# Performance Evaluation of Interference Aware Resource Allocation in OFDMA Systems based on IEEE 802.16a

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*Abstract*—**This paper deals with the challenges in the design of dynamic resource allocation schemes in the MAC layer of broadband OFDMA systems that operates in the presence of interference. The investigated MAC is based on IEEE 802.16a. Two different OFDMA subchannel schemes, distributed and adjacent, are compared in this work concerning interference estimation properties and the capacity gain due to diversity exploitation. To explain the effects of the difference subchannel schemes, comprehensive performance evaluations for a reference scenario have been conducted by means of stochastic event driven simulations.**

***Keywords*—OFDMA, IEEE 802.16a, interference estimation, MAC, resource alloaction**

## I. Introduction

The OFDMA transmission technique is a promising candidate for future broadband radio systems. It shows great benefits in handling inter symbol interference and supports high flexibility in the resource allocation. OFDMA is used as a transmission scheme in IEEE 802.16a, and currently also several research projects address the design of broadband OFDMA systems, e.g. [1][2]. The adaptive scheduling of radio resources in the frequency domain offers the possibility to exploit diversity and significantly increase the system capacity [3]. In an OFDMA system like IEEE 802.16a, radio resources are not allocated for data transmissions in form of single subcarriers. Subcarriers are grouped to subcarrier sets, namely subchannels, which are then used for data transmissions. This technique has the advantage that the signaling overhead concerning channel estimation and allocation announcement can be decreased.

The way in which the subcarriers that form a subchannel are mapped onto the frequency channel has a great influence of the system behavior. In this work, the performance of two different OFDMA schemes is compared in the presence of interference. In the first scheme, subchannels consist of adjacent subcarriers in the frequency domain with correlated fading properties. Such a subchannel can be considered as clustered. In the second investigated scheme, which is currently used in IEEE 802.16a, the subcarriers of a subchannel are pseudo-randomly distributed over the frequency channel [4]. This leads to an averaging effect concerning both the fading and the interference. Subcarriers with low *SINR* values can be compensated by subcarriers large *SINR* values. This can be achieved by the application of interleaving and convolutional coding with a long constraint length [5].

Performance evaluations have shown that the capacity of a broadband OFDMA system can be significantly increased with the combination of clustered subchannels and the exploitation of diversity in a multiuser scenario [6]. In this work we analyze the performance of the two different OFDMA subchannel scheme in the presence of interference. The problem is that accurate interference estimation is required for the reasonable selection of a modulation and coding scheme for data transmissions.

Concerning the handling of interference, the two described subchannel schemes show a different behavior. The distributed subchannels show a low variance of the interference and fading property. This enables accurate interference estimation. But at the same time, possible capacity gains due to the exploitation of multiuser diversity can not be achieved because all subchannel show the same mean characteristic. In contrast, the clustered subchannel scheme enables the exploitation of diversity at the expense of increased uncertainty in the interference estimation. This paper explains this effect in detail and provides an analysis of the different subchannel schemes by the means of stochastic simulations.

In the next section, interference aware resource allocation is described. After that, section III gives an overview of the investigated OFDMA system and in section IV results of the performance evaluation for a reference scenario are presented. Finally, the paper ends with some concluding remarks.

## II. Interference Aware Resource Allocation

For an optimal allocation concerning the systems capacity, accurate estimations of fading and interference for all resources are required. Compared to the estimation of the fading, the interference estimation is directly affected by the resource scheduling of co-channel cells in a multi-cellular scenario. When the scheduler exploits the diversity of the resources, the interference has a random characteristic since the channels of spatially separated cells are uncorrelated. The interference obeys a distribution function with a possibly large variance.

### *A. SINR Estimation*

The calculation of the *SINR* for a subchannel, which is required for an adaptive selection of code and modulation, is given by Equation 1. It contains the transmission power *P*, the path loss *L*, the thermal noise *N*, the fading loss *F*, and the interference level *I* on the subchannel. All power levels are given in dBm, and the path loss and the fading loss are given in dB. With the assumption of accurate channel knowledge at the scheduler, only the interference is afflicted with uncertainty.

$$SINR_i = P_i - L - N - F_i - I_i$$

*Equation 1*

Due to the uncorrelated scheduling in all cells, the distribution function of the interference is the same for all resources. The problem is that the exact interference level on a dedicated resource can not be anticipated. However, the distribution function can be predicted based on moment estimations. In this work, the expectation and the standard deviation of the interference level are estimated.

