Multi-User Diversity in the Cooperative Transmissions

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Abstract— **Cooperative transmission ('virtual' MIMO) schemes can offer benefits in terms of diversity and/or multiplexing gain compared with conventional direct transmission. However, in a centralized packet delivery cellular system the multiuser gain also has to be considered. In this paper we evaluate how we can adapt proportional fair scheduling techniques to cooperative protocols and so evaluate the impact of the multiuser gain for such schemes. Then, we measure which is the global gain of cooperative transmission in a cellular system with respect to conventional transmission in terms of throughput and delay.**

***Index Terms*—Cooperative transmission, MIMO, Multi-User Diversity and Scheduling.**

I. INTRODUCTION

RECENTLY, cooperation between users has been considered as a promising solution for capacity increase in the downlink (DL) because of the associated diversity and/or multiplexing gain [1],[2]. Using cooperation, the link to mobile stations (MSs) performs as if they had additional "virtual" antennas thanks to those provided by the relay station (RS) and the base station (BS) [3]. Depending on the operating mode of the relay, cooperation methods may be classified into regenerative systems (Decode and Forward – D&F) and non-regenerative systems (Amplify and Forward – A&F) [2].

Assuming that the relaying stations will operate in half duplex, a centralized packet cellular system based on orthogonal access (TDMA) has been considered in this work. The system is made up of the BS, MSs and RSs with *M*, *N*, and *R* antennas respectively. In order to implement the cooperative transmission, see figure 1, there are slots reserved for direct transmissions (from the BS to MS, DL transmission) and one slot devoted for the relay transmissions. The cooperative transmission increases the capacity providing new virtual antennas. However, because of the additional transmission from the relay, the effective per-connection rate decreases unless we allow relays associated to different users transmit simultaneously. Note that we are transmitting to K users using K+1 time slots, there is a reuse factor of $\Pi = K/_{K+1}$. In case of a high number of users the reuse factor is $\Pi \approx 1$ and the effective rate per connection does not decrease. Of course, a new problem arises in the relay link (RL), which is the interference generated by the RSs associated to other users. An appropriate power control algorithm is required as a consequence. In [3] an algorithm based on game theory is proposed, showing significant cell capacity gains for circuit switched-type connections.

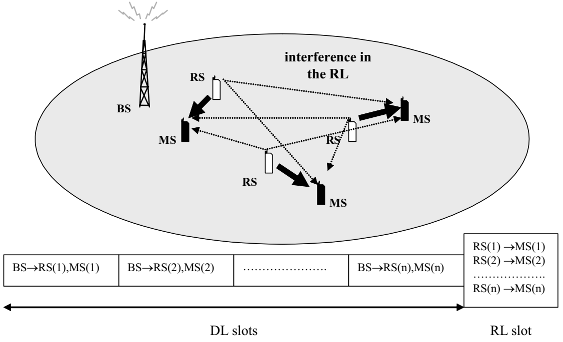

Figure 1.- Cooperative scenario with reuse of the RL. TDMA is assumed for the different users in the downlink. In the relaying slot, multiple RS-MS pairs are allowed to transmit simultaneously so interference is present

Additionally, in a downlink multiuser packetised MIMO system another gain to be considered is the multiuser gain [4]. This gain is achieved by assigning all the transmission resources to the user with the best instantaneous channel. Nevertheless, aspects related to the fairness among users also have to be considered. This task is performed by the scheduling algorithms. In the cooperative scenario the best instantaneous channel depends not only on the state of the BS-MS link but also on the selection of a suitable RS and which RSs are selected to simultaneously transmit in the RL. Consider for instance the TDMA in downlink cooperative transmission. Some time slots are assigned to DL transmissions, whereas in the relay slot, all RSs transmit simultaneously so that MSs have to combine the transmission in the DL with the transmission in the RL, see figure 1.

In this work we present redefinitions of the conventional scheduling algorithms to allow the cooperative transmission achieves multiuser gain and maintain some degree of fairness among users.

