

# Aspects of Multiuser MIMO for Cell Throughput Maximization

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**Abstract** – We consider a multiuser MIMO downlink scenario where the resources in time, frequency and space are allocated such that the total cell throughput is maximized. This is achieved by exploiting multiuser diversity, i.e. the physical resources are allocated to the user with the highest SNR. We assume perfect channel knowledge at the transmitter which may be obtained from estimation of the uplink signal in a TDD system or from a feedback from the receiver.

In this paper, we do not give mathematical details on the proposed algorithm. We rather provide an illustrative view on the principle idea. The potential for cell throughput improvement is demonstrated by capacity results based on measured channels in a large office environment. Finally, video streaming is used as a potential application with high data rate and low latency demands. It is shown that the proposed method has the potential to exploit multiuser diversity while still providing stable video streams even though QoS constraints are not explicitly taken into account by the scheduler.

## 1. Introduction

The application of multiple antennas at both transmitter and receiver (multiple-input multiple-output, MIMO) is agreed to be a key ingredient for future wireless communication systems in order to meet the required improvements in terms of spectral efficiency compared to today's systems.

Significant gains can be obtained over single antenna systems, particularly if the channel impulse response is known at both transmitter and receiver. Channel knowledge at the transmitter can, e.g., be assumed in a TDD system.

The best thing to do is diagonalization of the channel using a singular value decomposition (SVD) as indicated in Figure 1: The transmitter multiplies the transmit signal with the right singular vectors of the channel matrix  $\mathbf{H}$ , the receiver multiplies with the left singular vectors. With  $n_T$  transmit and  $n_R$  receive antennas, this

yields  $\min\{n_T, n_R\}$  decoupled channels which we refer to as spatial dimensions. For reasons of cost and size, the number of antennas at the terminal will be smaller than the number of antennas which can be implemented at the base station. Consequently, the number of spatial dimensions which can be exploited is limited by the terminal. It is in general smaller than the number of spatial dimensions which could be supported by the base station.

A possibility to exploit all spatial dimensions which are supported by the base station is multiuser MIMO. I.e. the base station serves multiple users at the same time on the same subcarrier by spatial separation.

However, since the receive antennas belong to different users, a singular value decomposition of the total multiuser channel cannot be computed. I.e., the channel cannot be decoupled and inter-user interference occurs. Our proposed algorithm CZF-SESAM (cooperative zero forcing - successive encoding successive allocation method), which will be described in the next

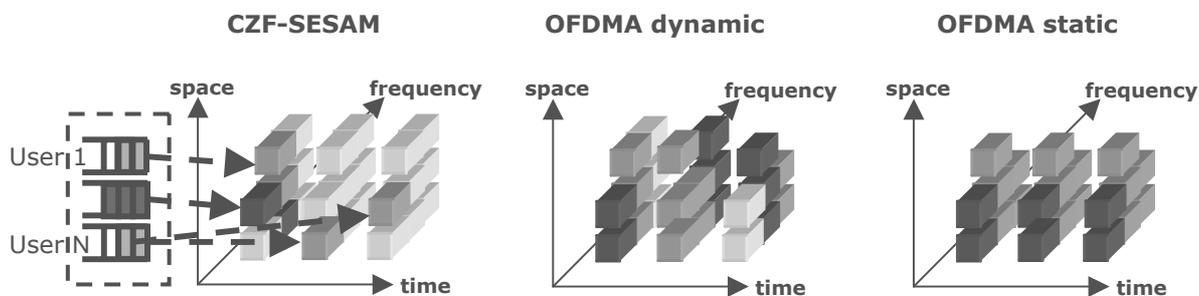


Fig. 1: Considered multiuser MIMO scheduling options.

