# Impact of Signaling Constraints on the MAC Level Performance of OFDMA Systems

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***Abstract*— Frequency adaptive scheduling in OFDMA systems requires accurate channel state information at the transmitter. In this paper we investigate the performance degradation in the downlink of a WiMAX based OFDMA system under the assumption of signaling constraints in the uplink. The active mobile terminals are not allowed to transmit the channel state information of all available subchannels to the associated base station but only a subset which is defined by a maximum number of subchannels. The impact of this constraint on the system behavior is discussed with the help of simulative performance evaluations. These are mainly focused on the interaction between physical layer and medium access control and therefore provide specific insight into the characteristics of broadband OFDMA systems.**

***Index Terms*— OFDMA, medium access control, WiMAX, signaling overhead, frequency adaptive scheduling**

## I. Introduction

In recent years OFDMA (*Orthogonal Frequency Division Multiple Access*) emerged as one of the key technologies for wireless broadband systems. Due to its good performance in multi-path environments without line-of-sight it is currently adopted in IEEE 802.16e [1] which is the basis for Mobile WiMAX [2]. Furthermore, also 3GPP LTE (*Long Term Evolution*) considers OFDMA as the transmission scheme for the downlink [3]. In an OFDMA system, the frequency channel is divided into orthogonal narrowband subcarriers and these subcarriers are grouped to subchannels. The subcarriers which form a subchannel can be either distributed or adjacent in the frequency domain. The distributed approach results in an averaging effect concerning both interference and fading. Hence all subcarriers show the same quality from MAC perspective [4]. With the use of adjacent subchannels, the objective is to exploit the diversity of the frequency subchannel by using only subchannels with good channel conditions. This is also known as frequency adaptive scheduling. It is known that this can significantly increase the system performance in multi user scenarios [5]. The problem with the use of adjacent subchannels is the additionally required signaling overhead compared to the distributed scheme. The transmitter has to know about the channel conditions at the receiver. Since distributed subchannels have all the same quality, the signaling overhead with adjacent subchannels is $N$ times higher if $N$ subchannels are used for frequency adaptive scheduling. An approach to reduce the singling overhead is to set constraints for the number of subchannels whose quality levels are reported to the transmitter. In this paper, the impacts of such constraints on the MAC level performance are investigated by means of stochastic event-driven simulations. The evaluation is focused on the MAC layer, which means that not bit-streams and full transmission queues are considered but packet data transmissions with variable transmission queue occupancies. For a comprehensive analysis of QoS (*Quality of Service*) in OFDMA systems this is an inevitable approach since both capacity and delay have to be considered.

The rest of the paper is organized as follows. In the next Section, the impact of signaling overhead is described. Section III characterizes the investigated OFDMA system focusing on medium access control and dynamic resource allocation. The simulative performance results are presented and discussed in Section IV. Finally, the paper ends with some concluding remarks.

## II. Signaling Overhead in OFDMA Systems

In a centrally controlled OFDMA system like Mobile WiMAX all resource allocations, both up- and downlink, are done by the BS (*Base Station)*. That means that the BS has to inform the associated MSs (*Mobile Terminals*) periodically about resource allocations. Furthermore, CSI (*Channel State Information*) of the associated MTs has to be transmitted to the BS. Hence, the signaling overhead which is required comprises two fractions. The first is the description of resource allocations based on the scheduling. The second fraction of overhead concerns the gathering of at the transmitter. The latter is especially required for the exploitation of diversity in adjacent subchannels. How this information can be obtained by the transmitter depends on the structure of the system. In a TDD system CSI may be known for several subchannels at the transmitter due to reciprocity of the channel, but the amount of information depends on the uplink transmissions patterns. In an FDD system this has to be transmitted by the receiver. In the performance evaluation presented in this paper we consider the case that from an overall set of $N$ subchannels only quality levels of the $K$ subchannels with the highest expected SNR level are know at the transmitter. The second constraint is that CSI for a subchannel is only reported to the transmitter if the expected SNR is greater than a defined margin which depends on the provided modulation and coding schemes. Hence the number

