Adaptive Radio Resource Management in a Sectored Cell for Broadband Wireless Access Systems.

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Abstract: - **In this work, we analyze the performance of a multi-user sectored MIMO/OFDMA system under the limited feedback constraint. Dynamic radio resource management methods are used to a reuse-one sectorized cell in order to reduce the cross-sector interference. Simulation results show that the proposed strategy reduces the co-channel interference and maintain at the same time high spectral efficiency.**

I. INTRODUCTION

New service providers wishing to offer traditional and novel mobile services may select WiMAX as their technology for mobile broadband access. IEEE 802.16e targets mobile/portable markets and operates in Non Line Of Sight (NLOS) environments by introducing Multiple Input Multiple Output (MIMO) technology and Adaptive Antenna Systems (AAS) [1]. “Scalable” QoS classes, adaptive modulation and coding schemes and OFDMA multiplexing methods constitute WiMAX a reliable and robust system. In the downlink (DL) direction, the basic unit of resource allocation is a slot (48 data subcarriers over a period of two symbols) which represents a sub-channel. The two subchannelization methods that are proposed- PUSC (Partial Usage of Subchannels) and FUSC (Full Usage of Subchannels) - select tones in a pseudo-random manner to setup any slot from the entire subcarrier pool [1] . PUSC and FUSC methods ensure frequency diversity and are used in mobile applications to mitigate frequency selective fading. AMC (Adaptive Modulation and Coding) is used in conjunction with an adjacent subcarrier subchannelization method where slots are constructed from contiguous set of subcarriers, that are all using the same modulation and coding combination. AMC can be used with AAS to reduce the number of estimated weights of the adaptive antennas at the BS. Despite the attractive features and capabilities of the current generation of WiMAX systems, achieving higher data rates and QoS will require further evolution. The structure of OFDMA allows to effectively exploit the so-called multi-user diversity in wireless networks.

Due to the fact that each user is allocated sub-channels of the full OFDMA band, Fractional Frequency Reuse (FFR) is effectively employed. Cell sectoring is a highly efficient technique used in current cellular systems. Cell sectoring improves the average signal to interference plus noise ratio (SINR) and the related spectral efficiency, since frequencies can be reused in each sector. At the same time, co-channel interference among the sectors is introduced which is one of the major sources of performance degradation. To reduce co-channel interference, cell planning with a high frequency reuse factor (3 or 7) is a well used scheme in cellular systems that trades off the number of available subcarriers in each sector for increased SINR (and thus throughput) per subcarrier. Small sectors also result in unbalanced number of users per sector, which limits the throughput in the highly populated sector and wastes at the same time throughput in the low populated sectors. Universal FFR (f=1) simplifies cell planning but increases co-channel interference at the edge of the sectors.

We present a reuse-1 (f=1) scheme, based on multi-user beamforming MIMO techniques. A four beam adaptive array is proposed, in which each beam module captures a different sector. The capability of resolving multiple time slots at the same time and frequency is referred as space division multiple access (SDMA) and increases system capacity. Additionally, dynamic sub-carrier and slot assignment is integrated into downlink scheduling. This allows limiting the cross-sector interference without introducing more packet delays for the edge users with great channel fluctuations in the time domain. The problem of finding the minimum length SDMA/TDMA subframe in order to accommodate a set of users, is an NP-complete problem [2].

The organization of this paper is the following: Section II describes reduced feedback schemes, an adaptive beamforming technique and a time-sharing algorithm in a synchronous Time Division Duplexing (TDD) single cell WiMAX system with high speed users. In section III, we examine a cell structure with four adjacent sectors that share the same frequency band while section IV investigates how the new techniques can be implemented to the 3GPP Long Term Evolution (LTE) radio interface. Simulation results are presented in section V. Finally, section VI concludes this paper.

