Coordination Across Base Stations for Effective Control of Space Division Multiple Access Enhanced IEEE 802.16m Systems*

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Abstract— **In recent years, smart antenna technologies are of ever-increasing interest to boost the capacity of existing and future wireless systems. Several standards support these techniques such as the wireless metropolitan area network IEEE 802.16 (WiMAX) [1] and IMT-Advanced candidates. In applying smart antenna beamforming and Space Division Multiple Access (SDMA) techniques, adaptive antennas are able to increase cell capacity by reducing inter-cell interference and by allowing concurrent transmissions.**

As a downside, an SDMA enabled cell generates less predictable interference than a conventional cell, because a changing number of mobile stations (MS) are sending uplink data in parallel and downlink streams with changing direction are transmitted by the base station (BS). Thereby the SINR estimation becomes less precise and the link adaptation sub optimal.

This work investigates the potential of coordination across BSs on MAC layer for further mitigation of inter-cell interference and increasing precision of SINR estimations in an SDMA enhanced system. The developed concepts are evaluated in a cellular deployment by means of system-level simulations for up- and downlink. The performance of a coordinated system is compared with a non-coordinated reference case.

Keywords-IEEE 802.16m, IMT-Advanced, SDMA, Beamforming, Coordination across base stations, system-level simulation

I. INTRODUTION

Incorporating smart antenna techniques into an SDMA-capable WiMAX BS not only requires antenna arrays and advanced signal processing facilities but also calls for extensions to the Medium Access Control (MAC) protocols, as described in [4]. Scheduling algorithms serving multiple users jointly in space and time are optimized in [5] and [6] in terms of complexity and performance; by a two step approach, first spatial grouping and second scheduling of resulting groups in time domain.

How smart antennas can be used to mitigate inter-cell interference by beam-forming techniques is well known in literature [7], [8], [9] but only evaluated on physical layer. Multiple antennas are utilized in the physical layer to form adaptive antenna patterns which have high gains in the direction of desired users and signal suppression (further referred to as directing zeros) in the directions of other users, e.g. inter-cell interferes.

The contribution of this work is to apply these concepts to the MAC layer and evaluate them on system-level in a cellular scenario. Inter-cell interferers can possibly be considered in the beamforming algorithm when BSs mutually exchange their scheduling decisions and the position of their MSs. If its interferes are known, an SDMA enhanced BS can further mitigate the inter-cell interference and improve the SINR estimation.

In the following, a system is assumed with multiple antenna elements at the BS and a single antenna at the MS. Hence the uplink (UL) and downlink (DL) case differ. In uplink a BS increases its links by directing zeros towards interfering (jamming) MSs of adjacent cells. Whereas in downlink the link of interfered (disturbed) MSs can be improved if a neighbor BS puts zeros towards it.

The remainder of this paper is organized as follows: Section II introduces the coordination scheme by describing the process of information exchange, the impact on the beamforming and scheduling algorithms. Next, Section III describes the multi cellular simulation scenario and all related assumptions. In Section IV we present the results of our dynamic, event-driven, stochastic simulations. Section V concludes the paper and gives an outlook on future work.

II. COORDINATION SCHEME

Coordination of BSs relies on exchange of information about scheduling decisions and the position of MSs. The knowledge when interference occur and from where is exploited. We propose a coordinated scheduling scheme with two iterations. First, a BS allocates its resource in conventional manner as in [6] without coordination. Secondly, the received coordination information is utilized for adapting the beam-forming pattern accordingly. All scheduling decisions and position of MS are assumed to be exchanged.

A problem in coordination is the prediction of upcoming traffic. By assuming CBR traffic in the following, we are regarding a best case scenario. Nevertheless with mobile stations, the spatial separability of MS and thereby the SDMA groups differ over time and hence the frame slowly changes.

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Thus, a periodic update of the coordination information is required.

A. *Beamforming*

In a multi cell system a receiving station suffers from intra- and inter-cell interference. The optimal beam-forming algorithm [7] and the SINR heuristic grouper [5] almost cancel the received intra-cell interference.

