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Joint Optimization of Beamforming, User Scheduling, and Multiple Base Station Assignment in a Multicell Network

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Abstract—This paper presents a practice oriented approach for an optimization of user scheduling, base stations assignment and beamforming with multipoint transmission in a multiuser multicell scenario using statistical channel knowledge. Especially the cell edge users gain if they are served by multiple base stations (BSs). The max-min beamforming optimization balances the signal to interference and noise ratio of all scheduled users. An additional optimization of the scheduling decisions and the assignment of BSs to users can additionally improve the individual rates of the users. A multiuser multicell simulation based on the WINNER II channel model proves the enhanced performance of the presented low complexity algorithm for the network-wide optimization of the three degrees of freedom: optimal transmit beamforming, temporal user scheduling and base station to user assignment.

I. INTRODUCTION

The challenge in mobile broadband access is non-lineof-sight (NLOS) propagation. In the standards Long Term Evolution (LTE) or Worldwide Interoperability for Microwave Access (WiMAX) Orthogonal Frequency Division Multiple Access (OFDMA) is the preferred technique to overcome problems of a NLOS propagation. The use of multiple narrow band orthogonal subcarriers in OFDMA helps to overcome inter-symbol and inter-carrier interference in an efficient manner, thus, eliminating the intracell interference. However, limited available bandwidth means reuse of these subcarriers in neighbouring cells and as a result intercell interference (ICI) emerges as the most significant performance limiting factor when employing multicell networks. Different techniques are being explored to eliminate or circumvent intercell interference. Multiple antennas have been employed to exploit the spatial domain and different scheduling schemes are being explored for more intelligent allocations of users to base stations (BSs) and, e.g., time slots such that the interference to other users is mitigated.

In this paper, the resource allocation of a multiuser multicell network is divided into three parts,

- 1) beamforming,
- 2) user to base station allocation,
- 3) user to orthogonal channel resources allocation (here, temporal scheduling).

The multiuser multicell optimization presented in this paper considers two optimization criterions: fairness among the users in the network and maximized rates of all users. In this paper beamforming was used to improve the fairness of the throughput of the jointly scheduled users.

Closed-loop downlink beamforming makes use of the channel state information (CSI) at the base station to compute the beamforming weights of the transmitting antenna elements. However, the availability of perfect instantaneous CSI is too idealistic for practical multiuser multicell optimizations but partial (statistical) CSI can be assumed. Considering scenarios where receivers are moving slowly, long-term channel statistics like spatial correlation can give a good estimation of the channel conditions using a low-rate signal feedback from the mobile receivers. With max-min beamforming [1], [2], a fair (balanced) signal to interference and noise ratio (SINR) distribution for a set of scheduled users can be achieved. In [3], this technique is extended to a networkwide coordinated ICI mitigation to balance the SINR of all users in the network jointly. The beamforming problem was formulated as a multicast beamforming problem for each cell, which corresponds to a network-wide adaptation of the sector pattern. In [4], this scheme was extended to the case where a group of BSs serves a group of users. Both problems are NPhard, i.e., neither a closed form solution nor an exact solution in polynomial time exist.

In contrast to [4], this paper considers a special case of the max-min beamforming problem with multiple BSs assignment, where only one user per user group is served by multiple BSs. For an a priori defined assignment of BSs to scheduled users, this problem can be efficiently solved and a low complex algorithm was presented in [5]. Very weak users with worse shadowing conditions can reduce the performance of all jointly scheduled users in this case, because of the SINR balancing approach. Bad shadowing conditions and high intercell interference are given especially at the cell edge region, where the useful signal is mostly quite low and the distance to the adjacent interfering BSs is minimized. Therefore, in this paper max-min beamforming with an optimization of the assignment of multiple BSs to one user to improve the SINR especially for the cell edge users is investigated.

