

COORDINATION AND COOPERATION FOR NEXT GENERATION WIRELESS SYSTEMS- OVERHEAD SIGNALLING REQUIREMENTS AND CROSS LAYER CONSIDERATIONS

Angeliki Alexiou and Federico Boccardi

Bell Labs, Alcatel-Lucent, UK
{alexiou,fb}@alcatel-lucent.com

ABSTRACT

In the evolution of wireless systems to the next generation, it is becoming increasingly important to offer substantial improvements, not only in terms of peak and average cell rates but also in terms of outage performance. To this end, interference management by means of coordination between different base stations and coverage/capacity improvements by means of cooperation with relays are considered potential candidate technologies. The introduction of multiuser MIMO processing principles and cross-layer optimized resource allocation may offer promising performance gains for coordination and cooperation but their feasibility depends on overhead signaling constraints and system deployment assumptions.

In this paper, we present two realistic approaches for coordination and cooperation, analyze their performance merits and discuss their complexity requirements.

Index Terms— Relays, intercell coordination, cooperation

1. INTRODUCTION

Future wireless systems are expected to support high data rates in a variety of scenarios and various Quality of Service (QoS) requirements under cost efficient and scalable deployment constraints.

A key enabling technology for achieving the required high spectral efficiency is the application of multiple input multiple output (MIMO) techniques, which exploit spatial diversity, array gain or spatial multiplexing gain. Another source of diversity – inherent to wireless systems- is that of the multiuser diversity. Multiuser (MU) MIMO algorithms combine both MIMO gains with multiuser diversity benefits [1]-[3]. Although MU MIMO techniques have been extensively studied and were shown to provide considerable average cell throughput gains, they often prove inadequate to cope with intercell interference and can only offer poor cell-edge performance.

Network coordination (multisite MIMO) can be applied in this case, which can achieve significant improvements for the users including those at the cell edge, based on coordinated transmission and reception by multiple base stations. Such an approach, however, would impose certain backhaul requirements that may prove critical for its implementation feasibility. To address this challenge, partial coordination was introduced, attempting to reduce backhaul requirements by means of applying coordination only in parts of the network (clusters) and/or by limiting the required signaling and data exchange between base stations at the expense of Channel State Information (CSI) accuracy and adaptation rate.

Furthermore, the paradigm shift from the traditional cellular/centralized to more heterogeneous/self-organized network deployment structures (e.g. femto cell, mesh networking, etc) calls for flexible/distributed alternatives to address challenges such as cell-edge rate requirements. To this end, relaying has been explored as a possibility for coverage/capacity improvements. As the potential enhancements offered by relaying heavily depend on the network deployment characteristics, the trade-off between performance gains and required cost/complexity and the associated business models have not been yet adequately understood.

To provide some insight on the relative merits between coordination and cooperation, we present two promising approaches, one for partial intercell coordination and one for user cooperation by means of information relaying. Both approaches rely on cross layer principles to minimize the complexity and fully exploit the available degrees of freedom. The associated signaling overhead is discussed and a comparative analysis of their system level performance in the presence of intercell interference is presented.

2. COORDINATION WITH MULTISITE MIMO

In conventional cellular networks intercell interference is usually addressed by frequency planning, soft handoff, intelligent receiver structures and resource allocation. High spectral efficiency requirements for future wireless systems,

both in terms of average cell and cell edge performance, impose more challenging targets for intercell interference management.

Network coordination has been proposed in [4] as a way to address this challenge by introducing coordinated transmission across base stations in the entire network. In this case the resulting performance is equivalent to that of a MU-MIMO system with a distributed antenna array consisting of all the antenna arrays on all base stations. More than a factor of 10 of improvements in spectral efficiency is reported in [4], when full coordination and 4x4 antenna systems are assumed, compared to the baseline of uncoordinated transmissions with single antenna terminals. These impressive enhancements can only be realized under the assumptions of perfect channel knowledge (for all interfering channels) and sufficient backhaul bandwidth to allow for the exchange of control and data signaling among all base stations.

To address realistic backhaul constraint, coordination is applied in [5],[6] only to a subset of selected users, achieving the best possible capacity and fairness under certain backhaul requirements. The *grouping of users* is implemented considering only average and not instantaneous CSI. Partial coordination in the form of *cell clustering* is studied in [7]. As opposed to the static approach, dynamic clustering is proposed in [8], where for the users scheduled to be served at each time slot, the best cluster of base stations is selected for coordination.

The challenge of multisite MIMO is to identify a framework for optimization of the tradeoff between network coordination gains and backhaul signaling requirements. The main parameters involved in this optimization are the effective network size selection (static/dynamic clustering) and the coordination decision metrics and their granularity (instantaneous/average CSI, SINR/fairness, etc).