This paper is organized as follows. Section II describes the

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most common scheduling algorithms considered for the wireless networks and presents the challenges to take into account when cooperative transmission is considered. In section III the proposed solution is presented. Section IV is devoted to show the results in terms of throughput and individual inter packet delay of the users. Finally section V presents the conclusions.

II. SCHEDULING

Scheduling algorithms are important components in the provision of guaranteed quality of service parameters such as the efficient link utilization and fairness among the users. Basically, we have considered the *Proportional Fair* (PF). This algorithm requires the channel state information (CSI) for all MSs. Its performance in terms of multiuser gain and fairness can be adjusted. The MS in the time *n* is selected according to the following criterion:

$$i^* = \arg \max_{i \in \{1,\ldots,N_{users}\}} \frac{C_i(n)}{T_i(n)} , \qquad (1)$$

where C$_i$(n) and T$_i$(n) are the instantaneous capacity and the average throughput served of the *i-th* user respectively. The average throughput is measured using a exponentially decaying window and is given by,

$$T_i(n+1) = \begin{cases} (1-\alpha)T_i(n) + \alpha C_i(n) & i = i^* \\ (1-\alpha)T_i(n) & i \neq i^* \end{cases} , T_i(0) = 1 . \qquad (2)$$

Depending on the value of α in (2), the PF performance is similar to the *Round Robin* (RR) performance for α=1 (the best fairness without multiuser gain). Moreover, for α=0 it has a Greedy scheduler performance (only multiuser gain). For intermediate values of α the performance is something between both.

These algorithms are usually applied in the DL scenarios with direct transmissions. However, when taking into account the cooperative transmission proposed in figure 1, our scenario also presents cochannel interference in the RL. In [5] these scenarios with interference are analysed showing the benefits in terms of throughput of a suitable power control. In [6], an ad-hoc scenario is contemplated and the interference is mitigated by means of the scheduling process, which selects the most suitable users, along with power control. Similarly, for cooperative transmission schemes we need to cope with the interference in the relay slot. Then, the scheduling algorithm should consider the following aspects:

- **Reuse Factor**: In order to increase the efficiency of the relay link slot, a cell-wide high reuse of this link is desirable.
- **RS selection**: The interference level of the RS needs to be minimized by means of a suitable relay selection and power control.
- **CSI of the cooperative link**: The CSI of every user should be known at the scheduler for the greedy and the proportional fair cases. A feedback channel is assumed.

III. PROPOSED SOLUTION

The search space between the powers and the suitable RS selection in function of the others selected MS in the frame grows in an exponential manner with the total number of users in the cell. Therefore a suboptimal solution is proposed by dividing the problem in three phases: Neighbor search, Admission control and Scheduling.

A. Neighbor search and RS selection

It is assumed that an underlying probing protocols is present allowing the exchange of broadcast information among neighboring terminals, as in [7]. In this phase we consider that every MS choose the RS as nearest idle terminal, in order to mitigate the generated interference. The distance r_0 between MS and the closest selected RS is a r.v. depending on the user cellular density, ρ. Its probability density function (pdf) assuming a circular cell with uniformly distributed users is assumed to be,

$$f_1(r_0) = 2\pi\rho r_0 \exp\left(-\rho\pi r_0^2\right) . \qquad (3)$$

Therefore, in the following phases of the algorithm the MS and RS can be considered as the same "entity". In this work we have considered that the pair RS-MS is fixed for the duration of the simulation (which is realistic for low mobility scenarios).

B. Admission Control for Cooperative Transmission

During the second phase, the decision of which pairs transmit simultaneously and their respective power level is carried out. First, the power of the simultaneous transmitting relays is adjusted using the game theory-based iterative distributed algorithm in [3] and briefly described below. Also, the BS decides which are the active relay-user pairs in a given relay slot.

