Block diagonalization precoding and power allocation for clustering small-cell networks

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ABSTRACT

The clustering network is a solution to improve data-rate transmission in small-cells. In this case, clustering small-cells (CSCs) adopt a multiple antennas concept. The multiple antennas are used to maximize the downlink data-rate transmission at the users, but it requires precoding techniques to minimize interference among CSC users. This paper proposes a block diagonalization (BD) as a precoding technique for minimizing interference among CSC users. The performance of the BD precoding implemented on the clustering network under various numbers of small-cells. The CSC also implements a water-filling power allocation (PA-CoopWF) to distribute the available transmission power along with the CSCs antennas. To show the performance, our paper simulates two types of precoding techniques; those are the proposed BD and minimum mean square error (MMSE) in CSCs. Based on the receiver user parts under the overlapping coordination of CSCs, our method based on the BD precoding achieves considerably higher data-rate transmission compared to the MMSE precoding, especially on larger clusters. The simulation also shows that by implementing CSC with the BD in short-range distances and higher numbers of antennas, it promotes better data-rate performances compared to the MMSE precoding by 2.75 times at distance 100m and 67% at 50 antennas.

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1. INTRODUCTION

The implementation of small-cells is one of the effective solutions to improve data-rate in cellular networks [1]. Small-cells are also a solution to extend cellular coverage. Small-cells are commonly installed in urban or indoor building areas, so small-cells access-point is connected via cable backhaul to the gateway. In [2], the authors propose an architecture of small-cells based resource allocation for wireless backhaul in two-tier heterogeneous networks. The authors only focus on the backhaul transmission on the clustered small-cells. Small-cells are also allowed to exchange their channel state information (CSI) over the gateway [3, 4]. Therefore, the architecture of small-cells enables easy implementation of a clustering network. There are some researchs in clustering focused on the small-cells network [5, 6]. The main concept of clustering networks is that some cells in a network coordinates each other [7]. This method manages coordination information for improving the performance of communication [8]. Clustered small-cells is one of the solutions in order to improve the data-rate, particularly for the user in the cell edge, which has interference effect from the neighbor small-cells [9, 10]. The coordination method is one of the key technologies to improve the data-rate of cell-edge users [11]. The interference problem is exploited or mitigated by the coordination method between small-cells [12]. The coordination method improves the efficiency of radio resources as well as satisfying the requirements of high data-rate, improve spectral and energy efficiency [13-15].

One of the solutions to improve data-rate in a network is by employing multiple-input and output (MIMO) concepts. MIMO concepts manage the frequency-time resources from transmitters to receivers [16]. On the other hand, interference problems appear in this multi-user MIMO concept. Therefore, a precoding technique is a scheme to guarantee orthogonality across parallel channels and suppress interference before the transmission signal. There are some techniques for employing precoding techniques, namely linear and non-linear. A linear precoding is described by standalone matrix, for example, zero-forcing (ZF) [17, 18] and minimum mean square error (MMSE) [19, 20]. The benefit of the linear precoding is the low complexity in computations. In [21], the authors proposed a multi-user MIMO precoding technique in order to reduce the negative impact of co-tier interference in the heterogeneous network. In [22], the authors investigated a network of small-cells where the BSs were ready to form multiple clusters and coordinate to maximize the overall sum-rate. The authors used a multi-user multiple antennas precoding based zero-forcing beamforming (ZFBF) schemes. However, ZF and MMSE precodings are restricted only with one of the receiver antennas. The antenna receiver cannot manage interference itself and only receive one spatial channel. In this case, the transmitter must perform precodings in order to suppress the inter-user interference. In [23], the authors proposed a regularized channel inversion (CI) precoding technique to enhance the sum-rate assuming only single-antenna users are available in the system. In [24], the authors proposed a novel of cooperative block diagonalization (BD) precoding to eliminate inter-user interference users under the error model on the CSI. Therefore, the BD precoding is a great solution to be implemented in the clustering and multi-user systems.

This paper proposes clustering small-cells (CSCs) using the BD precoding in order to manage interference between the users in order to improve the data transmission rate of the networks. This paper also investigates the impact of the additional number of antennas and the increment of distance between the CSCs and the users on the performance. Moreover, the effect of changing the number of antennas is also analyzed. This research assumes that CSCs use different channels with BS; therefore, there is no interference between small-cells and BS users. In order to show the performance, our proposed algorithm is compared with other linear precoding, MMSE techniques [25]. The rest of the paper is organized as follows: In section 2, we describe the system model. Section 3 investigates our proposed method that is the interference mitigation and the power allocation method. Section 4 explains the result and discussion of the simulations. Finally, section 5 explains the conclusion of this paper.

