Region Coordination Across Space Division Multiple Access Enhanced Base Stations in IEEE 802.16m Systems[1]

Benedikt Wolz, Francisco Niño, Maciej Mühleisen, Karsten Klagges,
Communication Networks (ComNets), Faculty 6,
RWTH Aachen University, Germany
{bmw, fna, mue, kks}@comnets.rwth-aachen.de

M. Einhaus
NEC Laboratories Europe, Heidelberg, Germany;
Michael.Einhaus@nw.neclab.eu

Abstract—**In recent years, smart antenna technologies are of ever-increasing interest to boost the capacity of future wireless systems. Several standards support these techniques such as the wireless metropolitan area network IEEE 802.16 (WiMAX) 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 schemes of coordination, across BSs on MAC layer, for highly variable traffic for further mitigation of inter-cell interference and increasing precision of SINR estimations in an SDMA enhanced system. One concept considers the coordination of regions instead of single stations. 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 and with simple coordination schemes of former work.

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

I. INTRODUCTION

IMT-Advanced systems demand for high spectral efficiencies which are promised to be provided by several transmission schemes relying on multiple antennas. Although MIMO techniques such as spatial multiplexing and code diversity are capable to increase the capacity or the robustness (and thereby coverage) of a link, they have unsustainable drawbacks. Multiple antennas are required at the transmitter and the receiver and the performance depends heavily on a very precise (and thereby costly) estimation of the channel state. Also, MIMO techniques perform only well with channel characteristics of indoor- or urban microcell scenario but their performance suffer with increasing cell size and LOS probability such as given in urban macro- and rural scenarios [8]. Another promising multi antenna technique is cooperative transmissions also known as virtual MIMO. Its drawbacks are premature MAC-layer support and severe synchronization problems in real test applications [6], [7].

Beamforming is the most promising multi-antenna technique since it allows for increased system capacity and extended cell coverage. The antenna gain of the adaptive array significantly enhances the signal quality at the cell edge, which results in extended coverage. In good SINR regions, SDMA allows for simultaneous data streams, which increases system capacity. Furthermore, beamforming and SDMA requires multi antennas only at the BS. End-user devices do not need multiple antennas. As a downside, an SDMA enabled cell generates less predictable interference than a conventional cell, because a changing number of MS are sending uplink data in parallel and downlink streams with changing direction are transmitted by the BS. Thereby the SINR estimation becomes less precise and the link adaptation sub optimal. 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.

This work investigates two schemes of coordination across BSs on MAC layer for further mitigation of inter-cell interference and increasing precision of SINR estimations. Both new schemes aim for solving the limitations of the previous scheme [3]. One scheme reduces the number bursts and thereby the overhead. The other scheme is designed for coping with variable bit rate (VBR) traffic by creating spatial regions and coordinating the interference of the set of stations within this created region, instead of predicting the traffic of a single station.

Several approaches for interference coordination exist and can be classified with respect to the degree of distribution [1] and to the time scale of operation [2]. Types of different degrees of distribution are 1) Global-, 2) Distributed-, 3)

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Decentralized- , and 4) Local interference coordination schemes. To 1), Global schemes have one omniscient central device and are not implementable in a real network but provide an important upper limit for the potential gain of interference coordination. To 2), Distributed schemes rely on one or more central components, which exchange information relevant for coordination among BSs in the network (e.g. placed at the Radio Network Controller (RNC) in UMTS networks). To 3), Decentralized schemes do not have a central entity but coordination is performed by information exchange among equal BSs. To 4), Local schemes base purely on locally available information at every BSs. Coordination is implicitly or explicitly performed by measuring the interference or by running certain synchronised scheduling algorithms in every BSs, respectively.

Besides the degree of distribution, the time scale of operation is an important property of an interference coordination scheme. Three basic classes can be identified, namely a) static schemes, b) semi-static schemes, and c) dynamic schemes [2]. To a), static schemes do not have a time variant component. Planning of the interference is conducted usually during the network planning process or with a time scale of operation in the order of days or longer (Fractional Frequency Reuse [14] is in this category). To b), semi-static schemes can handle uneven and variable load distributions among cells as well as an uneven terminal distribution within a cell, operating with a time interval of several seconds or even minutes. To c), fully dynamic schemes can instantly adapt to changing network conditions such as changing traffic or user distributions. Their time scale of operation is in the order of a few MAC frames.