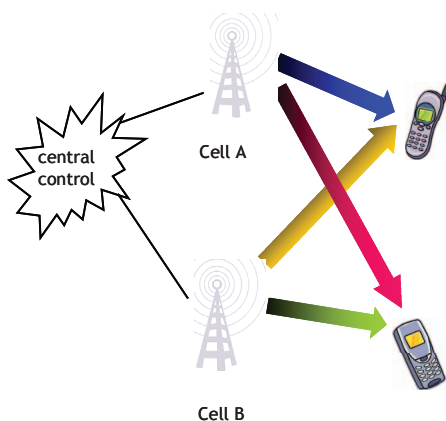


Figure 1 Intercell coordination (Multisite MIMO concept)

2.1. Dynamic MAC coordination

In the dynamic MAC coordination approach proposed in [9], the clustering of base stations and scheduling of users, performed by a central control unit, is based on the CSI – instantaneous estimates of which are sent by the base stations – and the scheduling requirements. Clustering and user selection decisions are made to achieve maximum sum-rate, taking into account also other QoS criteria imposed by the scheduler requirements.

In order to evaluate the sum-rate obtained using a certain clustering and user group, the algorithm needs to calculate the beamforming coefficients and the power allocation. The central unit then sends to the base stations the beamforming coefficients, the power allocation, the indices of the coordinated cells and of the selected users. The base stations share data only within each coordination cluster.

The proposed approach allows for substantial reduction of the required signaling compared to the full coordination, due to data sharing limited in this case by the cluster size, as opposed to the entire network in the full coordination case. It should be noted here that data sharing in coordination represents, under low Doppler conditions, the 90% of total required backhaul traffic overhead.

3. COOPERATION WITH RELAYS

The use of relays is targeting –at a first degree – the range extension and coverage optimization. Since full-duplex relaying implementation is considered not feasible, half-duplex relaying immediately introduces a factor of $\frac{1}{2}$ in the achievable throughput, meaning that the use of relaying alone can provide coverage enhancements at the expense of the overall capacity.

The introduction of multiple antenna processing at the relay nodes was investigated as a means to improve the spectral efficiency of relay networks by exploiting spatial multiplexing, diversity and interference mitigation gains [10][11]. Furthermore, MIMO concepts have been extended to a cooperation framework [12], where protocols are designed applying space-time processing across different relay nodes, in a form of a distributed MIMO approach.

The notion of *multi-hop diversity* to enhance link reliability in diversity-limited fading environments is discussed in [13]. Cross-layer aspects are further explored in [14] on how to exploit multiuser diversity in a relay-assisted cellular scenario. These studies exemplify the fact that performance optimization, in terms of both coverage and throughput-delay, of a multihop network is a *cross-layer problem* of jointly designing the transceiver, relay protocol and resource allocation / routing schemes.

In this paper we consider a simple but effective half-duplex relay. For a given user the achievable rate is calculated as a maximum between the rate achievable with

direct transmission between base station and user, and the rate obtainable by selecting the best possible relay. To calculate the maximum rate we define the following thresholds

$$\begin{aligned} R_{BU} &= \log_2 (1 + SINR_{B \rightarrow U}) \\ R_{BR} &= 0.5 \log_2 (1 + SINR_{B \rightarrow R}) \\ R_{RU} &= 0.5 \log_2 (1 + SINR_{R \rightarrow U}) \\ R_{best\ relay} &= \max_{R \in \Psi} \min(R_{BR}, R_{RU}) \end{aligned}$$

where $SINR_{B \rightarrow U}$, $SINR_{B \rightarrow R}$ and $SINR_{R \rightarrow U}$ are the signal to noise plus interference ratio values at respectively the user side for the base's transmission, at the relay side and at the user side for relay's transmission, and Ψ is the set of users that are willing to cooperate. The maximum rate is given by

$$\max(R_{BU}, R_{best\ relay}).$$

4. SYSTEM LEVEL PERFORMANCE COMPARISON

A system simulator has been developed with 19 single antenna base stations and wraparound. Each single-antenna user is dropped with uniform probability inside each cell. Fairness is guaranteed by a proportional fairness scheduler. A centralized scheduler is considered for the case of cell coordination, whereas for the case of no coordination (with and without relays) each base runs an independent scheduler. The SNR is defined as the reference SNR at the cell vertex. The channel model considers fast fading (i.i.d. fading), shadowing (with a standard deviation equal to 6 dB) and path loss (path loss exponent equal to 3.5) effect. The relays are randomly deployed in the network, and each user can select (opportunisticly, as a function of the instantaneous SINR) up to 1 relay. The transmit power at the relay side is 100 times less than the one at the base station.

