Performance Analysis of Coordinated Base Stations in Multi-Cellular Network Using Multistream Transmission and Different Size Cells

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***Abstract*—As a promising approach to mitigate the performance degradation of multi-cellular network in cell-edge region, Base Station Cooperation (BSC) is collecting attentions. This paper investigates "how much" BSC using practical algorithm could improves the performance of the system, when the shape and size of cells are flexibly changed based on BS location and inter BS-UT channel condition. Here, we consider multistream transmission assuming that BSs and User Terminals (UTs) are all equipped with multiantenna. In multistream case, interferences arriving from surrounding cells consist of larger number of data sequences than single stream case, hence first, we investigate the nature of inter-cell interference. Next, the performance gain of BSC is evaluated using five types of algorithms with and without BSC through computer simulations. The results show that BSC achieves about three times larger capacity compared to cooperation less scheme.**

***Keywords*-Coordinated Multi-Point (CoMP) transmission, Multiple Input Multiple Output (MIMO), cellular network, spatial multiplexing.**

I. Introduction

It is well known that the performance of multi-cellular network is degraded in the cell-edge, because the desired signal from the target Base Station (BS) is weakened due to the relatively large attenuation, while the interferences from adjacent cells become stronger. As a mitigation strategy of this problem, Base Station Cooperation (BSC) is collecting attentions (overview of BSC is found, for example, in [1], [2]) (cooperation is considered also in uplink [3], [4]). By sharing information among multiple BS, increment of throughput in the region other than cell edge could be also anticipated. There are many works presenting transmission schemes and resource allocations for BSC, but conventional works mainly focused on the cases of regular cell geometry, and the performance improvement by BSC has not been quantitatively evaluated under practical communication strategy.

This paper investigates the effect of BSC under multistream transmission assuming that BSs and User Terminals (UTs) are all equipped with multiantenna, and the shape and size of cells are flexibly changed based on BS location and inter BS-UT channel condition. In case of multistream transmission, the interferences contains more number of data sequences compared single stream schemes. Therefore, to investigate the behavior of interferences and to find adequate cluster size (number of cooperative BSs), first, the interference analysis is carried out. Then, we move onto the main topic of this study, namely, evaluate "how much" the performance is improved by BSC based on five typical algorithms with and without BSC through computer simulations. Those results are useful to know how the effect of BSC changes if the multistream scheme is used utilizing spatial multiplexing ability of Multiple Input Multiple Output (MIMO) system.

The organization of the rest of this paper is as follows: after Section II presenting state of art, namely, past works and the novelty of this paper, Section III describes the system model considered in this study and design algorithms. In Section IV, the effectiveness of BSC under given situation is verified through computer simulations. Section V gives conclusion and future works of this study.

II. Past Works and Novelty of This Study

BSC problems contain design of transmission scheme, resource allocation [5], system design (e.g., clustering strategy [6]), and analysis from propagation aspect [7], [8]. But those works mainly considering "how to" achieve BSC, and it has not well been investigated "how much" performance improvement is anticipated by practical BSC algorithms (information theoretic analysis based on the capacity is considered using 3-cell model in [9], but it is for a single antenna case).

Hence, in this paper, authors focus on performance analysis of BSC using linear processing (For multiuser MIMO including multi-cellular network, nonlinear methods represented by Dirty Paper Coding (DPC) are also known (e.g., [10]). But those methods are accompanied by demand of complicated power control problem, so here we limit our interest in linear processing approaches.) based on MIMO communication. In addition, majority of previous works have premised on fixed cell geometry, the most typical is the hexagonal one. But BSs might not be located in the cell

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center because of physical (there's not adequate space for BS setting) or social (BS setting is not permitted) reason, and in this case, the regular cell shape does not fit in with the reality.

In authors' previous work [11], we carried out BSC assessment in the codition of irregular cell geometry derived from Voronoi diagram which changes the cell shape and size based on BS location, but there, only the single stream transmission has been considered. This paper extends assessment to multistream transmission fully utilizing the fact that BSs and UTs are all equipped with multiantenna, and to the case where the shape and size of cells are flexibly determined based on not only BS location but also inter-BS-UT channel condition.