The presented schemes in section II can be classified as distributed- and dynamic interference coordination, i.e., 2c according to the above classification. Here we assume ideal signaling which refers to zero delay and no message loss for any coordination signaling message.

The remainder of this paper is organized as follows: Section II introduces the coordination schemes 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. ADVANCED COORDINATION SCHEME

Coordination of BSs relies on exchange of information about scheduling decisions and the position of MSs. The knowledge is exploited when interference occurs and from where. We propose a coordinated scheduling scheme with two iterations. First, a BS allocates its resources in the conventional SDMA manner as in [11] 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 periodic update of the coordination information is required due to the VBR traffic. Also with mobile stations, the spatial separability of MS and thereby the SDMA groups differ over time and hence the frame additionally changes. An SDMA group is a set of users which can be well spatially separated and hence are served at the same time and sub-channel. First coordination scheme I is explained and thereby the common principles of all three coordination schemes and then their differences are presented.

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 [11] almost cancel the received intra-cell interference.

The following coordination approach further mitigate inter-cell interference in uplink[2] by directing zeros towards all jamming MSs in neighbor cells, as depicted in Fig. 1. In the downlink, zeros are directed towards all interfered 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. Decoupling & Signalling

It is obvious that a countrywide cellular network cannot be coordinated by one central coordinator. Here, the coordination considers the next tier of interferers or cells. Still in order to cope with large coordination areas we apply decoupling of the cells. Otherwise the scheduling of a BS depends on the interfering BSs but also on their interfering BSs and so on. BSs are sorted in classes, e.g., in three as shown in Fig. 2. BSs of different classes update their coordination information asynchronously.

Scheduling information is exchanged just before the start of each frame. For the example of coordination with three classes, a BS forwards its scheduling decision every third frame, 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 transmitted bursts. For more details refer to [3].

C. 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 duration, e.g., based on the fill level of the queues in downlink or based on

[2] In uplink, the optimal beam-former [9] 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.

bandwidth requests in uplink. In the second iteration, inter-cell interfering MSs are suppressed in the receive beam pattern. When inter-cell interferers 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. 3 depicts an example of uplink MAC sub-frames of three BSs: interferred BS1 and interferring BS2 and 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 Group 9. In this manner an increased number of information elements in the map is required indicating more shorter bursts.

D. *Advanced Coordination Schemes (one burst per group)*

1) *Coordination Scheme II*

As described in the previous section, the first scheduling iteration generates one burst per SDMA group. This scheme preserves the single burst per group and thus also called "*1 burst per group*" in the following. It calculates one new beamforming pattern that considers all interferers which occur during that burst. In this manner, scheme II prevents the scheduling from too many small bursts, see also Fig. 3. A sufficient number of antenna elements (≥ 12) is required.

2) *Coordination Scheme III (regions)*

The following scheme is designed for coping with variable bit rate (VBR) traffic such as MPEG4 [12] with which traffic up come and its interference can be hardly forecasted. Instead of predicting the traffic of a single station, this approach creates spatial regions and coordinates the interference of the set of stations within this created region. The same principle of interference estimation based on regions is proposed in [13]. These spatial regions are assumed to approximately the same number of packets to be tranmitted in every frame (i.e. a constant-bit-rate (CBR)-like traffic characteristic). The following coordination concept is called *regions coordination* and is first defined for the uplink case and then for downlink.

For uplink, Fig. 4 (a)-(c) show how sectors are divided into spatial regions of the same size. BS *A* and *B* are interfered by sector *C*. The BS defines the spatial regions of its interfering cells. Only one MS of each region is scheduled at once and thus a region is perceived as one MS. In this manner, the spatial regions scheme simulates within the coordination process a fixed number of sources of inter-cell interference each with CBR-like traffic. The number of regions equals the maximum number of concurrent beams. If a BS interferes more than one BS, sub-regions are created by the superposition of regions of the different interfered BSs as shown in Fig. 4 (d). Each sub-region is labeled by a number, with as many digits as interfered BSs, each digit indicates the regions of one interfered BS. The spatial regions scheme requires modifications of the SDMA grouper and an introduction of a spatial condition: *a group of currently served stations is valid if it contains at most one station of each region*. In the example of Fig. 4, valid groups can be built with MSs of sub-regions 11 and 22 or 12 and 21. The algorithm creating the spatial regions is explained at the example of circular cells with three sectors. The relative position between the two BSs has to fulfill the following constrains also to allow for same size regions, see Fig. 5:

