Downlink Transmission Optimization and Statistical Feedback Strategies in a Multi-User IEEE 802.16m System

Christos Papathanasiou[1], Nikos Dimitriou[2], Leandros Tassiulas[1]

1. Department of Computer and Communications Engineering, University of Thessaly, Greece
2. Institute of Accelerating Systems & Applications, National & Kapodistrian University of Athens, Greece

Email: cpapa@uth.gr, nikodim@phys.uoa.gr, leandros@.uth.gr

***Abstract:* - A multi-user MIMO/OFDMA system for the next generation Broadband Wireless Access (BWA) networks is studied, in which the Base Station (BS) has only knowledge of the statistics of the channel. A combination of MIMO, OFDMA and FDD could be suitable to increase spectral efficiency in a high speed network. We investigate methods with scalable channel feedback and we analyze the trade off between the amount of Channel State Information (CSI) to the transmitter and the system performance. Simulation results demonstrate that substantial gain is obtained by the proposed schemes which take advantage the statistical information of the highly dynamic channel.**

I. INTRODUCTION

Wireless Metropolitan Area Networks (MANs) are under extensive investigation in recent years as they are envisaged to support broadband services and IP connectivity over wide geographical areas. 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 MIMO technology and Adaptive Antenna Systems (AAS) [1]. "Scalable" QoS classes, adaptive modulation and coding schemes and OFDMA multiplexing methods make 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-randomly 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 (Automatic 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 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 evolutions. The IEEE 802.16m amendment provides an advanced air interface that can ensure higher mobility, throughput and spectral efficiency, essential characteristics for a packet-based wireless system. It shall have optimum performance for low speed users (from stationary to pedestrian) that will be gracefully degraded as the user speeds (and the channel dynamics) increase [2]. Additionally, IEEE 801.16m will be backward compatible with the current 802.16e standard.

In realistic systems, the channel changes over time due to mobility of the users and the scattering environment. The influence of user mobility in multi-path propagation environment can be modeled by an individual Doppler shift on each signal path. Information about the channel quality cannot be instantaneous and is outdated to some degree. Second order statistics describe the fluctuation of channel parameter with time. We define the covariance matrix of channel gain $H(t)$, $R = \mathcal{E}\{H(t)H^H(t)\}$. The symbol $\mathcal{E}\{.\}$ denotes expected value. The channel is fast fading and the feedback information could be only low rate. Therefore, feedback is used for the next transmission process. The mobiles perform channel estimation, average over N_D slots and send back the covariance matrix by explicit feedback. This technique has been referred in literature as covariance feedback. In [3], an optimization problem is solved for a MIMO point to point system. The transmitter has partial channel knowledge (mean or covariance of the channel coefficient). It was found that the capacity improvement can be significantly high and the beamforming performs close to the optimal strategy. A similar problem is studied in [4], where it's shown that transmitting to the direction of the eigenvectors of correlation matrix is the optimal transmission strategy. The statistical model depends on the time scale. In short term, correlation of channel matrix $H(t)$ reflects the geometry of a particular propagation environment. Over a long term, channel coefficient may be uncorrelated due to the averaging over several propagation environments.

The key idea of our design is based on the short-term CSI at the transmitter by averaging the channel covariance matrix over the duration of one frame (5 msec). We derive

This work is supported by European Commission WiMAGIC STREP (FP7-ICT-215167)

coarse channel estimation via closed loop schemes, suitable for Frequency- Division Duplexing (FDD). Also, we assume that the receiver has perfect channel knowledge (full CSI). In a MIMO system, the application of multiple antennas at the transmitter and the receiver increases the number of channel state parameters. The feedback requirements grow with the product of the transmit antennas, receive antennas, delay spread and number of users. Statistical feedback in a channel that varies rapidly reduces the feedback requirements. Given a low–rate feedback channel with FDD, this information may be easy to obtain at the BS. An OFDM system divides a large spectrum into small narrow bands using an Orthogonal Transformation in order to have signals at each narrow band experiencing flat fading. The statistical feedback techniques designed for narrowband MIMO systems can be successfully used in MIMO – OFDM systems. But the number of sub-carriers in the OFDM may be considerably large, e.g. 1024 or 2048. In [5], the transmit antenna in the pair with the best subchannel is selected to transmit non-zero information. Aiming to reduce the feedback load in frequency domain, we utilize the feedback scheme proposed in [6]. N subcarriers are divided into Q clusters of L adjacent subcarriers each, so that $N = Q\ L$. The number of clusters Q is scaled down until it gets the value $Q = 1$ when the channel varies rapidly and is scaled up to exploit strong channel modes associated with a static or slowly varying channel (stationary, pedestrian users). Additionally, in the downlink direction, when the BS transmits over the same channel to multiple users, inter-user interference, named Multiple Access Interference (MAI) is present. The BS constructs appropriate beams in order to mitigate MAI, if CSI is available at the transmitter. In our case, where the channel is changing rapidly, accurate CSI is difficult to obtain. Therefore, second order statistical information can be used to form beams at each cluster but not to separate users in the spatial domain. Beamforming seeks to improve the total throughput or minimize the total transmit power. Our approach is robust and non risky taking account the coarse estimation of CSI at the transmitter. Statistical information can be used for scheduling the users in a time-division multiuser MIMO-OFDM system. We optimize the time sharing of the users at each cluster in order to achieve maximum overall throughput or minimize emitted power guaranteeing a QoS for all users. The aim of this paper is to combine MIMO, OFDM and FDD research challenges in a high mobility environment to offer better performance compared to the current 802.16e standard.

