Coordinated Multi-point Multistream Scheme for Disaster Recovery in MIMO Multi-Cellular Systems

Tetsuki Taniguchi Yoshio Karasawa Nobuo Nakajima
Department of Communication Engineering and Informatics *Department of Informatics*
Advanced Wireless Communication research Center (AWCC)
The University of Electro-Communications (UEC), Chofu, Tokyo 182-8585, Japan
E-mail: {taniguch,karasawa}@ee.uec.ac.jp, n.nakajima@hc.uec.ac.jp

***Abstract*—Conventionally, CoMP (coordinated multi-point) transmission has been utilized for the performance improvement in the cell edge of multi-cellular systems. This paper describes CoMP scheme using multistream transmission for the disaster recovery: if base stations (BSs) lose their function by disaster attacks in some cells, user terminals (UTs) in those cells should connect to BSs in a long distance located outside their own cells under the situation where demands for the communications increase. In this case, cooperative transmission/reception of signals is considered to be helpful to keep the quality of communications. Here, our investigation is on two typical patters of allocation of cells with BS destruction, and the effectiveness of the cooperation in downlink scenario is shown through computer experiments using cooperative and noncooperative methods in the entire cell.**

***Keywords*-CoMP (coordinated multi-point); MIMO (multiple input multiple output); cooperative communication; cellular system; disaster recovery.**

I. Introduction

It is well known that CoMP (coordinated multi-point) scheme is effective for the performance improvement in the cell edge of multi-cellular systems where the signal from the target base station (BS) to user terminals (UTs) severely attenuates because of the path loss, and interferences from adjacent cells are relatively strong [1] [2]. There are many reports concerning CoMP from the viewpoint of information theoretic aspect, evaluation by computer simulation [3], measurement campaign [4], and analysis based on wave propagation [5]. All of those papers refer to the significant advantage of introducing cooperative scheme into cellular systems. Also, in our laboratory, on-computer investigation of performance is carried out in case where all of BSs, relay stations (RSs), and UTs are equipped with multiantennas, namely, multiple input multiple output (MIMO) structure.

But, when we think about the principle of CoMP, its usefulness is not restricted to the communication in peacetime – One potent candidate of application is the cooperative communication for the disaster recovery. If BSs in some cells are destroyed by an accident like landslide, UTs in those cells should connect to a BS in the next adjacent active cell, and it is normally located in a far way position. On the other hand, the traffic of disaster cell can be increase to provide their safety confirmation or to receive the further disaster and rescue information. Cooperative nature of CoMP is considered to be suitable for the improvement of this situation. From this standpoint, in this paper, a quantative evaluation of the effect of cooperation for the disaster recovery is considered based on MIMO cellular system.

The rest of this paper is organized as follows: first, Section II describes past works and what is novel in this study, and then Section III provides the system model used throughout this study and explains the simulation method. After computer simulations are carried out in Section I, Conclusions and future works are given in Section V.

II. Past Works and Novelty of This Study

Some works have been presented as communication methods for the disaster recovery: one example is the wireless network based on virtual access point by mobile nodes in [7], and heterogeneous networks are also utilized [8]. In addition, we can easily find lots of papers concerning CoMP for the conventional use, i.e., the improvement of the cell edge performance. But, application of CoMP to disaster recovery has not been considered. We have described the primitive idea in [6] for single stream case in cell edge; it is useful as an initial investigation, but it cannot demonstrate the total ability of the system utilizing multiantenna feature. This paper extends the analysis to the multistream scenario in which UTs are located in a random position of the entire cell. In this sense, the results shown in this paper provide the tighter limit of the CoMP effect which is useful for the design of disaster-robust infrastructure.

