EUROPEAN COOPERATION
IN THE FIELD OF SCIENTIFIC
AND TECHNICAL RESEARCH

EURO-COST

COST 2100 TD(10)11036
Ålborg, Denmark
2010/June/02-04

SOURCE: Institute of Communication Networks and Computer Engineering (IKR)
Universität Stuttgart
Germany

Selection strategies for distributed beamforming optimization

Matthias Kaschub, Thomas Werthmann, Christian M. Blankenhorn
and Christian M. Mueller
Institute of Communication Networks and Computer Engineering (IKR)
Universität Stuttgart
Pfaffenwaldring 47
D 70569 Stuttgart
Germany
Phone: +49 711-685-67966
Fax: +1 711-685-57966
Email: matthias.kaschub@ikr.uni-stuttgart.de

Selection strategies for distributed beamforming optimization

Matthias Kaschub, Thomas Werthmann, Christian M. Blankenhorn and Christian M. Mueller

Abstract – Inter-cell interference (ICI) is a major performance-limiting issue in OFDMA networks. The amount of ICI can be drastically reduced if directional antennas are used and if resource allocations are coordinated among neighboring base stations.

We present an interference coordination algorithm based on main-lobe steering beamformer antennas. The algorithm is implemented in the base stations and works in a distributed way. In case a mobile terminal experiences high ICI, a base station tries to find a better resource allocation and possibly initiates a sequence of resource allocation changes in neighboring base stations. Eventually, a better resource allocation with less ICI is found. In this article, we focus on different resource allocation strategies and evaluate their impact on coordination gain.

Index Terms – Cellular radio access networks, Interference coordination

Introduction

1.1 Motivation

For cellular radio access networks, the ever-growing demand for capacity makes spectrum a scarce resource. To use the available spectrum as efficiently as possible, these networks use the same frequency resources in all base stations (reuse 1) and try to maximize the spectral efficiency using only these resources. In reuse 1 scenarios, the achievable spectral efficiency is limited by the interference from neighboring base stations, whereas noise does not play a significant role. Therefore, the goal of most interference coordination mechanisms is to reduce the interference from neighboring cell sectors on the transmissions in the current cell sector. Especially for users at the cell edge this improves the channel quality.

We consider the downlink of cellular OFDMA networks such as IEEE 802.16e WiMAX or 3GPP LTE. We assume the base station to be equipped with multiple antennas, that are used in combination with main-lobe steering beamformers.

1.2 Related Work

There are several approaches to deal with inter-cell interference [3]. While classic static frequency reuse scheme as used for GSM are relatively inefficient, more sophisticated schemes have been proposed. With fractional frequency reuse, a cell is split into different areas. Primary and secondary frequency resources are defined and allocated to these areas. The so-called soft reuse schemes further reduce transmission power for secondary resources [1]. The partitioning of the resources is usually done during network planning or in a semi-static way on a large time scale. Higher gain is achieved with more dynamic schemes, which adapt to traffic variations and user distribution [2].

When base stations are equipped with multi-antenna arrays, multiple signal sources can be distinguished and the spatial domain can be utilized to avoid interference at the transmitter side [3]. The coordination of transmissions of multiple base stations with directional antenna systems is denoted as coordinated beamforming in the 3GPP specifications [4].

In this paper, we investigate an interference coordination scheme using main-lobe steering antenna arrays in the downlink of an OFDMA mobile communication system. Previous work has shown that large gains can be achieved by joint optimization of the scheduling and beamformer orientations of multiple base stations [5], [6]. In contrast to the coordination algorithm presented here, the algorithms in [5], [6] are not fully distributed.

An algorithm similar to the presented one is used in [7]. There, interference in a 60 GHz WPAN is mitigated by changing the set of used resources when the transmission is jammed by interference. The authors did not deal with the situation when all available resources are used at the same time, whereas we consider a reuse-1 scenario with full transmit power and full system load in all cells.