1) Relay power adjustment

The game in [3] is a non-cooperative game, where each user computes and tries to maximize its own utility function. Here, the utility function considered is:

$$u(\mathbf{p}) = \frac{\tilde{I}_k(p_{r(k)}, \mathbf{p}_{r(-k)})}{p_{r(k)} + P_{BS}} \quad (bits / Joule), \qquad (4)$$

The utility function maximizes the average number of transmitted successfully bits per unit of energy, since $\tilde{I}_k$ is the approximation of the ergodic mutual information for the *k*–th user and $p_{r(k)} + P_{BS}$ is the total power used in the cooperative transmission, including the power spent by the base station and the relay station. Note that the utility function depends on the actions of the other users since $\tilde{I}_k$ depends of the measured interference (hence the dependence on **p**). [3] shows that this game has at least one equilibrium point. The analysis is not simple due to the non-linearity of equation (4) but it has been practically observed that this point is always the same. Additionally, this equilibrium point is reached with fast convergence (typically less than 10 iterations).

2) *Admission*

This process is performed over control channels (grey boxes in figure 2). A low amount of data needs to be exchanged between each RS-MS pair: only the power transmitted by the relay and optionally the BS-RS channel condition, for this reason it will be possible to use only a part of 1 TDD slot.

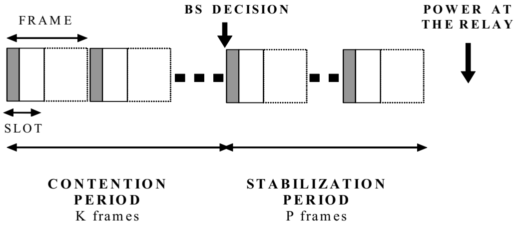

Figure 2.- Admission control

Within the admission control process we consider three phases: the *contention* period, *selection* of active pairs by BS and the *stabilization* period, as it is shown in figure 2.

- **Contention period:** Here all the pairs RS-MS play the game of the power control described in (4) using DL and RL own measures to compute the utility function. Specifically, the MS does the following tasks:
  - It estimates the RS-MS channel and the interference, taking into account that each RS uses different midambles (sequences with good auto/cross- correlation properties).
  - It calculates the power level of its associated RS that maximizes (4).
  - It transmits to the RS the new power level for the next iteration. This communication can be done using another sub-slot in the same frame (interfering channel) or through the BS (assuming that exist another broadcast control channels between the BS and the pair RS-MS).

  This process is done during *K* frames. Note that in each frame only 1 sub-slot is used for the admission process, therefore the remaining slots are devoted to other tasks. After that, some pairs will have selected a relay power equal to zero in case of cooperative transmission is not useful due to the interference of the relay link. Therefore, the set of pairs candidate to share a given relay link will have been obtained in a distributed way.

- **Centralised selection of pairs:** Due to the limited number of DL slots, only a fixed maximum number of users, N_{coop}, can be allocated in a same frame. For this reason the BS needs to select the best pairs with the maximum obtained cooperative capacity within the candidate set to share the relay link. Note that N_{coop} is a configurable parameter which has to be studied in the simulations section.

- **Stabilization period:** After the BS has selected the best N_{coop} pairs and informed to everybody about its decision, the power control game has to be played again with N_{coop} pairs during *P* frames, note that the scenario has changed. The power levels obtained at the end of this phase will be fixed during the cooperative transmission of packets until the next admission control.

Additionally, the use of G sub-slots will allow the construction of G disjoint cooperative groups simultaneously. Therefore the scheduler has to select among the different cooperative groups. Note that G depends on the number of the total users and N_{coop}.

C. *Scheduling using TDMA*

Once the admission control has finished (after K+P+1 frames), the cooperative scheduling is executed. In this work it is considered that the scheduling process is performed in each frame. The slots required per frame devoted to cooperative scheduling are showed in figure 3. The frame has a control part, composed of the RL sub-slots where the instantaneous cooperative capacity is measured (all cooperating RS transmit simultaneously) and the UL slot devoted to inform the BS about cooperative and DL metrics. Moreover the frame also has data part, composed of slots devoted to cooperative transmission and slots reserved only for direct transmission. This partition is based on the number of cooperating users of selected group, $N_i \leq N_{coop}$. Moreover, there will be users which are not allowed to transmit in cooperative way. These users will be served anyway only in the downlink.