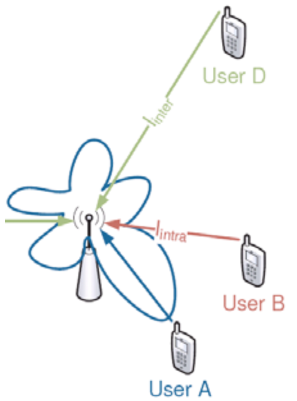

Figure 1. Antenna pattern with zeros towards intra- and inter-cell interferes

The following coordination approach further mitigate inter-cell interference in uplink [†] by directing zeros towards all jamming MSs in neighbor cells, as depicted in Fig. 1. In the downlink, zeros are directed towards all disturbed MSs. This is not possible if the jammer is in the direction of a main lobe. In this case the interference is at least known and hence the interference estimation is significantly improved. Below, for sake of simplicity, the concept is only explained for the uplink. The downlink case is similar.

For each transmission of an interfering MS the following station information is forwarded to a neighbor BS that is disturbed: the position of the MS, the transmit power, transmit antenna gain, the transmission start- and end time, as well as the sub-channel. With the position, the BS is able to estimate the path loss and the Rx antenna gain ($G_{RXAntenna}$). With the information from adjacent cells, the BS estimates the inter-cell interference of each inter-cell MS using (1):

$$I_{inter}[dBm] = Power + G_{RXAntenna} + G_{TXAntenna} - PathLoss_{BS-MS} \quad (1)$$

B. *MAC Frame*

This section outlines the impact of coordination on the MAC frame. In the first scheduling iteration, groups of well separable users are generated and then resulting groups are scheduled in time domain to bursts of the same size, e.g., based on the fill level of the queues in downlink or based on bandwidth request in uplink. In the second iteration, inter-cell

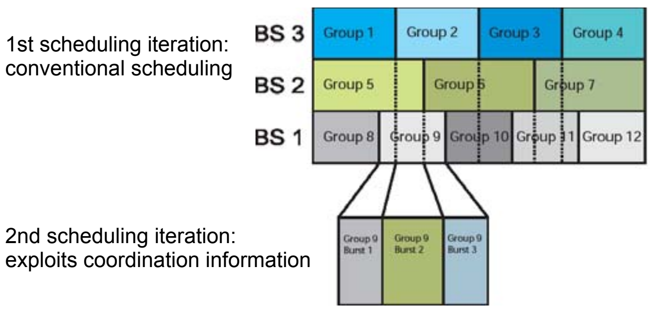

Figure 2. MAC frames of disturbed & jamming BSs

[†] In uplink, the optimal beam-former [7] also mitigates inter-cell interference by maximizing the SINR. It computes the array correlation matrix with the training sequence at the beginning of each burst, but does not account for changed interferers during the burst and hence is suboptimal.

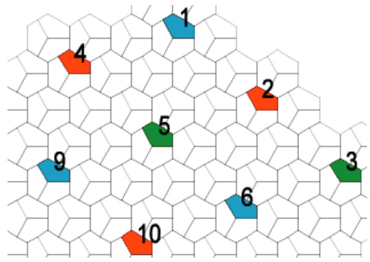

Figure 3. Decoupling by classification of BS

interfering MSs are suppressed in the receive beam pattern. When interferes change during a burst a new pattern and thereby a new burst needs to be applied. Hence, one burst of the first iteration is subdivided into shorter bursts which have the same spatial group and the same total allocated time.

Fig. 2 depicts an example of uplink MAC sub-frames of three BSs: interferred BS1 and interferring BS2 & BS3. Group 9 of BS1 has three different sets of interferers: Group 1 & 5, Group 2 & 5, and Group 2 & 6. The initial single burst of Group 9 is divided into three bursts in order to apply three different patterns and direct zeros to the current interferers in each burst of Group9. In this manner an increased number of information elements in the map is required indicating more shorter bursts.

In case of sufficient antenna elements ($\geq$ 12), one new pattern can be used for the initial burst which directs zeros to all interferers which occur during this burst. This approach prevents the scheduling from too many small bursts, but is not studied in the following.

C. *Decoupling*

System coordination requires decoupling of cells. Otherwise the scheduling of a BS depends not only on the interfering BSs but also their interfering BSs and so on, because an interfered BS of course interferes an other BS In order to decouple the coordination process, BSs are sorted in three classes as shown in Fig. 3. BSs of different classes update their coordination information asynchronously.