In [8], the authors describe an interference coordination algorithm for LTE using codebook-based precoding matrices. Each mobile station measures the channel to the neighbor cells and signals which precodings the neighbor cells shall avoid. In contrast to our algorithm their algorithm requires more measurement by the mobile stations and more signaling between mobile stations and base stations as well as between base stations.

The remainder of this document is structured as follows. The following section presents the coordination algorithm. Section 3 describes the applied evaluation methodology. The coordination algorithm is evaluated in Section 4. Section

5 concludes the paper.

2. Interference coordination algorithm

The overall goal of the presented algorithm is to improve the systems capacity by using beamforming and by directing the beams to the targeted receivers. Steering the beams provides a degree of freedom, which we exploit to minimize the overall interference. Since the geographical position of the mobiles varies over time, the basestation adjusts the beams continuously. We also assume non-greedy traffic, which imposes additional boundary conditions.

2.1 Assumptions

The presented algorithm was designed to be real world implementable. Thus, we assume, mobile stations cannot measure single interfering signals but only the interference sum. In current and future cellular networks, mobile stations have or will have information on the RSSI and the CQI. The interference power and the SIR can be derived from these values.

For our simulations, we consider on-off traffic. In order to derive throughput values, there are always 8 active mobile stations in each sector. An extension to different numbers of users is straightforward.

Since we designed the algorithm for low measurement overhead, we do not assume frequency selective scheduling. The algorithm uses logical channels, that are created by frequency diverse permutation of sub-carriers to average out fast fading channel variation.

2.2 Key idea

Assigning radio resources and steering the beams to their associated mobile stations is one degree of freedom, that base stations can exploit to improve the interference situation. Keeping the resource assignment static for several subsequent frames gives the base station the possibility to measure the interference level that its mobile stations receive. In contrast, only changing the resource assignment can improve a suboptimal interference situation. These are conflicting goals.

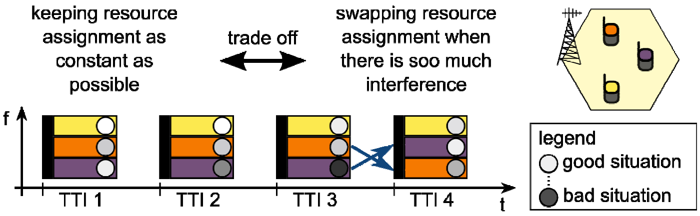

Figure 1: Principle of coordination algorithm

The presented algorithm tries to find the optimal point in time for changing resource assignment. The approach is to keep resource assignment over multiple frames as constant as possible. Fig. 1 shows an example of this behavior for TTIs 1 to 3, where the resource assignments do not change although the interference situation changes. As soon as the interference level supersedes a certain level, the base station changes the resource assignment of the affected mobile stations. In the given example, this is the case for the purple (third) mobile station after TTI3.

Algorithm 1: Interference mitigation algorithm

```
for all TTI do
    for all mobile station do
        Obtain reports of previous TTI ($\gamma$ and $i$)
        Calculate cost function: $c(\gamma,i)$ and change probability $p := s(c)$
        if (random value $u(0,1) < p$) then
            Choose pivot partition and perform change
        end if
    Schedule to assigned resource partition
    end for
end for
```

Algorithm 1 gives a pseudo code representation of the algorithm. At each TTI, a base station estimates the interference situation by evaluating report messages from the mobile stations. In order to find an interference-minimal resource assignment in a decentralized fashion, base stations need to change the resource assignments and observe the effects of the change. A base station's decision whether to perform a change is based on a cost value. So far, we considered the following cost functions α, where γ represents the SINR in dB and i the interference sum in dBW/Hz measured for the resources of the corresponding mobile station:

$$\begin{aligned}
&\text{CONST}: && c_{\text{CONST}}(\gamma,i) &&= 0\\
&\text{IFSUM}: && c_{\text{IFSUM}}(\gamma,i) &&= i\\
&\text{SIR}: && c_{\text{SIR}}(\gamma,i) &&= -\gamma\\
&\text{IF}-\text{SIR}: && c_{\text{IF-SIR}}(\gamma,i) &&= i-\gamma
\end{aligned} \tag{1}$$

