Bit-Map Based Resource Partitioning in LTE-A Femto Deployment

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Abstract—Self-organizing network techniques are needed to manage serious two-tier interference in an ad hoc operation of dense femtocell deployment. This paper considers downlink frequency domain inter-cell interference coordination (ICIC) in femtocell deployment. The studied resource partitioning method works such that each active femtocell may adapt, determine, and advertise a so-called binary resource partition sequence indicating which physical resource blocks (PRBs) the femtocells may occupy for their current operation. The main idea is to avoid interference from neighbor femto access points (FAPs) and try to achieve guaranteed bit-rate to femto users. The considered coordination method requires only low rate, infrequent updates in stationary phase and enables ICIC in distributed self organizing manner. The resource partitioning strategies are simulated in an LTE compliant system level simulator. The system level results show that different resource partitioning methods provide substantial gain when MRC receiver is used. When LMMSE receiver is used gains are smaller but at least one of the resource partitioning methods provided a gain over the case without ICIC. Furthermore, it is shown that proposed method works in two different femto environments.

I. INTRODUCTION

Femtocells have been considered as a promising solution to provide high data rate offloading from conventional cellular networks [1]. The idea is that femtocells are low cost plug-and-play devices installed by users, which could increase indoor data rates notably and release resources from overlying macro network [1]. An ad hoc operation and a potentially dense deployment of femtocells cause inter-tier and intra-tier interference which is challenging to manage [2], [3] due to frequency reuse in macro and small BS. Therefore, interference management of heterogeneous networks has been recently considered in existing literature [2]–[4]. Power control as well as interference management in time, frequency and space domain have been studied to improve the downlink performance in interference limited heterogeneous network.

Downlink inter-cell interference coordination in long term evolution (LTE) cellular networks is based on the relative narrow band transmit power (RNTP) indicator which tells the physical resource block (PRB) power level information to neighbor cell enabling interference avoidance in frequency domain. X2 interface has been used to exchange RNTP information between cells in the LTE standard [5]. Stand alone femtocell deployment lacks X2 interface and therefore different solutions have been discussed for information exchange [6].

In this paper, the performance of the cellular network with macro base station (MBS) and FAPs is studied. The performance evaluation is undertaken by using LTE compliant system level simulator. The aim is to study different resource allocation and enhanced ICIC methods. The main interest is in the resource allocation methods which avoid interference from FAPs and from neighboring MBSs. The proposed resource partitioning method works such that each active femtocell may adapt, determine, and advertise a so-called binary resource partition sequence indicating which PRBs the femtocells may select to occupy for their current operation. When femtocells start operating they may detect the resource partition sequences of active femto access points and eNodeBs nearby and then select available resources. The goal is to find efficient resource allocation schemes for different environments.

The rest of this paper is organized as follows. Section II introduces the signal model for the considered system. In Section III, link model is presented, followed by description of different resource partitioning methods in Section IV. The performance results for different resource partitioning methods are presented in Section V. Finally, the conclusions are given in Section VI.

II. SYSTEM MODEL

A network with single user single-input multiple-output (SU-SIMO) and single user multiple-input multiple-output (SU-MIMO) transmission schemes with orthogonal frequency-division multiple access (OFDMA) are considered. Each MBS consists of three sectors with \( N_t \) transmit antennas (Tx), which serve \( K \) users with \( N_r \) receive antennas (Rx). The frequency domain consists of \( N_c \) subcarriers.

This paper considers downlink frequency domain inter-cell interference coordination (ICIC) in femtocell deployment. The studied resource partitioning method follows the idea proposed by the NSN.
A. SU-SIMO