D. *Message Sequence Chart*

Scheduling information is exchanged just before the start of each frame. The message sequence chart in Fig. 4, for the example of coordination with three classes, shows that a BS forwards its scheduling decision every third frame,

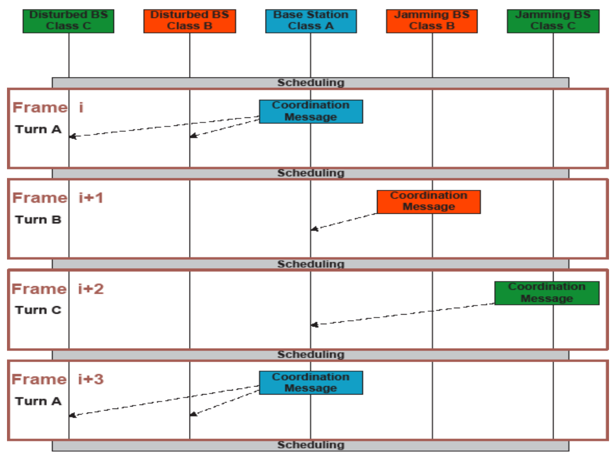

Figure 4. Coordination message sequence chart

simultaneously with BSs of the same class. Hence, a BS uses the same information of an adjacent cell for three frames. A coordination message comprises the station information for all the transmitted bursts.

III. SIMULATION SCENARIO

The evaluated scenario consists of 7 cells, each with a central BS and 10 MSs. The locations of the BS is in the centre of the cell with a 120° sector, as shown in Fig. 5. Measurements are only performed in the central sectorised cell (black) for the corresponding BS and MSs. The stations in the surrounding 6 sectors only produce interference and are not evaluated. Nevertheless, the same event driven stochastic simulation, with identical average traffic loads, and with the same degree of detail, is conducted at all 77 stations. The cells have a radius of R = 333m and an N = 3 cell cluster order is used as shown in Fig. 5. Cells that are not shown are assumed to operate on different frequency bands, which means their interference can be ignored. The nearest interfering cells (red) have a distance of $D = \sqrt{3N}R = 1000\ m$. Scenrio parameters such as the cluster order and cell radius are selected according to the Urban Macro cell scenario in [2]. As the cells are synchronized, all base stations transmit their DL and UL MAPs at the same time. They have to use an omnidirectional broadcasting pattern which means that the users experience worst case SINR levels during these times.

Simulation parameters that are still not available in the IEEE.16m draft [3]are taken from [1].

A. Simulator and Traffic Model

The open Wireless Network Simulator (openWNS) developed at ComNets [10] is a time discrete, event driven simulator. The load generator of each station generates IP data packets according to a specified arrival process and feeds them into the WiMAX data link layer (DLL) via the suitable Service Access Point (SAP). When a packet is scheduled, it is forwarded to the physical layer (PHY) module that adds the packet's transmission to the set of currently active transmissions in the scenario. Until the transmission is over, all other packets transmitted at the same time on the same frequency band experience the interference generated by the transmission, taking into account pathloss and antenna characteristics in form of the beam pattern and sectorization. For all MSs we apply symmetric traffic loads in DL and UL direction to and from all users. For each run, the following performance values are derived and evaluated:

Modulation and Coding Scheme (MCS): the MCS used for the packet transmission. Six MCS are employed and namely given e.g. by "QPSK 3/4". MCS is selected accordingly to the SINR thresholds of Table I.

Delta MCS: Here MCS (namely ["Not Valid", QPSK1/2, …, 64QAM3/4]) are mapped to integer numbers [0-6]. Delta MCS indicates the deviation of the MCS estimation. It is the difference between the optimal and the estimated MCS. Negative values indicate a too optimistic MCS choice, i.e., packet loss.

Throughput: Measured in Bit/s as the total bits of all packets successfully arriving at the WiMAX SAP of the destination station during a fixed time window. Separate values are measured for packets traveling to/from every MS in UL and DL direction.