The result of a Bernoulli Experiment determines, whether the base station will perform the resource assignment change. The following s-curve transforms the cost values into probability values for the Bernoulli Experiment:

$$s(x) = \begin{cases} 0 & x \le \alpha - \delta \\ 2\left(\dfrac{x-\alpha-\delta}{2\delta}\right)^2 & \alpha-\delta < x \le \alpha \\ 1-2\left(\dfrac{\alpha-x+\delta}{2\delta}\right)^2 & \alpha < x \le \alpha+\delta \\ 1 & \text{else} \end{cases} \tag{2}$$

The parameters α and δ define the position of the s-curve's turning point and the width of the s-curve. Simulation studies have shown that δ has only little influence on the algorithms behavior, while α directly influences the frequency of resource assignment changes, since it defines the cost threshold of a change.

Once a change decision is made to change the resources of a mobile (referred to as swapper mobile), the base stations selects a second mobile (referred to as pivot mobile) to exchange resources. Different strategies to select a pivot mobile will be introduced and evaluated in the next section.

2.4 Pivot selection strategies

Given the assumption that all cells are fully loaded and the resources assigned to the mobiles are of equal size. Then selecting a resource partition is equivalent to selecting another mobile station and swap with its resource partition.

This selection can either be performed randomly or by taking into account additional information about the interference situations. We use the following two sources of additional information:

1) Mobile stations measure the SINR on all resource partitions and report the results to their basestation. This information allows a basestation to predict the channel quality a mobile would get on a resource where it was not served before. The reporting is expensive, since it is performed on the air interface.
2) Neighboring basestations communicate their scheduling decision among each other. For each resource, they indicate the geographical position of the served mobile. This position is quantized to one of six "subsectors" per sector. We assume that for each pair of subsectors in the system, the expectation of the interference received at a mobile in the first subsector from a basestation serving a mobile in the second subsector is known. This information can be derived from network planning calculations. From the scheduling information of the basestations and the interference relations between the subsectors, a basestation can predict the interference a mobile would get after a change in the resource allocation. This prediction can be performed for local mobiles as well as for mobiles served by foreign basestations. The communication between the basestations is performed on the backhaul and therefore cheaper than the signaling from mobiles to base stations.

We investigated different strategies for the selection of the pivot MS, which will be described in the following paragraphs. We apply additional randomization to each strategy to avoid local hill climbing.

RANDOM The simplest strategy is to choose a pivot mobile from all mobiles except the swapper mobile randomly with equal probability. This does not require any additional measurement, reporting or communication.

SWAPPER This strategy strives to optimize the interference level of the swapper mobile. Therefore, for every resource the channel quality the swapper mobile would get is estimated (see Fig. 2). The resource with the best channel quality is then selected with the highest probability. The mobile which is currently served on the chosen resources is used as pivot mobile. The strategy ignores whether the pivot mobile gains or suffers from the swapping.

SWAPEE This strategy strives to optimize the interference level of the pivot mobile. For all mobiles except the swapper mobile, the basestation estimates the channel quality they would get on the resource released by the swapper mobile (see Fig. 2). The mobile which would get the highest gain from getting this resource assigned is chosen as the pivot mobile. The strategy ignores whether the swapper mobile gains or suffers from the swapping.

BOTH This strategy is a combination of the strategies SWAPPER and SWAPEE. The pivot mobile is chosen such that the expected gain for the swapper mobile and for the pivot mobile is optimized jointly.

