Multi-user frequency domain scheduling for WiMAX OFDMA

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***Abstract*—This paper introduces the performance analysis of 802.16e OFDMA system in UL mode with respect to multi-user scheduling algorithms in frequency domain. Different scheduling algorithms – from the simplest round robin to the optimal iterative scheduling, along with practical maximum element and two-step algorithms are analyzed and compared. It is shown that multi-user scheduling in frequency domain potentially can greatly improve OFDMA system efficiency in frequency-selective broadband channel.**

***Index Terms*—IEEE 802.16e, WiMAX, scheduling algorithms, system level simulations**

I. Introduction

WiMAX 802.16e [1,2] is a brand new standard in wireless communication. It supports not only OFDM with time division multiple access transmissions, but also OFDMA (orthogonal frequency division multiple access). OFDMA technology provides multiple access by allocating groups of subcarriers (in time-frequency domain) to the individual receiver. In typical scenarios, broadband channel (and interference) may greatly vary in frequency that gives an opportunity to exploit frequency domain scheduling algorithms in addition to the common time domain prediction schemes. In this paper we investigate uplink (UL) performance of WiMAX OFDMA system in typical urban scenarios and compared four different scheduling algorithms impact on system spectral efficiency. The main purpose of the paper is to determine potential performance limits of the interference-aware scheduling algorithms for OFDMA systems which operates on per-frame basis. Considered in this paper optimal iterative scheduling algorithm may serve as an upper bound, while Round Robin scheduling represents the lower bound. Two other scheduling algorithms, described in next section are have reasonable performance and complexity and are first candidates for practical implementation.

II. Scheduling algorithms

A. Round Robin

This algorithm does not perform any optimization of the throughput or any other objective (cost) function. For example the Round Robin (RR) algorithm may consequently choose the slots of the OFDMA frame and assign them to consequent SS.

B. Maximum Element algorithm

The maximum element (ME) algorithm first chooses the frequency subchannel having the best scheduling metric across all the SS and associates slots of this frequency subchannel to a SS having the best metric in that frequency subchannel. After all slots of that frequency subchannel (or SS) are assigned, next frequency subchannel (or SS) having best scheduling metric is chosen, and the procedure is repeated.

C. Two-steps algorithm

The two-steps algorithm is based on Vogel approximation of the solution for the transportation problem. This algorithm searches in each frequency subchannel for two subscribers having two best scheduling metrics and also for each subscriber it searches for two subchannels having two best scheduling metrics. After that the difference between two maximal metrics is computed for every subscriber and for every subchannel, and maximum difference is found. This maximum difference may correspond either to a subchannel or to a SS. If the maximum difference corresponds to a subchannel, the SS having best metrics in that subchannel is selected for scheduling. If the maximum difference corresponds to a SS, the subchannel, in which this station has the best metric, is selected for scheduling.

D. Optimal iterative scheduling algorithm

The optimal iterative algorithm finds the optimal schedule in iterative manner, i.e. first the algorithm accepts some initial scheduling plan and then iteratively improves it (by using methods of the linear programming) until the optimal plan is found. To reduce the number of iterations in the algorithm, the initial schedule must be taken as close as possible to the optimal. In this regard, it is a good approach to use the 2-step scheduling algorithm described above to find the initial schedule.

III. Overview of WiMAX system level simulator

A. Subcarrier allocation schemes in 802.16e UL

IEEE 802.16e standard uses OFDMA (orthogonal frequency division multiple access) modulation technique allowing data transmissions over multiple subcarriers simultaneously. OFDMA is distinguished from common OFDM (orthogonal frequency division multiplexing) by an opportunity of transmitting data to different users using different subcarriers of the same symbol, whereas OFDM only allows transmissions to users that occupy all the subcarriers of the symbol. WiMAX OFDMA in UL mode supports two major subcarrier allocation modes: partial usage of subchannels (PUSC) and adaptive modulation-coding scheme (AMC). In PUSC mode, subcarriers, allocated to the certain user are spread in frequency to increase frequency diversity. In AMC mode, on the contrary, user receives the same adjacent subcarriers throughout the frame, allowing effective multi-users scheduling in frequency selective broadband channel.