Packet Delay: Measured at the destination station's WiMAX SAP for all packets that have been successfully transmitted. Defined as the time elapsed between entering the sender's WiMAX protocol layer until leaving it at the destination's WiMAX SAP. In particular, all delays experienced in buffers are counted. It should be kept in mind that in overload conditions, the mean delay values are only partly meaningful. The reason is that the infinite delay of packets that are never transmitted is neither included in mean values nor counted because these packets never reach the destination's WiMAX SAP. The delay figures are always given in seconds.

B. Link Adaptation and Error Modeling

The scheduling strategy performs link adaptation based on the SINR estimations provided by the spatial grouper. For each packet that is scheduled for transmission to a subscriber station, a modulation and coding scheme (MCS) (also referred to as PHY-mode) with the respective PHY data rate is chosen according to the SINR threshold values shown in table I. The SINR threshold values aim at a target residual bit error rate (BER) of 10^{-6}.

C. WiMAX Frame Structure and Overhead

In our simulations the total frame duration is assumed to be 5 ms. We divide this time equally between DL and UL data transmission phases. UL and DL MAPs are always transmitted using an omnidirectional antenna pattern. Beamforming for concurrent SDMA transmissions are only used for the DL and UL bursts. When operating in SDMA mode, the BS can schedule multiple concurrent bursts and has to set beam patterns accordingly to separate the co-scheduled users' signals. Of course, individual map entries (information elements, IEs) for parallel bursts have to be signaled. OFDMA parameters are chosen accordingly to IEEE 802.16m documents [2], [3] with a nominal channel bandwidth of 20 MHz and a cyclic prefix factor of 1/8. The OFDMA symbol length is 102,857 µs, making for a total of 47 OFDMA

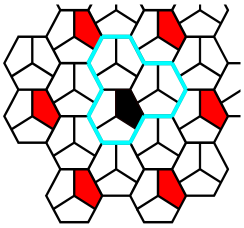

Figure 5. Positions of sectors in central (black) and co-channel (red) cells of evaluated clustered cellular deployment

TABLE I: MCS SWITCHING THRESHOLD AND PHY DATA RATES [1]

No.	Modulation	Code rate	Min. SINR $[dB]$	PHY data rate $[MBit/s]$
1	QPSK	1/2	5.0	14.93
2	QPSK	3/4	8.0	22.4
3	16 QAM	1/2	10.5	29.87
4	16 QAM	3/4	14.0	44.80
5	64 QAM	2/3	18.0	59.73
6	64 QAM	3/4	20.0	67.20

symbols in each 5 ms frame (excluding 165.714 10^{-6} s dedicated to transition gaps). Each map is transmitted using QPSK 1/2 as the modulation and coding scheme. Using 1536 subcarriers, 1536 bits can be transmitted with one symbol. Thus, an UL MAP holding 25 information elements is 7 full OFDM symbols long (0.97% of the frame). A DL MAP holding 75 information elements needs 19 symbols (2.7% of the frame). 4 OFDM symbols are deducted from the frame capacity to account for the different phases of the preamble. In total, the organizational overhead for the whole frame is around 4.3%.

D. Other Simulation Parameters

In order to rule out other influencing factors when evaluating the performance of the coordination scheme, neither Segmentation and Reassembly (SAR) nor Automatic Repeat Request (ARQ) mechanisms are used. Each base station is equipped with a 12-element linear antenna array used to serve one sector. The sector is modeled by a superimposed antenna pattern with the gain factor of one for the 120° sector width and zeros for the other 240°.

The MSs are equipped with standard omnidirectional antennas. The transmit power is 49 dBm for a BS ,i.e., 44.23 dBm for a sector, and 23 dBm for a MS. No further power control / adaption is performed. A mid frequency of 2.5 GHz is used. MSs are moving with a speed of 30 km/h inside their sector with a Brownian motion. Handovers do not occur. As a roof-top deployment is envisioned for the MS's antenna, the pathloss model presumes LOS conditions. The "LOS C2" path loss model for the urban environment [2] is used in the following. Shadowing or fading effects are not considered. Table II gives an overview of all relevant simulation parameters.