III. System Model and Design

A. Example of system model

The system is given in Fig. 1. Reflecting the fact that the uniform BS allocation is generally not possible in actual environment, the cell geometry is based on Voronoi diagram which shows the border inside which the maximum average power is derived from the BS in the same cell. As the situation before the disaster, we consider that there's one

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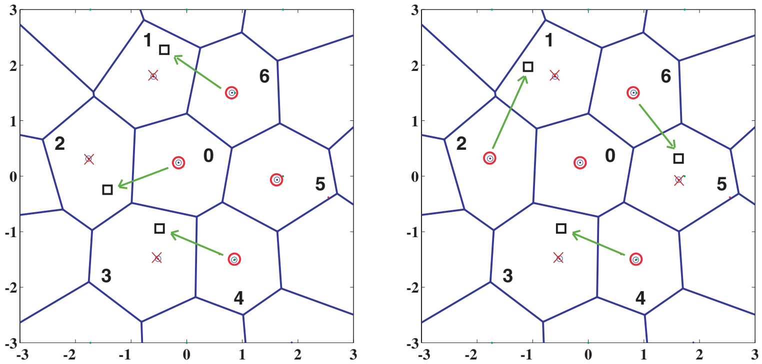


(a) Pattern A (b) Pattern B

	Connection
$M_d = 1$	$\mathrm{UT}_1 \leftarrow \mathrm{BS}_0$
$M_d = 2$	$\mathrm{UT}_1 \leftarrow \mathrm{BS}_6$ $\mathrm{UT}_2 \leftarrow \mathrm{BS}_0$
$M_d = 3$	$\mathrm{UT}_1 \leftarrow \mathrm{BS}_6$ $\mathrm{UT}_2 \leftarrow \mathrm{BS}_0$ $\mathrm{UT}_3 \leftarrow \mathrm{BS}_4$
$M_d = 4$	$\mathrm{UT}_1 \leftarrow \mathrm{BS}_6$ $\mathrm{UT}_2 \leftarrow \mathrm{BS}_0$ $\mathrm{UT}_3 \leftarrow \mathrm{BS}_0$ $\mathrm{UT}_4 \leftarrow \mathrm{BS}_5$

(c) Defect cells and new connection.

Figure 1. System model. Circles, cross marks, and box marks in (a) and (b) respectively denote working BSs, broken BSs, and active UTs in defect cells. Table (c) shows alternative BSs for UTs in defect cell (Pattern A), which is used in Section IV.

Table I
SIMULATION CONDITIONS.

BS Position	on a circle with radius r_b and rotatio θ $r_b \sim U[0, 0.4]$ $\theta \sim U[0, 2\pi)$
UT Position	Uniform Distribution in Entire Cell
Defect Cells	$M_d = 3$
(BS,UT) Antenna Number	$(N_{b,m}, N_{u,m}) = \begin{cases} (14, 2) & L_m = 2 \\ (21, 3) & L_m = 3 \end{cases}$
Modulation	QPSK
SNR	$\mathrm{SNR}_m = 10 \sim 30$ dB (default : 20dB)
Path Loss Exponent	$\alpha = 3.5$
Shadowing	Log Normal Distribution Standard Deviation $\sigma = 6$
Fading	i.i.d. Quasistatic Rayleigh

BS in each cell and one UT connects to each BS. Here, we deal with the cooperation of $M = 7$ cells (numbered by $m = 0, \cdots, M-1$) in downlink, and BS_m with $N_{b,m}$ antennas transmits its data $\{s_{m,\ell}(t);\ \ell = 0, \cdots, L_m - 1\}$ using transmit weight vector $\boldsymbol{w}_{b,m,\ell}$, and after passing through MIMO channel $H_{m,n} \in \mathbb{C}^{N_{u,n} \times N_{b,m}}$, UT_n with $N_{u,n}$ antennas receives it using receive weight vector $\boldsymbol{w}_{u,n,\ell}$.

In this study, two disaster patterns are considered: in pattern A, M_d BSs in the connected cell region are broken. In pattern B, M_d cells with broken BS are distributed among working cells. If the BS is broken, UT of that cell should connect to a BS in an adjacent cell, and the strength of link becomes weak. Our aim is to recover the communication quality by the cooperative work of BSs, and the performance improvement is evaluated not only in the cell edge but in the entire cell.

