Scheduling and Feedback Reduction in Coordinated Networks

Hans Jørgen Bang and Pål Orten

Abstract: **Base station coordination has received much attention as a means to reduce the inter-cell interference in cellular networks. However, this interference reducing ability comes at the expense of increased feedback, backhaul load and computational complexity. The degree of coordination is therefore limited in practice. In this paper, we explore the trade-off between capacity and feedback load in a cellular network with coordination clusters. Our main interest lies in a scenario with multiple fading users in each cell. The results indicate that a large fraction of the total gain can be achieved by a significant reduction in feedback. We also find an approximate expression for the distribution of the instantaneous signal to interference-plus-noise ratio (SINR) and propose a new effective scheduling algorithm.**

Index Terms: **Base station coordination, feedback reduction, scheduling.**

I. INTRODUCTION

The spectral efficiency of a cellular downlink is severely reduced by inter-cell interference (ICI). One promising way to tackle ICI is to allow the base stations (BSs) to coordinate their transmissions through joint processing [1], [2]. However, from a practical viewpoint, BS coordination presents some challenges. There will inevitably be an increase in feedback, backhaul load and computational complexity. Practical deployment of BS coordination therefore requires a compromise between performance and computational complexity.

A commonsensical way to limit the complexity is to divide the network into *coordination clusters* [3], [4]. With this approach, each BS and cell belongs to one cluster, and all coordination is constrained to occur within the same cluster. The BS transmissions can therefore be computed locally per cluster. In a practical implementation of cluster-based coordination, the BSs can either be inter connected by high-capacity links or they can communicate directly with a central cluster processor. The practicality of intra cluster coordination has increased further with the growing trend toward smaller cells in modern networks.

An inherent limitation with finite clusters is that interference originating from outside the cluster cannot be mitigated. This is especially problematic for users close to the cluster edge. In principle, one could envisage overlapping clusters [5]. However, distributed computation of beamforming vectors and power allocation for the downlink does not seem straight forward in the case of such a scheme.

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In this paper, we focus on the amount of channel state information (CSI) fed back by the users. Cluster-based coordination already has the advantage that users only feed back CSI pertaining to the BSs within their own cluster. Nevertheless, the amount of feedback is still an issue and there is a strong incentive to reduce the feedback load even further. Motivated by this we investigate the effect of constraining the feedback to a subset of the intra cluster BSs for each user. By adjusting the size of the subsets, we obtain a graceful trade-off between total throughput and feedback load.

The trade-off of capacity versus feedback for a network with three cells and round robin scheduling was evaluated in [6]. Here, we consider a larger network and focus on a scenario with opportunistic scheduling. The present paper builds partly on the previous work in [7]. In that regard, we considered network-wide coordination in the form of zero-forcing beamforming (ZFBF). In the present paper, we generalize much of the analysis to a clustered network with incomplete feedback. Notably, we find an approximate expression for the effective signal to interference-plus-noise ratio (SINR) and its distribution function. Based on this result we also formulate a new scheduling criterion.

We will assume throughout the text that the CSI is fed back with full resolution. Of course, in practice, some degree of quantization is a strict necessity. In fact, efficient quantization of CSI is essential for reducing the total feedback load [8]. Nevertheless, since the problem of feedback quantization is largely orthogonal to the selection of coordinating BSs, it will not be considered here.

II. SYSTEM MODEL

We consider the downlink of a wireless network with m cells. In each cell, there are n single-antenna users and one single-antenna BS. We assume intra cell time-division multiplexing (TDM) with synchronous time slots (scheduling intervals) across the network. The time slots are assumed to be sufficiently short for the channel coefficients to be constant within a slot, yet contain enough symbols to employ capacity-achieving codes. In the following, we will focus on an arbitrary symbol-transmission interval within an arbitrary time slot and omit explicit reference to time. The received signal for user k in cell i is given by

$$y_i(k) = \sum_{j=1}^{m} h_{ij}(k) x_j + z_i(k)$$

where x_j is the output from BS j, $h_{ij}(k) \in \mathcal{CN}(0, \beta_{ij}^2(k))$ is the corresponding fading gain and $z_i(k) \in \mathcal{CN}(0,1)$ is normalized Gaussian noise.