TABLE II: OVERVIEW OF SIMULATION PARAMETERS

Parameter	Value
Cluster Order	3
Cell radius	333 m
Number of sectors	3
MS velocity	Brownian motion 30 km/h
Height BS/MS	32 m / 1.5 m
Tx Power BS(per cell) / SS	44.23 (49dBm) / 23 dBm
Mid frequency	2.5 GHz
Pathloss	WINNER „LOS C2"
Shadowing & Fast Fading	No
Antenna array/elements	ULA / 12
Max. number of beams	4
Channel bandwidth	20 MHz
Traffic type	Symmetric CBR
packet size	190 Bytes (fixed)
MAC Frame length	5 ms (47 OFDM symbols)
Number of subchannels	32
Data subcarriers	1536
Nominal OFDMA symbol duration	102.857 µs
SAR & ARQ	None
Scheduling strategy: No coordination Coordination	Proportional Fair Round Robin
Spatial grouper:	Tree-based SINR heuristic [5]

IV. SIMULATION RESULTS

In this section, we present and discuss the results of the performed simulations. First, we discuss the link adaptation by regarding the probability of used MCS and the MCS estimation error for a conventional and a coordinated system. The impact on cell throughput and packet delay is studied as well.

In UL, the coordinated system outperforms the uncoordinated system in terms of link adaptation. Fig. 6 depicts the probability density function of the MCS used for transmission in a conventional (black) and a coordinated system (blue) at an offered traffic of 10Mbps. The highest MCS, i.e., 64QAM3/4, is used for 75% of the transmissions in a conventional system. Coordination increases the use of 64QAM3/4 by 15% to a value of 86%. With coordination higher MCS are used than in a conventional system because inter-cell inference is mitigated.

Fig. 7 shows the density of the delta MCSs metric [section III-A] at 10Mbps offered traffic. The conventional system (black) uses the correct MCS scheme in less than 70%. The other transmissions use incorrect MCSs based on SINR estimation which are either too optimistic or too conservative. The first causes packet losses whereas the second wastes resources by choosing too robust PHY modes. With coordination (blue) correct MCSs are employed for 90% of the transmissions and packet loss does approximately not occur. Coordination improves precision of the estimation of the suitable MCS. Inter-cell interference is more predictable with coordination because inter-cell interferes are mostly known.

In the Fig.9 the mean UL MAC throughput is presented. Coordination increases saturation throughput from less than 10 Mbps for the conventional system to 60 Mbps. Packet loss occurs for almost 20% of the conventional system at an offered traffic of 10 Mbps. This indicates the lack of precision in the SINR estimation. In this interference limited scenario coordination can be regarded as enabling technology given the poor performance of the conventional system.

Fig. 8 presents the mean packet delay. The packet delay starts to increase at less than 10 Mbps (no sample between 1 and 10 Mbps offered traffic) for the conventional system, and around 60 Mbps offered traffic with coordination. These values verify the saturation throughput identified in Fig. 9. In overload conditions, the mean delay values are only partly meaningful because the infinite delay of packets that are never transmitted is not included in mean values. The link adaptation in the coordinated system is not stable in this scenario. The oscillation of the black graph with increasing offered traffic is

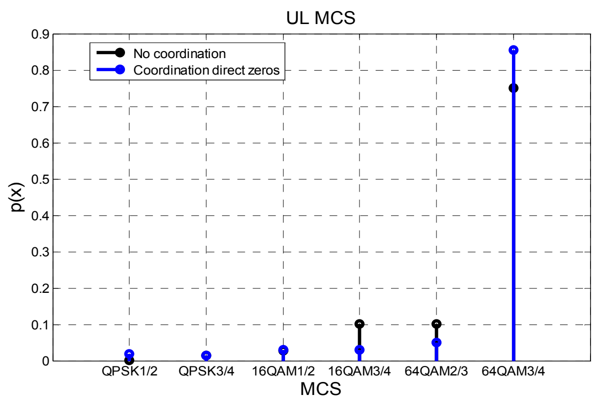

Figure 6. Probability Density Function (PDF) of used MCS at 10Mbps offered traffic