2. SYSTEM MODEL

In this paper, we consider a various number of CSCs in a network as an example shown in Figure 1. This paper investigates massive small-cells using transmit antennas N_t and u_j user equipments (UEs) with the number of users $j = 1...N$, and receiver antennas having N_r. In this case, each transmitter N_t is equipped with two antennas and each receiver N_r is also equipped with two antennas, and also the number of CSCs is with three small-cells. The users are randomly located at the cell edge zone and within the overlapping of the neighbor cells. This system assumes that each small-cells has the same frequency. The rest of the main simulation parameters are shown in Table 1

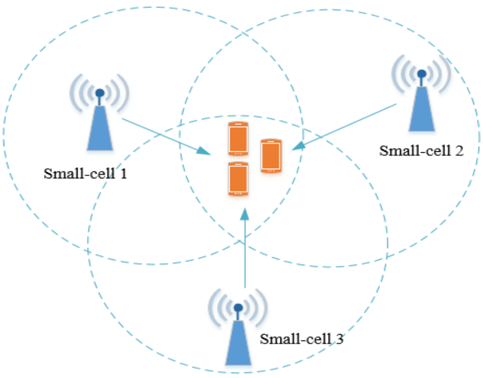

Figure 1. Clustering small-cells with coordination method

Table 1. Simulation parameters

Parameter	Value
Carrier frequency	2 GHz
System bandwidth	5 MHz
Transmission Power	23 dBm
Noise Spectral density	-174 dBm/Hz
No. of antenna each SC	2 antennas
No. of antenna each user	2 antennas
Pathloss model	ITU indoor
Antenna pattern	Omni directional

3. PROPOSED METHOD

This paper proposes CSC in order to improve the data-rate of the user in the cell edge. This scheme mitigates the inter small-cells interference because the coordination in CSC facilitates a sharing of channel feedback between the small-cells over a gateway. As illustrated in Figure 2, the proposed algorithm is performed in three stages, each associated with exchanging the coordination request, coordination response, the last stage is a sending the channel feedback and transmission of the data.

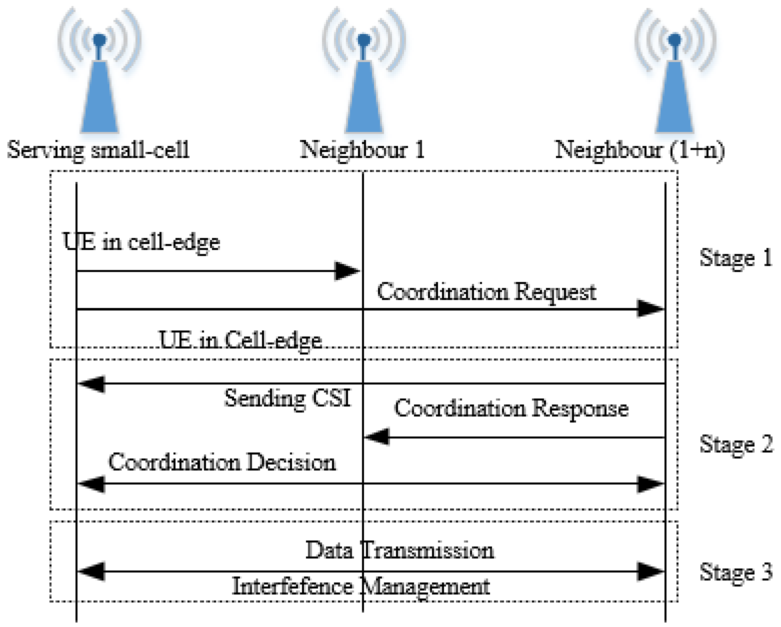

Figure 2. Stage of coordination methods of clustering small-cells, contain serving and neighbor small-cells

- Stage 1, this stage is a coordination REQUEST that user u_j is monitored at the cell edge of serving small-cells. The user u_j uses the channel gain H without considering the quality of the channels; therefore, there is inter-cell interference between small-cells and neighboring small-cells. If the serving small-cells increase the transmission power, the SNR of the cell edge user u_j might be lost.
- Stage 2, in this stage, the method of CSCs coordinates their neighbors for making CSCs. First, we calculate the number of CSCs antennas. The equation is formulated by $N_t = \sum_{i=1}^{C} n_{t,i}$ where the number of CSCs containing serving and neighbor small-cells is C. Second, the total number of receiver antennas u_j is calculated by $N_r = \sum_{i=1}^{C} n_{r,u_j}$. Therefore, the channel matrix to receiver user u_j is given by $H_{u_j} = \left[H_{u_j}^1 \dots \ H_{u_j}^C\right]$. Third, the channel matrix of the multiple antennas for user u_j given by $H_{u_j} = \left[H_{u_1}^H \dots \ H_N^H\right]^H$ where H superscript with $i = 1 \cdots N$ is the conjugate transpose of a channel matrix. And last, the channel matrix at the user u_j is calculated by

$$y_{u_j} = \sum_{i=1}^{C} H_{u_j}^i w_{u_j}^i u_{u_j}^i + \sum_{i=1}^{C} H_{u_j}^i \sum_{u_n \neq u_j} w_{u_n}^i u_{u_n}^i + n_{u_j} \tag{1}$$