1. α_a (angle between interfering BS and interfered BS) $-30^\circ \leq \alpha_a \leq 90^\circ$

2. $\psi_a \geq 0^\circ$ (angle between left point (P_l) and interfered BS)

3. $\xi_a \leq 60^\circ$ (angle between right point (P_r) and interfered BS)

For coordination and estimation of inter-cell interference, a region is modelled as a virtual MSs at the weight point of each region. A interfered BS directs zeros towards the directions of virtual MSs of each interfering region. The inter-cell interference at the interfered BS is estimated by the following expression.

$$I_{inter}[dBm] = Power + G_{RXAntenna} + G_{TXAntenna} - PathLoss_{BS\text{-}vMS} \quad (2)$$

The total inter-cell interference at a BS is estimated as the sum of the interference generated by its virtual MSs (vMS).

In downlink the interference is generated by the BSs which's positions are known.

The same regions as in uplink (or the virtual MSs) are only utilized in order to direct zeros towards the interfered region and thereby mitigate the inter-cell interference. The spatial condition is applied to the grouping in each sector as in uplink.

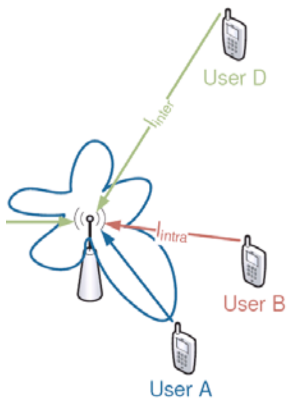


Figure 1. Antenna pattern with zeros towards intra- and inter-cell interferes

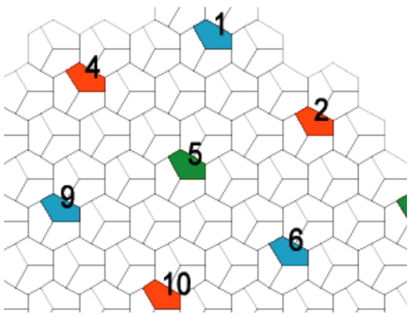


Figure 2. Decoupling by classification of BS

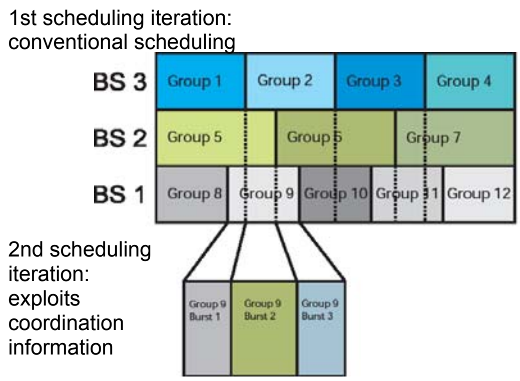
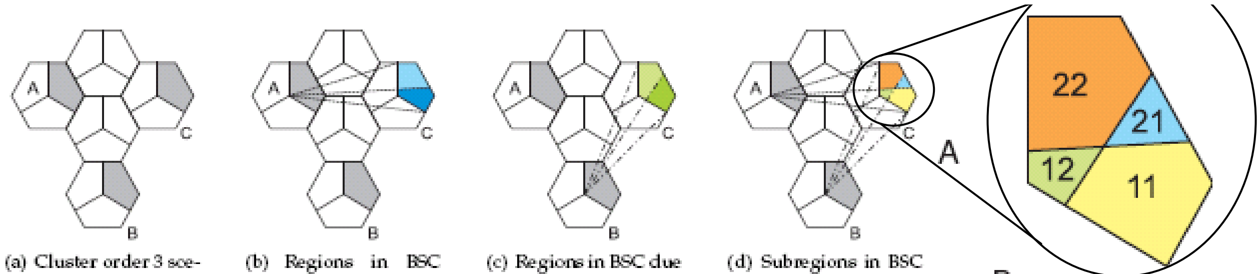


Figure 3. MAC frames of disturbed & jamming BSs



(a) Cluster order 3 scenario (b) Regions in BSC due to BSA (c) Regions in BSC due to BSB (d) Subregions in BSC due to BSA and BSB

Figure 4: Creation of spatial regions and sub-regions (example of two interfered BSs and two concurrent antenna beams)

One interfered MS is always assumed in each region and a zero is directed towards the region's weight point.