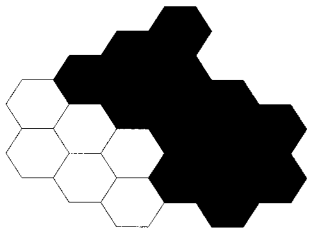

Fig. 1. Example of network with three cell clusters.

In each time slot, there is one user, denoted by k_i^*, which is scheduled in each cell i. Focusing on the scheduled users the relationship between the received signals $\boldsymbol{y} = (y_1(k_1^*)\ y_2(k_2^*) \cdots y_m(k_m^*))^T$ and the BS outputs $\boldsymbol{x} = (x_1\, x_2 \cdots x_m)^T$ can be expressed as

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{z} \tag{1}$$

where $[\boldsymbol{H}]_{i,j} = h_{ij}(k_i^*)$ and $\boldsymbol{z} = (z_1(k_1^*) \cdots z_m(k_m^*))^T$.

In order to satisfy a per-BS power constraint, we require $\mathbb{E}|x_i|^2 \leq \rho$ for each BS i.

III. CLUSTER-BASED COORDINATION

In the following, we consider a scenario in which each BS (and cell) belongs to exactly one coordination region or cluster. There are a total of L clusters, and the BSs in the lth cluster are denoted by $\mathcal{C}_l$. We can assume that the BSs are indexed in such a way that $\boldsymbol{x} = (\boldsymbol{x}_1^T \boldsymbol{x}_2^T \cdots \boldsymbol{x}_L^T)^T$ with $\boldsymbol{x}_l = \{x_i\}_{i \in \mathcal{C}_l} \in \mathbb{C}^{|\mathcal{C}_l| \times 1}$. The BSs within a cluster are interconnected and are able to coordinate their transmissions through linear preprocessing. In other words, for each cluster l there is a beamforming matrix $\boldsymbol{B} \in \mathbb{C}^{|\mathcal{C}_l| \times |\mathcal{C}_l|}$ such that

$$\boldsymbol{x}_l = \boldsymbol{B}_l \boldsymbol{s}_l$$

where $\boldsymbol{s}_l = \{s_i\}_{i \in \mathcal{C}_l}$. Here, s_i is the desired information symbol for user k_i^*.

A. Intra Cluster Zero-Forcing Beamforming

The performance of the system will now be largely dependent on the specific choice of beamforming matrices. As a starting point, we consider a strategy in which the beamforming matrices are selected to cancel the intra cluster interference completely. To this end define $\boldsymbol{H}_{lq} \in \mathbb{C}^{|\mathcal{C}_l| \times |\mathcal{C}_q|}$ to be submatrices of $\boldsymbol{H}$ such that

$$\boldsymbol{H} = \begin{pmatrix} \boldsymbol{H}_{11} & \boldsymbol{H}_{21} & \cdots & \boldsymbol{H}_{1L} \\ \boldsymbol{H}_{21} & \boldsymbol{H}_{22} & \cdots & \boldsymbol{H}_{2L} \\ \vdots & \vdots & & \vdots \\ \boldsymbol{H}_{L1} & \boldsymbol{H}_{L2} & \cdots & \boldsymbol{H}_{LL} \end{pmatrix}.$$

The intra-cluster zero-forcing beamforming matrix for cluster l can now be written in the form

$$\boldsymbol{B}_l = \boldsymbol{H}_{ll}^{-1} \boldsymbol{D}_l$$

where $\boldsymbol{D}_l \in \mathbb{C}^{|\mathcal{C}_l| \times |\mathcal{C}_l|}$ is diagonal. The vector of received signals, $\boldsymbol{y}_l = \{y_i\}_{i \in \mathcal{C}_l}$, is in turn given by

$$\boldsymbol{y}_l = \boldsymbol{D}_l \boldsymbol{s}_l + \sum_{\substack{1 \leq q \leq L \\ q \neq l}} \boldsymbol{H}_{lq} \boldsymbol{x}_q + \boldsymbol{z}_l$$

where $\boldsymbol{z}_l = \{z_i^*\}_{i \in \mathcal{C}_l}$. Thus, the received signal is composed of the desired signal, out-of-cluster interference and noise.

