

Throughput Improvement for Cell-Edge Users Using Selective Cooperation in Cellular Networks

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Abstract—Cooperative transmission schemes are used in wireless networks to improve the spectral efficiency. In a multi-cell environment, inter-cell interference degrades the performance of wireless systems. In this paper, we study the downlink capacity of edge users in a cellular network and see whether base station cooperation improves the spectral efficiency. 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. Selective Cooperation, where the selection criteria is based on throughput, is proposed. The capacity achieved through Cooperation is shared equally among the cell-edge users. Results show that, the proposed hybrid scheme, provides a better result compared to full-time cooperation. Finally, an example from UMTS is presented.

Keywords: Cooperative transmission, MIMO, Capacity

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 and achieve higher data rates for cell edge users.

Cooperative transmission utilizes the inherent user diversity available in a multi-user environment to provide higher spectral efficiency [1–3]. In [1] and [3], cooperation among active users for the uplink channel in wireless networks is described. The active users under cooperation have its own information to transmit, and therefore, do not simply act as a mobile relay stations. Since the inter-user link is also a noisy channel, there is a possibility that the information received by a user from the other user is corrupted. In [3], coded cooperation is proposed where each user decodes the signal of the other user that needs to be relayed, and will relay only if it is successfully decoded. In case of unsuccessful decoding,

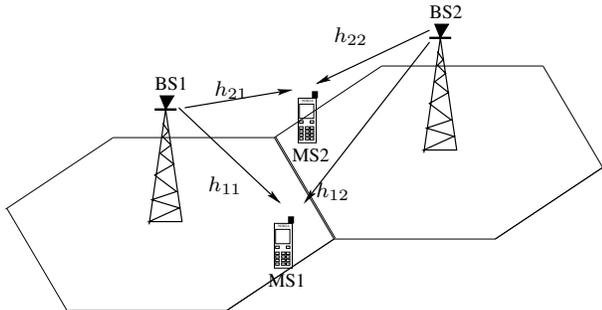
the users go to non-cooperative mode. In [2], cooperative strategies like amplify-forward and decode-forward for adhoc or per-to-peer wireless networks are proposed. In [4], it is shown that the downlink efficiency can be improved using Coherent Coordinated transmission (CCT) from multiple base stations. Two types of coordination transmission are proposed, namely, Equal Rate using Zero Forcing and Equal Rate Using Dirty Paper Coding. In Equal Rate using Zero Forcing, the transmission from all base stations intended for a particular user do not interfere with other users. In the Dirty Paper Coding scheme, knowledge of the interference is used at the transmitter for coding. Comparison of different coordination schemes like full coordination, partial coordination and no coordination is presented in [5] for a downlink Multiple Input Multiple Output (MIMO) system in a slow fading channel. In the full coordination scheme, the transmit covariance matrix for all the possible downlink channels between base stations and the users is computed using Dirty Paper Coding by a central coordinator to provide maximum sum throughput, based on the Channel Quality Information (CQI) provided by the base stations. These covariance matrices are then sent to corresponding base stations. However, this entire process adds significant latency. A new partial coordination scheme, where the base stations transmit in Time Division Multiple Access (TDMA) mode is proposed in [5]. In the allotted slot, each base station transmit to its associated users using Space Division Multiple Access (SDMA).

Cooperative encoding and scheduling in a Networked MIMO system is discussed in [6], in order to suppress Other Cell Interference (OCI) and thereby achieve maximum capacity in MIMO downlink channel. In [7], 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. This leads to a question whether it is worth doing cooperation all the time, i.e., whether the performance gains are worth the cost addition in terms of the extra complexity added in the signal processing to perform cooperation.

In this paper, we analyse the cooperation scenario in a multi cell environment where the other cell interference is significant. The capacity achieved through cooperation is shared equally among the cell-edge users, i.e., resources are shared fairly among the cooperating users. The transmission rate to each user is determined based on the signal to interference

plus noise ratio (SINR). Cooperative transmission by two base stations can improve this SINR by transmitting jointly to one user at a time. However, the increase in terms of throughput may not always be enough to increase the throughput of each of the users. In such a scenario, we propose a selective cooperation scheme based on user throughput that provides better capacity than full cooperation. The downlink environment under consideration will not have any interference from users in the same cell. They are properly separated in time, frequency or code such that orthogonality exists. Inter-cell 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 SINR for different modes of Cooperation considered in this paper. Section 4 presents the cooperation selection algorithm and an example for UMTS. Section 5 presents the simulation results and conclusions are presented in section 6.