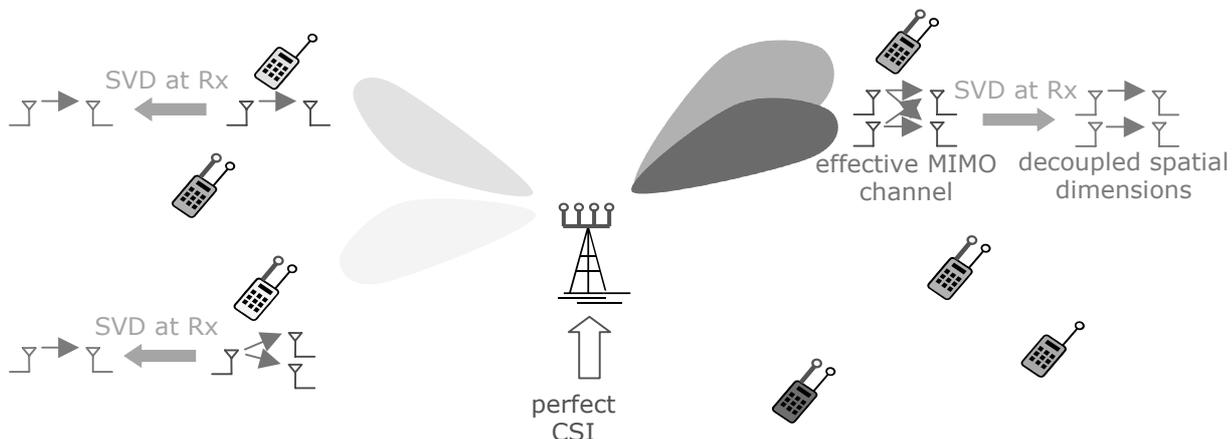


Fig. 2: Principle of multiuser MIMO.

section, avoids inter-user interference by means of signal processing at the transmitter.

Another important advantage of multiuser MIMO is exploitation of multiuser diversity. Each spatial dimension can be assigned to the user with the best SNR. Particularly in case of a large number of users, this can significantly improve the cell throughput.

In this paper, we consider a downlink scenario as depicted in Figure 1 where a large number of users compete for the available resources. Three basic options for allocation of the resources in time, frequency and space are indicated in Figure 2: Static OFDMA is a fair scheme in the sense that the same amount of resources is allocated to all users. Each user exploits MIMO, but all spatial dimensions on a subcarrier are allocated to the same user. Dynamic OFDMA increases the cell throughput or sum capacity, respectively, by exploiting multiuser diversity. I.e. a subcarrier is allocated to the user which has the highest SNR, but still all spatial dimensions on a subcarrier are allocated to the same user. Our proposed algorithm CZF-SESAM additionally includes the spatial dimension in the scheduling, i.e. different spatial dimensions on the same subcarrier can be allocated to different users.

## 2. Principle of CZF-SESAM

In order to avoid interference between the spatial dimensions of different users, CZF-SESAM applies successive encoding where each beam (spatial dimension) lies in the null space of previously allocated beams and interference of previously allocated beams is cancelled at the transmitter by means of dirty paper coding which can be implemented as Tomlinson-Harashima precoding.

Here, we describe the principle idea of the algorithm. For mathematical details, we refer to [1]-[4]. We illustrate the successive steps in Figure 3. For simplicity, we restrict ourselves to two users for the explanation. The base station is equipped with  $n_T=4$  transmit antennas, i.e. it can support 4 spatial dimensions. Each user has  $n_R=2$  receive antennas, i.e. it can resolve 2 spatial dimensions. The broken lines in Figure 3 indicate the transmission paths.

The algorithm allocates spatial dimensions successively to users such that in each step the user with the highest SNR is served. In order to determine, to which user the first spatial dimension should be allocated, the SNR for both candidates is computed as indicated in the top figure of Figure 3. If the first spatial dimension was allocated to user  $i$ , the base station would form a beam using the right singular vector corresponding to the largest singular value of the channel to user  $i$ . The receiver would apply beamforming using the left singular vector corresponding to the largest singular value of the channel to user  $i$ . The tap gain of the effective spatial dimension is given by the respective singular value. In the example of Figure 3, the singular value of user 2 is higher than that of user 1. Consequently, the first spatial dimension is allocated to user 2. For the next spatial dimension, it has to be guaranteed that no interference to the already allocated spatial dimension occurs. This is achieved by zero forcing. I.e. we project the channel matrix to a new channel matrix which lies in the null space of the previously allocated spatial dimension. Then, the algorithm tests to which user the second spatial dimension should be allocated in the same way as described before. The algorithm proceeds accordingly until all  $n_T$  spatial dimensions which can be supported by the base station have been allocated.

By doing so, we make sure that successive spatial dimensions do not interfere to previously allocated spatial dimensions. However, there is interference from previously allocated spatial dimensions to later allocated spatial dimensions. This interference is cancelled at the transmitter by means of dirty paper coding, e.g. by Tomlinson-Harashima precoding.

In case of OFDM, the algorithm can be run on each subcarrier or resource block. It essentially performs resource allocation in space, time and frequency where the scheduling is done according to the criterion of cell throughput/sum capacity maximization.