The matrix $D_l = \text{diag}\{d_1 \cdots d_{|\mathcal{C}_l|}\}$ must be selected to fulfill the power constraint. Specifically, a per-BS power constraint requires that the Euclidean norm of the rows of $\boldsymbol{B}_l$ be upper bounded by $\sqrt{\rho}$. Hence, the following matrix inequality must be satisfied.

$$\begin{pmatrix} |u_{11}|^2 & \cdots & |u_{1r}|^2 \\ \vdots & & \vdots \\ |u_{r1}|^2 & \cdots & |u_{rr}|^2 \end{pmatrix} \begin{pmatrix} |d_1|^2 \\ \vdots \\ |d_r|^2 \end{pmatrix} \leq \rho \begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix} \tag{2}$$

where $\{u_{ij}\}$ are the entries of $\boldsymbol{H}_{ll}^{-1}$ and $r = |\mathcal{C}_l|$ is the number of BSs in the cluster. A solution to this problem is guaranteed whenever $\boldsymbol{H}_{ll}^{-1}$ exists. For example by setting

$$d_k = \frac{\rho}{\max\limits_{1 \leq i \leq |\mathcal{C}_l|} \sum_{j=1}^{|\mathcal{C}_l|} |u_{ij}|^2}$$

for all $k = 1, \cdots, |\mathcal{C}_l|$ one obtains the max-min solution. Alternatively, one can attempt to maximize the sum rate by solving a non-concave maximization problem [9].

Here, we will require instead that all BSs transmit at full power, i.e., the inequality in (2) is replaced with an equality. A solution to this problem requires that the vector $\mathbf{1} = (1 \cdots 1)^T$ lie in the convex cone spanned by the columns of the matrix $\boldsymbol{U}_s = \{|u_{ij}|^2\} \in \mathbb{R}_+^{|\mathcal{C}_l| \times |\mathcal{C}_l|}$. Even though a solution cannot be guaranteed in general, we will argue later that a solution is likely given appropriate scheduling and a sufficiently high number of users.

B. Partial Intra-Cluster Zero-Forcing Beamforming

The construction of the local channel matrix $\boldsymbol{H}_{ll}$ at the network side requires that the users feed back all intra cluster CSI. For user k in cell i in cluster l this corresponds to the following set of coefficients $\{h_{ij}(k)\}_{j \in \mathcal{C}_l}$. In an effort to reduce the feedback load further we now consider an approach in which each user only feeds back CSI pertaining to a subset $\mathcal{F}_i(k) \subseteq \mathcal{C}_l$ of the intra cluster BSs.

An immediate effect of a reduction in feedback is that the channel matrix $\boldsymbol{H}_{ll}$ can no longer be completely constructed. A straightforward way to proceed is to set the unknown coefficients of $\boldsymbol{H}_{ll}$ to zero. Thus, the beamforming matrix in cluster l becomes

$$\hat{\boldsymbol{B}} = \hat{\boldsymbol{H}}_{ll}^{-1} \hat{\boldsymbol{D}}_l$$

where $\hat{\boldsymbol{H}}_{ll}$ results from $\boldsymbol{H}_{ll}$ by setting the missing coefficients to zero. The matrix $\hat{\boldsymbol{D}}_l = \text{diag}\{\hat{d}_1 \ldots \hat{d}_{|\mathcal{C}_l|}\}$ is uniquely determined by the matrix equation $\hat{\boldsymbol{U}}_s \hat{\boldsymbol{d}}_l = \rho\mathbf{1}$. Here, $\hat{\boldsymbol{d}}_l = (d_1 \cdots d_{|\mathcal{C}_l|})^T$ and $\hat{\boldsymbol{U}}_s = \{|\hat{u}_{ij}|^2\}$ where $\hat{u}_{ij}$ is the ij-entry of $\hat{\boldsymbol{H}}_{ll}^{-1}$. The use of the beamforming matrix $\hat{\boldsymbol{B}}_l$ leads to a partial cancellation of the intra-cluster interference. For example, assuming that $\hat{h}_{ij}$ is set to zero, the inter-cluster component of the received signal for user k_i^* is