Frame #1 for BS1 transmission		Frame #2 for BS1 transmission	
MS1	MS2	MS1	MS2
MS1	MS2	MS1	MS2
Frame #1 for BS2 transmission		Frame #2 for BS2 transmission	

Fig. 1: System Model

II. SYSTEM MODEL

The basic system model and transmission protocol is as shown in Figure 1. Base stations BS1 and BS2 are the candidates 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.

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

A. No Cooperation

Under normal operation that is when there is no cooperative transmission, the signal to interference noise ratio (SINR) in the downlink for MS1 is given by

$$\text{SINR}_{\text{nc}} = \frac{|h_{11}|^2 E \{X_1^2\}}{\sigma_n^2 + \sum_{k=2}^{12} |h_{1k}|^2 E \{X_k^2\}} \quad (2)$$

where h_{ij} represents the the channel between the terminal i and base station j , $E \{X_i^2\}$ is the average transmit power of Base Station i , and σ_n^2 is noise variance.

The capacity (or throughput) for terminal MS1 in bits/sec/Hz can derived from the Shannon Capacity as

$$C_{\text{nc}} = \log_2(1 + b\text{SINR}_{\text{nc}}) \quad (3)$$

where, b is determined by the SNR gap between the practical coding scheme and the theoretical limit.

B. Cooperation

When terminal MS1 is in cooperation with BS1 and BS2, $\text{SINR}_{\text{coop}}$, SINR of the downlink channel will depend on the type of cooperation scheme. The details of different ways of combining the signal is presented in next section. The capacity (or throughput) for terminal MS1 under cooperation in bits/sec/Hz will be

$$C_{\text{coop}} = \alpha \log_2(1 + b\text{SINR}_{\text{coop}}) \quad (4)$$

The factor α in eq. 3 defines the proportion of resource sharing among the terminals under cooperation. In our system, considering resource fairness, the value for α is $\frac{1}{2}$.

III. MODES OF COOPERATION

In this section, we describe different modes of combining the two signal received by MS1 from base stations BS1 and BS2 for cooperation. The following schemes are considered and their SINR expression is obtained.

1) Cooperative MIMO

In this scheme, the base stations BS1 and BS2 together transmit information signal to MS1, thereby forming an Alamouti transmit diversity of order 2. This scheme is

referred in some literature as Network MIMO. The SINR expression for this scheme will be of form:

$$\text{SINR}_{\text{coop}} = \frac{(|h_{11}|^2 + |h_{12}|^2)E\{X_1^2\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\{X_i^2\}} \quad (5)$$

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:

$$\text{SINR}_{\text{coop}} = \frac{|h_{11} + h_{12}|^2 E\{X_1^2\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\{X_i^2\}} \quad (6)$$

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 [8]. The SINR expression for this scheme will be of form:

$$\text{SINR}_{\text{coop}} = \frac{(|h_{11}|^2 + |h_{12}|^2 + 2\Re(h_{11}^* h_{12}))E\{X_1^2\}}{\sigma_n^2 + \sum_{k=3}^{12} |h_{1k}|^2 E\{X_i^2\}} \quad (7)$$

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 [9]. 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.

IV. COOPERATION SELECTION

Under the resource fairness constraint, the users in the serving cell and the neighbour cell who decided to cooperate for an SINR improvement, will share the available resource (time, frequency or code) between them equally. Therefore, the individual user throughput is $\frac{1}{2}$ of the actual capacity of the cooperative transmission as in (4). Considering $b = 1$ in the capacity expressions (3) and (4), for a low SINR regime, as $\log(1 + x) \approx x$, for the user capacity in ‘‘Cooperation mode’’ to be atleast equal to what the same user could achieve under ‘‘No cooperation’’, the SINR in the former must be twice of the latter, i.e., should be ≥ 3 dB. The exact expression for the capacity (or user throughput) for cooperative scheme with resource constraint, to perform better than normal transmission, i.e., $C_{\text{coop}} > C_{\text{nc}}$ is shown below:

$$\frac{1}{2} \log(1 + b\text{SINR}_{\text{coop}}) > \log(1 + b\text{SINR}_{\text{nc}})$$

$$1 + b\text{SINR}_{\text{coop}} > (1 + b\text{SINR}_{\text{nc}})^2$$

$$1 + b\text{SINR}_{\text{coop}} > 1 + b^2\text{SINR}_{\text{nc}}^2 + 2b\text{SINR}_{\text{nc}}$$

$$\text{SINR}_{\text{coop}} > b\text{SINR}_{\text{nc}}^2 + 2\text{SINR}_{\text{nc}} \quad (8)$$