In the SU-SIMO transmission scheme the signal vector received by the macro user $k$ at the subcarrier $c$ can be written as

$$ y_{k,c} = h_{k,c} x_{k,c} + \sum_{i \neq k} h_{i,c} x_{i,c} + \sum_f h_{FAP,f,c} x_{f,c} + n_{k,c}, \quad (1) $$

where $x_{k,c} \in \mathbb{C}^{N_t}$ is transmitted signal from the desired sector to user $k$ at subcarrier $c$, $h_{k,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel vector from desired sector to the $k$th user at the $c$th subcarrier, $x_{i,c} \in \mathbb{C}^{N_t}$ is the transmitted signal from the $i$th interfering sector at subcarrier $c$, $h_{i,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel vector from the $i$th interfering sector to the $k$th user at subcarrier $c$, $h_{FAP,f,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel vector from the $f$th FAP to the $k$th user at subcarrier $c$, and $n_{k,c} \sim CN(0,N_01_{N_r})$ denotes the additive noise with zero mean. Similarly, if the signal vector received by the femto user $f$ at the subcarrier $c$, indexes $f$ and $k$ are exchangeable.

Inter-cell interference is denoted for user $k$ at subcarrier $c$ as $z_{k,c}^{\text{inter}} = \sum_{i \neq k} h_{i,c} x_{i,c} + \sum_f h_{FAP,f,c} x_{f,c}$, and, thus, (1) simplifies to form

$$ y_{k,c} = h_{k,c} x_{k,c} + z_{k,c}^{\text{inter}} + n_{k,c}. \quad (2) $$

At the receiver, maximum ratio combining (MRC) is used. The MRC weight vector $w_{k,c} \in \mathbb{C}^{N_r \times N_t}$ is given by

$$ w_{k,c} = h_{k,c}^H, \quad (3) $$

where $(\cdot)^H$ denotes the conjugate transpose.

B. SU-MIMO

The difference between SU-MIMO transmission scheme and SU-SIMO is that the channel is a matrix not a vector. The received signal vector by the user $k$ at the subcarrier $c$ is given by

$$ y_{k,c} = H_{k,c} x_{k,c} + \sum_{i \neq k} H_{i,c} x_{i,c} + \sum_f H_{FAP,f,c} x_{f,c} + n_{k,c}, \quad (4) $$

where $H_{k,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix from desired sector to the $k$th user at the $c$th subcarrier, $H_{i,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix from the $i$th interfering sector to the $k$th user at subcarrier $c$, and $H_{FAP,f,c} \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix from the $f$th FAP to the $k$th user at subcarrier $c$.

At the receiver, linear minimum mean square error (LMMSE) filter is used. The weight matrix $W_{k,c} \in \mathbb{C}^{N_r \times N_t}$ of the LMMSE receiver is given by

$$ W_{k,c} = \arg \min_{W_{k,c}} \mathbb{E}[\|x_{k,c} - \hat{x}_{k,c}\|^2], \quad (5) $$

where $\hat{x}_{k,c} = W_{k,c}^H y_{k,c}$ is the vector of estimated received data. Therefore, the weight matrix can be written as [7]

$$ W_{k,c} = (H_{k,c} H_{k,c}^H + R_{k,c})^{-1} H_{k,c}, \quad (6) $$

where $R_{k,c}$ is the inter-cell interference plus noise covariance matrix and it is assumed to be known at the receiver.

When LMMSE and two Tx is used LTE specific precoder providing the best performance has been applied in transmission. Estimation error has been added to the MIMO channel matrix of the serving link, i.e., Gaussian noise whose variance depends on the received signal to interference and noise ratio (SINR), models an estimation error.

III. LINK MODEL

The link model between a BS and a user is illustrated in Fig. 1. Since link-to-system interface is used in the simulations, coding/decoding and modulation/demodulation parts are omitted. Antenna gains, path losses and shadowing losses are calculated for all link types. Each user is then paired to the MBS/FAP providing the strongest link. The considered fast fading channel model follows a geometry-based stochastic channel modeling [8], [9]. Channel parameters are determined stochastically, based on the statistical distributions extracted from channel measurements. Further details on the model are available in [10]. Femto related assumptions for links are adopted from the BeFEMTO project [11]: all links are always inside of the buildings and macro users are outside or inside of buildings [12].

