# DOWNLINK PERFORMANCE OF 2-CELL COOPERATION SCHEMES IN A MULTI-CELL ENVIRONMENT

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## Abstract

Cooperative transmission schemes are used in wireless networks to improve the spectral efficiency. In a multi-cell environment, other cell interference (OCI) degrades the performance of wireless systems. In this paper, we study the performance of downlink sum rate for cell-edge users in a multi-cell environment under base station cooperation. The base-stations coordinate their transmission to the two cell-edge users in order to improve their Signal-to-interference-noise ratio (SINR) and throughput. Sum Capacity of cell-edge users for different transmit cooperation strategies is compared. Results show that Dirty Paper Coding (DPC) scheme, in a 2-cell cooperation, has significant gain in sum-rate compared to other cooperative schemes. However, when interference from all the other cells are considered, DPC performance is only marginally better than other low complexity cooperation schemes.

*Keywords:* Cooperative transmission, MIMO, Capacity, Dirty Paper Coding (DPC)

## I Introduction

Ever increasing demand to support higher data rates for broadband services like triple play, online gaming etc., over wireless networks, requires a large capacity. However, with scarcity of available radio resources, to achieve a good capacity and Quality of Service (QoS) efficient utilization of channel resources is important. In a conventional cellular network, a terminal receives signals not only from the base station of that cell, but also from other cell base stations. Using a proper frequency reuse, such interference is reduced to a tolerable limit. However, this method of using different frequency bands for different cells will decrease the spectral efficiency. In a full frequency re-use network, this interference degrades the system performance, and thereby reduces network capacity. Using Base Station Cooperation, this ability to receive signals from multiple base stations can be utilized as an opportunity to improve the spectral efficiency of the cellular network.

Cooperative transmission utilizes the inherent user diversity available in a multi-user environment to provide higher spectral efficiency [1–3]. In [4], it is shown that the downlink efficiency can be improved using Coherent Coordinated transmission (CCT) from multiple base stations. Comparison of different coordination schemes using Dirty Paper Coding (DPC) is presented in [5] for a downlink Multiple Input Multiple Output (MIMO) system in a slow fading channel. A new partial coordination scheme, where the base stations transmit in Time Division Multiple Access (TDMA) mode is proposed in [5] to minimise the latency involved in a full coordination using DPC.

In [6], it is shown that in a multi-cell environment, using cooperation the overall interference can be reduced only marginally, whereas the interference within the cooperation region is largely reduced as shown in Figure 1. It can be observed that the average interference power in a 19 cell case is only reduced marginally, compared to interference reduction in the collaborative region as described in [6]. Cooperative encoding and scheduling in a Networked MIMO system is discussed in [7], in order to supress Other Cell Interference (OCI) and thereby achieve maximum capacity in MIMO downlink channel. DPC is one such encoding scheme that can cancel the interference, if the interference channel information is available at the transmitter. It is shown that such an encoding scheme can achieve maximum capacity for a multi-user downlink channel. However, it is difficult for practical implementation of the such scheme, as it requires exact channel information of all the interfering stations. Since DPC can give a theoretical upper bound, we study the performance of other lower complexity cooperation strategies in [8] and compare it with DPC.

In this paper, we present a performance analysis through simulations for different cooperation scenarios in a multi cell environment where the other cell interference is significant. The sum capacity achieved through cooperation is presented for two different interference environments. In the first case, a network with only two cell is considered to study the performance of different cooperation schemes. In the second case, a 19 cell re-use1 environment is considered where the interference from the other base stations not in the collaborative region is treated as noise by the users in cooperation. The downlink environment under consideration will not have any interference from users in the same cell. They are properly seperated in time, frequency or code such that orthogonality exists. Intercell interference is allowed by doing a full frequency re-use in each cell.

The rest of the paper is organised as follows: Section 2 describes the system model, signal to interference noise ratio (SINR) and user throughput with and without cooperation. Section 3 describes the different schemes of 2-cell cooperation considered in this paper and their sum capacity calculations. Section 4 presents the simulation results and conclusions are presented in section 5.