$k_i$ of reported subchannels of terminal $i$ is smaller than or equal to $K$. Although the number of reported subchannels per terminal can be smaller than $K$, the overall number of usable subchannel at the transmitted can be $N$ if enough terminals are available for the exploitation of multi user diversity since the subchannel fading levels for different terminals are uncorrelated. The use of signaling constraints involves two kinds of impact. At first the mean SNR is increased since only the best subchannels for each terminal can be used for data transmissions. This results in an increased efficiency in the resource utilization since more high capacity modulation and coding schemes can be used. This shall not be mistaken for the effect of a scheduling approach in which only the best subchannel-terminal pairs are used for data transmission to maximize the system capacity. In that scheme fairness can not be supported. The second effect is that it can happen that not all resource can be used for the scheduling process, if the number of terminals is not sufficient. Thus, there is in general the effect that the efficiency of the resource scheduling will be increase but the number of available resource might be reduced at the same time. This relation and the impact on the MAC level performance of an OFDMA system will be discussed in detail in the following performance evaluation.

## III. System Description

### A. Physical Layer

The downlink OFDMA parameters of the investigated system are based on Mobile WiMAX [2]. The system operates at 5 GHZ with 20 MHz channel bandwidth. The channel is divided into 2048 orthogonal subcarriers. The latter are grouped into 32 subchannels each consisting of 48 adjacent data subcarriers. This results in overall 1536 data subcarriers. The remaining subcarriers are used as pilots and guard subcarriers. The overall symbol length, including guard time, is 100.8 µs.

### B. Medium Access Control and Resource Allocation

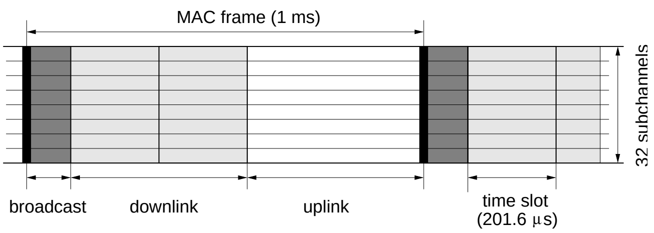


Fig. 1: MAC frame format

The MAC frame structure is depicted in Fig. 1. The frame consists of a transmission phase which is reserved for broadcast signaling, 2 time slots for the transmission of downlink data, and the uplink transmission phase. Each downlink slot consists of 2 OFDMA symbols. The resource element which comprises one time slot and one subchannel is the smallest entity which can be assigned to a data connection by the scheduler. This resource size is used because in combination with the used modulation and coding schemes and a fixed packet size of 18 bytes no capacity is wasted due to clipping. The MAC frame has a fixed length of 1 ms. Dynamic resource allocation for both up- and downlink is conducted in a centrally controlled manner by the BS. This allocation is done periodically at the beginning of each MAC frame and reported to the MTs in the broadcast transmission phase. Concerning the channel state estimation, which is required for the OFDMA resource scheduling in the downlink, it is assumed that the measurement is conducted by the MTs during the broadcast transmission phase. The results are reported to the BS in the next uplink phase.

The frequency adaptive scheduling process is described in the following. At first, a queue is selected from the set of active connections in a Round Robin fashion. A connection is considered active if there is at least one data packet to be transmitted. The according connection then gets the resource with the best quality regarding the effective fading from the set of not assigned resources within the MAC frame. Finally, the transmission power and an appropriate modulation and coding scheme are selected, and the data packets that fit into the allocated resource element are removed from the queue. The latter is considered as an adaptation for the requirements for the next scheduling step. This procedure is repeated until either all active connections have been able to transmit all data packets or all resources within the MAC frame are allocated. This resource scheduling scheme can in general be used for both up- and downlink, but in this paper only the downlink is considered. Furthermore, a fixed transmission power is used for each data transmission. Hence the adaptation to the current channel state is done via selection of modulation and coding scheme. We chose to use Round Robin resource allocation in this paper since it is expected to provide maximum fairness compared to schemes which maximize the system capacity.