E. Qualitative Coordination Cost

The signaling overhead with coordination I and II over the backhaul between a central coordination entity and the specific BSs is linear with the number of MSs and includes information for every burst such as the position of the MS, the transmit power, transmit antenna gain, the transmission start- and end time, as well as the used sub-channel. Coordination II has a reduced overhead by a factor of 2 to 3 linear to the reduced number of bursts. Coordination scheme III has a reduced signaling overhead which is constant and independent of the number of served MSs. Same information is exchanged as before but only for each region instead of for each MSs. All Coordination schemes tend to require a higher number of antenna elements,

Coordination scheme I and II have the same demand on the backhaul delay in the order of a few frames especially with variable traffic rate users. The requirement on the backhaul delay from the scheme III can be relaxed since only regions are coordinated and detailed packet scheduling can be adjusted rather independently.

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. 6. Performance measurements are only conducted 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 = 333 m and an N = 3 cell cluster order is used as shown in Fig. 6. 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 [5]. As the cells are synchronized, all BSs transmit their DL and UL MAPs at the same time. They have to use an omni-directional 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 802.16m draft [5] are taken from -16e [3].

A. Simulator and Traffic Model

The Open Source Wireless Network Simulator (OpenWNS) developed at ComNets [14] 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 with CBR or VBR traffic in DL and UL direction to and from all users. The VBR traffic is modeled as MPEG4 for high quality movie trace with a resolution for a small device. 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". A MCS is selected accordingly to the SINR thresholds in [3].

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

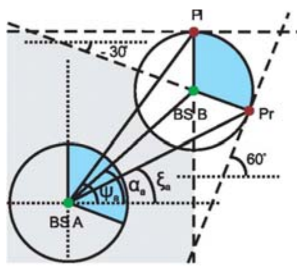


Figure 5: angular constraints

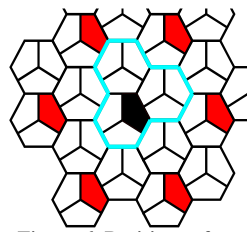


Figure 6. Positions of sectors in central (black) and co-channel (red) cells of evaluated clustered cellular deployment

DL direction.

B. Link Adaptation and Error Modeling

Link adaptation is conducted based on SINR estimations. For each packet to be transmitted to a MS, a modulation and coding scheme (MCS) with a specific PHY data rate is chosen according to SINR threshold values in [3], with a target residual bit error rate (BER) of 10^{-6}. For more details refer to [3]

C. WiMAX Frame Structure and Overhead

In simulations of section IV the total frame duration is 5 ms, equally divided 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. Scheduling strategies [16] are Proportional Fair for the uncoordinated- and Round Robin (equal time) for the coordinated system. OFDMA parameters are chosen accordingly to IEEE 802.16m document [5] with a nominal channel bandwidth of 20 MHz and a cyclic prefix factor of 1/8. In total, the organizational overhead for the whole frame is approximately 4.3%. Table II gives an overview of all relevant simulation parameters. For more details refer to [3]

IV. Simulation Results

In this section, we present and discuss the results of the performed simulations for a conventional reference system and three systems enhanced by different coordination algorithms I, II and III; I) a coordinated system according to [3], [section II A-C]; II) *one burst per group* coordination [section II-D-1]; and III) *spatial region coordination* [section II-D-2]. First, we discuss the link adaptation by regarding the probability of used MCS and the MCS estimation error. The relative impact of different coordination algorithms on cell throughput is studied as well. Simulations are conducted first with CBR- and second with VBR traffic [section III A.].

A. Constant Bit Rate Downlink Traffic with 30 MSs

Fig. 7 depicts the probability density function of the MCS used for transmission in a conventional (black), a system with coordination I (blue points), with coordination II (blue cross) and coordination III (green) at an offered DL traffic of 10Mbps.The coordinated systems select higher MCS with higher probability than the uncoordinated system because inter-cell inference can be mitigated. Coordination I performs best and for instance increases the use of highest MCS (i.e. 64QAM3/4) by 21% to a value of 84% compared to a conventional system.