Beside the beamforming with an assignment of multiple BSs to cell edge users, an optimized user scheduling can be used to improve the sum rate of the network. In [6], a low complex algorithm for a joint optimization of beamforming and user scheduling for a fixed, a priori defined assignment of a single BS to a user, is presented. The result is an improved SINR of the scheduled users and, therefore, an improvement of the overall sum rate. In this paper, this idea is extended to the case, where a user is served by multiple BSs. Beside the temporal user scheduling, additionally an optimal assignment of multiple BSs to users is investigated as well.

Notations: Lower case and upper case boldface symbols denote vectors and matrices, respectively and the transpose conjugate of a matrix \mathbf{A} is denoted by \mathbf{A}^{H} . The matrix element of \mathbf{A} with index i, j is given by $[\mathbf{A}]_{i,j}$. The *i*th row vector and the *j*th column vector of \mathbf{A} are defined by $[\mathbf{A}]_{i,:}$ and $[\mathbf{A}]_{:,j}$ respectively. $E\{x\}$ denotes the expectation value of the variable x.

II. SYSTEM SETUP

Throughout this paper it is assumed that multiple BSs can serve a single mobile station (MS) at a time instant. N_C is the number of active BSs at a particular time instant and M is the number of users scheduled at that time instant. The transmitted signal is assumed to have a sufficient cyclic prefix length and perfect synchronization, hence no deformations of the useful signal due to intercarrier or intersymbol interference can be observed at the receiver. The received signal, therefore, for a user *i* at a given time instant is given by:

$$r_i = \sum_{c \in \mathcal{B}_i} \mathbf{h}_{i,c}^H \mathbf{w}_c s_i + \sum_{j \in \bar{\mathcal{B}}_i} \mathbf{h}_{i,j}^H \mathbf{w}_j s_j + n_i,$$
(1)

where $\mathbf{h}_{i,c} \in \mathbb{C}^{N_t \times 1}$ is the channel vector of the N_t antenna elemets from the *c*-th BS to the *i*-th user, \mathcal{B}_i is the set of BSs serving user *i*. $\overline{\mathcal{B}}_i$ are the interfering BSs such that $\mathcal{B}_i \cap \overline{\mathcal{B}}_i = \emptyset$ and $\mathcal{B}_i \cup \overline{\mathcal{B}}_i = \mathcal{C}, \mathcal{C}$ denotes the set of the currently active BSs. Also $\mathbf{w}_j \in \mathbb{C}^{N_t \times 1}$ is the transmit beamforming vector at BS *j*, s_i is the information signal for user *i* with $E\{|s_i|^2\} = 1, n_i$ is the sum of the interference from the surrounding networks and complex additive Gaussian noise with zero mean and variance σ_i^2 .

III. MAX-MIN BEAMFORMING BASED ON CORRELATION KNOWLEDGE

In contrast to many other beamforming approaches [7], in this paper a user is served by multiple BSs. The max-min optimization of the beamforming weights results in a balanced SINR of all jointly scheduled users [4], [5]. For a given assignment of BSs to MSs, a low complexity algorithm for the optimization of the beamforming weights is presented in [5]. To consider additionally the scheduling decisions and the assignment of BSs to users, a matrix

$$[\mathbf{S}]_{c,k} = \begin{cases} i & \text{user } i \text{ is scheduled by BS } c \text{ in step } k \\ 0 & \text{cell } c \text{ contains no user} \end{cases}$$
(2)

is needed. With the matrices $\mathbf{R}_{i,c} = E\{\mathbf{h}_{i,c}\mathbf{h}_{i,c}^H\}$ and (2) the downlink SINR for the scheduled users $i \in [\mathbf{S}]_{:,k}$ in a scheduling slot k is given by

$$\gamma_{i,k}^{D} = \frac{\sum_{c \in \mathcal{B}_{i}} \mathbf{w}_{c}^{H} \mathbf{R}_{i,c} \mathbf{w}_{c}}{\sum_{j \in \bar{\mathcal{B}}_{i}} \mathbf{w}_{j}^{H} \mathbf{R}_{i,j} \mathbf{w}_{j} + \sigma_{i}^{2}}.$$
(3)