III. System Model and Design Algorithms

In this section, the model of cellular system and its design algorithms are shortly described.

A. System Model

In the cellular system considered here (imagine cell geometry like Fig. 1), one BS exists in each cell, and it communicates one active user chosen from UTs (both sides are equipped with multiantenna). If different frequency band is used in all the cells, no interference occurs among cells, but frequency efficiency becomes quite low. Hence members of a group consisting of some cells use common frequency, and it brings the problem of inter-cell interference. The interference cancellation is possible utilizing the multiantenna processing, but if BS are connected through backhaul link, they can share information (e.g., channel and data), which enables BSC to derive a higher total performance. This effect is larger in the cell edge where the target signal is attenuated and interferences become relatively strong. The rest of this subsection provides a model suitable for the analysis of BSC under practical conditions.

In this study, BS location is nonuniformly allocated, and their location is expressed by the displacement from the conventional hexagonal center. The conventional cells are shown by green dashed line in Fig. 1: they are numbered anti-clockwise from the inside to the outside (Cell n corresponds to User n). Actual BS location is moved onto a circle with radius r_b and rotation angle θ from the hexagon center, and then cell borders are given as Voronoi diagram as shown by solid line in Fig. 1. This geometry means the domain where the maximum mean power connection is derived against the BS inside of the same cell, and used as a guideline for giving the concept of cell edge. The cell layers are defined as in Table I, where Cell 0 (= Layer 0) is surrounded by 6 cells, and they are further embraced by 12 cells, and outer layers are given in a similar manner. The cell edge is defined as in Fig. 2 ($r_c = 1 - d'_{m,n}/d_{m,n}$ means cell edge ratio, which is the width of shaded region against inter BS distance $d_{m,n}$, and for the simplicity, cell edge is defined

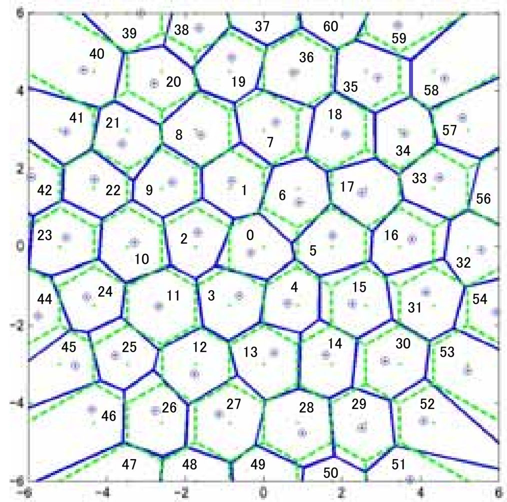


Figure 1. Example of multi-cell geometry.

TABLE I
LAYER CONSTRUCTION

	Cell Numbers
Layer 0	0
Layer 1	$1,\ 2,\ \cdots,\ 6$
Layer 2	$7,\ 8,\ \cdots,\ 18$
Layer 3	$19,\ 20,\ \cdots,\ 36$
Layer 4	$37,\ 38,\ \cdots,\ 60$

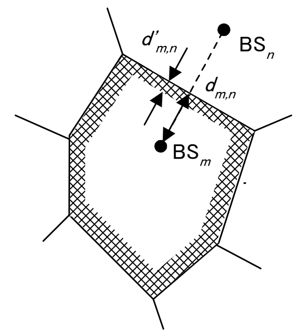


Figure 2. Definition of cell edge.

even if $d_{m,n}$ is small, namely, the UT is located relatively near the target BS), and one active UT can exist in this area for each cell. All the BSs and UTs are equipped with N_b and N_u antennas respectively, and BS of User m (BS_m) transmits L data streams $\{s_{m,\ell};\ \ell = 0,\ \cdots,\ L-1\}$ using weight set $\{\boldsymbol{w}_{b,m,\ell};\ \ell = 0,\ \cdots,\ L-1\}$ to the corresponding UT (UT_m), and UT_m produces the output signals by using weight set $\{\boldsymbol{w}_{u,m,\ell};\ \ell = 0,\ \cdots,\ L-1\}$ (By choosing adequate weights in UTs, the amplitude and phase of the signal after passing the channel is adjusted so that the power of the desired component is maximized against those of noise plus interferences through the work as a spatial filter. A similar effect could be anticipated also by weights in BS side.). The MIMO channel between BS_m and UT_n is given by $N_u \times N_b$ matrix $H_{n,m}$.