$H_{u_j}^i$ is the channel matrix from small-cells i to user u_j, $\sum_{u_n \neq u_j} w_{u_n}^i u_{u_n}^i$ represents the inter small-cells interference experienced by user u_j , $w_{u_n}^i$ is explained in the next section, and n_{u_j} is complex gaussian noise entries with zero-mean and variances σ_n^2. The interference between small-cells may lose its diversity gain and the precoding technique manages inter small-cells interference nulling for CSCs. Therefore, the objective of this clustering RESPONSE step is to ensure that the interference CSCs are optimally managed. This step is used to find $Si\dots N$ from the neighboring serving small-cells. S is the serving small-cell and N is the number of neighbor small-cells. Neigbour small-cells are used for clustering if all off them can reach to the cell edge user. Then, the CSC is generated with $C = Si \ldots N$. To manage this step, CSI is informed to the gateway of small-cell networks. Therefore, all access-points small-cells exchange information to each other and make DECISION.

- Stage 3, this stage is used to manage the data transmission rate of cell-edge users. The data transmission rate of the user in the cell-edge is managed without reducing the quality of the CSCs. Inter user interference management is performed by employing a BD precoding technique and it is described in the next section.

3.1. Interference management

In this section, the proposed scheme implements the BD precoding in CSCs. Strengthening the earlier statement, the BD precoding is used for mitigating inter-user interference in CSCs. The SNR for the user u_j with the BD precoding under perfect CSI is as follow:

$$y_{u_j} = \sum_{i=1}^{C} H_{u_j}^i w_{u_j}^i u_{u_j}^i + n_{u_j} \quad \textit{for all } j \neq n \tag{2}$$

In order to obtain $w_{u_j}^i$, at the first, we must define $H_{u_j}^i$ from

$$H_{u_j}^* = \left[\left(H_1\right)^H \ldots \left(H_{u_j-1}\right)^H \left(H_{u_j+1}\right)^H \ldots \left(H_N\right)^H \right]^H \tag{3}$$

and singular value decomposition (SVD) to decompose the channel matrix into parallel non interference spatial layers. The channel matrix is calculated by

$$SVD[H_{u_j}^*] = U_{u_j}^* \left[V_{m,u_j}^* \quad 0 \right] \left[S_{u_j}^{*(1)} \quad S_{u_j}^{*(0)} \right]^H \tag{4}$$

V_{m,u_j}^* is a diagonal matrix with non-zero elements devote sub-channel's gain. $S_{u_j}^{*(1)}$ and $S_{u_j}^{*(0)}$ are composed of vectors that are corresponding to zero singular and non-zero singular values. Thus signals from other users are not received.

3.2. Power allocation

In this paper, we use a power allocation (PA) using coordination water-filling (CoopWF) [26]. PA-CoopWF is a technique used to distribute the total available power along with the various antennas based on the SNR distributions. The PA-CoopWA gains a better performance for the coordination channel compared with the equal power for small-cells. The PA-CoopWF is calculated as follows:

$$P_{u_j} = \mu - \frac{\sigma^2}{Lu_j} = \frac{1}{N}\left\{ P_c + \sum_{u_j=1}^{N} \frac{\sigma^2}{Lu_j} \right\} - \frac{\sigma^2}{Lu_j} \tag{5}$$

P_c is coordination power CSCs and Lu_j is path-loss propagation for user u_j. Finally, the formula to get the data-rate R_{u_j} for the user u_j using the PA-CoopWF is as follows:

$$R_{u_j} = \sum_{u_j=1}^{N} B \log_2 \left[1 + \frac{P_{u_j} H_{u_j}^*}{\sigma^2} \right] \tag{6}$$

4. RESULTS AND DISCUSSION

This section describes the simulation results of the proposed methods and compared it to the previous works. Figure 3 shows that the performance of proposed methods is slightly better almost 10 Mbps compared to MMSE investigated in single small-cells of each SNR target. The simulation also investigated a number of CSCs in each SNR target. As an example, the CSCs with N_t=4, 6, and 8 antennas, our proposed scheme improves sum-rate about 10%, 21%, and 40% compared to MMSE with the same number of antennas, respectively. Since the MMSE precoding technique works without removing the noise of each channel, the channel interference cannot be mitigated perfectly at the receiver parts.