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II. ADAPTIVE BEAMFORMING AND TIME-SHARING WITH STATISTICAL FEEDBACK FOR A SINGLE CELL SYSTEM

In this section, we give a formal description of cluster beamforming and time sharing optimization problems for BWA network with predetermined target rates of the users and statistical information about the channel knowledge at the BS [3]. The proposed algorithms help us further explore and understand the radio resource management related issues in a sectored cell. The simplified feedback design based on clustered OFDMA is considered. L adjacent OFDMA sub-carriers are grouped into Q clusters so that N=Q L, N being the total number of subcarriers. Each user feeds back information only about the clusters. This technique greatly reduces the amount of uplink control information. In situations when the channel changes rapidly, the channel information feedback to the transmitter is outdated. Only the statistics of the channel coefficient would be of significant benefit for the system design. If the matrix $H_{k,c}^l$ of size M_r x M_t (M_r and M_t are the number of receiver and transmitter antenna elements respectively) represents the channel between the user k and BS at subcarrrier $l \in \{1, 2 \cdots L\}$ of frequency cluster $c \in \{1, 2 \cdots Q\}$, we define the covariance matrix of the channel gain as

$$R_{k,c}^l = \mathcal{E}\{H_{k,c}^l (H_{k,c}^l)^H\} \quad (1)$$

that is derived from averaging in the time domain over the duration $T_f = 5ms$ of the DL frame. The representative value is obtained from averaging the covariance matrix of all subcarriers that belong to cluster c

$$R_{k,c} = \frac{1}{L} \sum_{l=1}^{L} R_{k,c}^l \quad (2)$$

This feedback strategy is referred in [3] as *Mean over subcarrier covariance metric (MSC)*. Assuming that V_c is the beamforming vector (of size M_t x 1) operated to the transmitter antenna at frequency cluster c and σ_0^2 is the variance of the Gaussian noise applied at the input of the receiver, we design beamforming weights among clusters with the goal of minimizing total transmitted power (sum subcarriers power) under the constraint of keeping a Quality of Service (QoS) e.g. on providing at least a predetermined Signal to Noise Ratio (SNR).

$$\begin{aligned}
&\mathcal{C} && \min \|V_c\|_2^2 \\
&s.t. && \frac{\left|V_c^H R_{k,c} V_c\right|^2}{{\sigma_0}^2} \geq \gamma_k \\
&\forall k \in \{1, 2, \cdots K\} && \forall c \in \{1, 2, \cdots Q\}
\end{aligned}$$

The roblem $\mathcal{C}$ is NP-hard but it can be relaxed into a convex optimization problem which can be solved by any Semi Definite Programming (SDP) solver such SeDuMi [4]. OFDMA may provide scheduling flexibility of resource units in both frequency domain (subcarriers) and time domain (time slots). QoS constraints impose a minimum rate required R_{min}^k in bits per second and a maximum BER ϵ. For M-QAM modulation with M equal to $2^{b_{k,c}}$, where $b_{k,c}$ in bits per symbol is the modulation level selected from a set $\mathcal{M} = \{1, 2, 4, 6\}$ of available QAM constellations, the minimum required SNR $\gamma(b_{k,c})$ to achieve a BER lower than 10^{-5} is given in table 266 in [1]. Considering that the number of time slots, allocated to user k, at each subcarrier l belonging to cluster c is $S_{k,c}^l$, the total number of time slots must be at least equal to a value S. For the current WiMAX systems, the DL sub-frame has duration $T_f = 5ms$ and consists of $S = 8$ time slots of length $T_{slot} = 0.5ms$. The exact order of time slot allocation is not important because channel statistics are known at the transmitter. Only the number of time slots assigned to users at each cluster is of interest in our case. In addition, each subcarrier of the same cluster supports the same modulation level. Therefore, we could use LS timeslots and not require specific sub-carriers for each cluster. If the number of symbols S_{OFDM} transmitted in a slot is equal to $S_{OFDM} = \frac{T_{slot}}{T_{OFDM}}$ with T_{OFDM} being the total OFDM symbol duration, the rate of user k , calculated for one frame duration is

$$R_k = \frac{S_{OFDM} \sum_{c=1}^{Q} \sum_{l=1}^{L} b_{k,c} S_{k,c}^l}{T_f} \quad (3)$$