ALTRUISTIC This strategy changes the resource assignment to minimize the interference caused to mobiles in neighboring sectors. To predict the interference which would be caused to foreign mobiles after a swapping of the resource allocations, the second estimation scheme of those introduced above has to be used. This strategy ignores whether swapper or pivot mobile gain or suffer from the swapping.

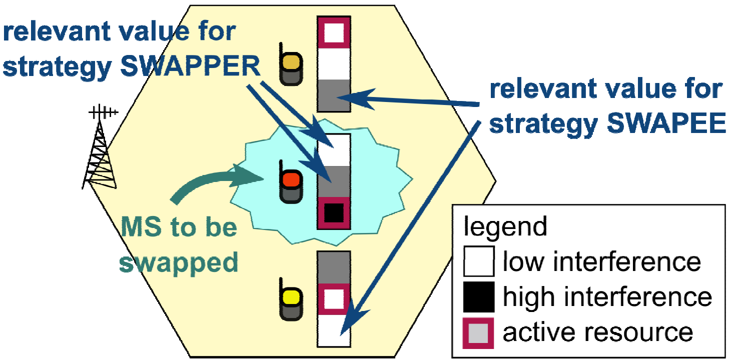

Figure 2: Relevant channel quality values for the pivot strategies SWAPPER and SWAPEE.

3. Simulation methodology

The performance evaluation has been conducted using an LTE-like system level simulator based on the IKR SimLib [9]. Our scenario consists of 19 three-sectorized sites on a regular grid with 1000m inter-site distance. Each sector is equipped with a main-lobe steering beamformer, consisting of a linear array of 4 sector antennas. The antenna pattern is derived from measurements of a real setup as described in [12]. The influence of scatterers is not taken into account. For each resource block, the main lobe is pointed at the receiving mobile station. The accuracy of the beam is 1° and ideal tracking of the mobiles is assumed. The 1000 mobile stations are uniformly distributed and move with a constant speed of 10 km/h. They are equipped with a single isotropic antenna without gain.

The pathloss model corresponds to [10]. Shadowing is lognormal with std. deviation 8dB and time-correlated with correlation distance 50m and inter-site correlation factor 0.5 [11]. We do not model any small-scale fading, given that the algorithm is assumed to be used with a frequency diverse permutation scheme. To avoid any border effects wrap-around is used.

The 10MHz system bandwidth is divided into 8 equally sized allocation units. The scheduling interval is 1ms and the scheduler assigns one of these allocation units to each mobile station. The SINR value is calculated for each allocation unit according to the scheduling and the beamformer orientations of the other base stations. Only the downlink is regarded. Feedback in the uplink direction is assumed to be ideal and without delay.

The traffic model in an on-off model with a mean length of the ON phase of 0.2s. During the ON phase, a mobile terminal always has data to send. The traffic model is designed such that the number of active mobile stations remains constant. If the ON phase of one mobile station in a cell ends or a mobile station leaves a sector, one of the previously inactive mobile stations in this cell is switched on.

4. Performance evaluation results

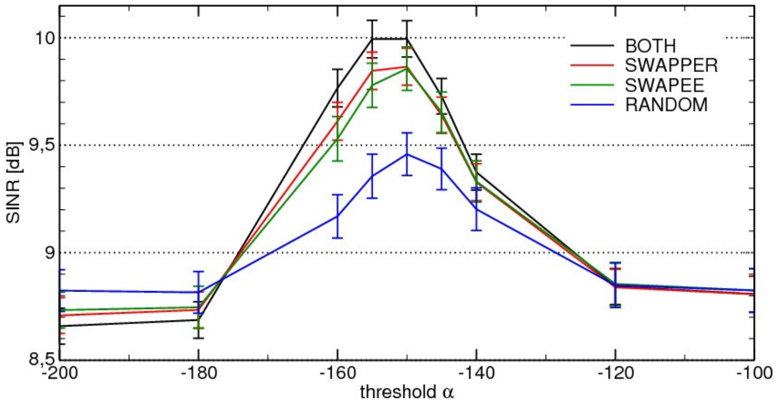

Figure 3: Average SINR for different pivot selection strategies using information source (1).