Based on the results, the expected *SINR* for a subchannel is calculated. The effective interference is assessed by Equation 2. It is the expectation plus the standard deviation multiplied by a factor $\alpha$. The larger $\alpha$ is, the smaller is the probability that the real interference is higher than $\tilde{I}'$. The magnitude of $\alpha$ directly affects the system performance concerning the capacity and the delay.

$$\tilde{I}' = \tilde{E}[I] + \alpha \cdot \tilde{\sigma}[I]$$

*Equation 2*

Based on the *SINR* estimation, an OFDMA subchannel and a modulation and coding scheme is selected for the data transmission. In general, a large $\alpha$ will lead to a high probability for the use of a robust modulation scheme like QPSK. The effect is a low probability of transmission errors. But it will also result in an inefficient exploitation of the radio resources. This tradeoff can be seen in the performance evaluation results presented in section IV of this paper.

### *B. Effects of different OFDMA subchannel schemes*

As already explained in the introduction, the two OFDMA subchannel schemes that are considered in this work differently affect the interference estimation. The schemes are shown in Figure 1. The upper part (*A*) of the figure shows the clustered (adjacent), and the lower part (*B*) shows the distributed subchannels.

The different cells are assumed to be perfectly synchronized and all cells use the same subchannel scheme. Due to the synchronization there is no interference between adjacent subcarriers in the frequency channel. Therefore also different subchannels in the clustered scheme are orthogonal in different cells. When a cell is operating on a single clustered subchannel, it causes interference only on that subchannel for other cells and other subchannels are not affected. With the used of distributed subchannels there is a different behavior. Since all cells distribute the subcarriers of an OFDMA subchannel independent of each other in the frequency spectrum, a subchannel in one cell affects all other subchannels in an interfering cell. The interference is distributed on all subchannels. This technique can be regarded as a CDMA scheme with a processing gain depending on the number of OFDAM subchannels [5].

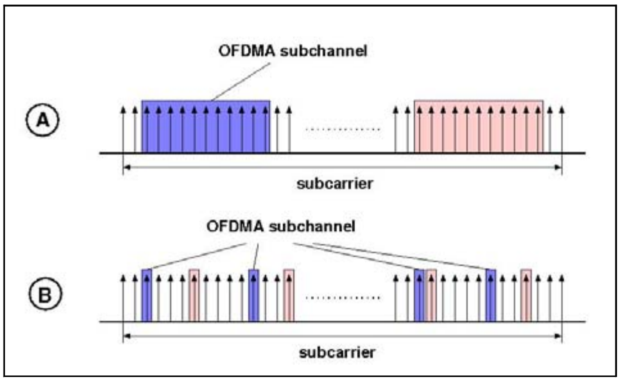


*Figure 1 : OFDMA subchannel schemes*

Concerning the interference estimation, the distributed subchannels show a low variance of the interference distribution which results in an accurate estimation. In contrast to that, the interference on the clustered subchannels has a large variance which makes it hard to estimate the precise interference level on a resource based on preceding measurements. At the same time the clustered subchannel scheme has a big advantage compared to the distributed subchannels since it allows the exploitation of diversity in the frequency channel. In distributed subchannels, this inherent diversity is already averaged like the interference.

So there are two properties that affect the choice of a subchannel scheme for an OFDMA system. The use of clustered subchannels offers the possibility to exploit the channels diversity and at the same time increases the uncertainty in the interference estimation. Distributed subchannel support accurate interference estimation at the cost of losing possible capacity gains due to diversity exploitation.

## III. System Description

### *A. Physical Layer*

The bandwidth of the investigated system is 40 MHz and the frequency channel is subdivided into 512 subcarriers. The overall symbol length is 13.6 µs, comprising a cyclic prefix of 0.8 µs. There are 16 OFDMA subchannels, each comprising 32 subcarriers. Within a subchannel 2 carriers are reserved for pilot signals and 30 are used for the transmission of data.

## B. Medium Access Control

The medium access control is based on a centrally controlled scheme like in IEEE 802.16. Since this paper focuses on the dynamic resource allocation, a rather simple MAC frame us used for the performance evaluations. The structure is shown in Figure 2.