The combinations of modulation and coding scheme that have been used for the performance analysis are given in Table 1. These form a subset of the combinations supported by Mobile WiMAX [2]. A single element in the grid of timeslots and subchannels is defined as a resource element (RE). The SINR values in the table the table determine the margins for a PER which is lower than 0.01. This depends on the coding scheme and the data packet length.

Table 1: PHY modes

| *PHY mode* | *SINR* | *Capacity* |
|---|---|---|
| QPSK¾ | > 8.25 dB | 1 Packet/RE |
| 16QAM¾ | > 15.00 dB | 2 Packets/RE |
| 64QAM¾ | > 21.00 dB | 3 Packets/RE |

The PER has been calculated based on the equations for an AWGN channel [6] and an assumed fixed coding gain of 2 dB. A complete mapping of SINR levels onto PER and resource capacity is given in [5]. Such a mapping is required for accurate MAC level simulations. Since the impact of interference is not considered in this paper the SINR reduces to SNR. An SR-ARQ scheme (*Selective Repeat ARQ*) is used to handle transmission errors.

## IV. Performance Evaluation

The simulations have been conducted with an OFDMA extension for the NS-2 simulator [8]. This extension has been developed for the simulative performance evaluation of broadband OFDMA system. It comprises a centralized MAC scheme based on WiMAX, an OFDMA physical layer, and a comprehensive channel model with accurate interference calculation. In contrast to conventional link level simulators, this tool is event-driven. And therefore it supports detailed performance evaluation concerning QoS based on packet transmissions and variable traffic conditions.

### A. Simulation Setup

The scenario consists of a single BS and 16 MTs which randomly move around within a radius of 200m around the BS. Each MT has a single downlink connection which is modeled by a Poisson source. During a simulation run all downlink connections have the same traffic load. The pathloss exponent of the used single slope channel model is 2.5, which is a typical value for an urban environment. Jakes' model [7] is used for the generation of the effective fading level of the adjacent OFDMA subchannel from MAC point of view. The subchannel fading processes for the different subchannels are mutually uncorrelated. The Doppler shift is 100 Hz, which corresponds to a mobile terminal speed of 21.6 km/h. The thermal noise per OFDMA subchannel has a magnitude of -100 dBm and the fixed transmission power per subchannel is 15 dBm. This results in a sum transmission power of approximately 30 dBm when all 32 subchannels are used in parallel.