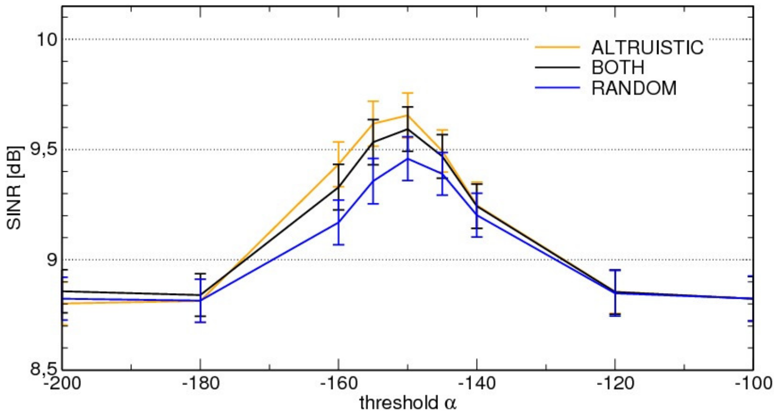

Figure 4: Average SINR for different pivot selection strategies using information source (2).

Fig. 3 shows the average channel quality over all mobiles in the simulation for different pivot strategies with information source (1). The parameter alpha, which is shown on the x axis, determines the probability to change resource allocations (as described in section 2.3). The left border of the plot (low values of alpha) corresponds to a swap probability close to one (random scheduling), while the right border corresponds to swap probability close to zero (static scheduling). In both cases, the algorithm cannot coordinate, because the resource allocation cannot converge. The channel quality achieved with this parameterization can therefore serve as reference. A coordination gain can be achieved with values of alpha in the range of -160 to -140. This corresponds to a swap probability of about 17% to 0.2%.

The simplest pivot selection strategy RANDOM does achieve a coordination gain of about 0.6 dB. This coordination gain is expected because the algorithm decides to change a resource allocation when a mobile suffers high interference, only. Even if the pivot mobile is selected randomly, the algorithm eventually converges to a good situation.

The coordination gain can be increased by using more sophisticated pivot selection strategies. The strategies SWAPPER and SWAPEE achieve a coordination gain of about 1 dB. With the strategy SWAPPER, the number of changes required to get a mobile to the optimal resource is decreased. However, a single resource may be the best one for multiple mobiles. In that case, the mobiles "compete" for this resource, which leads to an oscillation and drastically reduces the interference coordination gain in the neighboring sectors. In contrast, the strategy SWAPEE prohibits this competition for good resources, because it prohibits that the pivot mobile is displaced to a resource with a low channel quality. However, the probability that the situation is improved for the swapper mobile is not higher as with the strategy RANDOM.

The strategy BOTH, which combines the strategies SWAPPER and SWAPEE, leads to a slightly higher coordination gain of about 1.2 dB. Even when the pivot mobile is selected such that the channel situation is optimized, each swap causes unpredictable changes for the neighboring sectors. Therefore, the algorithm cannot achieve any coordination gain when the swap probability is too high.

Fig. 4 shows the gain achieved with selected pivot strategies in combination with information source (2). The performance of the strategy RANDOM is the same as in Fig. 3, because this strategy does not utilize the additional information. The strategy BOTH performs much worse than with information source (1). The reason for this behavior is that the estimation based on the quantized mobile positions reported by the neighbor sectors has a low quality.

The strategy ALTRUISTIC shows a slightly better result. In contrast to all other strategies, this strategy strives for a globally optimal resource allocation by making use of the knowledge of interference relations between subsectors. It does therefore have the chance to reduce the amount of those swaps, which are done as reaction to a swap in a neighboring sector. Nevertheless, it does not take into account whether the channel quality of the swapper mobile is improved.