$$\begin{aligned} (\boldsymbol{H}_{ll}\boldsymbol{x}_l)_i &= ((\hat{\boldsymbol{H}}_{ll} + h_{ij}\boldsymbol{E}_{ij})\hat{\boldsymbol{B}}_l \boldsymbol{s}_l)_i && (3) \\ &= \hat{d}_i s_i + h_{ij} \sum_{k=1}^{|\mathcal{C}_l|} \hat{b}_{jk} s_k && (4) \end{aligned}$$

where $e_i \in \mathbb{R}^{|\mathcal{C}_l|}$ is the ith column of the identity matrix. Thus, the interference part of the signal from BS j does not cancel when $j \notin \mathcal{F}_i(k_i^*)$.

The strategy of setting unknown channel coefficients to zero is introduced here as a heuristic. Nevertheless, it seems unlikely that there can be any superior strategy in the absence of relevant channel information. Setting an unknown channel coefficient to any other numerical value will tend to increase the interference if the true and estimated value is uncorrelated.

IV. Scheduling and Allocation of Feedback Resources

The inter-dependence of the user rates in coordinated networks poses a challenge in realizing effective scheduling. Ideally, the scheduled users within a cluster should be selected jointly. For most interesting performance metrics, optimal scheduling even requires a complete search through all scheduling combinations. Thus, with several cells in each cluster and multiple users in each cell optimal scheduling quickly becomes unattractive. We therefore propose a less ambitious approach in which the scheduling decisions for each cell are made independently. To achieve this, we derive first an approximate expression of the SINR that does not rely on the scheduling decisions in other cells.

A. An Approximate Expression of the SINR and its Distribution

Let us consider cell i in cluster l and assume that user k is scheduled. The received signal can be written as

$$y_i(k) = \underbrace{\sum_{j\in\mathcal{F}_i(k)} h_{ij}(k)x_j}_{Y_1} + \underbrace{\sum_{j\in\mathcal{N}\setminus\mathcal{F}_i(k)} h_{ij}(k)x_j}_{Y_2} + z_i(k)$$

where $\mathcal{N} = \{1, 2, \cdots, m\}$. Assuming partial ZFBF, the first part Y_1 is the zero-forcing part and therefore contains no net interference. The second part Y_2 is composed of the inter- and intra-cluster interference in addition to a signal component. As an approximation of the total interference power, I we use

$$I \approx \phi_i^I(k) := \rho \sum_{j\in\mathcal{N}\setminus\mathcal{F}_i(k)} |h_{ij}(k)|^2 \quad (5)$$

which (i) assumes that the signal part of Y_2 is negligible and (ii) neglects the fact that there will be some degree of constructive or destructive combining. As an estimate of the received signal power S, we propose

$$S \approx \phi_i^S(k) := \rho\Big[|h_{ii}(k)|^2 - \sum_{j\in\mathcal{F}_i(k)\setminus i} |h_{ij}(k)|^2\Big]_+ \quad (6)$$

where $[x]_+ = \max\{x, 0\}$. The intuition behind the expression is that the interference canceled by zero-forcing leads to a reduction in useful signal power. A more detailed discussion is provided elsewhere [7]. Finally, by combining (6) and (5), we obtain an estimate of the SINR after partial zero-forcing,

$$\phi_i(k) := \frac{\phi_i^S(k)}{1 + \phi_i^I(k)}. \quad (7)$$

We should point out that the above expression is a rough estimate that is unreliable for a wide range of channel scenarios. Nevertheless, we will demonstrate numerically in Section V that $\phi_i(k)$ is accurate when the channel to the host BS is stronger than that to the neighboring BSs. The intuition behind this result is that the impact of the power penalty and the received interference power (and therefore the modeling error) will be small whenever $|h_{ii}(k)|^2 \gg \sum_j |h_{ij}(k)|^2$.