From the expression (8), for low SINR regime, our earlier approximation is valid. However, in the high SINR regime, the relationship between the two SINR is not linear, rather it is exponential. Even though, the SINR under cooperation ($\text{SINR}_{\text{coop}}$) is always better than the normal SINR (SINR_{nc}), the user throughput of former is not always better than the latter. Hence, it is worthwhile, for the user to decide whether to perform cooperation in the downlink channel. A brief description of the selection algorithm is given in Algorithm 1. This selection algorithm is of low complexity as it is approximation of the exact expression presented in (8) with $b = 1$. The user decides on cooperation with the measurements of its own channel and the nearest neighbor. The decision is informed to the base station of the serving cell. The serving station informs the neighbour station whether to do cooperation or not with a single bit information based on the input from the user. As an example, the sequence of operations required to do this selection algorithm in UMTS is given here and the message flow diagram is shown in Figure 2.

- **UE Initial State:** UE is allocated dedicated resources and is connected to Node B1 and RNC1 Called Controlling RNC (CRNC)
- **Step 1:** UE is given list of neighbouring cells and measurements to perform
- **Step 2:** UE triggers measurement report of neighbouring cells to network (RRC is situated in CRNC), if the pre-set conditions to add a cell from Node B2 (for cooperation) to the Active Set.
- **Step 3:** CRNC decides to add a new Radio Link in Node B 2 to the UE based on the available resources.
- **Step 4:** CRNC sends information to Node B 2 to set up resources for Transmission
- **Step 5:** Once Node B 2 is ready to Transmit, CRNC sends ActiveSetUpdate Message to UE. Active Set Update is the message to indicated addition/deletion of Radio links.
- **Step 6:** UE starts Reception on new Radio Link from Node B 2 together with that of Node B1.
- **Step 7:** UE sends Active Set Update Complete message.

V. SIMULATION AND RESULTS

A 19 cell full re-use multi-cell environment is simulated based on Monte Carlo methods to analyse the performance of user capacity and SINR for three transmission scenarios namely, *i*) Without Cooperation, *ii*) With Cooperation and *iii*) Selective Cooperation. Selective Cooperation is a hybrid scheme, where cooperative transmission is performed only if the (4) is greater than (3) as described in algorithm 1. 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 [10] 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

Algorithm 1 Cooperation Selection

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1: Get the channel measurement of the serving DL and
   nearest DL
2: Calculate the SINR under normal operation( $SINR_{nc}$ )
3: Calculate the SINR under cooperative transmission
   ( $SINR_{coop}$ )
4: case: Low SINR regime
5: for  $SINR_{nc} \leq 0$  do
6:   if  $SINR_{coop} > 2 * SINR_{nc}$  then
7:     Base stations goes to Cooperative Transmission State
8:   else
9:     Normal Transmission
10:  end if
11: end for
12: case: High SINR regime
13: for  $SINR_{nc} \geq 0$  do
14:  if  $SINR_{coop} > SINR_{nc}^2$  then
15:    Base stations goes to Cooperative Transmission State
16:  else
17:    Normal Transmission
18:  end if
19: end for

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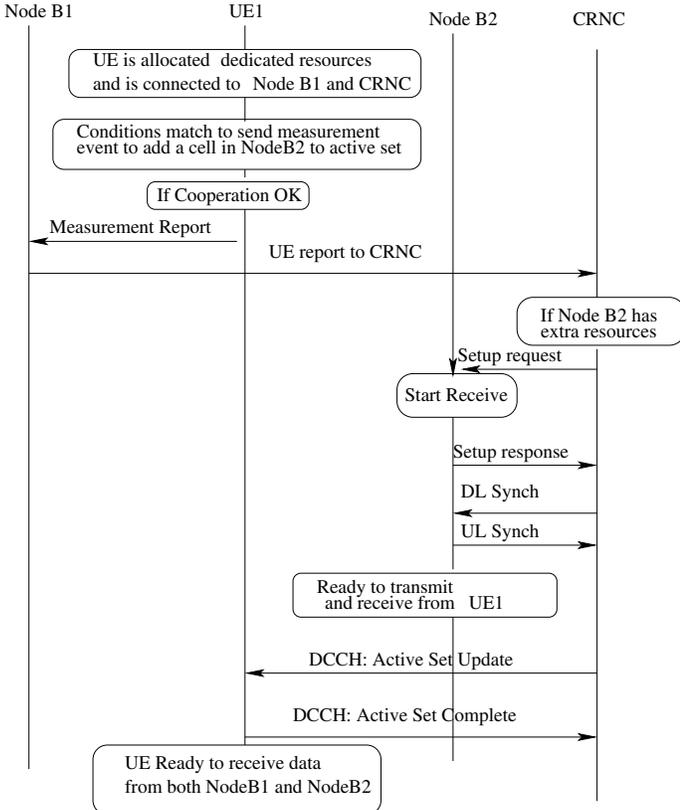


Fig. 2: Message flow for an Use Case in UMTS

TABLE I: Average Throughput for cell Edge user (bits/sec/Hz) for different Cooperation schemes

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

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.