The transmitted power at cluster c can be written as

$$P_c = \sum_{k=1}^{K} \sum_{l=1}^{L} \frac{\|V_c\|^2 S_{k,c}^l}{S} \quad (4)$$

and therefore the optimization problem of minimizing the overall transmit power guaranteeing a specified QoS by optimizing the time-sharing $S_{k,c}$ is given as

$$\begin{aligned}
&\mathcal{P} && \min \frac{\sum_{c=1}^{Q} \sum_{k=1}^{K} \|V_c\|_2^2 S_{k,c}}{LS} \\
&s.t. && \frac{S_{OFDM} \sum_{c=1}^{Q} b_{k,c} S_{k,c}}{T_f} \geq R_{min}^k \\
& && \sum_{k=1}^{K} S_{k,c} \leq LS \\
& && S_{k,c} > 0 \\
&\forall k \in \{1, 2, \cdots K\} && \forall c \in \{1, 2, \cdots Q\}
\end{aligned}$$

The problem $\mathcal{P}$ is Linear Programming (LP) problem and it could be solved optimally by using SeDuMi [4].

III. NETWORK DEPLOYMENT AND ADAPTIVE RADIO RESOURCE MANAGEMENT

The IEEE 802.16e reference network (as a 3G cell communication system) uses cell sectoring and frequency reuse techniques [5]. Cell-sectoring replaces an omni-directional BS antenna with several directional antennas collocated at the same site. The hexagonal cell is divided into sectors. Each sector can be viewed as a mini-cell using different sets of radio resources. Frequency reuse planning is denoted by frequency reuse factor (c,s,n) where c represents the number of cells needed to realize the frequency partitioning; s represents the number of sectors per cell and c the number of frequency subsets used. Most of multi-cell network planning schemes use a (1,3,3) configuration: 1 cell,3 sectors and 3 subsets of frequencies. Since each cell is split into three sectors, the cell capacity is multiplied by three but 1/3 of the available channels are available in each sector. Therefore the (1,3,3) scheme does not affect the capacity. However, it minimizes the interference at the cell edge and improves SINR without increasing the transmitted power due to directional antennas. Since the operating spectrum is a scarce resource in network deployment and must be utilized efficiently, there is significant interest to transmit data at every sector using the same frequency band (universal frequency reuse). In this case, the radiation patterns of adjacent antennas are overlapping. For the users located in the overlapping regions between adjacent sectors even though they are near the BS, their own received power is weak (low transmit antenna gain) and the co-channel interference from the adjacent sector is high therefore the received SINR is low. For the users located in the direction of main beam, the transmit antenna gain is high and the desired received signal strength is high. The interference power is low because the antenna gains from adjacent sectors are low. A simple way to handle the interference is to allocate different sub-carriers to different sectors (static separation) or to avoid using in overlapping regions the sub-carriers already in use in other regions (dynamic separation). Both schemes are particular cases of FFR and therefore the spectral efficiency drops due to a larger reuse factor. Additionally, the cell-edge users suffer from loss of frequency selectivity gain.