It turns out that the cumulative distribution function (CDF) of $\phi_i(k)$ can be expressed in closed form. We have the following result.

Proposition 1: The CDF $F_{\phi_i(k)}$ of $\phi_i(k)$ is

$$F_{\phi_i(k)}(x) = 1 - \frac{e^{-\frac{x}{\rho\beta_{ii}^2(k)}}}{\prod_{j\in\mathcal{F}_i(k)\setminus i}\left(1 + \frac{\beta_{ij}^2(k)}{\beta_{ii}^2(k)}\right)\prod_{q\in\mathcal{N}\setminus\mathcal{F}_i(k)}\left(1 + \frac{\beta_{iq}^2(k)}{\beta_{ii}^2(k)}x\right)}$$

for $x \geq 0$ and $F(x) = 0$ for $x < 0$.

Proof: Let $\mathcal{I} := \mathcal{N}\setminus\mathcal{F}_i(k)$ and let $F_{\phi_i(k)}(x|\{y_q\}_{q\in\mathcal{I}})$ denote the CDF of $\phi_i(k)$ conditioned on $|h_{iq}(k)|^2 = y_q$ for $q \in \mathcal{I}$. By marginalizing over $\{y_q\}_{q\in\mathcal{I}}$ we have

$$F_{\phi_i(k)}(x) = \int_{\mathbb{R}_+^{|\mathcal{I}|}} F_{\phi_i(k)}(x|\{y_q\}_{q\in\mathcal{I}}) \prod_{q\in\mathcal{I}} f_{iq}(y_q)dy_q$$

where $f_{iq}(y)$ is the probability density function (PDF) of $|h_{iq}(k)|^2$. In [7], it was shown that Proposition 1 holds for $\mathcal{I} = \emptyset$, in which case $\phi_i(k) = \phi_i^S(k)$. Since $F_{\phi_i(k)}(x|\{y_q\}_{q\in\mathcal{I}}) = F_{\phi_i^S(k)}(x(1 + \rho\sum_{q\in\mathcal{I}} y_q))$, where $F_{\phi_i^S(k)}(x)$ is the CDF of $\phi_i^S(k)$, it follows that

$$F_{\phi_i(k)}(x) = \int_{\mathbb{R}_+^{|\mathcal{I}|}} \left[1 - \frac{e^{-\frac{x(1+\rho\sum_{q\in\mathcal{I}} y_q)}{\rho\beta_{ii}^2(k)}}}{\prod_{j\in\mathcal{F}_i(k)\setminus i}\left(1 + \frac{\beta_{ij}^2(k)}{\beta_{ii}^2(k)}\right)}\right] \prod_{q\in\mathcal{I}} \frac{e^{-y_q/\beta_{iq}^2(k)}}{\beta_{iq}^2(k)} dy_q.$$

The result now follows from straightforward integration. □

B. Scheduling

A key property of $\phi_i(k)$ as an approximation of the SINR is its independence on the scheduling decisions of neighboring cells. This is a useful property in relation to distributed scheduling. A straight forward approach is to apply $\phi_i(k)$ directly as a scheduling metric. Thus, the users are scheduled according to

$$k_i^* = \arg\max_{1\leq k\leq n} \phi_i(k) \quad (8)$$

in each cell i. This is a natural strategy if the objective is to maximize the per-cell sum rate.