Fig. 8 shows the density of the delta MCS metric [section III-A] at 10Mbps offered traffic. The conventional system (black) employs the optimal MCS scheme in 50%. The Coordinated systems improve the precision of the SINR estimation and select the optimal MCS in 68%-87% of the transmissions with highest gains for scheme I. The other transmissions use incorrect MCSs based on inexact 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. Coordination II

Table I: 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) / MS	44.23 (49 dBm) / 23 dBm
Mid frequency	2.5 GHz
Pathloss	WINNER „LOS C2" [10]
Shadowing & Fast Fading	No
Antenna array/elements	Uniform Linear / 12
Max. number of beams	4
Channel bandwidth	20 MHz
Traffic type	symmetric CBR or VBR
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 [11]

chooses MCSs too pessimistically in 30% of its transmissions. This occurs because interferes, which are only interfering parts of the burst, are assumed for a whole burst. With coordination, packet losses do only occur with scheme III (green). These too optimistic estimations arise because interference is suppressed towards the direction of the weight point of a region which is several degrees beside the actual position of the interfering station. Inter-cell interference is more predictable with all coordination schemes because inter-cell interferes are known (or better known with scheme II and III).

In Fig.9 the mean DL MAC throughput is presented. The reference system (black) saturates at less than 10 Mbps. Packet losses occur for almost 30% in the uncoordinated system at an offered traffic of 10 Mbps [Fig. 8]. This indicates the imprecise SINR estimation (or too low capacity for specific MSs) of the uncoordinated SDMA enhanced system. Coordination increases the saturation throughput to more than 50 Mbps with scheme I and II. A higher maximum throughput is reached with coordination II (73Mbps) than with coordination I (69Mbps). The gain by 4Mbps accounts for the reduced number of bursts and thereby reduced padding. The MAP is simulated with constant resource consumption. An increased MAP overhead of approximately 1MB/s due to the increased number of bursts is not considered in the results of Fig.9. Coordination III (green) outperforms the uncoordinated system in terms of throughput but is not able to serve all MSs below 10 Mbps and thereby can not achieve the performance of the other coordination schemes due to the less precise link adaptation (as shown in Fig. 7 and 8).

B. Variable Bit Rate Uplink Traffic

In the following results the offered traffic is stimulated by the number of MSs each having a MPEG4 uplink stream with a mean rate of 0.55 Mbps.

Fig. 10 depicts the probability density function of the MCS used for uplink transmission at an offered VBR traffic of 10Mbps [in a conventional system (black), a system with scheme I (blue points), with scheme II (blue cross) and with

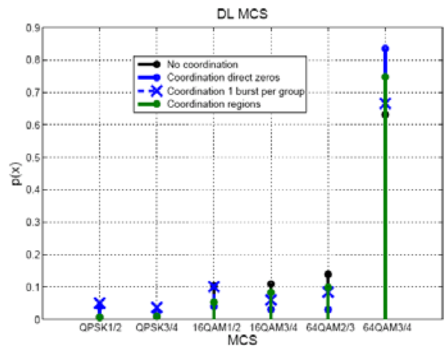


Figure 7. Probability Density Function (PDF) of used MCS at 10Mbps offered traffic - CBR

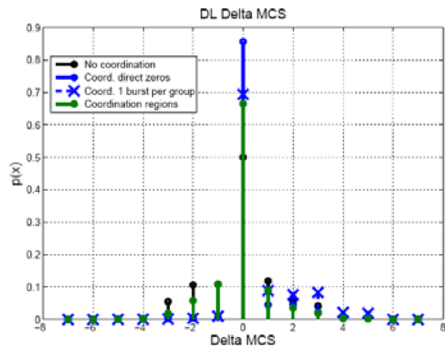


Figure 8. Delta MCS between MCS used for Tx and MCS based on measured SINR during Rx, at 10Mbps offered traffic –CBR

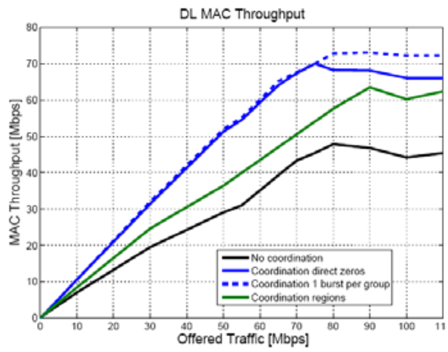


Figure 9. Mean cell throughput in DL – CBR

scheme III (green)]. As with CBR downlink traffic Fig. 7, the coordinated systems tend to select higher MCS than the uncoordinated system because inter-cell inference can be still mitigated. Still, scheme I performs best and for instance increases the use of highest MCS (i.e. 64QAM3/4) by 12% to a value of 84% compared to a conventional system.