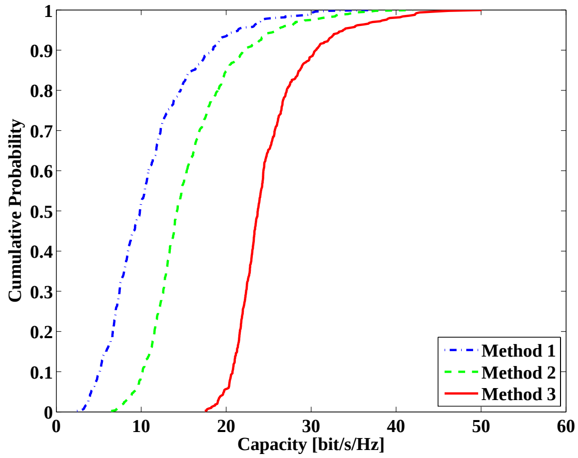
B. Design

Three kinds of cooperative and noncooperative algorithms described here are same as previous studies except that they are multistream version, and selected for the main objective of this paper, CoMP effect evaluation under disaster situation. In this paper, CoMP scheme means the cooperative work of BSs utilizing the shared channel state information (CSI) and transmission data among BSs.

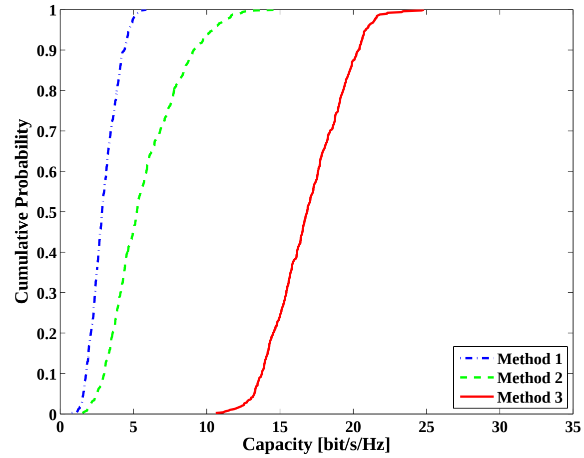
Method 1: This method does not consider the cooperation of BSs, and BS_m knows only its own channel $H_{m,m}$. First, the transmit weights are designed user by user like single user design, namely, $\{\boldsymbol{w}_{b,m,\ell}\}$ are designed by singular value decomposition (SVD) of $H_{m,m}$ (utilization from the largest to L_m-th largest singular value and related vectors). Then $\boldsymbol{w}_{u,m,\ell}$ is designed for the beamforming to minimize the sum of the power of all the signal except $s_{m,\ell}(t)$. In this method, the transmission interference mitigation to other users are not paid attention.

Method 2: This method considers the cooperation of BSs by sharing only CSI, and BS_m knows channel $\{H_{m,n};\ n = 0, \cdots, M-1\}$ including those of nontarget UTs. The receive weights are first designed by SVD (utilization from the largest to L_m-th largest singular value and related vectors). Then $\boldsymbol{w}_{b,m,\ell}$ is designed to steer nulls to all the undesired stream except the target weight $\boldsymbol{w}_{u,m,\ell}$ (zero forcing which consumes only one degree of freedom for the nulling to one stream). By this method, the transmit interference mitigation to other users could be achieved.

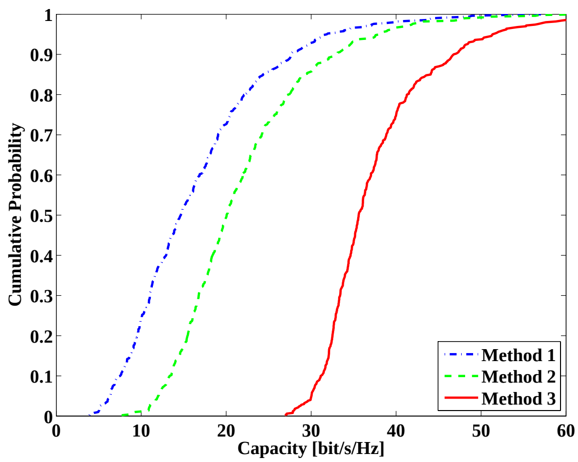
Method 3: This method considers the cooperation of BSs, and BS_m knows, in addition to CSI in Method 2, the data of all users $\{s_{m,\ell}(t);\ m = 0, \cdots, M-1, \ell = 0, \cdots, L_m - 1\}$ through backhaul link. By this condition, all the (working) BSs can construct a virtual array of $\sum_{n \in \mathcal{A}} N_{b,n}$ antennas, where $\mathcal{A}$ is the set of cell number with a working BS, which means the enhancement of desired link is possible avoiding the interference to undesired users utilizing sufficient degree of freedom. The transmit and receive weights are designed by block diagonalization [9].