## II System Model

The basic system model and transmission protocol is as shown in Figure 2. Base stations BS1 and BS2 are the candidates

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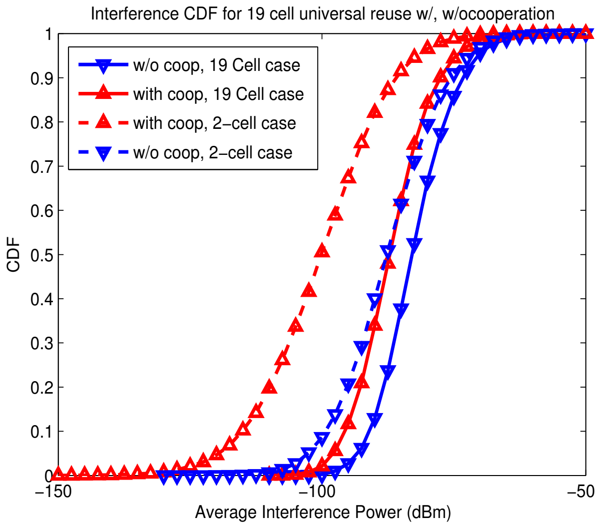


Figure 1: CDF of Average Interference Power

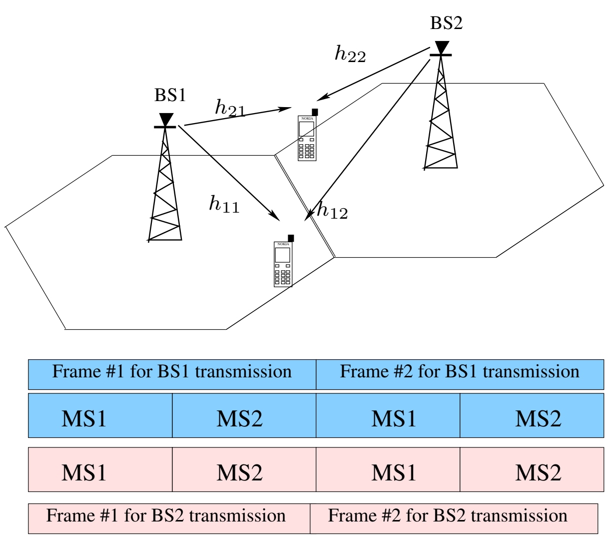


Figure 2: System Model

for cooperation, to transmit signals to mobile terminals MS1 and MS2. For BS1, BS2 is one of the interfering base stations among the total 12 base stations in a re-use1 network. More than one base station can be involved in cooperation, but for simplicity we are considering only two stations to form a coalition. The observation still holds good even for three station coalition. The signals from the serving BS and from the neighbor BS arrives at the terminal at the same time, i.e., received signal by the terminal from the two base stations are frame synchronized. The frame duration in which the BS1 transmits to MS1 is divided into two sub-frames, where the first sub-frame is used for signal transmission to MS1 and the second one to MS2. Similarly, BS2, which is under cooperation with BS1, transmits in the same sequence of BS1. The received signals at MS1 and MS2 is $y_1$ and $y_2$, and is given by system equation 1, where $h_{ij}$ is the channel between terminal $i$ and BS $j$. $x_1$ is transmit signal of BS1 and $x_2$ is that of BS2.$z_i$ is the total interference received by MS $i$ due to transmissions from all the base stations other than the one under cooperation (in this case BS2) and $n_i$ is the additive white Gaussian noise.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (1)$$

## III 2-Cell Cooperation Schemes

In this section, we describe different types of transmission cooperation schemes between two cells and Signal to Interference plus Noise Ratio (SINR) expressions of the received signal at the user terminal MS1. The sum capacity (or throughput) of the terminals under cooperation in bits/sec/Hz is also provided.