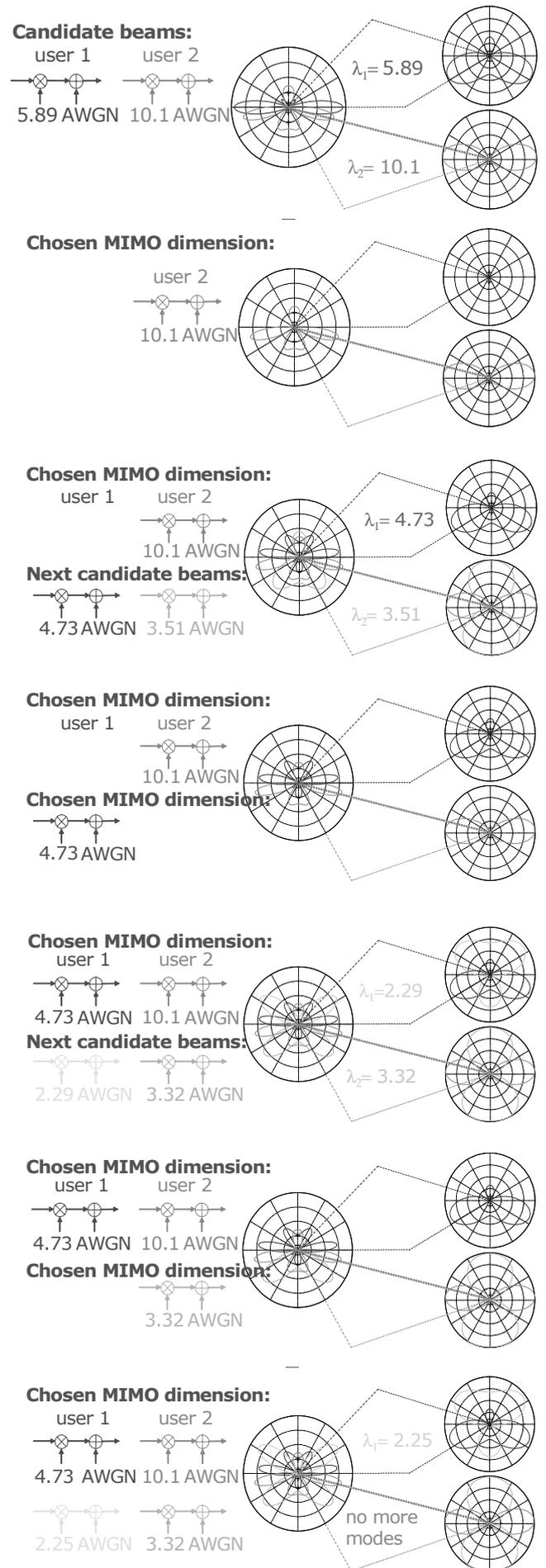


Fig. 3. Successive allocation of spatial dimensions by CZF-SESAM.

### 3. Sum Capacity and Rate Distribution

For evaluation of the CZF-SESAM algorithm, we computed the achievable sum capacity for an indoor large office environment with measured channels. The measurements have been carried out at Aalborg University, Denmark [5]. The floor plan is depicted in Figure 4.

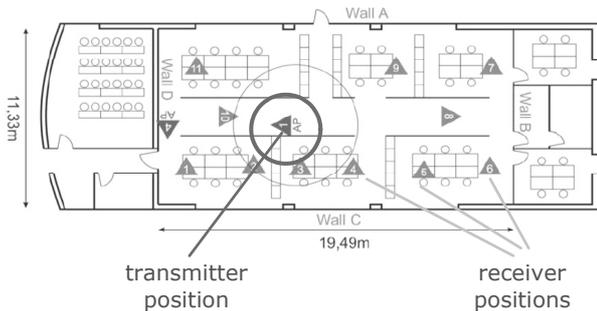


Fig. 4. Floor plan for channel measurements.

We used the access point AP1 in the middle of the room as base station with a uniform linear array (ULA) with 4 antennas. Eleven users with 2-element ULAs whose antenna orientation is indicated by the green arrows compete for the resources. We used OFDM with 1024 subcarriers within a bandwidth of 65 MHz. Results on the achievable sum capacity are depicted in Figure 5. It is interesting to see that even though CZF-SESAM includes in general suboptimum parts such as zero forcing, the theoretical bound for the sum capacity, the Sato bound [6], can be reached. This is not true for all scenarios, but in all simulated scenarios we observed results very close to the Sato bound.