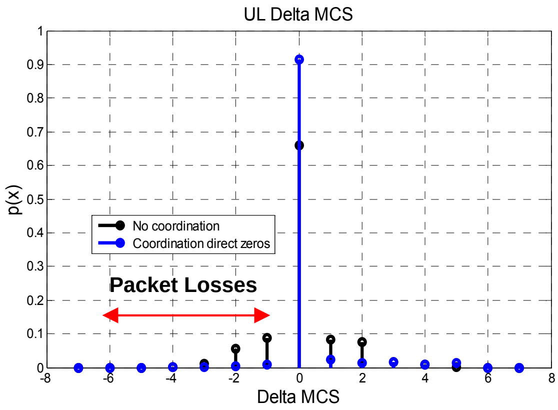

Figure 7. Delta MCS between MCS used for Tx and MCS based on measured SINR during Rx, at 10Mbps offered traffic

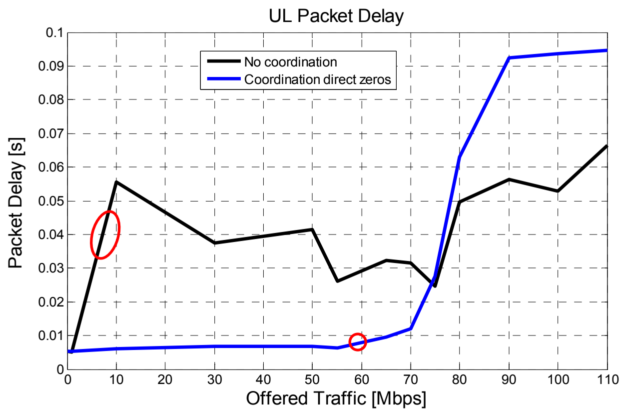

Figure 8. Mean UL packet delay over offered traffic

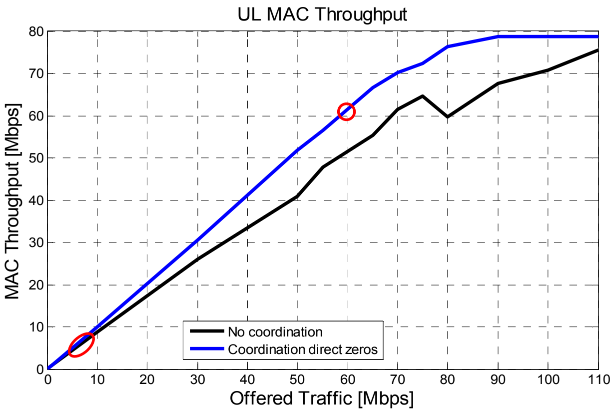

Figure 9. Mean cell throughput in UL

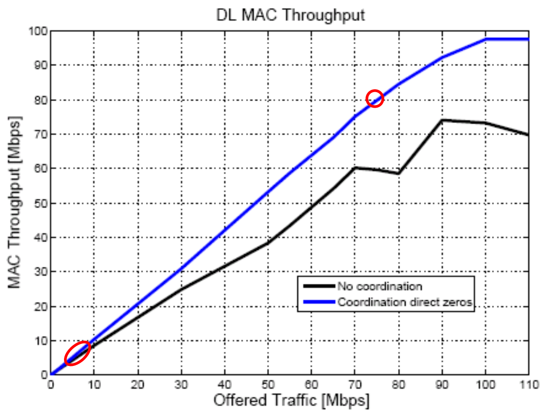

Figure 10. Mean cell throughput in DL

caused by the fluctuating number of packets which are discarded at MSs (in the buffers) and at the BS (in the CRC module).

Fig. 10 depicts the mean DL MAC throughput. Saturation throughput increases from less than 10 Mbps for the conventional system (black) to 75 Mbps for the coordinated system (blue). The imprecise SINR and MCS estimation in the conventional system causes packet loss even in low load (<10Mbps) and hence the offered traffic can not be carried. Coordination in downlink also allows for higher MCS by decreasing inter-cell interference and decreases estimation errors in link adaptation (not shown); similar to uplink case shown in Fig. 6 and 7.

V. Conclusion

Shown results proved that coordination mitigates inter-cell interference and increases its predictability. Hence the developed concept improves system capacity and let a coordinated- outperform an uncoordinated system. The cost of coordination across BSs is the increase of system complexity (scheduler, grouper, beamformer) and of coordination overhead (exchanged messages, increased MAP size due to increased number of bursts).

Future work will quantitatively investigate the costs of coordination. Also, the impact on variable traffic models on coordination is in the interest of further studies.

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