n_1 denotes the index of the selected antenna.

② The *i*th ($i \ge 2$) pairing step: Select another transmit antenna to join in the pairing group on the basis of i-1th pairing step, by setting $q_{n_i} = 1$, thus to make $\Delta\overline{BER(i)}$ minimum, where q_{n_i} is an element of the pairing indication vector $\boldsymbol{Q}(i)$ and n_i denotes the index of the selected antenna.

③ Compare N_q with N_R, where N_q, the number of users already in the pairing group, is given by $N_q = \sum_{n=1}^{N} q_n = \sum_{j=1}^{i} q_{n_j}$. If $N_q < N_R$, execute ④,otherwise ⑤.

④ Compare $\eta(i)$ with η_c. If $\eta(i) \le \eta_c$, set i=i+1 and execute ② to continue the next pairing step, otherwise execute ⑤.

⑤ The pairing procedure is accomplished, and the pairing indication vector $\boldsymbol{Q}(i)$ is the optimal solution for the pairing problem under SA-BPS algorithm, and $N_T = i$ is the number of the chosen receive antennas. Thus, HeNB informs all the N_T users in the pairing group to transmit signals simultaneously at the begging of the next scheduling period.

IV. SIMULATION RESULTS

In this section, the performance of the proposed SA-BPS algorithm is presented by simulation results. A single femtocell scenario is considered, where one HeNB severs several users. The HeNB is configured with two antennas while each UE equips one antenna. The users in the pairing group form a V-MIMO system with HeNB. The overall simulation parameters [12] are shown in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	**Value**
Channel bandwidth	20MHz
Sampling rates	30.72MHz
Modulation	QPSK
Number of total sub-carrier	2048
Number of carrier for user	1200
Channel model	3GPP EPA channel 7 path
Maximum doppler frequency	6.67Hz
Subcarrier mapping	Localized mode
Channel codes	Turbo codes
Channel estimation	Perfect
BER growth control coefficient	0.1

Fig.3 shows the comparison of the BER performance of SA and SA-BPS algorithm. As is depicted in Fig.3, the proposed SA-BPS algorithm outperforms the conventional SA algorithm on BER under different signal to noise ratio (SNR) scenario. Fig.4 demonstrates that the BER gap between SA and SA-BPS algorithm will be widened, when the number of users in femtocell increases. Moreover, as a growth control coefficient is adopted in SA-BPS to control the growth of average BER of users in the pairing group, the gap will be even greater when the number of receive antenna doubles, which is not show in the figure.

V. CONCLUSION

In this paper, we propose a SA-BPS algorithm in the femtocell uplink Virtual-MIMO System. Compared with the conventional SA algorithm, the proposed pairing algorithm suits the femtocell case more properly, and achieves better BER performance. Besides, as a growth control coefficient is adopted by SA-BPS, rapid user BER deterioration can be prevented. The results can serve as plan for femtocell uplink user pairing scheduling.

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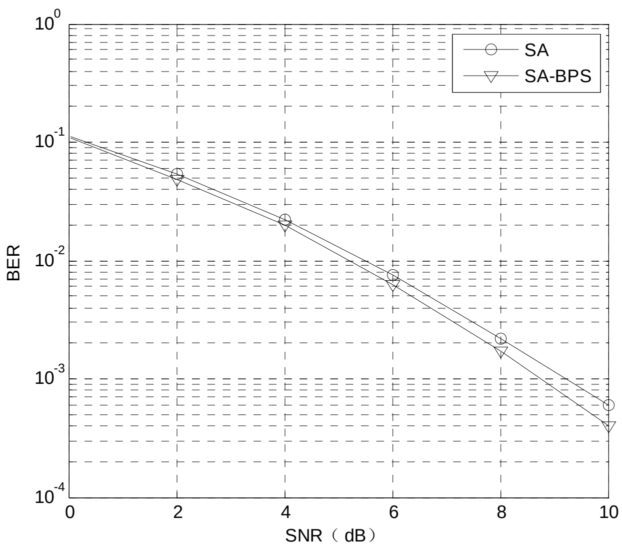

Fig.3 BER of SA and SA-BPS algorithm, N_0=4

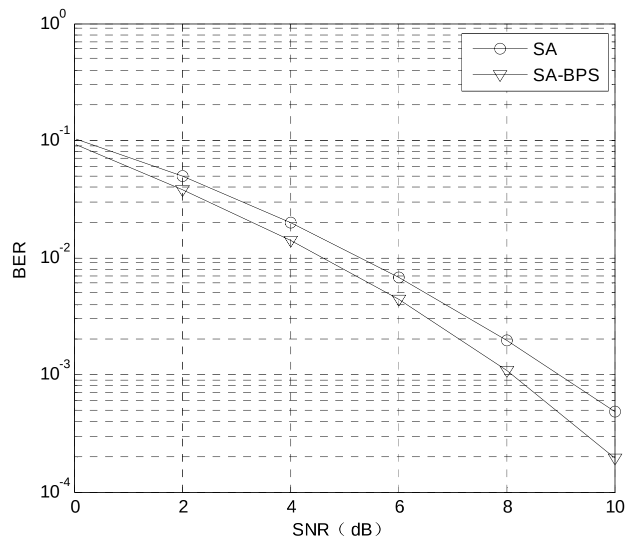

Fig.4 BER of SA and SA-BPS algorithm, N_0=8