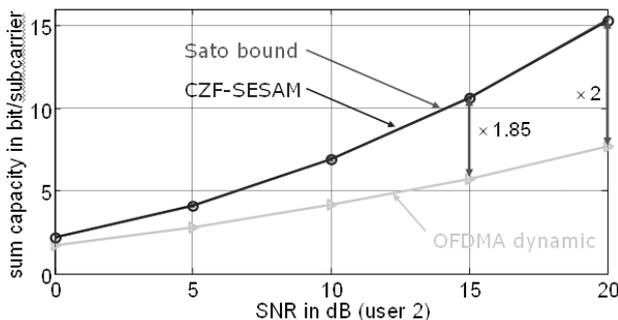


Fig. 5. Sum capacity for large office room environment.

For comparison, we included the sum capacity of dynamic OFDMA according to the middle of Figure 2. CZF-SESAM achieves a gain of a factor 1.8-2 in terms of sum capacity over dynamic OFDMA. This is due to the fact that the maximum number of spatial dimensions can be exploited.

Multuser diversity aims at maximization of the sum capacity, i.e. the cell throughput. However, it does not include fairness aspects. It can happen that a certain user is not served at all whereas another user gets almost all of the available capacity. It is a nice feature of CZF-SESAM, that including the spatial dimension in the scheduling process inherently brings some fairness. This can be seen in Figure 6 where we compare the rate distribution of the options given in Figure 2 for an indoor scenario with four users. OFDMA static allocates the same amount of resources to each subcarrier. All users are served but the sum rate is rather poor. On the other hand, dynamic OFDMA is rather unfair since one user gets almost all of the available capacity. CZF-SESAM achieves the highest sum capacity and serves all users with significantly higher rate than static OFDMA. Since fairness is not explicitly taken into account by the scheduler, this fairness cannot be guaranteed. However, it can be observed in most relevant scenarios. An extension of the algorithm could be a useful preselection of users who compete for the resources using CZF-SESAM such that fairness is achieved with high probability.

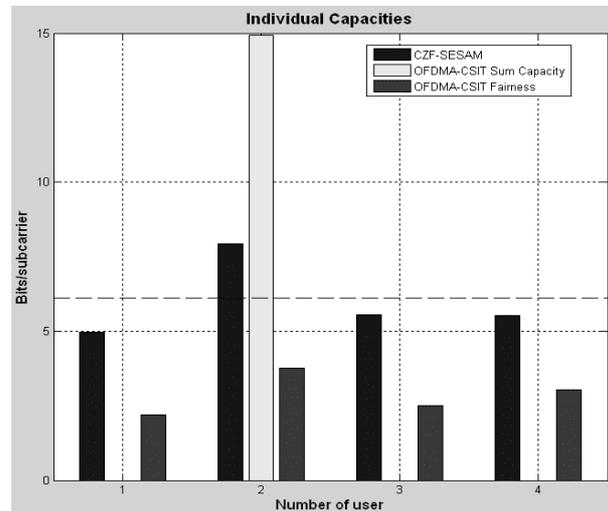


Fig. 6. Rate distribution for indoor scenario. SNR = 20 dB for reference user 2.

### 4. Applicable Service: Video Streaming

Video streaming is a data rate demanding service which requires a stable data stream. Hence, application of multiuser diversity, where it can happen that a certain user is not served for some-time, seems to be in contradiction to the requirements of video streaming. However, the inherent fairness aspect of CZF-SESAM which was described in the previous section may allow to benefit from the increased sum capacity and at the same time provide a stable video stream to the users. We consider an indoor scenario as depicted in Figure 7. Six users each with 2 receive antennas need to perform video streaming. We make the simplifying assumption that the source coding rate can be adapted independently from one frame to the next according to the allocated resources and there is no inter frame coding (motion JPEG). The buffers of the users are never empty. All users have the same average SNR.

We give exemplary results for one of the users who transmits the ITU test sequence "foreman." We show the PSNR versus the frame index of the respective user in Figure 8 for the three scheduling options given in Figure 2. The PSNR is a quality indicator for video. It can be observed that static OFDMA has the most stable performance. Dynamic OFDMA has sometimes significantly higher PSNR but on the other hand also often severe fades when the user is not scheduled. With CZF-SESAM, the PSNR is almost always higher than with static OFDMA. This indicates that the inherent fairness of CZF-SESAM allows stable video transmission even though fairness is not explicitly taken into account by the scheduler.

### 5. Conclusion

We have described a multiuser MIMO transmission scheme for maximization of cell throughput based on successive zero forcing and interference cancellation at the transmitter based on dirty paper coding. The scheme has been evaluated based on measured channels for an indoor office environment. The theoretical limit for the sum capacity can be reached in most cases. Furthermore, we showed that including the spatial domain in the scheduling using the proposed scheme includes some inherent fairness even though QoS is not explicitly taken into account by the scheduler. E.g. for video streaming, the cell throughput can be significantly improved by exploiting multiuser diversity while the data rate per user is stable enough in order to provide stable video streams to several users.