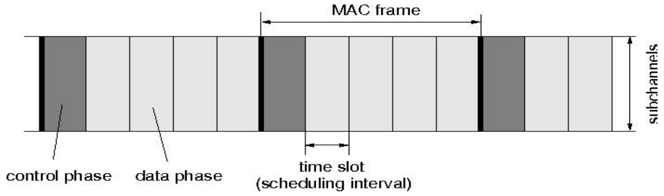


*Figure 2 : MAC frame structure*

It consists of 5 time slots, each with a length of 8 symbols (108.8 µs). The first slot is reserved for the MAC signaling overhead. An SR-ARQ scheme is used on top of the MAC layer for the handling of packet errors. Furthermore, a packet segmentation process is conducted for the mapping of MAC PDUs onto resources.

The MAC frame consists of a control phase and a data phase. The control phase is considered to be used for the signaling, both channel estimation and the announcement of resource allocations. A fixed length of one time slot for the control phase is considered in this work. Within the data phase resource are assigned to data connections based on an OFDMA scheduling algorithm.

## C. Resource Scheduling

The applied OFDMA scheduling algorithm supports the exploitation of multiuser diversity and fairness at the same time due to a combination of round robin connection selection and the dynamic selection of resources according to the estimated *SINR*. QPSK¾, 16QAM¾, and 64QAM¾ are used as modulation and coding schemes. Such a combination of modulation and coding scheme is called PHY mode in the rest of the paper.

The OFDMA scheduling algorithm in general comprises a loop that consists of five steps [6]. The process is shown in Figure 3. In the first step, a connection is selected from the set of active connections. A connection is considered active if there is at least one packet to transmit in the according queue. The selected connection is then allowed to choose a resource from the set of all unassigned resources. After that generation of a connection-resource pair, transmission power is allocated to that pair. In the current implementation of the scheduler the overall downlink transmission power is equally distributed over the parallel transmissions in a time slot. Based on that assigned transmission power the expected *SINR* on the resource is estimated and an according PHY mode is selected. Finally, the resource requirements for the scheduled connection are adapted. This loop is finished when either all connections are served, meaning that all transmission queues are empty, or when all resources of a MAC frame have been allocated.

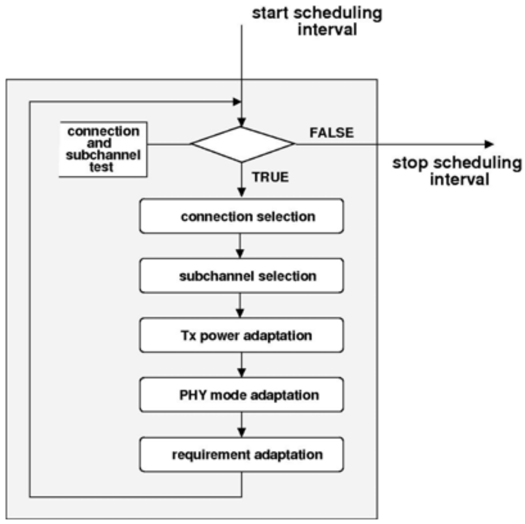


*Figure 3 : Basic OFDMA scheduling algorithm*

# IV. Performance Evaluation

## A. Simulation Model

The performance evaluation has been conducted by the means of stochastic event driven simulations. The NS-2 simulator [8] has been extended with a comprehensive OFDMA system and an according channel model including path loss, subchannel fading, and the mapping of *SINR* levels onto packet errors. Due to complexity, a detailed implementation of the PHY comprising subcarrier modeling, channel coder, etc. can not be deployed for MAC level simulations. This would end up in an extensive simulation runtime. Therefore, a simplified model for the OFDMA transmission is used. The granularity of the resources in the simulation is defined by the OFDMA subchannel.

The link adaptation curve for the used PHY modes is shown in Figure 4. It is determined based on the BER calculations for AWGN channels [7].

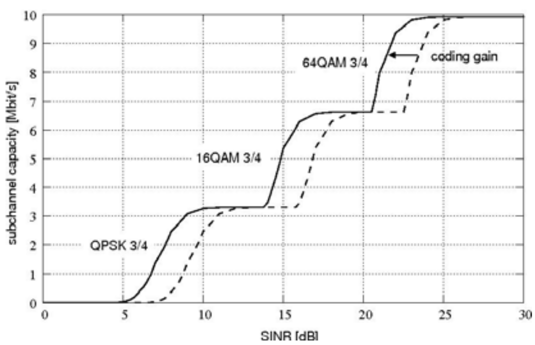


*Figure 4 : Link adaptation curve*

Since a channel coder is not implemented in the simulation environment, a fixed coding gain of 2 dB is assumed for all

PHY modes. This is a rather simple model, but the general effects that are of interest in this work can be shown anyway. The effective fading of a subchannel is modeled by a Rayleigh fading process in the case of clustered subchannels. For distributed subchannels, the fading is determined by the superposition of 16 Rayleigh processes due to the distribution of the subchannels in the frequency domain. In the model, the frequency channel consists of 16 adjacent frequency blocks with uncorrelated Rayleigh fading processes and a distributed subchannel is considered to use the same fraction of every frequency block in the mean. A clustered subchannel is directly mapped onto an adjacent frequency block.