In Figure 2 the performance of different schemes is shown in terms of average rate per user versus user index, under the assumptions of 30 users per cell, and reference SNR of 20 dB. In the case of full coordinated network, the 19 base stations cooperate together in order to serve up to 19 users at the same time. A zero-forcing algorithm with greedy user selection has been used, where the users are selected in order to maximize the weighted sum-rate [16] (the weights represent the proportional fair coefficients). The dynamic coordination approach [9] is simulated under two different assumptions:

- 1) 2 clusters of 9 and 10 bases dynamically created;
- 2) 10 clusters, nine of 2 cells and one of 1 cell dynamically created.

With respect to the full coordination case, assumption (1) allows for reduction of signaling in the backhaul due to data sharing of almost 50%, whereas assumption (2) allows

for reduction of signaling in the backhaul of about 90%. In both (1) and (2) the central control unit needs to know an estimate of the channel from each base station to each user. In TDD systems this estimation can be easily obtained at the base station side by exploiting channel reciprocity, whereas in FDD systems the channel must be estimated at the receive side, quantized and fed back to the base station.

The performance of a system without coordination between cells, but where relays are deployed in order to boost the performance of the users in outage, is also illustrated. We emphasize that the use of relays does not involve additional backhaul signaling. On the other hand, the feedback from relay to base station must be designed in order to allow an opportunistic-like scheduling at the base station side that takes into account the base to relay link, the base to user link and the relay to user link.

Finally, the base line of a system without coordination between cells and without relays deployed is assessed.

We firstly observe that the approach in [9] with 2 dynamically created clusters achieves a good fraction of the full coordination performance, while guaranteeing a backhaul reduction of almost 50%. When the number of clusters is increased to 10 the performance of the dynamic coordination drops significantly. The case of no coordination with relays achieves worse performance compared to the cases of full coordination and dynamic coordination with 2 clusters, but on the other hand it achieves the similar performance to that of the dynamic coordination with 10 clusters, with lower requirements on the backhaul signaling. We also observe that relays guarantee better performance for the users in outage with respect to the base line.

In Figure 3 a comparison between the same schemes is given in terms of cumulative distribution function (cdf) of the average rate per cell.

5. CONCLUSIONS

In this paper we considered the problem of interference management by means of coordination between different base stations and coverage/capacity improvements by means of cooperation with relays. The relative merits of different coordination and cooperation approaches have been analyzed in a realistic multicell system setup and their feasibility in terms of required overhead signaling was discussed.

Results were presented for a single antenna base station network with proportional fair scheduling but will be extended in future works to the multiple antenna case, in order to assess the impact of the additional degrees of freedom coming from the spatial dimension and investigate the performance enhancements resulting from cross-layer optimized resource allocation.

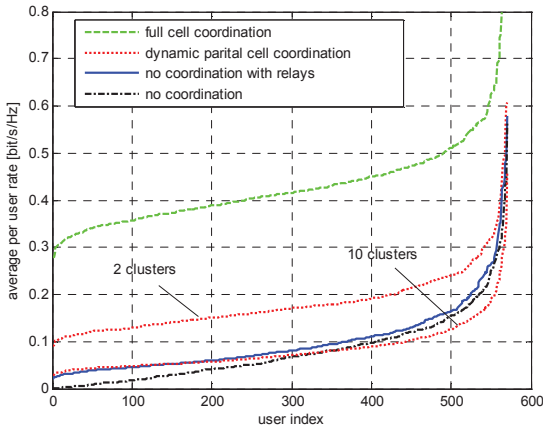


Figure 2. Performance of different schemes in terms of average rate per user vs user index, under the assumptions of 30 users per cell, and reference SNR of 20 dB.

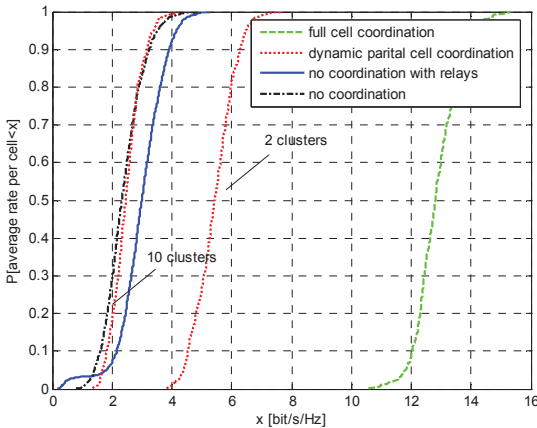


Figure 3. Performance of different schemes in terms of cdf of the average rate per cell.

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