B. Design Algorithms

For the performance comparison, following five algorithms are considered (they are not novel approaches, but remark that our aim in this paper is not to develop new algorithms, but the measurement of BSC effect). The definition of BSC in this paper is cooperative transmission utilizing share of Channel State Information (CSI) $\mathcal{H} = \{H_{n,m}\}$ and/or data signal $\{s_{m,\ell}\}$ among all BSs, and in this sense, among Case $1 \sim 5$, Case 4 and Case 5 are included in BSC method. The algorithms are briefly described below.

Case 1 and Case 2 (w/o interference cancellation)

Transmit and receive weights of User m are designed by Singular Value Decomposition (SVD) of channel matrix $H_{m,m}$ (utilization of left and right singular value vectors corresponding the first L largest singular values) [12] not considering interference cancellation. In Case 1, interferences from other cell are ignored in the simulation as if M parallel MIMO system exist, which is unrealizable scenario but used as an upper bound in case without BSC. On the contrary, Case 2 is fully exposed to interferences from $M-1$ users, and its capacity is used as a lower bound.

Case 3 (with interference cancellation, w/o BSC)

Transmit weights are designed by SVD as Case 1 and Case 2. But receiver weights are designed to achieve interference cancellation by beamforming using Minimum Mean Square Error (MMSE) criterion. Here, for the m-th user, the ratio of $|\boldsymbol{w}_{u,m,\ell}^H H_{m,m} \boldsymbol{w}_{b,m,\ell}|^2 P_{S,m}$ is maximized against $\sum_{(n,k)\in\mathcal{I}(m,\ell)} \boldsymbol{w}_{u,m,k}^H H_{m,n} \boldsymbol{w}_{b,n,k} \boldsymbol{w}_{b,n,k}^H H_{m,n} \boldsymbol{w}_{u,m,k} P_{S,n}$, where $\mathcal{I}(m,\ell) = \{(n,k);\ n \neq m\} \cup \{(m,k);\ k \neq \ell\}$. The solution is derived by conventional way of MMSE solution [13].

Case 4 (BSC with CSI sharing) [11]

The receiver weights are first designed by SVD as Case 1 and Case 2. Then utilizing the share of CSI, namely, set $\{H_{n,m}\}$ consisting of $|\mathcal{H}| = M^2$ matrices, transmit weights for the ℓ-th stream of User m are designed to eliminate the interferences $\{H_{n,m}\boldsymbol{w}_{u,n,k};\ (n,k) \in \mathcal{I}(m,\ell)\}$ to other cells and other streams using Zero Forcing (ZF) method. By designing receiver weights first, degrees of freedom required for ZF become $LM - 1$.

Case 5 (BSC with CSI and data sharing)

In this case, utilizing the share of data among all users, a virtual array with MN_b antenna elements could be configurated. Transmit and receive weights are designed by Block Diagonalization (BD) [14]. While large performance improvement by the increment of degrees of freedom could be anticipated, the traffic in backhaul is significantly increased from Case 4 for the data sharing.

The energy is allocated to each stream by water filling [13], and in this process, some streams with negative energy are excluded (in this case, streams less than the rank of channel matrix are used).

Other than those algorithms, various design criterion and conditions are presented and we can derive the exact/approximated solution for some of them, but here we adopted practical well known method which is suitable to implement in actual systems. Case 1, 2, 4, and 5 correspond to the optimal solution under certain zero forcing conditions, and Case 3 achieves MMSE optimality in the receiver.