### *B. Simulation Scenario*

The reference scenario, which is shown in Figure 5, consists of two cells with 8 mobile terminals each with a downlink connection. All mobile terminals except MT1 and MT2 randomly move around within a circle area with the radius *R*. The access points are placed in the centers of the cells with the distance *D* to each other. For the presented simulation results *D* is 500 m and *R* is 100 m. The path loss exponent $\gamma$ is 2.5. This basic scenario is used for the performance evaluation to allow a detailed analysis of the basic effects of interference aware scheduling from MAC point of view.

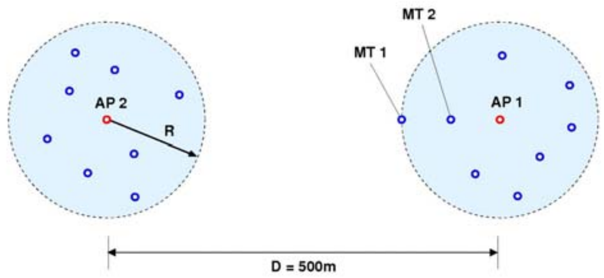


*Figure 5 : Reference scenario*

### *C. Simulation Results*

Figure 6 and Figure 7 show the cumulative distribution functions of the *SINR* and the interference estimation error for MT1 depending on the downlink traffic load per connection. These results reveal the impact of the different OFDMA subchannel schemes. The distributed scheme reduces the variance of the *SINR*. This enables precise interference estimations. In contrast, the clustered subchannel scheme causes an increased variance of both the *SINR* and the interference estimation error. This may lead to packet errors due to the selection of inappropriate modulation and coding schemes. It is shown that the mean *SINR* is larger for the clustered scheme due to the exploitation of subchannel diversity, but has a larger variance. In the worst case it has an even lower *SINR* than the distributed subchannel approach since under high traffic load conditions all resource have to be used.

The reason for the steps in the *SINR* curves for the clustered subchannels is the superposition of two cases. In the first case a resource is also used by the interfering cell, and in the second case the resource is not used by the other cell. This is exactly what has been expected. The distributed subchannel scheme does not show such an effect since all subchannels are affected by interference. For both subchannel schemes the mean *SINR* becomes larger when the traffic load is increased because more resources are used for data transmissions. The evaluation of the interference estimation error for clustered subchannels shows that the variance of the error distribution is reduced when the traffic load is increased. More resources are used and therefore the variability in the overall resource utilization is reduced. For the distributed subchannel scheme the traffic load does not affect the accuracy of the interference estimation.

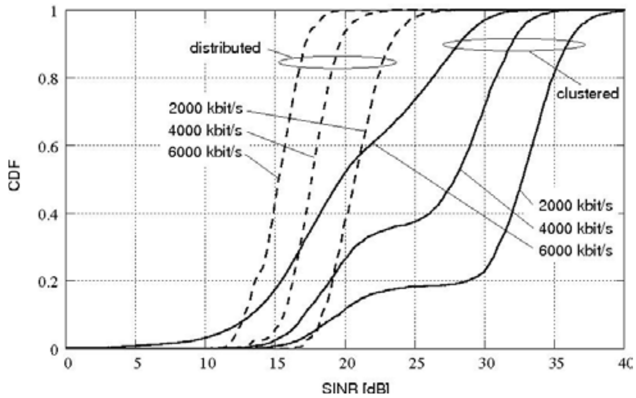


*Figure 6 : SINR depending on the traffic load per downlink connection*

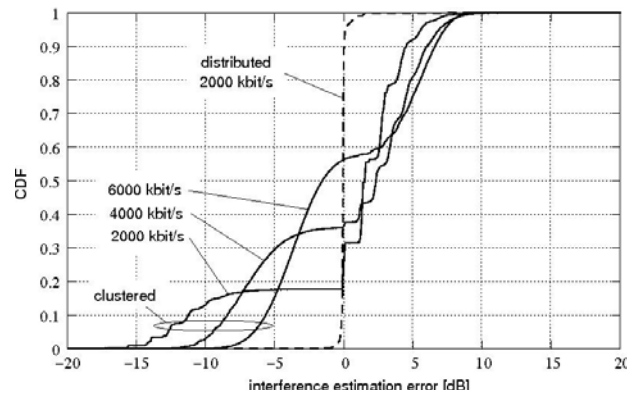


*Figure 7 : Interference estimation error ($\alpha$ = 0) depending on the traffic load per downlink connection*