To achieve the optimum fairness among the jointly scheduled users, it is desired to improve the worst SINR of the currently scheduled users with the power at each BS constrained by P_C . The max-min optimization problem can be stated as

$$\max_{\mathbf{W}_{k}} \min_{i \in [\mathbf{S}]_{:,k}} \gamma_{i,k}^{D}$$
(4)
s.t. $\mathbf{w}_{c}^{H} \mathbf{w}_{c} \leq P_{C} \quad \forall c \in \mathcal{C}$

with $\mathbf{W}_k = [\mathbf{w}_1, \dots, \mathbf{w}_{N_C}]$. This quadratic optimization problem (4) with quadratic non-convex constraint was solved in [5] a low complexity algorithm based on the uplinkdownlink duality. Thus for a given assignment of BSs to users an optimum solution can be efficiently computed.

IV. JOINT OPTIMIZATION OF BEAMFORMING, USER SCHEDULING AND BASE STATION ASSIGNMENT

The max-min beamforming algorithm maximizes the SINR of the user with the worst SINR in scheduling slot. The SINR is balanced for all scheduled users. In the case of unfavorable scheduling decision, two users close together, can be served by two different adjacent BSs. Thus each of these two BSs cause strong interference to the obverse user served by the adjacent BSs. Therefore, a low balanced SINR of all jointly scheduled users is the result after applying the maxmin beamforming optimization. This emphasizes the need for intelligent scheduling schemes as an unsuitable scheduling decision can have an adverse effect on the overall performance of the system.

Furthermore, the performance gain does not automatically increase with the assignment of multiple BSs to a user. Especially users close to the BS do not gain from the assignment of additional adjacent BSs [5]. Quite the contrary, the adjacent BSs have to transmit with a high power because of the large distance and, therefore, they will cause more interference to other users in the network. The best link for a user will not automatically be the best link for the system and a reduced sum rate can be the result.

Finally, the assignment of multiple BSs also causes a waste of scheduling slots, if they serve users with already good channel conditions. A smart assignment of multiple BSs to, e.g., cell edge users is needed to improve the overall system performance.

A. Optimization Problem

The presented scheduling and BS assignment optimization can be regarded as a multi-dimensional (MS to BS to time slot) allocation problem. The assignment problem of finding the optimal set of users of cardinality M, which can be served by N_C BSs in a given scheduling slot k, maximizing the overall sum rate of the network, results in an optimization of the scheduling matrix (2). In the optimization of the scheduling, the aim is to select users in a time-slot such that their total sum rate is maximized while keeping the scheduling fair. The objective function of this assignment problem is the maximization of the sum rate of the balanced SINR achieved with the optimization problem (4).

The sum rate over all scheduling slots and scheduled users is defined by:

$$R(\mathbf{S}, \mathcal{W}) = \sum_{k=1}^{K_S} \underbrace{\sum_{i \in [\mathbf{S}]_{:,k}} \log(1 + \gamma_{i,k}^D([\mathbf{S}]_{:,k}, \mathbf{W}_k))}_{=:R_k([\mathbf{S}]_{:,k})}$$
(5)

with $\mathcal{W} = \{\mathbf{W}_1, \ldots, \mathbf{W}_{K_S}\}$.

Besides a fair distribution of the mean SINR, a fair allocation of the scheduling slots is needed to achieve a fair distribution of the network resources. This is called **scheduling fairness constraint** in the following and means that the users in each cell are scheduled equally often.

Another important aspect especially in the case where multiple BSs serve a single MS is the allocation of a BS to a MS. Although the allocation of BSs to an MS is easier in the scenario where a single BS transmits to a single MS in a given scheduling slot, inappropriate allocation in the case of the scenario where multiple BSs serve a single MS can severely degrade the performance of the system.