B. Simulation setup

System level simulation of the WiMAX OFDMA system with multi-user scheduling consists of the following steps. At first, a number of subscriber stations (SS) is generated within hexagonal BS grid (see Figure 1). Each SS is associated with BS on the base of maximum SNR criterion. For the SSs in center cell, SINR (signal to noise plus interference) values are calculated for each frequency subchannel, taking into account the interferences from the other SSs, that occupies the same subchannel in neighboring sectors/cells. Using the PHY abstraction methodology, the most efficient modulation coding scheme (MCS) is calculated for each subchannel on the base of estimated SINR values. On the base of achievable data rate for each subchannel of each user, scheduling algorithm calculates user's allocation plan for each frame.
Further, the allocation plan is analyzed to obtain performance metrics.

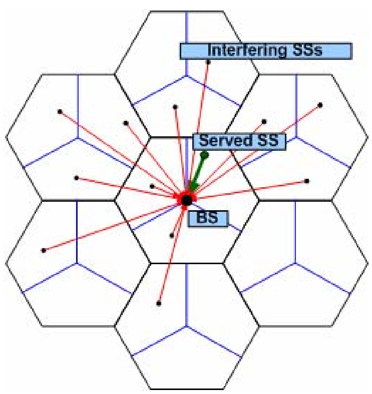

Figure 1 Cell structure diagram

Simulation conditions, environment parameters and BS/SS properties are summarized in the Table I.

TABLE I SYSTEM LEVEL SIMULATOR PARAMETER SUMMARY

Parameter name	Value	Units
Reuse (CellxSectorxFrequency)	1x3x1	
Cell radius	1000	m
Carrier frequency	2.3	GHz
Bandwidth per sector	10	MHz
Cyclic prefix duration	1/8	symbol duration
FFT size	1024	
MCS set	Convolutional Turbo Code + repetition	
Channel model	SCM-Urban Macrocell [3]	
Pathloss model	ITU vehicular/outdoor [4]	
BS parameters:		
Height, ΔhBS	10	m
Rms power/sector	42	dBm/sector
Beamwidth (HPBW)	70	deg
Antenna Gain	15	dB
Cable Loss	2	dB
BS receiver noise	4	dB
BS Antenna spacing	10	wavelengths
SS parameters:		
Rms power	20	dBm
Height, ΔhSS	1.5	m
Antenna Gain	omni	
MS receive noise	6	dB
MS Antenna spacing	0.5	wavelengths

C. Interference environment

In our simulations we have considered the UL mode of WiMAX system operation. For the case of reuse 1x3x1 (3 sectors per cell, all cells operates in the same band) all users in a certain sector should be scheduled in a different time-frequency slots. So, the interfering subscriber stations are in the other cells and in the other sector of the same cells. In that case, it is assumed that for each slot (allocation unit) there is an interfering slot somewhere in another sectors/cell.
Such interference environment, along with channel frequency selectivity and shadowing, leads to great variations in the slot's capacities for the SS-BS link. Typical SINR profile in frequency domain is shown in Figure 2. It can be seen, that adaptive multi-user scheduling may benefit a lot from the knowledge of channel and interference profiles.
In our simulations we have assumed ideal knowledge of the SINR profile at the base station.