Consequently, link model view starts from the scheduler that is responsible for resource allocation between users. Different resource allocation methods are given and explained in Table I. In each resource allocation method, a predefined target bit-rate is chosen. The channel-quality indicator (CQI) information is sent back to the BS and based on the CQI information resource allocation is performed. The CQI provides information for the BS about the link adaptation parameters. In the simulator, CQI is estimated from the received signal and for each user SINR is calculated for every PRB. In order to model practical closed loop system, periodic and delayed CQI and precoder matrix indicator (PMI) are assumed. After scheduling beamforming is applied by using LTE codebook based precoding. Precoding is performed only when LMMSE is used. User provides information for the BS about suitable PMI. After beamforming, modulation and coding scheme (MCS) selection is performed for scheduled users. Finally, before the data is sent over the
fading channel, transmitter side spatial and OFDM processing are performed. Cyclic prefix is assumed to be longer than the multipath delay spread, and, thus inter-symbol-interference is avoided.

At the receiver, perfect frequency and time synchronization is assumed. Link-to-system mapping is performed by using (mutual information effective SINR mapping) MIESM [13]. This significantly reduces the computational overhead compared to exact modeling of the radio links, while still providing sufficiently accurate results. In link-to-system interface, SINR is calculated and corresponding mutual information is taken from the mutual information curve. Mutual information mapping curve depends on the used modulation mode.

Average mutual information over used carriers is calculated. After this average mutual information is mapped to effective SINR value, i.e. MIESM value. Based on the MIESM value, the frame error probability (FER) is approximated according to a predefined frame error rate (FER) curve of used MCS. Based on link-to-system interface, successful and erroneous frames can be detected, and hybrid automatic repeat request (HARQ) can take the control for retransmissions. Consequently, acknowledged (ACK) or not acknowledged (NACK) message is sent back to BS to inform about the success or failure of the transmission, respectively.

When a predefined number of channel samples have been simulated the results can be calculated. The most interesting performance metric is the average mobile user throughput, which can be derived by dividing the sum of correct bits by the number of channel samples.

IV. RESOURCE PARTITIONING

The performance of bit-map coordination is evaluated by four different resource allocation methods. In each method, a predefined bit-rate is targeted. Bit-map is a partition sequence which indicates PRBs are being used by the interfering FAPs/MBSs, ones indicate used PRBs and zeros denote non occupied PRBs. The flow chart of the resource allocation algorithm is presented in Fig. 2

Fig. 3 illustrates an example of how the bit-map coordination works. In this example, there are one MBS, two FAPs, two MUEs and two FUEs. The available bandwidth for resource allocation is 1.4 MHz which in practise means that each base station can use 6 PRBs. The MBS 1 is sending bit-map 1100000 in which ones indicate used PRBs and zeros denote non occupied PRBs. FAP 1 sends bit-map 100100. Now FAP 2 can combine these two bit-maps to see used and interfering free PRBs. Now, FAP 2 can choose free resources and sends bit-map to network indicating used PRBs. This is simple example and in practice access points can also choose interfering resources if it is necessary, because the idea is that each FAP tries to achieve a predefined bit-rate.

Algorithm is applied to resource allocation methods which are given in Table I. This table shows abbreviations which are used to represent different resource allocation methods and description of each method. These different resource partitioning methods are evaluated by using LTE compliant system level simulator. The goal is to find efficient resource allocation schemes for different environments. The performance of different resource partitioning methods are compared with different receiver types and multiple antenna methods.

V. SYSTEM LEVEL PERFORMANCE RESULTS

The LTE system level simulator models an entire LTE cellular network, in this case a macro network overlaying femtocell deployments. System level simulations are particularly useful for considering network related issues such as resource allocation, interference management and mobility management. The simulator uses a hexagonal layout which includes 19 tri-sector MBS, resulting in total of 57 sectors. The network layout may also include femto layouts. It is possible to use 5x5 grid or dual stripe buildings. When femto layouts are included there is always one building in each sector, dual stripe or 5x5. In the dual-stripe layout there are 40 blocks 10mx10m per floor. The 5x5 grid includes 25 blocks 10mx10m. The difference between these layouts is that internal and external walls are modeled in dual-stipe layout, whereas the 5x5 grid includes only external walls. FAPs are dropped in blocks by using predefined probability. It is also assumed that if there is a FAP there is always a FUE. Network layout cropped to show three sectors is illustrated in Fig. 4

A wrap around model is used, in order to simulate a more realistic interference environment without a network edge. The selected number of macro users are distributed uniformly over the central cell layout. Each simulation run consist of 10 drops.
Fig. 3. Two-tier network with bit-map coordination between base stations.