Figure 8 shows the overall PHY mode usage for the simulated scenario depending on subchannel scheme and interference estimation. The traffic load per connection is 2000 kbit/s. It is shown that the usage of high capacity modes is reduced with the used of a large interference factor $\alpha$ in the interference estimation. This means that most of the time the estimated interference is larger than the actual interference. The effect is that the PER is reduced due to the selection of robust PHY modes, but this may also lead to an inefficient use of the radio resources since the robust PHY modes have a reduced capacity.

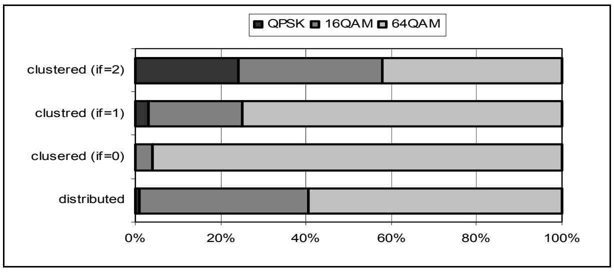


*Figure 8 : PHY mode usage*

The mean PER depending on traffic load per connection and interference factor α is shown in Figure 9 for MT1, which has a worst case position at the border of the investigated cell. As explained before, it can be seen that the PER is reduced with the used of large α values.

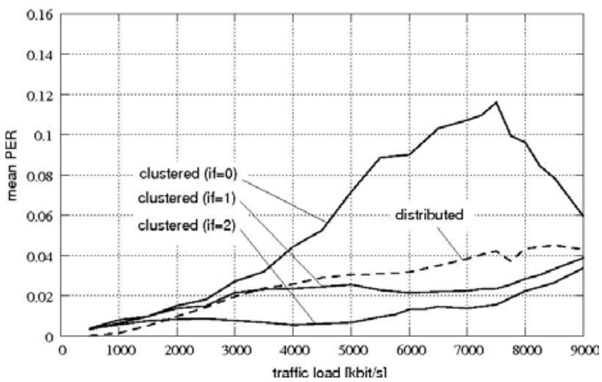


*Figure 9 : Mean PER*

Figure 10 shows the resulting mean throughput-delay characteristic of all downlink connections. It illustrates that the clustered OFDMA subchannel scheme can increase the system capacity compared to the distributed subchannel scheme

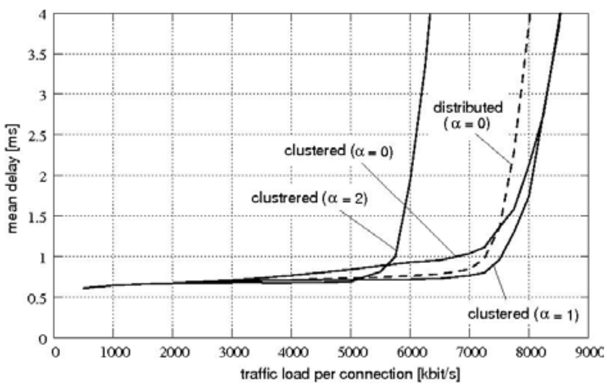


*Figure 10 : Throughput-delay characteristic*

The capacity gain approximately comprises 6.25 % in the investigated scenario. However, an improper choice of the interference factor α like 2 can also significantly decrease the system capacity.

In general the interference factor α is subject to an optimization process. The optimal value will thereby depend on a large set of system parameter like scenario setting, diversity of resources and usable PHY modes.

## V. Conclusion and Outlook

In this paper we described the problems of interference aware resource allocations in OFDMA systems. Two OFDMA subchannel schemes have been compared concerning their system performance under the influence of co-channel interference. It has been shown that there is a tradeoff between diversity exploitation and accuracy of interference estimation depending on the mapping of OFDMA subchannels onto the frequency channel. Detailed simulation results for a reference scenario have revealed that the performance of an OFDMA system depends to a great extent on the way how the interference is estimated. These performance evaluations have shown that with the used of clustered subchannels, which consist of subcarriers that are adjacent in the frequency spectrum, capacity gains can be achieved compared to an averaging approach even at the presence of high interference.

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