Our observation from simulation revealed that with probability 0.45, the user throughput with out cooperation (3) is better than (4) for $\alpha = \frac{1}{2}$. Since, cooperation in a multi-cellular environment with full resource fairness is advantageous only half the time, it is better to do a hybrid transmission of both normal operation and cooperation that can give a better user throughput. Average throughput and SINR for cell edge user for different cooperative schemes is shown in Table I and II. Averaging is done over 10^5 frames for each combination of cooperative scheme and selection of cooperation. The observed values from the simulation given in the table, clearly shows the advantage of selective cooperation over full cooperation. Eventhough, the average SINR of Scheme 2 with cooperation is same as Scheme 1 with Selective cooperation, the capacity of the latter is better than the former. User throughput captured over 1000 frames for scheme 1 for full cooperation and selective cooperation is shown in Fig. 3. Throughput captured for first hundred frames is captured and shown in Fig.4, which depicts the fact that there are crossovers in user throughput for with and with out cooperation. Hence, selective cooperation is a better option to get maximum throughput.

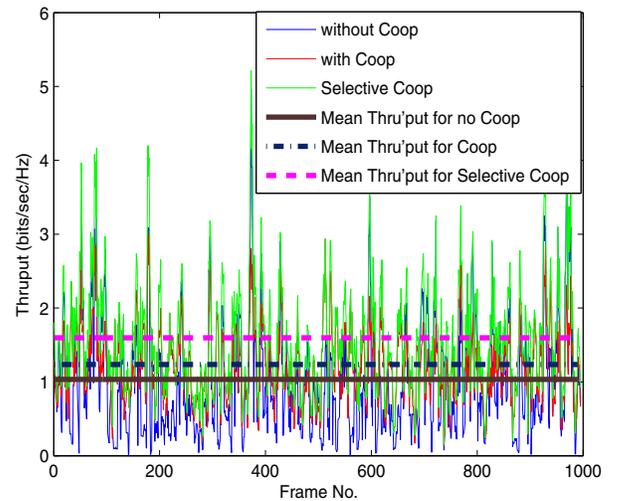


Fig. 3: User throughput for Scheme 1

TABLE II: SINR of cell Edge user (dB) for different Cooperation schemes

Type of Schemes	Scheme 1	Scheme 2	Scheme 3
Without Cooperation	-7.50	-7.50	-7.50
With Cooperation	3.52	2.79	4.70
Selective Cooperation	2.79	2.58	3.88

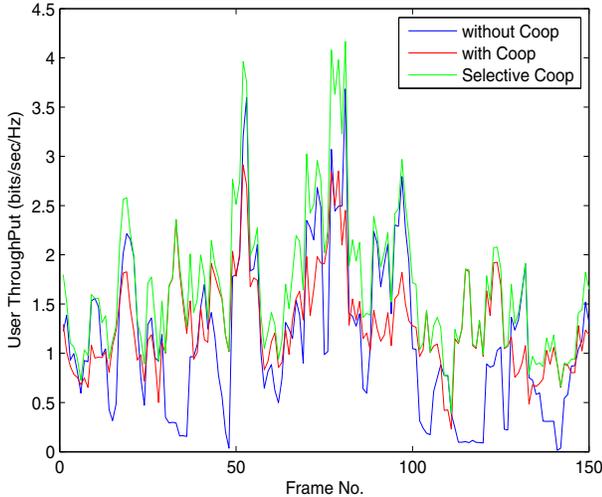


Fig. 4: Snapshot of User throughput for first 150 frames for Scheme 1

VI. CONCLUSIONS

In this paper, we presented simulation analysis of downlink cooperation in a multi-cell cellular network. In a resource fairness cooperation, the user capacity of a cell-edge user is not always better than normal transmission. The simulation results show that for almost half the time user capacity with cooperation is poorer than the capacity with normal operation. By doing a selective cooperation, both capacity and SINR is improved. The throughput improvement is about 33.3% from full cooperation to selective cooperation for same SINR. Also, for the same one-bit feedback overhead, selective cooperation with out phase feedback provides better throughput (an improvement of about 18.5%) for cell-edge users compared to one-bit phase feedback full cooperation scheme.

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