IV. Performance Analysis

In this section, computer simulation are carried out to assess how the effectiveness of BSC changes (or does not change) by adopting multistream transmission. Default simulation conditions are given in Table II.

The evaluation measure of the output signal of total users is sum capacity which is approximated by $C = \sum_m \log_2(1 + \Gamma_m)$ using Signal to Interference plus Noise Ratio (SINR) defined by $\Gamma_m = \frac{|\rho_m|^2}{1 - |\rho_m|^2}$ for the m-th user, where $\rho_m = \frac{E[\hat{s}_m(k) s_m^*(k)]}{\sqrt{E[|\hat{s}_m(k)|^2] E[|s_m(k)|^2]}}$. On the contrary, noise condition is expressed by Signal to Noise Ratio (SNR) given by $\gamma_m = P_{S,m}/P_{N,m}$ using noise power $P_{N,m}$ of the m-th user. Here, $P_{S,m} = 1$ for all m, and noise power is adjusted so that the SNR at the vertex of original hexagonal cell becomes $\gamma_m = 10 \sim 30$dB (remark that the hexagon vertex is normalized to one since the actual length (order of kilo meter) changes depending on the situation, and in this case, inter-BS distance is $\sqrt{3}$). The (sample) mean SINR and capacity are evaluated by randomly changing the pattern of BS displacement ($r_b \sim U[0, 0.4]$ and $\theta \sim U[0, 2\pi)$) using total 4,000 samples (20 BS positions $\times$ 20 UT positions $\times$ 10 channels).

First, to derive the guideline of system design, the power of interference arriving from outer cells is investigated.

Figure 3 depicts the layer number versus total energy of interferences arriving from the corresponding layer received using the weight corresponding to the first stream (which is the singular vectors belonging to the largest singular value). In each cell, BS ($N_b = 7$) transmits L streams to UT ($N_u = 3$) without interference cancellation (it corresponds to Case 2), where streams $\ell = 1$ and $\ell = 2$ become interferences. The energy in layer zero means that of thermal noise. From this figure, it can be seen that the amount of interference coming from each layer is not so much different between single and multiple stream transmission schemes, since the energy of BS transmission is kept to a constant even though the number of stream is inctreased. The total strength of interference decreases in outer cell though the number of the cell increases, but they are still stronger than that of the thermal noise, which means the importance of the interference cancellation.

As the energy of interferences become large, larger amount of their influence could be reduced by BSC, and in Case 5 they are utilized as sources of the desired signal. The results of interference assessment show the outer 6 cells occupies the significant part of energy, which means even if more than 7 cell have cooperation, its effect is very small

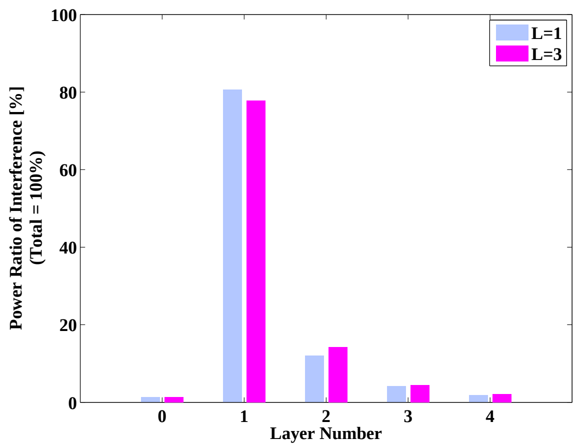
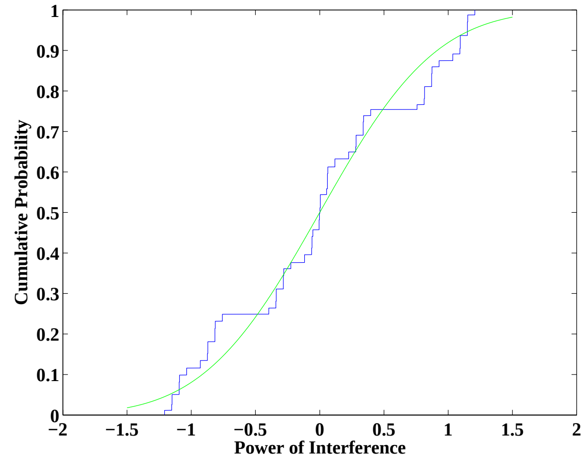