Based on this cost function and the temporal fairness constraint, the optimal beam switching optimization problem is given by:

$$\max_{\mathbf{S}} \qquad R(\mathbf{S}, \mathcal{W}) \tag{6}$$

In contrast to [6], here one user can be served by multiple BSs, therefore, the user index can be inserted multiple times into a column of the matrix S. The number of scheduling slots is denoted by $K_S \geq \max(n_1, n_2, \cdots, n_{N_c})$ where n_c denotes the number of users in cell c. To have a fair allocation of the resources, a user should be served equally often during the scheduling length of K_S slots. Thus all user in cell c are served n_c times during the interval of K_S slots. But there will be unused scheduling slots in cells (row vectors of the scheduling matrix) with $n_c < K_S$. An empty slot with the index tuple k, c in the scheduling matrix means, that in this time slot k no user of the corresponding cell c is scheduled. The BS of cell chas to serve a lower number of users compared to, e.g., a BS of an adjacent cell j with $n_j > n_c$ users. These empty slots of BS c can be used for an assignment to users of adjacent cells to improve their SINR. The result is then an assignment of multiple BSs to users.

The presented BS to user allocation is divided into three different categories. Because of the sectorization three BSs can serve a user like in Fig 1. The primary BSs have the minimum pathloss to their respective allocated users, the secondary BSs

have the second lowest pathloss to their respective allocated users and finally the tertiary BSs have the third lowest pathloss to their respective allocated users. The superscripts P, S, Trepresent primary, secondary and tertiary cells and users respectively in the following. A user can be served by its secondary or tertiary BSs in a slot k, if there are empty slots available at the secondary and tertiary BSs (empty slots in the rows of the scheduling matrix) and only if the user is already served by its primary BSs in that slot. Otherwise it would contradict the scheduling fairness constraint, which guarantees that the users in a cell are scheduled equally often.

B. Complexity

The problem (6) is NP-hard. In [6], an already NP-hard special case of the problem (6) is presented. There, a user is always served by a single BS and only the permutations of the row vectors to have an optimum assignment of jointly scheduled users are optimized.

C. Algorithm

The presented algorithm is an extension of the algorithm presented in [6] and bases on the Kuhn algorithm [8] as well. The algorithm consists of four steps: In a first (greedy) step, the primary BS are assigned to their users. Because of their pathlosses, they can give the largest contribution to the throughput for their users. The first step is needed for an initialization of the scheduling matrix. In a second step, the secondary and tertiary BSs are used to further improve the sum rate of the system. Thus, they will be assigned to users if they provide an additional gain for the sum rate. In the third step, again primary users can be scheduled into the scheduling matrix, which is now initialized by the previous two steps. Thus, there can be additional slots for primary users, which are only added to empty slots, if they do not contradict the scheduling fairness and if there will be no decrease in the sum rate. The new primary users, added in the third step, can be served by additional secondary and tertiary BSs. Therefore in a last (fourth) step, the additional secondary and tertiary BSs are added to serve the users of step three, if there is a possible increase of the sum rate.

In this paper, a modified Kuhn algorithm is presented. The algorithm needs a cost matrix C, which contains the cost of each possible new two-index assignment like in [6]. But a user is only scheduled to a BS if there is no decrease of the sum rate. Therefore, if there is a decrease in the sum rate, the corresponding cost value is set to $-\infty$. Users with $-\infty$ costs remain unallocated (there will be no assignment) by the modified Kuhn algorithm used in this paper. The modified cost matrix is given by:

$$\left[\mathbf{C}\right]_{k,n} = \begin{cases} -\infty & \text{if } R_k([\mathbf{S}]_{:,k}) < R_k(\left[[\mathbf{S}]_{:,k}, [\mathbf{u}_c]_n\right]) \\ R_k(\left[[\mathbf{S}]_{:,k}, [\mathbf{u}_c]_n\right]) & \text{otherwise} \end{cases}$$
(7)

where \mathbf{u}_c denotes the vector of candidate users of cell c.