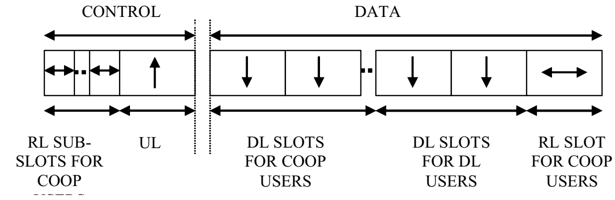

Figure 3.- Frame structure

The scheduler decides the amount of temporal resources assigned to each, but applied to the groups instead to applying to single users. The information received by the scheduler is:

- The instantaneous capacity of all the users only in the DL
- The instantaneous capacity of the cooperative users.

With this information the scheduler decides which users to transmit in the data part. The algorithms of section II need however be modified to take into account the cooperative transmission:

- **Cooperative-PF**: The best group of cooperative users is selected taking into account as metric the average PF metric per group:

$$g^* = \arg\max_{g\in\{1,..G\}} \frac{1}{N_g}\left(\sum_{k=1\ldots N_g} \frac{C_k^g(n)}{T_k^g(n)}\right), \qquad (5)$$

  with T_k^g the average served throughput for the *k*-th user in the g-th group (2). Additionally, for the direct transmissions, also the users from the cooperating groups which do not have been selected are taken into account, although using their DL capacity

IV. SIMULATIONS

For the simulations a square area of 900x900 m^2 has been considered. The BS is at the center of the cell using M=2 omnidirectional antennas with transmission power of 29 dBm. MSs are uniformly distributed in the cell with N=1 antenna each, although the cooperative transmission can double the virtual receiving antennas. The cellular density is ρ=1e-3 users/Km^2. The RSs are around the MSs according to (3) and they have R=2 antennas with a maximum transmission power equal to 23 dBm. The distance loss model has been obtained from [8], which takes into account the LOS and NLOS events and the shadowing effect. A Rayleigh flat fading channel has been assumed (uncorrelated between consecutives frames). All the users have infinite loaded queues The Decode and Forward protocol has been considered for cooperative transmissions. Results have been obtained from 200 independent runs scenarios of 60 users and using G_{max}=5 groups for cooperative transmissions. For simplicity of presentation one packet of information is transmitted in each timeslot. There are 10 of 15 slots/frame devoted for DL and cooperative transmissions (9+1 RL). The remaining ones are reserved for uplink and control data transmissions. The PF algorithm has simulated for: α=0.9 (enhance the fairness), α=0.01 (*greedy performance*) and α=0.06.

In figure 4 the cellular throughput is depicted for the NC-PF and C-PF for different values of α. It can be observed that for α=0.9 and 0.06 the C-PF improves the total throughput. That performance is due to the multiplexing gain obtained by the virtual MIMO. However, for α=0.01, the C-PF is not able to achieve a throughput better than NC-PF, because the cooperative groups are obtained from mean values of the channel and the selected users could not be optimal for instantaneous values.

Figure 5 shows the mean throughput served per user with regard to the distance between the BS and the MS. Cooperative transmission improves the throughput for α=0.9 and 0.06. However, for α=0.01 the throughput of closer users is worse than the NC-PF, see in figure 6 the throughput cdf at 150 meters. For farer users the throughput is improved, see figure 7, where an increase of 0.03 bits/s/Hz is obtained by the C-PF. In these figures it can be observed the effect of LOS/NLOS in the throughput of the selected users (step curves for NC-PF). At 120 meters around 50% of the users are in LOS obtaining high throughput values, whereas at 450 meters there are only 10% of the users.