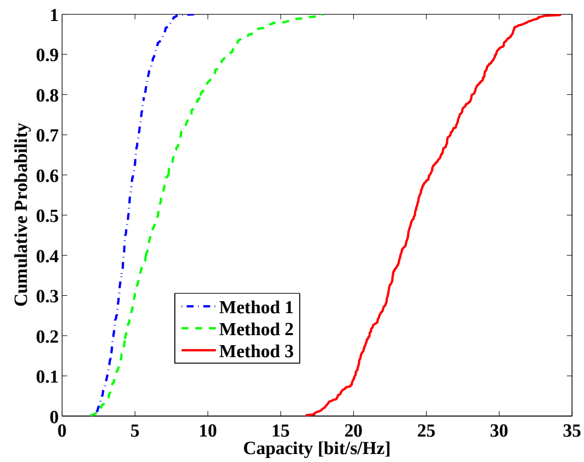
(a) Pattern A, $L_m = 2$, Cell 0.



(b) Pattern A, $L_m = 2$, Cell 1.



(c) Pattern A, $L_m = 3$, Cell 0.



(d) Pattern A, $L_m = 3$, Cell 1.

Figure 2. Distribution functions of sum capacity in two and three stream transmission for Patter A (SNR $= 20$dB).

IV. SIMULATIONS

In this section, the performance improvement by cooperative communication is verified through computer simulations using algorithms in the previous section. The default simulation conditions are summed up in Table I. In [6], UT position is restricted to the cell edge, but it is removed here since the CoMP under disaster recovery is required to work for the user anywhere in the cell. To avoid the complexity of resource allocation, here we assume that BSs have the enough power to allow $P_{s,m} = 1$ for the transmission to each user even if it is connected to multiple UTs (though more practical evaluation including this problem is an important future work, our experiment is sufficient to measure the CoMP effect under the equal conditions for Method 1$\sim$3). The BSs have enough number of antennas for steering zero to all the users, but UTs are equipped with $N_{u,m} = 2$ or 3 antennas because of the limitation of the physical size.

Figure 2 (a)$\sim$(d) plot the distribution functions of capacity in pattern A for the system with $L_m = 2$ and $L_m = 3$ streams, respectively. In those subplots, (a), (c) and (b), (d) correspond to Cell 0 (BS is working) and Cell 1 (BS is broken). It is first verified that shapes of curves are not so much different between (a)-(c) and (b)-(d) though the actual total capacity is significantly increased in (c) and (d) by the use of larger number of eigenpaths. Between Cell 0 and Cell 1, we can find the gap of capacity: in Cell 1 which uses BSs of adjacent cells cannot achieve sufficient performance improvement even by using cooperation of Method 2 in which all BSs have CSI of all the users. This is because the conventional CoMP schemes are designed to mitigate the generation of interferences to nontarget users utilizing CSI, but our problem is rather in the weakness of the target signal. On the contrary, Method 3 which assumes the share of CSI and data of all the users by all the cooperative BSs achieves much higher improvement since the large size virtual array has also the effect of the enhancement of the transmitted signal. Another feature of the curve of Method 3 is that it