Figure 4 shows a comparison of the proposed method and MMSE in the same massive-antennas deployment on CSCs scenarios. Based on the simulations, the graph informs that the average data-rate improves gradually with the increase of the number of antennas and the performance gap of the proposed precoding technique becomes larger in comparison to the MMSE methods. As an example, the simulations investigate with 50 and 100 antennas; the proposed method improves the average-rate about 67% and 90% compared to the MMSE precoding technique, respectively.

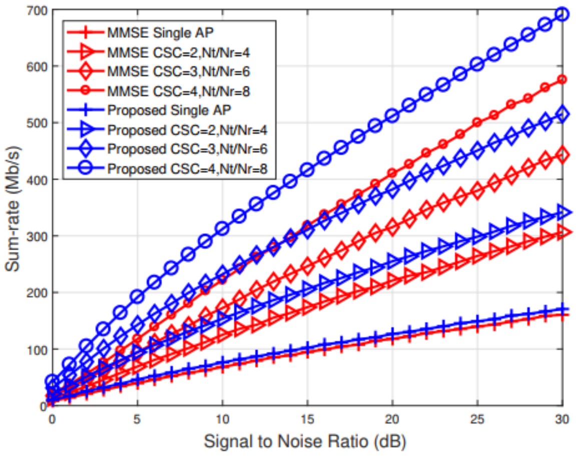

Figure 3. The impact of CSCs with difference level of SNR receivers

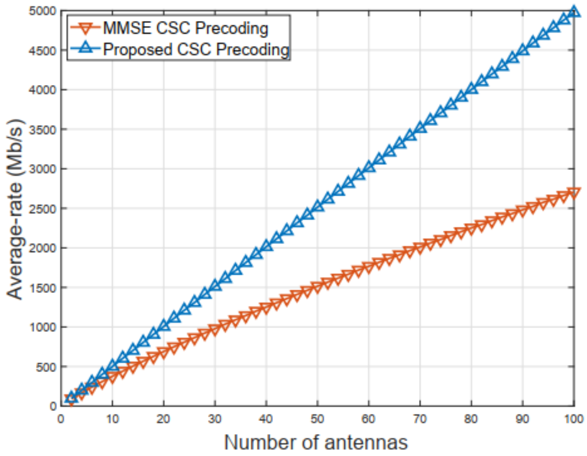

Figure 4. BD and MMSE precoding technique with various numbers of antennas

Finally, Figure 5 shows the average-rate when the CSCs and users are evaluated by the distances. The proposed methods archive an average data-rate gain about 2.75 times compared to the MMSE precoding at 100m. The graph shows that even though the average data-rate drops proportionally with the increment of the distance, the performance gap of the proposed precoding technique in comparison to the MMSE methods becomes larger. For the case that the distance of the receiver user fixed at 500m from the transmitter of CSC, the proposed method provides a better transmission rate about 5 times compared to the MMSE precoding technique. Therefore, our proposed precoding scheme is more efficient.

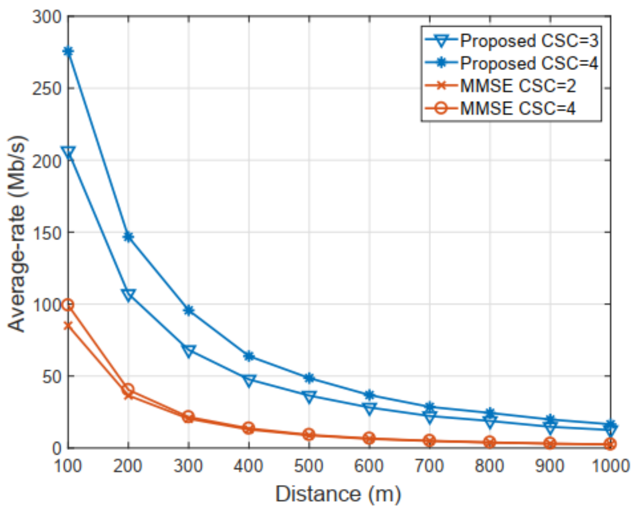

Figure 5. Downlink data-rate with difference distance from CSCs transmitter

5. CONCLUSION

This paper investigates the clustering small-cells and precoding technique for improving data-rate in the networks. The clustering small-cells methods employ the MIMO concept and implement a precoding technique to minimize interference. This paper formulates clustering small-cells contains multiple antennas for maximizing the downlink data-rate for the users. The BD precoding is proposed in clustering small-cells to mitigate the interference channel between the users. This research also implements a water-filling power allocation to improve the gain of each channel. Simulation results show that our proposed algorithms obtain better performance of data rate compared to the MMSE precoding technique by 67% at 50 antennas and 2.75 times at distance 100m. For future research, our research will investigate the implementation of small-cells in an indoor environment with channel error problems. Our future algorithm will also improve the precoding technique to optimize the impact of imperfect channel state information.

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