1. Cooperative MIMO
   In this scheme, the base stations BS1 and BS2 together transmit information signal to MS1, thereby forming an Alamouti trasmit diversity of order 2. This scheme is referred in some literature as Network MIMO. The SINR expression for this scheme will be of form:

$$\mathrm{SINR}_{\mathrm{coop}} = \frac{(|h_{11}|^2 + |h_{12}|^2)E\left\{X_1^2\right\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\left\{X_i^2\right\}} \quad (2)$$

2. Simple cooperation
   The signals transmitted by base stations BS1 and BS2 are added using simple vector addition. The SINR expression for this scheme will be of form:

$$\mathrm{SINR}_{\mathrm{coop}} = \frac{|h_{11} + h_{12}|^2 E\left\{X_1^2\right\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\left\{X_i^2\right\}} \quad (3)$$

3. Cooperation with 1-bit Phase feedback
   In this scheme, the addition of two signals is done with proper co-phasing the information signal from the second base station based on the 1-bit feedback of the phase information [9]. The SINR expression for this scheme will be of form:

$$\mathrm{SINR}_{\mathrm{coop}} = \frac{(|h_{11}|^2 + h_{12}|^2 + 2\Re(|h_{11}^* h_{12}|))E\left\{X_1^2\right\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\left\{X_i^2\right\}} \quad (4)$$

In all these schemes, the Channel State Information (CSI) for the downlink of the serving base station and cooperating base station is known at the user terminal. This assumption is valid and is used in schedulers for rate adaptation in 3G systems. Besides, scheme 3 has an additional overhead of 1 bit to provide the phase information of the cooperating signal in order to do co-phasing at the received terminal. The sum throughput for system under consideration in bits/sec/Hz can derived from the Shannon Capacity as

$$R_{\text{coop}} = log_2(1 + b\text{SINR}_{\text{coop}}), \tag{5}$$

where $b$ is determined by the SNR gap between the practical coding scheme and the theoretical limit. Under normal operation that is when there is no cooperative transmission, the signal to interference noise ratio (SINR) in the downlink for MS $i$ is given by

$$\text{SINR}_{\text{nc}_i} = \frac{|h_{ii}|^2 E\left\{X_i^2\right\}}{\sigma_n^2 + \sum_{k\neq i} |h_{ik}|^2 E\left\{X_k^2\right\}}, \tag{6}$$

where $h_{ik}$ represents the the channel between the terminal $i$ and base station $k$, $E\left\{X_k^2\right\}$ is the average transmit power of Base Station $k$, and $\sigma_n^2$ is noise variance. The sum throughput under normal operation in bits/sec/Hz is

$$R_{\text{nc}} = \sum_i log_2(1 + b\text{SINR}_{\text{nc}_i}). \tag{7}$$

4. Selective Cooperation
A low complexity cooperation selection algorithm based on user throughput is proposed in [8]. In this algorithm, each user calculates the achievable throughput for both cooperation and no cooperation from available measurements of its own channel and the nearest neighbor (or strongest interfering channel). The user throughput under cooperation will be $\alpha$ times $R_{\text{coop}}$, where factor $\alpha$ defines the proportion of resource sharing among terminals under cooperation. User requests the base station for a cooperative transmission only when its throughput under cooperation is greater than the no cooperation case. That is, cooperation is selected by user $i$ only when $\alpha\ R_{\text{coop}} > R_{\text{nc}_i}$.

5. Dirty Paper Coding
Dirty Paper Coding uses the knowledge of the interfering signals in calculating the optimal transmit covariance structure that can maximize the sum-rate for a Gaussian Broadcast Channel (GBC). Closed form result for achievable throughput for $t \times 1 : 2$ GBC, using successive dirty paper encoding with gaussian codebooks is given in [10]. The maximum achievable sum throughput $R$ given in [10] is

$$R = \begin{cases} log(1 + |\mathbf{h}^1|^2 A), & A \leq A_1 \\ log\frac{(Adet(\mathbf{HH}^H) + trace(\mathbf{HH}^H))^2 - 4|\mathbf{h}^2(\mathbf{h}^1)^H|^2}{4det(\mathbf{HH}^H)}, & A > A_1 \end{cases}$$

where $A$ is the maximum allowed transmit energy per channel use and

$$A_1 = \frac{|\mathbf{h}^1|^2 - |\mathbf{h}^2|^2}{det(\mathbf{HH}^H)}.$$

We use the same result for our calculation of cooperative throughput upper bound using DPC. The channel matrix used for our calculations $\mathbf{H}_z$, includes the effect of interference from the other cells and is defined as $\mathbf{H}_z = \mathbf{\Lambda}_z{}^{-1/2}\mathbf{U}^H\mathbf{H}$. $\mathbf{\Lambda}_z$ and $\mathbf{U}$ is obtained by performing SVD of the noise covariance matrix $\mathbf{\Sigma}_z$. Since the interference from other cells are treated as noise, the noise covariance matrix is obtained from the energy of the interfering signals from other cells that are not under cooperation. $\mathbf{H}$ is the cooperation channel matrix as defined in (1). The noise covariance matrix $\mathbf{\Sigma}_z$ is defined as