### B. Simulation Results

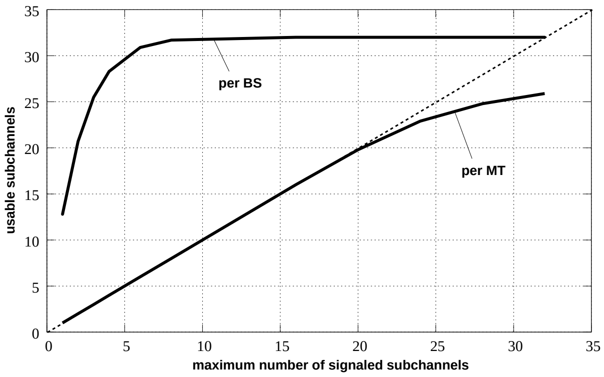


Fig. 2: Usable subchannels for scheduling

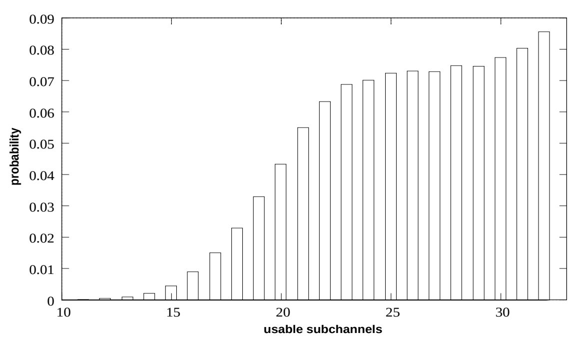


Fig. 3: Probability distribution of usable channels per mobile terminal

At first we investigate the interrelation between maximum number of signaled subchannels (signaling constraint) per MT and the overall number of usable subchannel for frequency adaptive scheduling. The results are depicted in Fig. 2. It can be seen that the mean number of usable subchannels per MT increases with the maximum number of signaled subchannels per MT. But even if it is allowed to report the channel quality of all subchannels (32), this can not be exploited, since in average only 25.9 subchannels per MT exhibit sufficient quality. This number depends on the simulation scenario since it is mainly determined by the channel conditions at the cell border. The larger the cell, the lower will be the mean number of usable subchannels. The probability distribution of the number of signaled subchannels per MT is shown in Fig. 3. This reveals that this number shows a large variance. Fig. 2 also shows the earlier discussed effect that it might happen that not all resources can by used by the BS for the frequency adaptive scheduling even if all MTs can fully exploit their signaling constraint. When for example all 16 MTs are allowed to transmit the channel quality of the best 2 subchannels, the mean overall number of usable subchannels is 20.7 and not 32. This is based on the fact that the reported subchannel sets of the different MTs are not mutually exclusive.

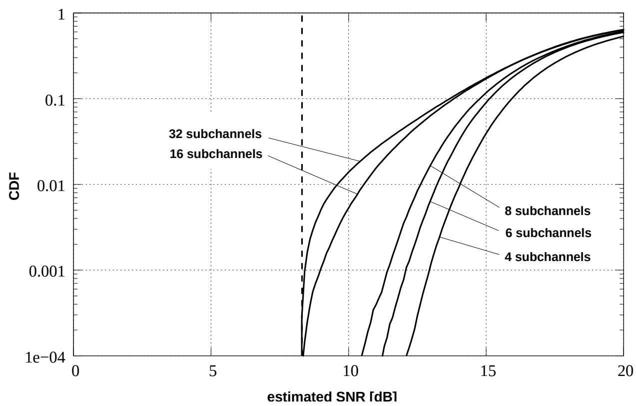


Fig. 4: Estimated SNR for scheduling

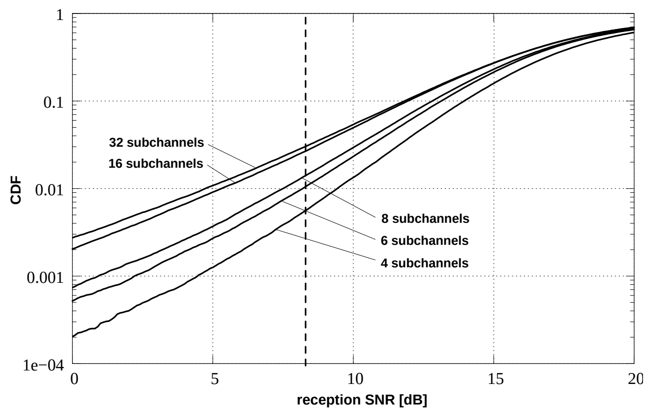


Fig. 5: SNR during data reception

The estimated subchannel SNR at the time of resource allocation in the BS and the real SNR during data reception at an MT is shown in Fig. 4 and Fig. 5. The dotted line marks the minimum SNR which can be used for data transmissions according to Table 1. If the SNR during data reception is below that margin this means that the PER is larger than the acceptable 0.01.

Two effects are shown in these figures. The first is that the SNR during data reception does not coincide with the estimated SNR during scheduling. The reason is that the subchannel fading level in general changes between the moment of scheduling or channel measurement and the data reception at the MT. The degree of uncertainty is determined by the Doppler shift, and hence the MT velocity. The second revealed effect is the SNR enhancement when the maximum number of signaled subchannels is reduced. Only the subchannels with the highest SNR are signaled and can therefore be used for downlink data transmissions.