The new algorithm is illustrated with the following example: **Example 1** Consider the scenario in Fig. 1 where $\mathbf{u}_1^P = [1, 2]$, $\mathbf{u}_2^P = [3, 4, 5]$, $\mathbf{u}_3^P = [6, 7]$ are the users that can be served by



Fig. 1: Small example: Users are denoted with an asterisk and the user index (*i). The BS/cell index is given by the numbers in the circles. The BSs are placed at the cell border and have a 120° sector pattern. The dashed lobes show the orientation of the used antenna pattern, which corresponds to the default mode without beamforming.

BSs/cells c_1, c_2, c_3 respectively. Let $n_{c_1} = 2$, $n_{c_2} = 3$, $n_{c_3} = 2$ be the number of users in each cell. A solution according to the scheduling algorithm presented in [6] could be:

$$\mathbf{S} = \begin{bmatrix} 1 & 2 & 2 & 1 & 1 & 2 \\ 3 & 4 & 5 & 5 & 3 & 4 \\ 7 & 6 & 6 & 7 & 6 & 7 \end{bmatrix}.$$
 (8)

In each cell, each user is served equally often. The new algorithm consists of the following four steps:

Step 1: Generally, this greedy step schedules all primary users \mathbf{u}_{c}^{P} of a BS c such that they are allocated only to a single scheduling slot and the rate of each user is maximized for the regarded scheduling slot. Thus the gain of the primary BSs is exploited. The users already achieve a good throughput if they are assigned optimally to their primary BSs. The step 1 starts with an empty scheduling matrix S and copies the first $n_{c_1} > 0$ primary users of an arbitrary cell c_1 , given by the vector $\mathbf{u}_{c_1}^P$, into the scheduling matrix \mathbf{S} , thus, $\mathbf{S} = \mathbf{u}_{c_1}^P$. In each iteration, a primary user $[\mathbf{u}_c^P]_n$ of a cell c is added to the scheduling slot and the sum rate $R_k([[\mathbf{S}]_{:,k}, [\mathbf{u}_c^P]_n])$ is observed. If the sum rate shows an increase with this user $[\mathbf{u}_{c}^{P}]_{n}$ against the previous sum rate $R_{k}([\mathbf{S}]_{:,k})$ without that user of that slot, the user will be allocated to that slot. If the sum rate $R_k([[\mathbf{S}]_{:,k}, [\mathbf{u}_c^P]_n])$ shows a decrease against the previous sum rate $R_k([\mathbf{S}]_{:,k})$ without that user, the user is unallocated. The optimum two index assignment is optimized by the modified Kuhn algorithm using the cost matrix (7). In the case a user is unallocated, the user $[\mathbf{u}_c^P]_n$ is added into a

new column vector

$$[\mathbf{s}]_l = \begin{cases} [\mathbf{u}_c^P]_n & \text{if } l = c\\ 0 & \text{otherwise} \end{cases}$$
(9)

which is appended at the scheduling matrix: $\mathbf{S} = [\mathbf{S}, \mathbf{s}]$. This first greedy step is repeated until each primary user is allocated to a scheduling slot. After this step the scheduling matrix is initialized and the number of scheduling slots K_S is determined.

Example 2 After step 1 the scheduling matrix of example 1 could be: $\begin{bmatrix} 1 & 2 & - \end{bmatrix}$

$$\mathbf{S} = \begin{bmatrix} 1 & 2 & - & - \\ - & 5 & 3 & 4 \\ 6 & - & 7 & - \end{bmatrix}$$
(10)

The primary users in each cell are served equally often by their primary BSs. After step 1, a good scheduling solution because of the (greedy) assignment of the primary BSs is found. But it is obvious, that the rates of cell edge users, like user 3 can be improved by a multipoint transmission. Therefore, in the next step multiple BSs are assigned to cell edge users if there is no degradation of the sum rate.