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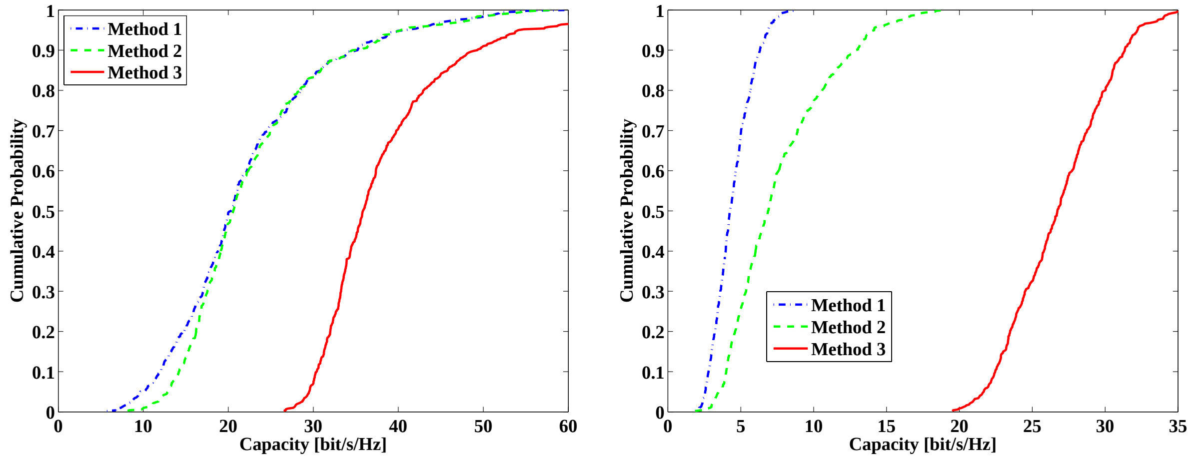


(e) Pattern B, $L_m = 3$, Cell 2.

(f) Pattern B, $L_m = 3$, Cell 1.

Figure 2. (Continued.) Distribution functions of sum capacity in two stream transmission for Patter B (SNR = 20dB).

has less steep gradient than that of others, which means the variance of the capacity becomes larger. This fact means that the quality is less stable, but the average capacity of Method 3 is more than 2.5 times of others, and it is much advantageous also in the point of outage capacity. Likewise, distribution functions of capacity in case of pattern B are given in Figure 2 (e) and (f). In subplot (e), characteristics of Cell 2 with working BS has a different behavior from (a) and (c) (curves of Cell 0 are similar to (a) and (c)): Cell 2 is located in the edge of the seven cells, and the influence of interferences is small, hence improvement by Method 2 is not anticipated. In Cell 1 with broken BS, the overall trend is not so much different from (c) and (d) except that the curve of Method 3 in (f) shifts to the right. This upgrade happens because in Pattern B, Cell 1 is surrounded by working cells which become the origin of source signal (in Pattern A, this is not consists), hence the cooperative transmission can invoke its advantage more effectively.

Figure 3 draws the relation between the input SNR and sum capacity for $L_m = 3$. Almost linear characteristic of curves of Method 2 and 3 means those algorithms well avoid the influence of interferences and synthesize the desired signal as strong as possible. On the other hand, without cooperation, such a linear improvement is not achievable, since the number of antennas in UTs is not enough to separate the signals from all the BSs. What is also remarkable is that the result of Method 2 (with CoMP) is worse than Method 1 (w/o CoMP) in low SNR region, what is not seen in the case of the conventional application [3]. The reason is considered as follows: The UT location is distributed over the entire cell and some of the origine of interference are destructed. Hence the noise becomes much dominant in the low SNR region, and Method 2 adopting ZF degrades due to high noise level [9].

The capacities other than $M_d = 3$ are given in Fig. 4.