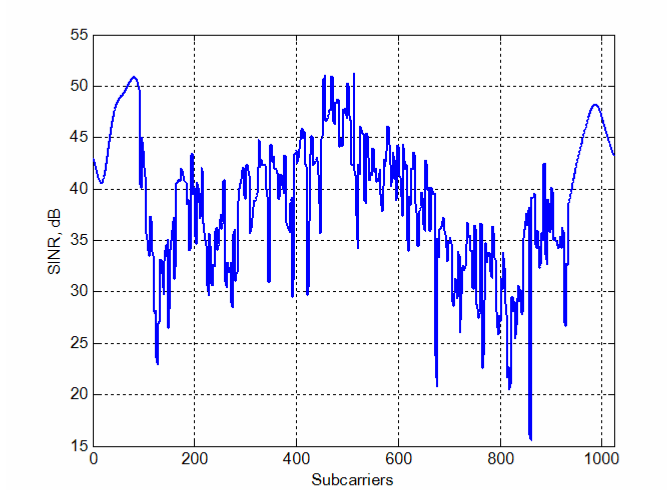

Figure 2 Typical SINR profile in frequency domain

D. Performance metrics

To describe the performance of different scheduling algorithms, several performance metrics were used.
Spectral efficiency (spectral efficiency per sector, measured in bps/Hz/sector) is the most important metric for evaluation of the system level performance. It can be easily recalculated to the total throughput/goodput and other system characteristics. In this paper, spectral efficiency is analyzed in the following ways.
Average spectral efficiency (SE) per sector – it is the primary characteristic for the system level analysis. It is calculated as average of the instantaneous spectral efficiencies over all served users and all trials (frames). For the proper comparison of the PUSC and AMC modes, we take into account difference in guard bands of these modes to calculate mean SE in a whole 10 MHz channel bandwidth.

Cumulative distribution function (CDF) of per-frame averaged SE allows to do the detailed comparison of different scheduling algorithms.
In our simulations, it was assumed, that total throughput requirement of the users chosen to be allocated per each UL subframe is exactly coincide with total available resources in this subframe. However, sometimes it is possible to encounter a situation when some subchannels (due to "bad" quality) may not be used by any of chosen users. So, initial user's throughput (slots) requirements per frame may not be met for all users. To take into account this possibility, we introduce the *outage* characteristic - the percentage of unallocated subchannels per frame. Spectral efficiency for such users and subchannels was set to zero and do taken into account in the all metrics calculation

IV. Simulation Results

To evaluate the performance of WiMAX OFDMA system with different scheduling algorithms, all of them were built in the system level simulator that operates in accordance to Table I scenarios. After signal and interference environment generation, the post-processing SINR is calculated for each time-frequency slot of certain SS-BS link. For the sake of simplicity, we have considered the SIMO case when only BS has multiple receive antennas and perform maximum ratio combining (MRC) signal processing. Employing the PHY abstraction, post-processing SINR recalculated into the error rate (for each modulation coding scheme), after that, MCS with acceptable error rate is chosen.

The scheduling algorithms operate on the table of possible MCS values for given time-frequency slot for all users and produce the scheduling plan – slots assignment for a certain subscriber. Scheduling plan allows estimating all performance metrics, described in section III. Mean spectral efficiencies per sector, in bit/s/Hz are shown in Table II for different number of receive antennas, scheduling algorithms and subcarrier allocation modes.

Table II

Mode	Scheduling algorithm	UL PUSC permutation		UL AMC permutation	
		SE, bps/Hz	Outage,%	SE, bps/Hz	Outage,%
1x2 MRC	RR	1.13	10.3	1.26	13.2
	ME	1.44	13.4	1.82	10.7
	2-step	1.44	7.8	1.86	6.4
	Optimal	1.54	10.0	1.97	7.5
1x4 MRC	RR	1.54	6.4	1.57	7.6
	ME	1.82	8.8	2.10	7.4
	2-step	1.84	3.5	2.15	3.4
	Optimal	1.96	6.3	2.28	4.8

Figures 3-4 shows the mean spectral efficiency CDFs for the described scheduling algorithms. It can be seen that Round Robin algorithm has the worst performance, since it does not use any information about the channel. Maximum Element and Two-steps scheduling algorithms have comparable performance and comparable complexity. Corresponding to these algorithms CDF curves are close to the optimal iterative scheduling curve, so the proposed practical algorithms are quite effective.