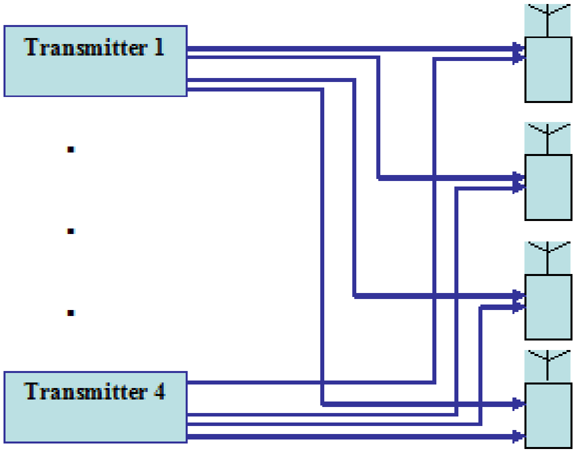

Figure 1. The proposed BS for cell sectoring

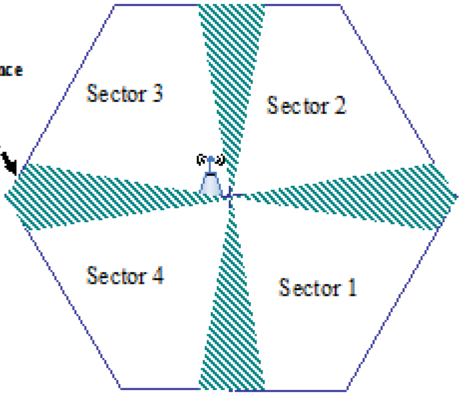

Figure 2. Interference regions in a cell with four sectors

The proposed solution uses a BS antenna with four elements and four transceivers. In fig.1, four beams are formed from the BS in the downlink (DL) direction. We handle the interference in the overlapping region of the antenna radiation diagrams in two adjacent sectors. The problem of universal frequency reuse pattern with a cell divided into four sectors is illustrated in fig. 2. The blank regions in this figure are low interference regions. By applying common transmission weight vectors in each cluster for the set of users belonging to sector $s \in \{1, 2, 3, 4\}$, we may suppress interference in neighboring sectors. The users of each sector can be treated indepedently of each other for designing beams with partial CSI. We minimize inter-sector interference and at the same time we keep the Quality of Service (QoS) at an acceptable level (by having a guaranteed minimum attained SINR by each user). By applying space division multiple access techniques (SDMA) and common weighting vectors at each cluster, we can theoretically improve the frequency utilization efficiency for the blank regions.The maximum number of beams at each BS is four (equal to the number of antenna elements M_t). If V_{cs} is the weighting vector applied at the sector s and cluster c and $R^s_{k,c}$ the covariance matrix calculated from user k belonging to sector s, the problem $\mathcal{C}$ is transformed as

$$
\begin{aligned}
\mathcal{C}'' \qquad & \min \|V_{cs}\|_2^2 \\
s.t. \quad & \frac{\left|V_{cs}^H R^s_{k,c} V_{cs}\right|^2}{{\sigma_0}^2} \geq \gamma_k \\
& \forall k \in \{1, 2, \cdots K\} \\
& \forall c \in \{1, 2, \cdots Q\} \\
& \forall s \in \{1, 2, 3, 4\}
\end{aligned}
$$

We transmit simultaneously V_{cs} beams and therefore mutual interference among these beams must be taken into account. The main source of interference comes from collisions among the same sub-carriers scheduled over the same time-slots in neighboring sectors. The burst allocation in the downlink subframe impacts the collision rate.

$$SINR_{k,c} = \frac{\left|(U_{k,c})^H R^s_{k,c} V_{c,s}\right|^2}{\sum_{l\neq s}\left|(U_{kc})^H R^s_{k,c} V_{cl}\right|^2 + \left\|U_{kc}\right\|^2 \sigma_0^2} \quad (5)$$

In (5), full cell loading and so maximum collision rate are considered. SDMA increases the number of time and frequency resources by four. Consequently, lower traffic conditions may occur compared to the available resources and subframes may be expected to be partially occupied in time. We find the remaining time slots which are not assigned at each cluster and sector

$$S_{c,s} = LS - \sum_{k=1}^{K} S^s_{k,c} \quad (6)$$

$$\forall k \in \{1, 2, \cdots K\}$$

$$\forall c \in \{1, 2, \cdots Q\}$$

$$\forall s \in \{1, 2, 3, 4\}$$

The minimum number of available time slots for allocation is given by

$$S_c^{min} = \arg\min_{\forall s} S_{c,s} \quad (24)$$

Then the optimization problem $\mathcal{C}''$ is applied for the shared regions $s \in \{12, 23, 34, 41\}$ (12 means interference region between sectors 1 and 2) while the problem $\mathcal{P}$ is now solved separately for four sectors by replacing the maximum number of time slots LS with S_c^{min}. If θ_s is one of the four fixed angular values that correspond to one of the four sector sites ($\theta_s \in \{45°, 135°, 225°, 315°\}$), $s \in \{1, 2, 3, 4\}$ is chosen such that θ_s is as close as possible to the mobiles' direction of arrival (DoA).