The drawback with (8) is that some users receive a disproportionate share of the system resources. In order to achieve a fair allocation of resources there must be some form of normalization of $\phi_i(k)$ prior to its use as a metric. In this paper, we will use the probability integral transform to this end [10]. With this approach the users are scheduled according to

$$k_i^* = \arg\max_{1\leq k\leq n} F_{\phi_i(k)}(\phi_i(k)) \quad (9)$$

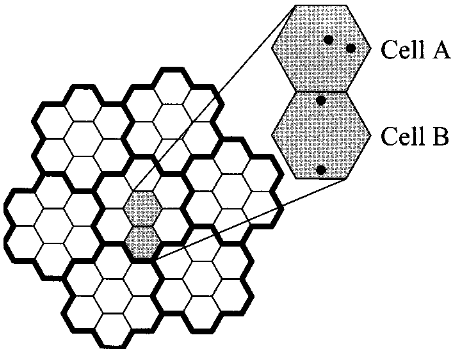

Fig. 2. Network layout used in the simulation examples. The dots in the magnified section indicate the positions of four test users. The users are indexed as 1 to 4 from top to bottom. The other users are uniformly distributed within each cell.

in each cell i. This scheduling strategy has been referred to as "CDF-based scheduling" in the literature and has the desirable property that all users are allocated the same fraction of time slots [11]. Another noteworthy characteristic is that the distribution of $\phi_i(k)$ given that user k is scheduled is given by its own order statistics. Specifically, we have

$$\phi_i(k|k=k_i^*) \overset{d}{=} \max\{\phi_i^{(l)}(k)\}_{l=1}^n$$

where $\{\phi_i^{(l)}(k)\}_{l=1}^n$ are n independent copies of $\phi_i(k)$ and $\overset{d}{=}$ denotes equality in distribution. From the theory of order statistics it follows that the CDF of $\phi_i(k|k=k_i^*)$ is [12]

$$F_{\phi_i(k|k=k_i^*)}(x) = \left[F_{\phi_i(k)}(x)\right]^n. \quad (10)$$

The above scheduling metrics can be extracted from the channel coefficients already fed back from the users. However, one can also envision a two-step approach in which each user first feeds back the scheduling metric and then only the scheduled user feeds back the required channel coefficients.

The use of $\phi_i(k)$ as a scheduling metric will ensure with high probability that the per-BS power constraints can be met with equality when the number of users grows large. This is because the ratio of diagonal to non-diagonal components for the channel matrix $\boldsymbol{H}_{ll}$ will tend to be large. This will carry over to its inverse $\boldsymbol{H}_{ll}^{-1}$ and in turn $\hat{\boldsymbol{U}}_s$. The complex cone spanned by the columns of $\hat{\boldsymbol{U}}_s$ will therefore tend to cover a large part of the positive quadrant ($\mathbb{R}_+^{|\mathcal{C}_l|\times|\mathcal{C}_l|}$), including the vector $\mathbf{1}$.

C. Allocation of Feedback Resources

The selection of the subsets $\{\mathcal{F}_i(k)\}$ is a key design choice. For a given user we assume that the BSs are selected in the order of mean channel strength. However, one is not obliged to allocate the same number of feedback coefficients to each user. In the end, it is the total number of feedback coefficients that counts [6]. Such an allocation would, however, depend crucially on the desired system objective. For example, a max-min rate objective would result in all feedback resources being allocated to cell edge users. Conversely, a sum rate objective favors users with strong channel conditions. Here, we will assume for simplicity that the same number of feedback coefficients is allocated to each user.

D. A Note on Selective Feedback

Finally, we point out that a *selective feedback* strategy can easily be included in the above framework. Since each user can evaluate their own scheduling metric they can also infer the probability of being scheduled for a given channel realization. By not feeding back CSI when the probability of being scheduled is low there can be large reductions in feedback with negligible reductions in the rate [13]. Nevertheless, we will not evaluate such a scheme here.

V. SIMULATION RESULTS

For the simulations, we consider a network of seven clusters with seven cells in each cluster (see Fig. 2). There is one omnidirectional BS in the center of each cell. The mean fading gain coefficients are modeled as

$$\beta_{ij}^2(k) = (d_{ij}(k)/r)^{-\alpha}$$

where $d_{ij}(k)$ is the distance from BS j to user k in cell i and $\alpha = 3.76$ is the path-loss exponent. r is the distance from the cell center to the cell edge (corner). The mean signal-to-noise ratio (SNR) without interference at the cell edge is set to $\rho =$ 18 dB.