Step 2: After allocating the primary users, the secondary and tertiary users of cell, e.g., j are served by multiple BSs. This is done by using the empty slots in a row c of the scheduling matrix for users of cell j and is done in a cell by cell manner as long as the overall sum rate does not decrease. Thus, secondary and tertiary BSs are only used if they improve the individual rates and, therefore, the overall sum rate (because of the SINR balancing). But secondary or tertiary users are added to a scheduling slot k only if they are already served in this slot by their primary BS, because of the fairness constraint. All users in a cell should be served equally often. The second step is initialized with a scheduling matrix S optimized by using step 1 of the algorithm and K_S is set to the length of **S**. The length of the scheduling matrix is variable and depends on the user drop and the channel statistics. In each iteration, a secondary or tertiary user $[\mathbf{u}_{c}^{S,T}]_{n}$ of a cell c is added to an empty scheduling slot where this user is also served by its primary BS and the sum rate $R_k([[\mathbf{S}]_{:,k}, [\mathbf{u}_c^{S,T}]_n])$ is observed. If the sum rate shows no decrease with this user $[\mathbf{u}_c^{S,T}]_n$ against the previous sum rate $R_k([\mathbf{S}]_{:,k})$ without that user of that slot, the user will be allocated to that slot. If the sum rate $R_k([[\mathbf{S}]_{:,k}, [\mathbf{u}_c^{S,T}]_n])$ shows a decrease against the previous sum rate $R_k([\mathbf{S}]_{:,k})$ without that user, the user is unallocated. The optimal twoindex assignment is also computed with the Kuhn algorithm.

Example 3 After step 2 the scheduling matrix of example 2 could be: $\begin{bmatrix} 1 & 2 & 3 & - \end{bmatrix}$

$$\mathbf{S} = \begin{bmatrix} 1 & 2 & 3 & -\\ 1 & 5 & 3 & 4\\ 6 & - & 7 & - \end{bmatrix}$$
(11)

Here again the primary users in each cell are served equally often by their primary BSs, but additionally the users 1 and 3 are now served by a second BS, because they get a higher rate by the multipoint transmission. **Step 3:** Now empty slots, which are still left are allocated to primary users such that there are no empty slots left. If the left slots are not allocable to the primary users based on the primary user scheduling fairness criteria or if this results in an overall sum-rate reduction, then these slots will not be allocated to users. In this step the scheduling matrix is initialized with **S** using the first two steps of the algorithm. In each iteration, a primary user $[\mathbf{u}_c^P]_n$ of a cell c is added to an empty scheduling slot, if the scheduling fairness of cell c is not contradicted and then the sum rate $R_k([[\mathbf{S}]_{:,k}, [\mathbf{u}_c^P]_n])$ is observed. The allocation of users to that slot is then done like in the previous steps by using the cost matrix and the Kuhn algorithm for the optimal two-index assignment.

Example 4 After step 3 the scheduling matrix of example 3 could be: $\begin{bmatrix} 1 & 2 & 3 & - \end{bmatrix}$

$$\mathbf{S} = \begin{bmatrix} 1 & 2 & 3 & -\\ 1 & 5 & 3 & 4\\ 6 & 6 & 7 & 7 \end{bmatrix}$$
(12)

Now, additional slots are used for user 6 and 7 without violating the primary user scheduling fairness.

Step 4: Finally, the remaining empty slots are used again to allocate possible secondary or tertiary BSs to the recently added primary users in step three to obtain further gain in the sum rate. The algorithm of this step is equal to the second step but with an initial scheduling matrix **S** computed by the first three steps.

Example 5 After step 4 the scheduling matrix of example 4 could be: $\begin{bmatrix} 1 & 2 & 3 & 7 \end{bmatrix}$

$$\mathbf{S} = \begin{bmatrix} 1 & 5 & 3 & 4 \\ 1 & 5 & 3 & 4 \\ 6 & 6 & 7 & 7 \end{bmatrix}$$
(13)

Finally, user 7 is served by an additional BS. All cell edge users are now served by multiple BSs and only users are scheduled together in the same slot if the interference of adjacent BSs is low enough not to decrease the sum rate.