IV. Mobile LTE Network

The above analysis for mobile WiMAX networks is applicable to the Long Term Evolution (LTE) radio interface as is defined by the 3rd generation partnership project (3GPP) [6]. OFDMA with data transmission on parallel narrow-band subcarriers is the basis of the LTE downlink radio transmission. The basic unit for data transmission is referred to as physical resource block (PRB) which has both time and frequency dimension. LTE supports both the FDD and TDD modes of operation. In FDD, during each frame duration of 10ms there are 10 downlink subframes, each of 1ms duration. Each subframe is divided into slots, each of 0.5 ms duration. Each slot consists of 7 symbols, separated by the OFDM cyclic prefix. A PRB consists of 12 consecutive subcarriers for one slot duration. It's the smallest resource allocation element. In our system, the mobile terminal averages the channel estimates over 2 (1ms) or more (up to 10ms) slots depending on the variation of the channel. The short subframe duration of 1ms allows relatively faster channel variations to be tracked compared to WiMAX where the subframe duration is 5ms. Our adaptive beamforming and channel-dependent scheduling in time and frequency domains, when they are applied to the LTE radio access, exploit better the variations in the channel quality and make more efficient use of available resources. Multi-antenna schemes with up to four antennas at the transmitter and receiver sides are also supported by LTE. Transmit diversity is based on space-frequency block coding (SFBC), complemented with frequency-switched transmit diversity. Spatial multiplexing provides simultaneous transmission of parallel data streams and is based on a precoder matrix of size 4x4 when four antennas and therefore four independent streams are assumed. In the special case, where the precoder vector is 4x1 (rank-1 transmission), beamforming is selected. Codebook-based beamforming is a special case of the spatial multiplexing (SM). LTE also supports non-codebook based beamforming. Our discussion is applicable also to "LTE-Advanced" that aims to further enhance the LTE radio access performance and capabilities.

V. SIMULATION RESULTS

First, the performance of optimization problem $\mathcal{C}$ is evaluated. A network deployment with one non sectored cell and Uniform Linear Arrays (ULA) with half wave length spacing at both ends are considered. Simulations are evaluated in MATLAB environment with C2 metropolitan scenario (a typical urban micro-cell) from the WINNER II channel model [8]. Table I shows the system parameters. Five clusters constitute the low rate feedback information. An omnidirectional BS with four antennas at the receiver – Single Input Multiple Output (SIMO) – compliant to an IEEE 802.16e in case of no CSI is available at the BS(high mobility) is used for comparison. Fig. 9 shows that fairness in a single cell is improved among the users with our beamforming design. In this scheme 10% of users achieve an SNR lower than 10 dB while in SIMO 1x4 scheme only 50% of mobiles present SNR values greater than 10 dB. In the sectorized cell study, the most important issue is the cross correlation between the beams of the neighboring sectors, that tend to maximize when the shaded area of fig. 4 is minimized. Fig. 18 shows the average PHY layer data rate of two users which are found on the edge of two sectors as a function of the distance from BS. The angle between the two sectors (the angle width of the shaded area) is a=20°. In other words, the direction of the transmitted beam patterns have a difference of a=20° as illustrated in fig. 19. An improvement of 2Mbits/s is achieved for R=400m and R=300m when two separate beams are used instead of one. When the users are located near the BS, the inter-beam correlation problem can heavily degrade the performance of a sectorized cell. The simulation results are taken for the feedback scheme with 3 clusters. The transmitted power of a single beam is assumed to be equal to 2 Watts.

VI. CONCLUSIONS

In this paper, we propose a sectorized cellular system for a OFDMA broadband wireless access system with high speed users and analyze downlink performance of the system. We have proposed system-level techniques that can be combined with the advanced algorithms already proposed in literature to reduce intra-cell interference. The new structure exploits efficiently adaptive beamforming, dynamic frequency allocation and scheduling in order to mitigate inter-sector interference and improve overall system performance.