We first consider the performance of four test users with positions given in Fig. 2. The achievable rate averaged over all scheduling instances for various levels of feedback is shown in Fig. 3. In each case, the scheduling policy in (9) is assumed and the rate is plotted as a function of the number of users in the cell. The numerical values are obtained in two distinct ways. The full lines are based on numerical integration of the CDF in (10). Specifically, using that $\mathbb{E}X = \int_{x\geq 0} 1 - F_X(x)\,dx$ for non-negative random variables, the rate for user i is obtained by evaluating the integral

$$R = \int_{\mathbb{R}+} 1 - \left[F_{\phi_i(k)}(2^r - 1)\right]^n dr.$$

Note that the above expression relies on the SINR approximation in (7). As a comparison the markers are exact values obtained from full-scale Monte Carlo simulations. The other users in this case are uniformly distributed within each cell. Note that there is a very good fit between the semi-analytical approximation and the simulated values. Fig. 3 also shows that there are some notable differences between the users with respect to the value of feedback. Notably, the increase in rate from 4 to 7 feedback coefficients is virtually non existent for test user 4, who is located at the cluster edge.

In Fig. 4, we plot the sum-rate of cells A and B (see Fig. 2) as a function of the number of feedback coefficients per user. The number of users is set to 30 in both cells. In each case, the proposed scheduling scheme in (9) (labeled scheme I) is considered. As a reference, we also show the performance when the probability integral transform of the SINR without BS coordination is used as a scheduling metric (labeled scheme II). For