In general, the strategies based on a channel measurement by the mobiles perform better. However, compared to the interference estimation based on communication between basestations, they introduce a higher overhead on the air interface. The strategy ALTRUISTIC leads to the best results when the measurement by the mobiles is not used.

5. Conclusion

We proposed a distributed interference coordination algorithm based on main-lobe steering beamformer antennas. The complexity of the algorithm is low, and it can operate even without additional channel measurements of the mobile terminals. Its basic principle is to keep the resource allocation of a mobile station static, unless a predefined interference and channel quality threshold is exceeded. In this case, the resource allocation of this mobile is changed, possibly initiating a sequence of resource allocation changes in neighboring base stations. Over a few frames, the system converges to more favorable resource allocations that cause less inter-cell interference.

In this article, we presented results for different resource allocation strategies. The coordination gains achieved by the respective strategies have been evaluated by simulation under an on/off traffic model. It has been shown that even if the time-frequency resources of a mobile terminal are selected by random, a considerable improvement in SINR is achieved. More sophisticated resource allocation strategies try to predict the impact of a resource allocation change on the channel qualities of mobiles in the same and in neighboring cells. This prediction is done using a history of channel measurements reported by the mobiles in the local cell or inter-BS signaling in combination with a coarse-grained static interference relation table from network planning.

ACKNOWLEDGEMENT

The authors would like to thank Hardy Halbauer and his group of the Alcatel-Lucent Bell Labs Germany and Magnus Proebster for the many valuable discussions and comments on this work.

6. References

[1] S. Halpern, “Reuse partitioning in cellular systems,” in Vehicular Technology Conference, 1983. 33rd IEEE, vol. 33, 1983, pp. 322–327.

[2] A. Stolyar and H. Viswanathan, “Self-organizing dynamic fractional frequency reuse for best-effort traffic through distributed inter-cell coordination,” in INFOCOM 2009. The 28th Conference on Computer Communications. IEEE, 2009, pp. 1287–1295.

[3] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, “Interference coordination and cancellation for 4G networks - [LTE part II: 3GPP release 8],” Communications Magazine, IEEE, vol. 47, no. 4, pp. 74–81, 2009.

[4] 3GPP, “TR 36.814 - further advancements for E-UTRA physical layer aspects (release 9), v1.0.0,” 2009.

[5] M. Necker, “Interference coordination in cellular ofdma networks,” Network, IEEE, vol. 22, no. 6, pp. 12–19, 2008.

[6] ——, “A graph-based scheme for distributed interference coordination in cellular OFDMA networks,” in Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE, 2008, pp. 713–718.

[7] M. Park, P. Gopalakrishnan, and R. Roberts, “Interference mitigation techniques in 60 GHz wireless networks,” Communications Magazine, IEEE, vol. 47, no. 12, pp. 34–40, 2009.

[8] L. Liu, J. Zhang, J. Yu, and J. Lee, “Inter-cell interference coordination through limited feedback,” submitted to International Journal of Digital Multimedia Broadcasting, 2009.

[9] Institute of Communication Networks and Computer Engineering, “IKR Simulation Library,” http://www.ikr.uni-stuttgart.de/Content/IKRSimLib/, Stuttgart, Germany, 2010.

[10] E. Damosso and L. Correia, COST 231 (Digital mobile radio towards future generation systems), Final report, 1999.

[11] ETSI, “TR 101 112, UMTS 30.03, V3.2.0,” 1998.

[12] M. Necker, “Towards Frequency Reuse 1 Cellular FDM/TDM Systems,” in Proceedings of the 9th ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2006), October 2006.

[13] ——, “A Novel Algorithm for Distributed Dynamic Interference Coordination in Cellular OFDMA Networks - Communication Networks and Computer Engineering Report No. 101,” Ph.D. dissertation, Universität Stuttgart, 2009.