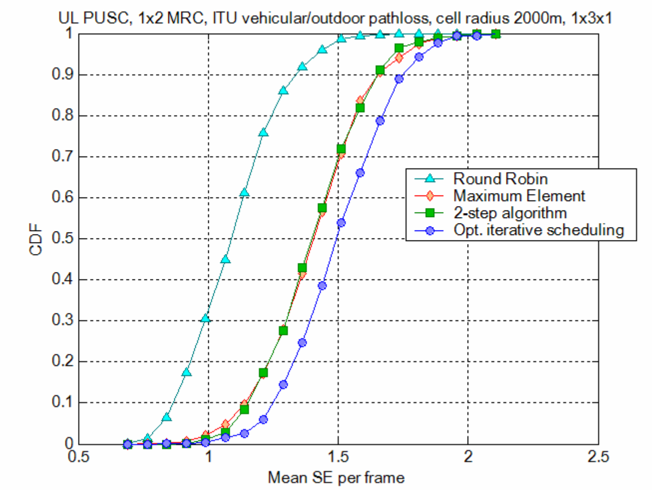

Figure 3: UL PUSC performance with different scheduling algorithms

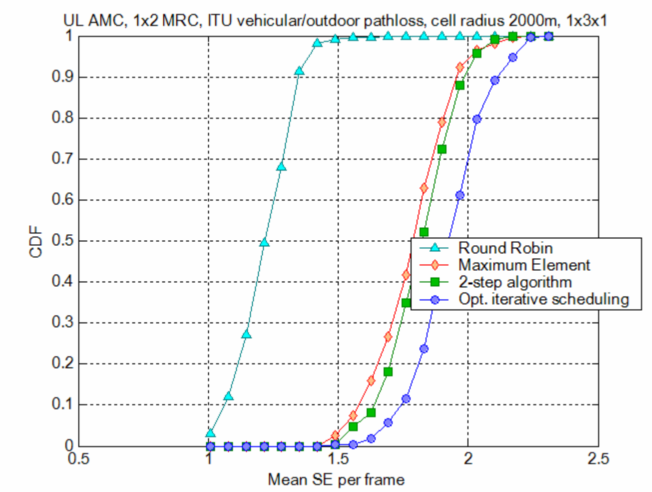

Figure 4: UL AMC performance with different scheduling algorithms

V. Conclusion

In this paper we have analyzed the performance of the WiMAX OFDMA system and investigated several multi-user scheduling algorithms. The main result is that appropriate scheduling in a frequency selective interference environment may increase system spectral efficiency up to 40%, in case of 802.16e UL AMC permutation in comparison with simple round robbing scheduling. Comparing the outage characteristic, we can find that for the RR scheduling the PUSC mode has outage less than AMC mode due to the frequency diversity of PUSC permutation. For other scheduling algorithms AMC mode has about 20-25% less outage than PUSC mode. Two schedulers with relatively simple practical implementation (Maximum Element and Two-steps algorithms) are nearly the same from the point of view of spectral efficiencies. However, Two-steps scheduler shows almost twice less outage than Maximum Element. So, while preserving the same spectral efficiency, Two-steps algorithm more effectively (and fairly) distributes available bandwidth resources among users. Iterative optimal scheduler is only 6-7% better than Two-steps in terms of spectral efficiency, and has a little more outage, but its efficient practical implementation is a matter of additional research.

Acknowledgment

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References

[1] *IEEE Standard for local and metropolitan area networks, part 16: Air Interface For Fixed Wireless Broadband Systems,* IEEE Standard 802.16, 2004.

[2] *IEEE Standard for local and metropolitan area networks, part 16: Air Interface For Fixed Wireless Broadband Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1,* IEEE Standard 802.16e, 2005.

[3] *3GPP & 5 Spatial Channel Model AHG, "Spatial Channel Model Text Description*", SCM Text V6.0.

[4] *Recommendation ITU-R M.1225, "Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000",* 1997