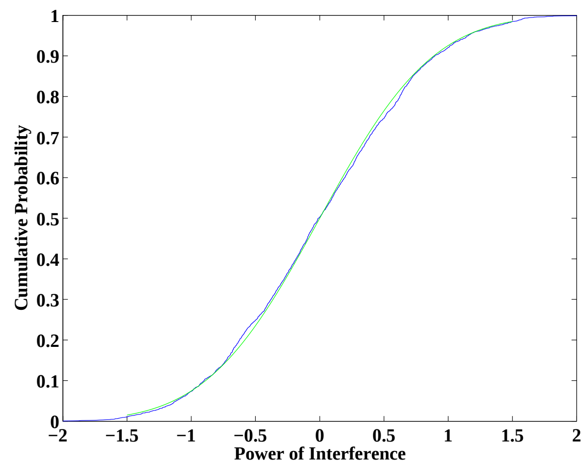
Figure 3. Energy of interferences arriving at Cell 0 from outer cells.

Table II
DEFAULT SIMULATION CONDITIONS.

Number of Cells	$M = 19$ or 61
Number of Cooperation BSs	$M = 7$
Cell Shape	Voronoi Diagram
Size of Henxagon	$d = 1$
BS Position	on a circle with radius r_b
UT Position	Uniform Distribution in Cell Edge
Cell edge ratio	$r_c = 0.8$
BS Displacement	$r_b \in U[0, 0.4]$
(BS,UT) Antenna Number $(N_{b,m}, N_{u,m})$	$(7, 3)$ interference analysis $(14, 2)$ performance comparison
SNR	$\gamma_m = 10 \sim 30$ dB (default : 20dB)
Path Loss Exponent	$\alpha = 3.5$
Shadowing	Log Normal Distribution Standard Deviation $\sigma = 6$
Fading	i.i.d. Quasistatic Rayleigh



(a) BPSK.



(b) QPSK.

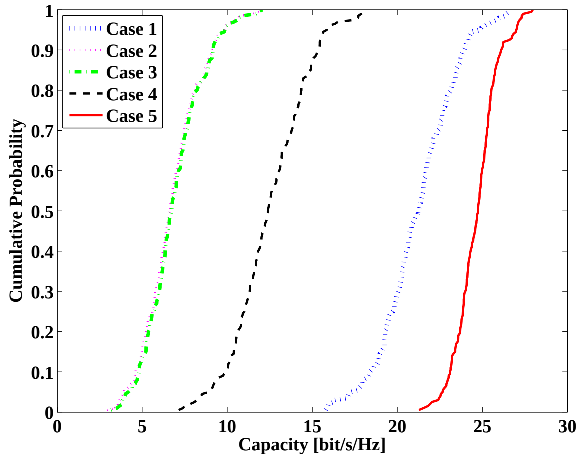
Figure 4. Examples of distribution functions of interference in Layer 1 (real part) ($L = 3$).

since there's small amount of component which could be utilized for the enhancement of the desired signal. On the other hand, increment of cooperative BS results in larger cost of implementation (backhaul connection) and computation cost, and more than 7 cell cooperation is impractical. So here we consider 7 cell cooperation, namely, those cells use the same frequency band, and the outer cells use different frequency.