$$\begin{bmatrix} (\sum_j |h_{1j}|^2)P + \sigma_n^2 & (\sum_j h_{1j}h_{2j}^*)P \\ (\sum_j h_{1j}^* h_{2j})P & (\sum_j |h_{2j}|^2)P + \sigma_n^2 \end{bmatrix} \tag{8}$$

where $P$ is the maximum transmit power in the downlink.

## IV Simulation and Results

Simulations to analyse the performance of sum capacity for four transmission scenarios namely, $i$) Without Cooperation, $ii$) With Cooperation $iii$) Selective Cooperation and $iv$) Dirty Paper Coding in multi-cell environment is done based on Monte Carlo methods. Selective Cooperation is a hybrid scheme, where cooperative transmission is performed only if the individual user throughput of Case $(ii)$ is greater than Case $(i)$. A cellular network of radius 500m, operating at 1800 MHz with one cell edge user per cell is considered for simulations. The channel gains for both signal and interference are based on COST-231 path loss model [11] including fading and log-normal shadowing. The correction factors for the path loss model are that of metropolitan/urban areas. The shadowing component is a gaussian random variable with zero mean and 10 dB of standard deviation. Fading component is an iid random variable with zero mean and unit variance. The transmission power of each base station (at the antenna) is 2W (33 dBm). The superposition of signals for cooperation is performed in three different ways as mentioned in section 3.

The simulations are performed for two different setup, where in the first case only two cells are considered in the network and therefore, $z_1$ ans $z_2$ in (1) will be zero. In second setup, a 19 cell full re-use multi-cell environment in which there will be interferences from other cells which are not part of cooperation. The sum capacity of all cooperation schemes described in section 3 are compared for both the cases.

- 2-cell simulation
For a two-cell network, the average sum capacity for different input SNR is shown in Figure 3. Averaging is done over $10^5$ frames for each combination of cooperative scheme and selection of cooperation. Dirty Paper Coding

Table 1: Average per User Throughput (bits/sec/Hz) for different Cooperation schemes in a Multi-cell environment

| Type of Schemes | Scheme 1 | Scheme 2 | Scheme 3 |
|---|---|---|---|
| Without Cooperation | 1.034 | 1.034 | 1.034 |
| With Cooperation | 1.235 | 1.197 | 1.347 |
| Selective Cooperation | 1.596 | 1.582 | 1.674 |

scheme sum throughput is best of all the other schemes with significant gain margin. However, the gain in DPC is reduced as noise/interference dominates the information signal. It can be observed from Figure 3 that at -20 dB SNR, DPC is better by only 1 bits/sec/Hz compared to simple cooperation schemes.

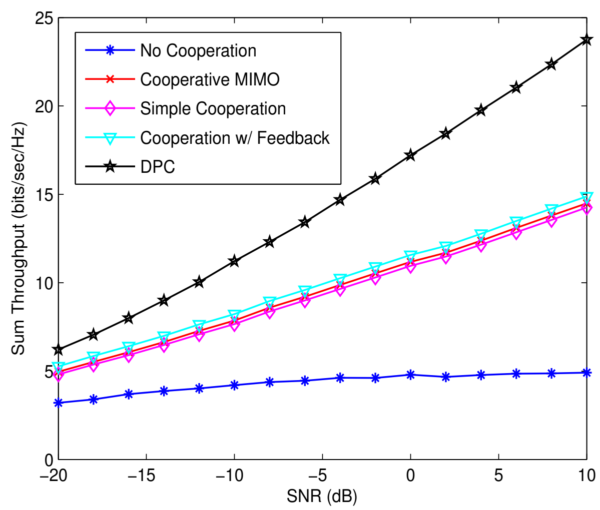


Figure 3: Sum Throughput for different Cooperation Schemes

- Multi-cell simulation
  Average per user throughput for different cooperative schemes for a multi-cell environment is shown in Table 1. The observed values from the simulation given in the table, clearly shows the advantage of selective cooperation over full cooperation. The average sum throughput of all cooperation schemes for a multi-cell simulation is given in Table 2. DPC still gives better sum throughput, but the gap is not significant. The sum throughput of selective cooperation performed on Scheme 1 is on par with DPC.