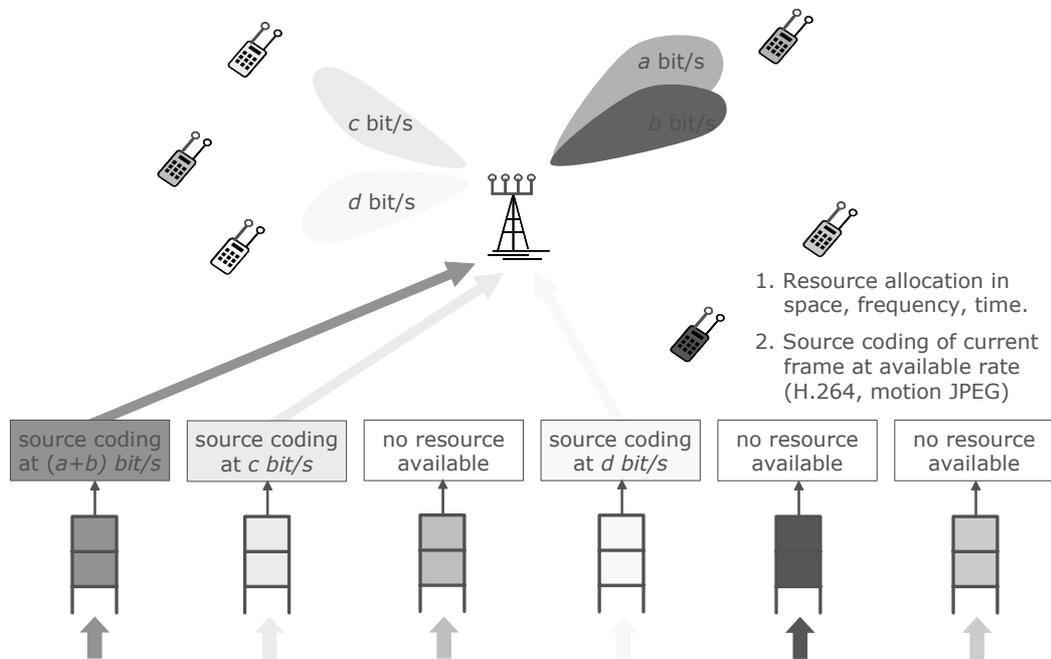


Fig. 7. Scenario for video streaming.

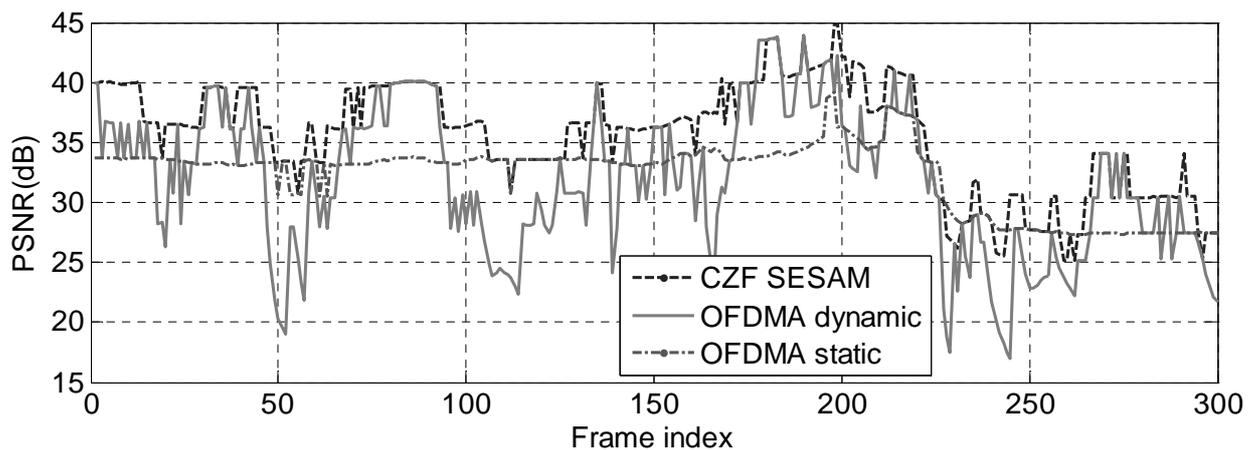


Fig. 8. PSNR for video streaming.

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