After these four steps, the scheduling matrix S and also the set of all beamforming matrices W are optimized and they can be reused until the long-term CSI becoms invalid.

V. SIMULATION RESULTS

A. Simulator

In this paper, the simulation scenario is limited to an island of $N_C = 21$ BSs with the capability of beamforming and sector layout according to Fig. 1, with a 120° antenna pattern. This island is surrounded by a ring of BSs with one antenna element to simulate the incoming intercell interference to the island from the outside world. The whole system layout is based on the Winner II model [9]. Further simulation parameters are listed in Tab. I.

B. Results

This paper regards intercell interference mitigation. Inside a cell, only one user is scheduled in a time slot, therefore, no intra-cell interference exists. The numerical results are based on 90 user drops with 40 users per drop, who are randomly distributed in the simulation world. The results of



Fig. 2: Simulation scenario: The green cells have the capability of beamforming. The asteriks denote users distributed in the world.

TABLE I: Simulation parameters

Channel Model	Winner II
Scenario	C1 Suburban
Number of antenna array elements at BS	4
Number of antenna array elements at MS	1
Site-to-site distance	1732 m
BS height	32 m
MS height	1.5 m
Number of paths	8
Antenna spacing	half wavelength
Mobility	3 km/h
Number of BSs	21
Number of MSs per user drop	40

the new algorithm are compared with the reference algorithm [6] with a full Resource Utilization Efficiency (RUE). The RUE is the average percentage of used scheduling slots of the scheduling matrix. The new algorithm is more flexible and uses empty slots to reduce the interference in the network and additional BSs to improve the rates of cell edge users. The reference algorithm is similar to the new algorithm but assigns always one BS to a user. In Fig. 3 the cumulative distribution function (CDF) of the mean SINR $\gamma_{i,k}^D$ after the 4th step of the algorithm is depicted and compared with the reference algorithm with single BS assignment [6] and a transmission with a single antenna at each BS with round robin scheduling (RRS). This figure shows an improvement of the SINR for all users in the network. Both algorithms have approximately the same sum rate $R_k([\mathbf{S}]_{:,k})$. Fig. 4.a shows that the most users are served by only one BS $|\mathcal{B}_i| = 1$, because the sum rate is mostly already maximized, if a user is served by only one BSs. But in some cases (especially for cell edge users) it is possible to add additional BSs ($|\mathcal{B}_i| > 1$) to a user to improve his individual rate without a degradation of the sum rate. The new algorithm achieves the gain for the individual rates, with no degradation of the sum rate with the multipoint transmission to cell edge users and at the expense of lower RUE (see Fig. 4.b). In the reference algorithm 100% of the slots of the scheduling matrices are used and the presented algorithm uses only approximately 80%.



(b) RUE each step

Fig. 4: Number of connections and RUE

VI. CONCLUSIONS

The higher individual rate and, therefore, an improved fairness is achieved by an optimized cooperative multipoint transmission to cell edge users and a lower resource utilization. This is achieved with no degradation of the sum rate of the network compared to the reference algorithm with

100% RUE. A reduced RUE improves the individual rates of users, because of the reduced interference. The cooperative multipoint transmission is only useful for some (cell edge) users in a multicell network, because a cooperative multipoint transmission to cell centre users results in higher transmission power of adjacent BSs, due to the large distance and, therefore, these BSs will cause more interference to other users in the network and a reduced sum rate will be the result. Furthermore, a cooperative multipoint transmission reduces the number of jointly scheduled users, because multiple BSs are used to serve a single user. The best link for a user will not automatically be the best link for the system and a reduced sum rate can be the result. The presented algorithm for scheduling and multiple BSs assignment is a practice oriented method to find smart assignments of multiple BSs to cell edge users for a cooperative multipoint transmission and scheduling decisions of jointly scheduled users so that the balanced SINR is maximized. With the presented algorithm cell edge users achieve higher rates and, therefore, an improved fairness will be the result. The algorithm is based on second order CSI and the optimization is valid as long as the second order CSI is stationary.

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