## V CONCLUSIONS AND FUTURE WORK

In this paper, we presented simulation analysis of 2-cell cooperation for downlink in a multi-cell cellular network. The simulation result shows that selective cooperation gives a user throughput improvement of 33.3% when compared to full cooperation for same SINR. Dirty Paper Coding scheme is the

Table 2: Average Sum Throughput (bits/sec/Hz) for different Cooperation schemes in a Multi-cell environment

| Type of Schemes | Scheme 1 | Scheme 2 | Scheme 3 | DPC |
|---|---|---|---|---|
| Without Cooperation | 2.0525 | 2.0525 | 2.0525 | - |
| With Cooperation | 2.4669 | 2.3935 | 2.6936 | 2.9960 |
| Selective Cooperation | 2.8234 | - | - | - |

best when compared to all other cooperation shemes for a 2-cell network. When more interference cells are considered, coordinated DPC across all the base stations will be complex to overcome the interference. When DPC is done only across 2-cells and all the other cell interference is treated as noise, the sum throughput of DPC is only marginally better (by 6%) than low complexity selective cooperation scheme.

As our future work, we are studying performance for a 3-cell collaborative region, where DPC with iterative waterfilling will be compared with simple cooperation schemes using 3 base stations.


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## REFERENCES


[1] A. Sendonaris, E. Erkip and B. Aazhang, ”User Cooperation Diversity - Part I System Descriptiuon,” *IEEE Transactions on Communications*, vol. 51, no. 11, pp.1927-1938, Nov 2003.

[2] J. N. Laneman, G. W. Wornell and D. N. C. Tse,”An efficient protocol for realizing cooperative diversity in wireless networks,” in Proc. IEEE ISIT 2001, p.294, Washington, D. C., June 2001.

[3] A. Nosratinia, T. E. Hunter and A. Hedayat, ”Cooperative Communication in Wireless Networks,” *IEEE Communications Magazine*, pp. 74-80, Oct 2004.

[4] G. J. Foschini, H. Huang, K. Karakayali, R. A. Valenzuela and S. Venkatesan‘, “The Value of Coherent Base Station Coordination”, *Proceeding of 2005 CISS‘*, The John Hopkins University, March 16-18, 2005.

[5] T. Tamaki, K. Seong and J. M. Cioffi,“Downlink MIMO Systems Using Cooperation among Base Stations in a Slow Fading Channel”, *Proceeding of IEEE International Conf. on Communications 2007*, pp. 4728-4733, June 2007.

[6] “Collaborative MIMO”, http://www.ieee802.org/16/tgm/contrib/C80216m-07-244r1.doc

[7] J. G. Andrews, W. Choi and R. W. Heath Jr, ”Overcoming Interference in Spatial Multiplexing MIMO Cellular Networks”, *IEEE Wireless Communications Magazine*, vol. 14, no. 6, pp.95-104, Dec 2007.

[8] M. R. Ramesh Kumar, S. Bhashyam and D. Jalihal, “Throughput Improvement for Cell-Edge Users Using Selective Cooperation in Cellular Networks”, *To Appear in Proceeding of WOCN 2008‘*, Indonesia, May 5-7 2008.

[9] J. Akhtar and D. Gesbert, ”Extending Orthogonal Block Codes with partial feedback”, *IEEE Transactions on Wireless Communications*, vol.3, no. 6, pp.1959-1962, Nov 2004.

[10] G. Caire and S. Shamai,“On the Achievable Throughput of a Multiantenna Gaussian Broadcast Channel”,*IEEE Transaction on Information Theory*, vol.49, no. 7, pp.1691-1706, July 2003.

[11] *Urban Transmission Loss Models for Mobile Radio in the 900 and 1800 MHz bands*, EURO-COST 231 Std.