Fig. 11 shows the distribution of the delta MCS metric [section III-A] at 10Mbps offered traffic. The conventional system (black) employs the optimal MCS scheme (Delta MCS = 0) in 57% of the transmission (50% in CBR downlink). The SDMA system in the uplink case has a more predictable interference level than in downlink. All coordination schemes improve the precision of the estimation of the suitable MCS. A system with Coordination III employs the correct MCS 80% of the transmissions and only 5% of the packets are lost (compared to packet losses of 25% in an uncoordinated system, 13% with scheme I, 6% with scheme II). Scheme III (green) shows the most precise link adaptation by coordinating the interference of regions and set of users instead of single users.

In Fig.12 the mean UL MAC throughput is presented. The uncoordinated reference system (black) can never properly carry the offered traffic. At less than 10 Mbps packet losses occur for 25% [Fig. 11]. The coordinated systems with scheme I (blue solid) or II (blue dashed) saturate at an offered traffic of more than 25 Mbps. They are limited due to their lack of predicting the interference with VBR traffic and efficiently coordinating a high number of users with the given *round-robin* scheduling. Coordination III (green) significantly increases the throughput to more than 40Mbps compared to all other systems due to its ability to predict the interference even with VBR traffic.

V. CONCLUSION

Two coordination schemes (scheme II, *one burst per group*, and scheme III, *region coordination*) for coordination of SDMA enhanced BSs and inter-cell interference mitigation are developed and evaluated in this work. The performance evaluation by means of system level simulations is conducted in a cellular scenario with CBR downlink and VBR uplink traffic. The developed coordination *one burst per group* further improves the scheme from previous work and overcomes its limitation by decreasing the number of bursts. But both schemes (I and II) are limited due to their lack of predicting the interference with VBR traffic and efficiently coordinating a high number of users with the given *round-robin* scheduling. Shown results proved that *region coordination* successfully predicts the interference with VBR uplink traffic with significant throughput gains towards all other systems by the cost of moderate gains in the downlink. All coordination schemes mitigate inter-cell interference and increase its predictability. Hence the developed concepts improve system capacity and let a coordinated- outperform an uncoordinated system. The cost of coordination across BSs is the increase of system complexity and of coordination overhead.

In future work, thresholds will be studied for an optimal coordination combining scheme I–III in a problem space spanned by the dimensions CBR/VBR, uplink/downlink traffic as well as low/high number of users.

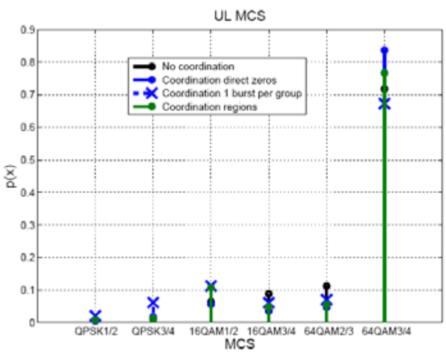


Figure 10. Probability Density Function (PDF) of used MCS at 10Mbps offered traffic – VBR

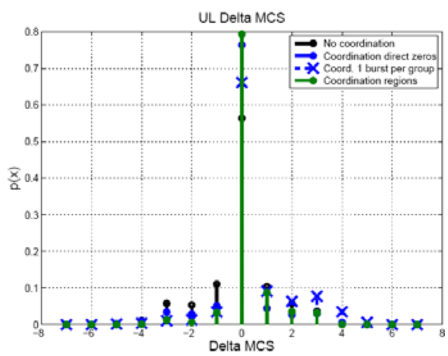


Figure 11. Delta MCS between MCS used for Tx and MCS based on measured SINR during Rx, at 10Mbps offered traffic -VBR

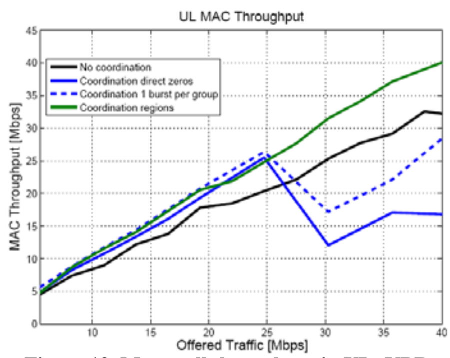


Figure 12. Mean cell throughput in UL -VBR

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