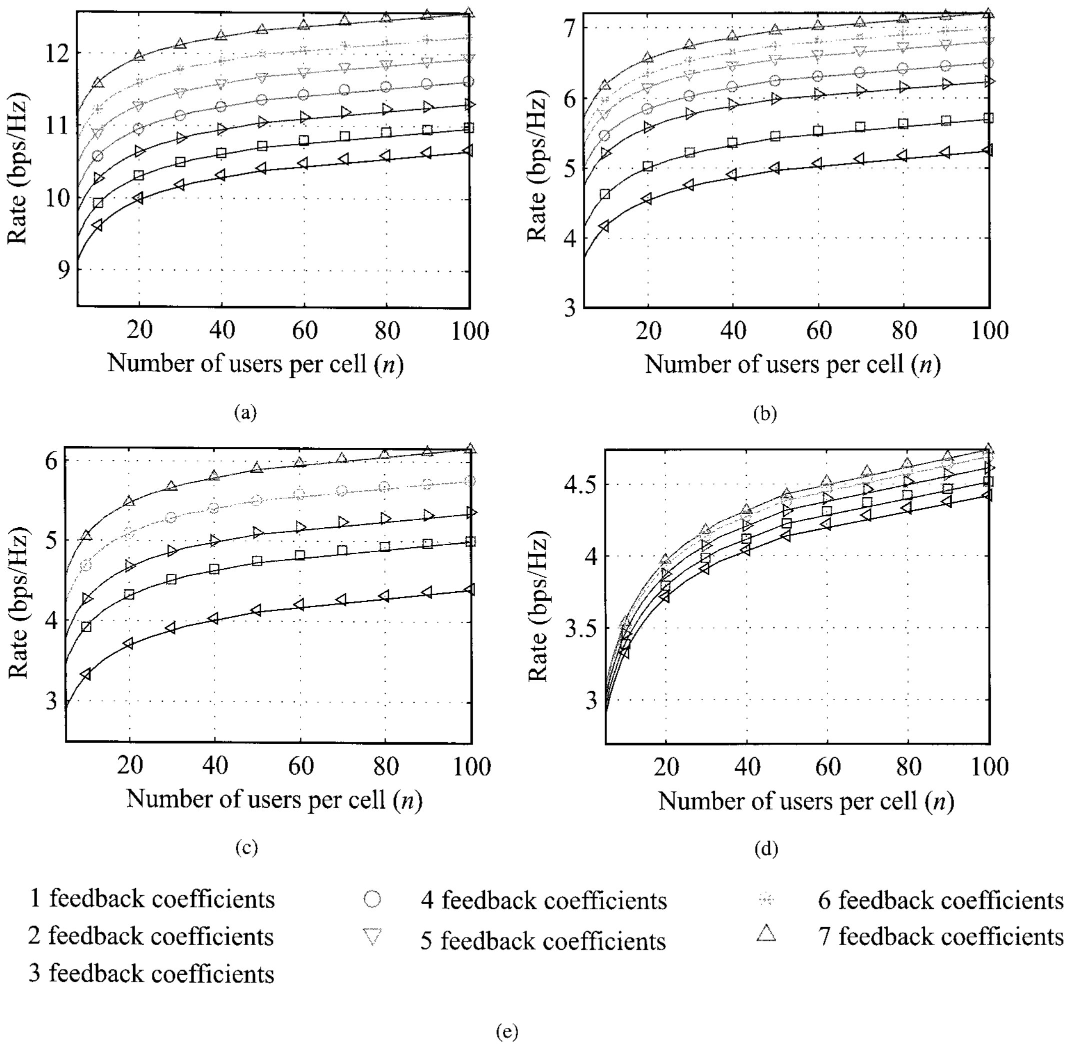

Fig. 3. The rate at scheduling instances for four test users. The marks correspond to Monte Carlo simulations, while the lines are approximations based on numerical integration of the CDF in (10): (a) Test user 1, (b) test user 2, (c) test user 3, (d) test user 4, and (e) legends.

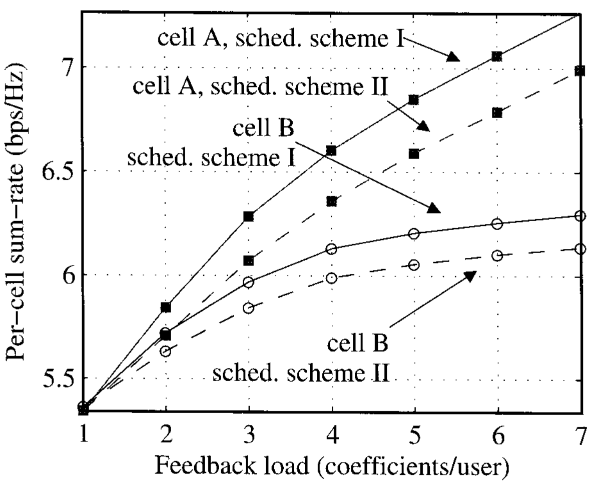

Fig. 4. The sum-rate as a function of the number of feedback coefficients per user. Cell A is at the cluster center while cell B is located at the cluster edge. There are 30 users in each cell.

both cells, there is a notable gain with the proposed scheduling scheme as the number of feedback coefficients increases. Observe also that there is a fundamental difference between cell A and cell B with respect to the value of increased feedback. For cell B, which is located at the cluster edge the value of increased feedback is quickly diminishing. In particular, 82% of the gain can be achieved by reducing the feedback from 7 to 4 coefficients. For cell A the gain is more linear in the number of feedback coefficients. In this case, 65% of the gain can be achieved with 4 feedback coefficients.

VI. CONCLUDING REMARKS

BS coordination in wireless networks depends crucially on feedback from users. In this paper, we have explored the tradeoff between feedback and throughput in a clustered cellular network. The results show that a large fraction of the coordination gain can be achieved by a significant reduction in feedback. To a certain extent this is a consequence of the limitations posed by static, non-overlapping clusters. In particular, the users close to the cluster edge are not able to exploit the full potential of coordination. The value of additional feedback for these users is therefore limited.

In the process we have introduced a distribution function that approximates the SINR after partial intra-cluster ZFBF. Numerical integration of this function led to accurate estimates of the rate in the case of an opportunistic scheduling scenario. Based on the same function we were also able to formulate a scheduling criterion especially tailored for multicell ZFBF. The use of this scheduling criterion resulted in a notable increase in performance.

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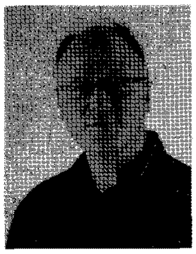

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