In figure 8 results in terms of inter-packet delay cdf are presented. It can be seen that NC-PF α=0.01 presents high inter-packet delays due to the users with the worst channels. The C-PF increases the fairness among the users with regard to the NC-PF.

Finally, in figures 9 and 10 the maximum number of users in the cooperating groups (N_{COOP}=5, 7 and 9) has been modified in order to improve the throughput and the fairness (inter-packet delay). Reducing the number of cooperating users per group the reuse factor is decreased, however the slots devoted for direct transmissions can be better used for those users with excellent DL channels. It can be seen how for N_{COOP}=9 users, the fairness is the best, but allowing N_{COOP}=5 the throughput is improved at the cost of the fairness.

V. CONCLUSIONS

In this work we have presented the main aspects to take advantage of the multiuser gain in cooperative schemes. We have presented a suboptimal solution based on three phases: neighbor search, admission control and scheduling. Results show how cooperative transmission improves cellular throughput compared with non-cooperative schemes for high values of α. Cooperation allows increasing the fairness among users. Results show a tradeoff between the reuse factor (maximum number of cooperating users) and multi-user gain.

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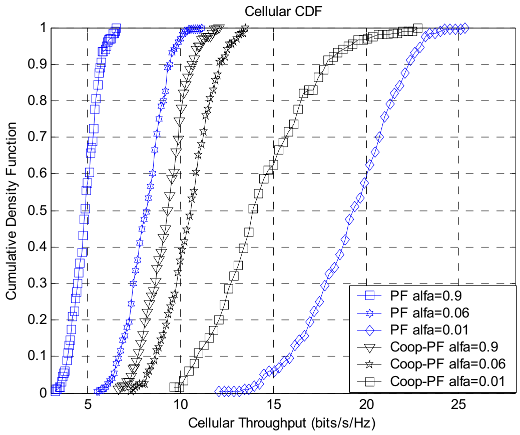

Figure 4.- Cellular Throughput. Maximum number of cooperating users N_{COOP}=7.

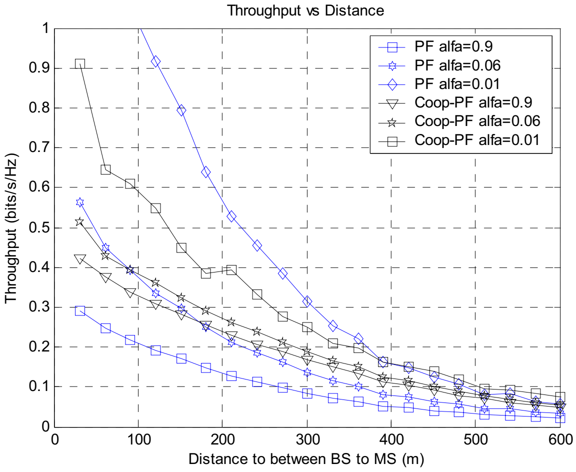

Figure 5.- Throughput served vs Distance. Maximum number of cooperating users $N_{COOP}=7$

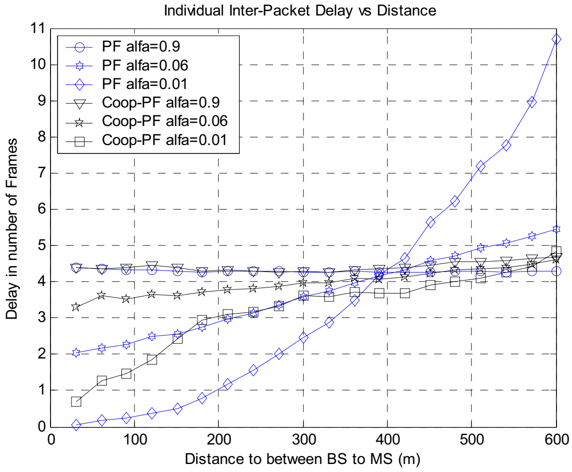

Figure 8.- Inter-packet Delay vs Distance. Maximum number of cooperating users $N_{COOP}=7$