The resulting mean packet delay depending on traffic load per connection is shown in Fig. 6. In addition to the curves for the adjacent subchannel scheme with different subchannel constraints also the throughput-delay characteristic of for distributed subchannels is shown. These results reveal that even under strict subchannel constraints the adjacent subchannel approach outperforms the distributed scheme. More than 20% capacity gain is achieved with a constraint of 4 signaled subchannels per MT. Corresponding to the overall usable number of OFDMA subchannels in Fig. 2, the system performance is reduced when the maximum number of signaled subchannels per MT is smaller than 8. In this case the maximum throughput per connection is reduced by approximately 20 kbit/s. With the assumption of 32 quantization levels for the subchannels quality the signaling overhead for a single subchannel per MT is 5 kbit/s when a MAC frame length and hence a signaling period of 1 ms is used. This means that the overhead can be reduced from a maximum of 160 to 40 kbit/s with a signaling constraint of 8 subchannels. This exhibits that the use of constraints can significantly increase the efficiency of the system.

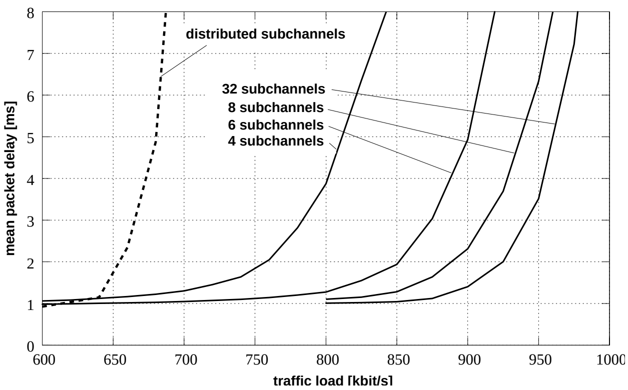


Fig. 6: Throughput-delay characteristic

The resource utilization depending on traffic load per connection is given in Fig. 7. The utilization can be approximated by two asymptotes. The first is applies for the range of traffic loads where the system is not saturated. In this range the resource utilization increases linearly with the traffic load. The efficiency of the system is determined by the slope. The second horizontal asymptote is determines the system saturation. At that point, the resource utilization is constant, independent of the traffic load. When the resource utilization in case of saturation is below 100% this means that not all available resource can be used for scheduling, either due to bad channel conditions or due to signaling constraints. The saturation resource utilizations in Fig. 7 perfectly match the overall number of usable subchannels for scheduling in the case of scheduling constraints in Fig. 2. With a maximum number of 6 signaled subchannels, the maximum utilization of resources is 96.6 %, corresponding to 30.9 subchannels. And with 4 signaled subchannels the maximum utilization of resources is 88.4 % or 23.8 subchannels.

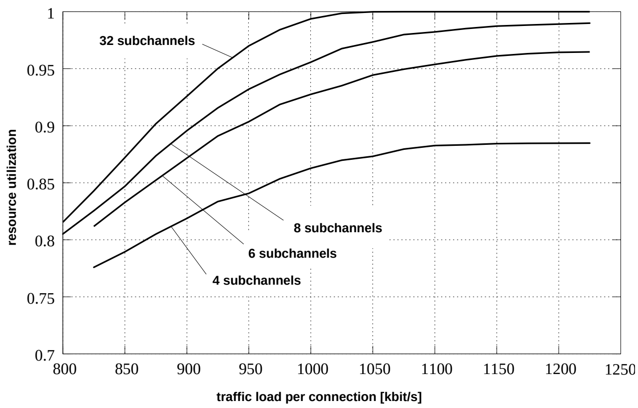


Fig. 7: Resource utilization

## V. CONCLUSION AND OUTLOOK

The impact of signaling constraints on the performance of a WiMAX based OFDMA system has been investigated by means of stochastic event-driven simulations. The general effects of signaling overhead reduction have been shown and discussed. The results show that the efficiency of an OFDMA system with frequency adaptive scheduling can significantly be increased with the use of signaling constraints. The outcomes presented in this paper form the basis for further investigations. A relevant topic is especially the required quantization for the transmission of channel state information because this significantly determines the signaling overhead. Furthermore, the impact of increased inaccuracy in the SNR estimation due to higher velocities and the impact of different scheduling strategies are open issues

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