TABLE I

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Method</th>
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<tr>
<td>no ICIC</td>
<td>1. Opportunistic resource allocation without any interference coordination is used as a reference scheme. The best PRBs are selected according to CQI values. Each user tries to achieve guaranteed bit-rate.</td>
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<tr>
<td>FF</td>
<td>2. FAPs form and share bit-maps. FAP is able to avoid interference from other FAPs, but it has no knowledge of MBS resource allocation. Interference free PRBs are first allocated. FAP may use also PRBs used by interfering nodes if needed to achieve the desired bit-rate.</td>
</tr>
<tr>
<td>FM</td>
<td>3. MBSs form and send bit-maps to FAPs. FAPs can only receive bit-maps from MBSs, but they do not generate their own bit-maps. In this case, FAPs are able to avoid macro interference only.</td>
</tr>
<tr>
<td>FMF</td>
<td>4. The interference coordination strategies FF and FM are combined. FAPs have knowledge of PRBs used by neighboring MBSs and FAPs. Interference avoidance is based on received interference power levels. FAP avoids all interference sources that are stronger than the interference threshold value (In the case of following simulations 60 dB less than desired signal strength.)</td>
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</table>

The main parameters related to simulations considered in this section are given in the Table II.

Fig. 5 shows the throughput cumulative distribution function (CDF) curves of SU-SIMO/MIMO for different resource allocation and resource partitioning strategies in dual-stripe layout. The simulation results show that there is noticeable difference in the throughput when different resource allocation methods are simulated in dual-stripe femto layout. When no ICIC is used, performance is the worst as expected. In the case of resource allocation based on the FM bit-maps, i.e., ICIC between FAPs and MBSSs, 11% more users achieved target bit-rate of 5 Mb/s, compared to method without ICIC. The FM curve indicates that macro interference is dominant, since MBS interference avoidance at FAPs provides better performance than ICIC between FAPs. When the LMMSE receiver and precoding is used, 15% more users achieved the target bit-rate of 5 Mb/s compared to case when the MRC receiver is used. Precoding increases the signal strength on the receiver side which leads to higher throughput. When different resource partitioning methods are compared in the LMMSE case the difference in throughput is smaller than in MRC case. This comes from the fact that when beamforming is applied interference in the network is more random, which means that the probability that a user is in a interfering beam is smaller.

Fig. 6 shows the throughput CDF curves of SU-SIMO/MIMO for different resource allocation and resource...
partitioning strategies in 5x5 grid layout. The overall performance in a 5x5 grid is worse compared to the performance in Fig. 5. This comes from the fact that FUEs experience more interference in this layout because there are no internal walls in the buildings. When MRC is analyzed, again the no ICIC method provides the worst performance. Now, FF and FM methods perform similarly which means that the interference coming from FAPs and MBSs are almost at the same level. In the 5x5 grid FMF method provides the best performance, 3% more users achieved the target bit-rate of 5 Mb/s when compared to the case without ICIC. When codebook based precoding and 2x2 antenna configuration results in an average of 13% more users achieving the target 5 Mb/s bit-rate, when compared to single antenna transmission. When different resource partitioning methods are compared in the LMMSE case the result is quite similar to that shown in Fig. 5. Now only FM method can provide gain compared to method without ICIC.

VI. CONCLUSION

The simulation results of resource allocation methods showed the benefits of using bit-map coordination as an interference avoidance method. These results show that even simple coordination between FAPs and MBSs can increase the femto network performance substantially. LMMSE receiver and LTE compliant codebook based precoding provided substantial throughput gain when compared to single antenna transmission with MRC combining. With these techniques at least one of the resource partitioning methods provided a gain over the case without ICIC. The reason was that MMSE receiver is capable of suppressing inter-cell interference since interference covariance is assumed to be known and only single layer transmission was considered. Moreover, the precoding has a significant impact on interference which is not taken into account in the considered ICIC methods.

REFERENCES