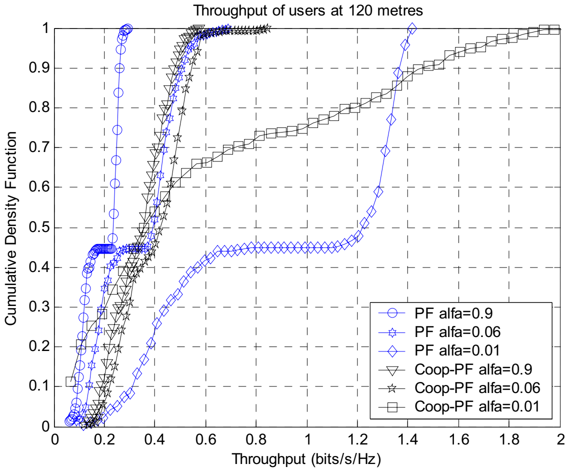

Figure 6.- Throughput CDF at 120 meters. Maximum number of cooperating users $N_{COOP}=7$

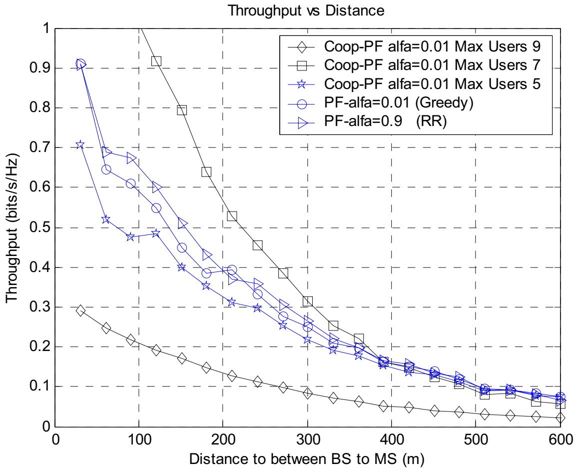

Figure 9.- Throughput vs Distance. Different number of cooperating users

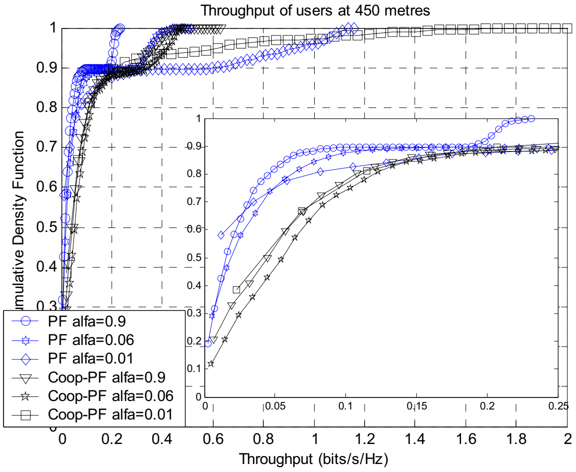

Figure 7.- Throughput CDF at 450 meters. Maximum number of cooperating users $N_{COOP}=7$

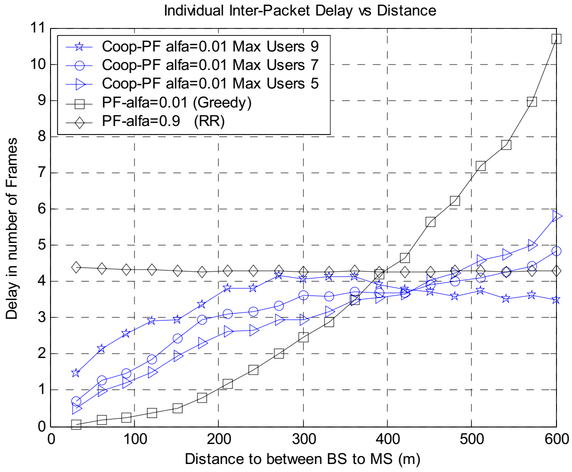

Figure 10.- Inter-Packet Delay vs Distance. Different number of cooperating users.