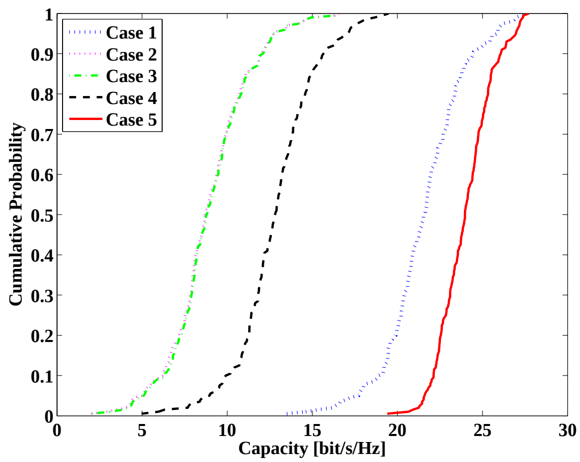
Figure 4 plots examples of distribution function of interference when the channel matrix is fixed. In most cases, the distribution could be approximated by normal distribution, though exceptions exist (particularly, for BPSK modulation, we should remark that the Gaussian approximation could not be applied in Layer 1 even in multistream case).

Next, the performance comparison of algorithms (evaluation of BSC effect) is carried out for 7-cell cooperation. If L streams are not realizable for User m in ZF schemes as a result of water filling, the maximum possible number less than L is adopted. Here, two-stream transmission is considered because, to pass L streams for each user, UTs (Case 3) or BSs (Case 4) should have $LM - 1$ antennas, and equipment of array elements which enables more than two stream is impractical (usually, UTs do not have space more than two antennas, hence in our simulation, we assume practical two-antenna UT system). The UT is connected to the BS with the best channel condition (here, the largest channel matrix norm), and if plural UT choose on BS, the one with the largest norm is selected. In the next round, UTs which could not find the pair BS in the first round try again to find their target BS which has the largest channel norm from BSs without pair UT, and repeat this operation until all the UTs find their partner (this procedure defines flexible cell geometry).

Figure 5 depicts the distribution functions of sum capacity of two streams ($L = 2$) for Cell 0 and Cell 6 for (the curves of Case 2 and Case 3 alomost overlap). In both figures, though the BSC only sharing CSI has a limited capacity



(a) User 0.



(b) User 6.

Figure 5. Distribution functions of capacity.

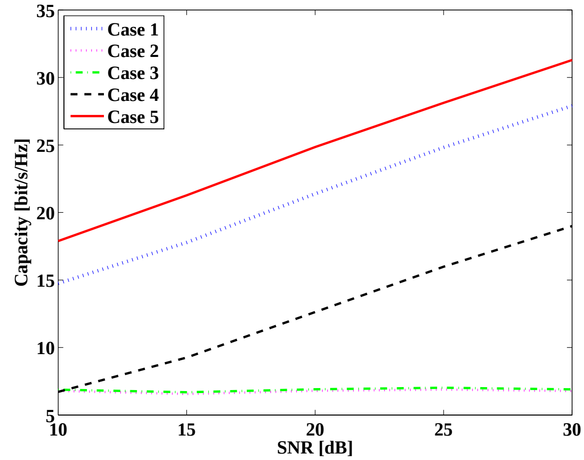


Figure 6. Input SNR versus capacity (User 0).

improvement, BSC with data sharing achieves about three times larger capacity than that of Case 3 without BSC, and in addition, its curve has a steeper gradient which means better outage characteristics. The amount of the improvement in Cell 0 surrounded by 6 cells is larger than in border cell (Cell 6), since the origins of interferences change to the sources of the desired signal.

The relation between input SNR and sum capacity is depicted in Fig. 6. While Case 3 without BSC cannot improve the performance because of the residual interference (degrees of freedom in UT are not enough), methods with BSC (Case 4 and Case 5) steadily increase the capacity as SNR becomes higher.

From those results, we can see that BSC is still effective in multistream transmission.

V. Conclusion

This paper has investigated the effect of BSC under multistream transmission assuming that BSs and UTs are all equipped with multiantenna, and the shape and size of cells are flexibly determined based on BS location and inter BS-UT channel condition. First, the nature of interferences from outer cells has been assessed. Then, the performance gain of BSC has been evaluated using five types of algorithms with and without BSC through computer simulations. The results show that BSC achieves about three times larger capacity compared to cooperation less scheme.

The future work is the investigation of BSC effect under the imperfect CSI. The extension of this work to relay aided BSC is also an attractive and important subject of study.

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