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TABLE I. SYSTEM MODEL PARAMETERS

Parameter	**Value**
Cell Radius (m)	500
Frequency Band (GHz)	5.25
Number of BS array antenna elements	4
Number of MS array antenna elements	4
Mobile Velocity (Km/h)	110
Channel Bandwidth (MHz)	10
Frame Duration (ms)	5
OFDM Symbol Duration (µs)	102.86
Number of Data Subcarriers	800
BS Transmit Power (W)	1
Channel Profile	WINNER II C2 Metropol
Mobile Station Distribution	Uniform, random positioning
Traffic Model	Full Buffer

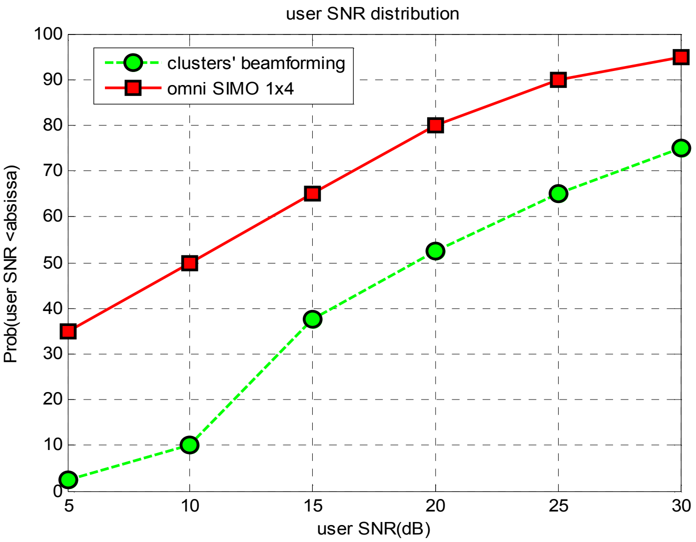

Figure 3. Figure 9. Users’ SNR distribution

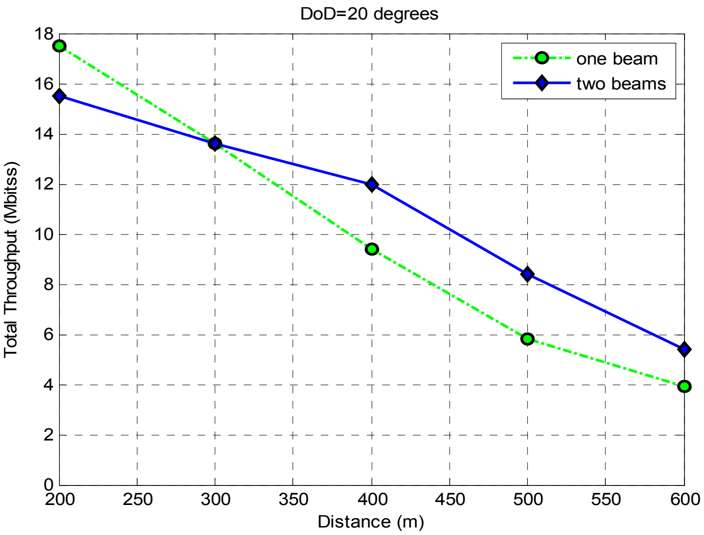

Figure 4. Performance of a sectorized cell system

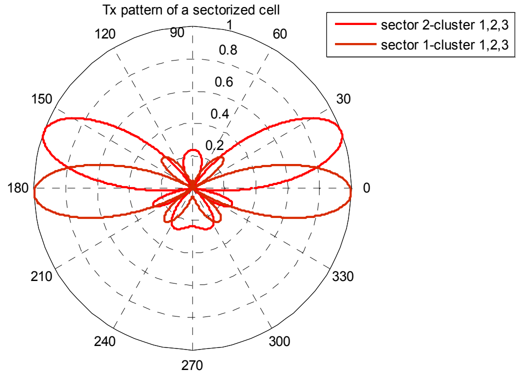

Figure 5. Tx patern of a two sectors with a=20°