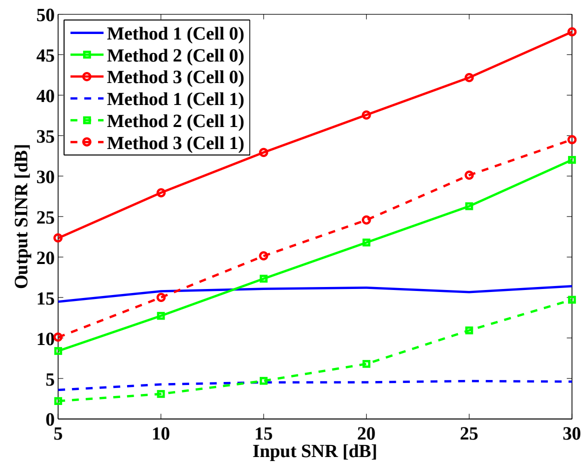
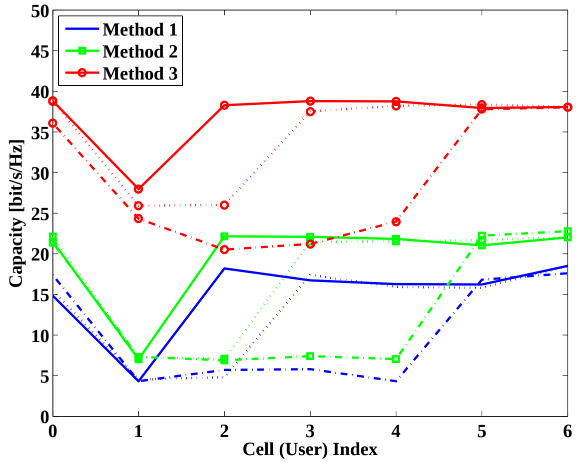


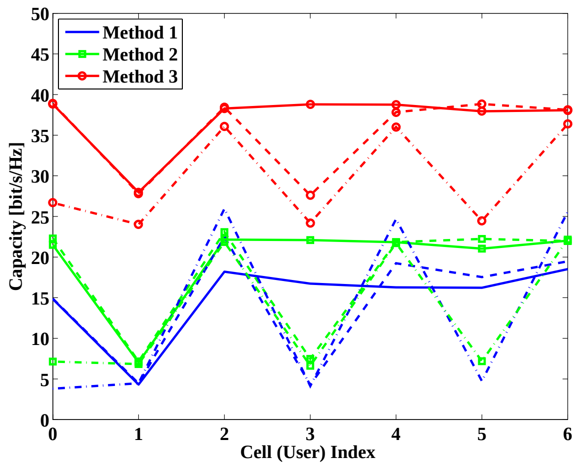
Figure 3. Input SNR versus sum capacity for $L_m = 3$.

We can observe the performance degradation in defect cells and the recovery by CoMP scheme. In (a), as M_d becomes larger, the capacity difference against working cells is not well improved since there's few BSs which can be utilized for cooperation, while the gap of them improved in (b) where defect cell is well surrounded by the working cells, the origin of desired signal.

From those results, we can conclude that the CoMP scheme is effective for the disaster recovery also in multistream case. As the reason of the advantage of CoMP scheme, it is considered that enhancement of target signal is dominant to interference cancellation, hence the virtual array sharing CSI and data brings significant performance improvement, and its effectiveness compare to Method 2 is larger than in case of conventional base station cooperation [3]. On the contrary, the effect of CoMP sharing only CSI



(a) Pattern A.



(b) Pattern B.

Figure 4. User index versus sum capacity for $M_d = 1$ (solid line), $M_d = 2$ (broken line), and $M_d = 4$ (dashed line).

is not sufficient in this application. What we can learn is that it is desirable to connect BSs around disaster risk area through backhaul link, which reinforces the result of [6]. Though the results are for downlink phase, they provide enough materials to infer the advatage of CoMP also in case of uplink scenario.

V. Conclusion and Future Works

This paper has evaluated the multistream cooperative communication scheme for the disaster recovery in MIMO cellular system where BSs in some cell are broken. We have considered typical two types of disaster-suffered cell patterns, and three kinds of cooperative and noncooperative algorithms, and evaluated the performance improvement by cooperative transmission in downlink through computer simulations under various conditions. The results show that the concept of CoMP scheme utilizing survived infrastructure is effective also for performance recovery in disaster area.

The future work is the relay-aided processing: in this case the relay station may be a portable type (e.g., mounted on a vehicle) and to keep the fairness of the user connection, mobile relay might be more suitable. In addition, the resource allocation putting importance on the disaster area becomes an important theme of the study.

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