The organization of this paper is as follows: Section II describes the system model. In section III feedback strategies are presented while in section IV the weights of the beams at the BS for each cluster are designed. In section V an algorithm which finds a time-sharing solution is proposed. Finally, section VI concludes this paper.

II. SYSTEM MODEL

The downlink scheduler is assumed to select K users. Each user $k \in \{1, 2, \cdots, K\}$ has M_r received antennas while BS has M_t transmitted antennas with maximum power constraint P_{max}. We assume that a matrix H_k^n of size M_r x M_t represents the channel between the user k and BS at subcarrrier $n \in \{1, 2 \cdots N\}$. Finally, we suppose that the channel is frequency-flat due to OFDM modulation, V_n is the beamforming vector (of size M_t x 1) operated to the transmitting antennas at subcarrier n and σ_0 is the variance of the Gaussian noise applied at the input of the receiver. In our design, the signals received from M_r antenna elements are linearly combined to improve SNR. Also, CSI is available at the receiver. The received signals are multiplied by a coefficient vector U_k^n of size M_r x 1. According to Maximum Ratio Combiner (MRC) technique, the antenna is aligned to the Rx direction of $H_k^n\ V_n$ and therefore the MRC weights are given by [7]

$$U_k^n = \frac{H_k^n\ V_n}{\|H_k^n\ V_n\|} \quad (1)$$

The SNR_k^n calculated at the receiver k is given by

$$SNR_k^n = \frac{\left|(U_k^n)^H H_k^n V_n\right|^2}{\left\|U_k^n\right\|^2 \sigma_0^2}$$

$$SNR_k^n = \frac{\left|V_n^H (H_k^n)^H H_k^n V_n\right|^2}{{\sigma_0}^2} \quad (2)$$

Statistical feedback contains information $R_{k,c}$ about covariance channel gain that corresponds to cluster $c \in \{1, 2 \cdots Q\}$.

$$R_{k,c} = \mathcal{E}\{H_{k,c}(H_{k,c})^H\} \quad (3)$$

Equation (2) could transform as

$$SNR_{k,c} = \frac{\left|V_c^H R_{k,c} V_c\right|^2}{{\sigma_0}^2} \quad (4)$$

Assuming that the transmitted signal Sc , M_t x 1 directed to receivers in cluster c is zero mean, temporally white with unit variance $(\mathcal{E}\{|S_c|^2\} = 1)$, the total radiated power at BS is

$$\sum_{c=1}^{Q} \|V_c\|^2 \leq P_{max} \quad (5)$$

A frame structure applicable to FDD mode is considered. The DL sub-frame has duration $T_f = 5ms$ and consists of $S = 8$ time slots of length $T_{slot} = 0.5ms$. If the number of time slots, allocated to user k, at each subcarrier $l \in \{1, 2 \cdots L\}$ belonging to cluster c is $S_{k,c}^l$, the total number of time slots must be at least S.

$$\sum_{k=1}^{K} S_{k,c}^l \leq S \quad (6)$$

If the total OFDM symbol duration is T_{OFDM}, the number of symbols S_{OFDM} transmitted in a slot is equal to

$$S_{OFDM} = \frac{T_{slot}}{T_{OFDM}} \quad (7)$$

A modulation level with $b_{k,c}$ bits per symbol is selected from a set $\mathcal{M} = \{1, 2, 4, 6\}$ of available QAM. For M-QAM modulation with M equal to $2^{b_{k,c}}$, $b_{k,c} \in \mathcal{M}$, the minimum required SNR $\gamma(b_{k,c})$ to achieve a BER lower than a pre-specified value ϵ is given in [8]

$$\gamma(b_{k,c}) = -\frac{\ln 5\epsilon}{1.5}(2^{b_{k,c}} - 1) \quad (8)$$

Given $SNR_{k,c} = \gamma(b_{k,c})$, $b_{k,c}$ is computed from equation (8). The rate of user k, calculated for one frame duration is

$$R_k = \frac{S_{OFDM} \sum_{c=1}^{Q} \sum_{l=1}^{L} b_{k,c} S_{k,c}^l}{T_f} \quad (9)$$

The transmitted power at cluster c can be written now as

$$P_c = \sum_{k=1}^{K} \sum_{l=1}^{L} \frac{\|V_c\|^2 S_{k,c}^l}{S} \quad (10)$$

III. REDUCED FEEDBACK SCHEME

In this paper we propose the simplified feedback design based on clustered OFDM. As it's referred in section I, L adjacent OFDM subcarrier are grouped into Q clusters so that $N = Q\ L$, with N 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 to the system design. We have defined the covariance matrix of the channel gain as

$$R_{k,c}^l = \mathcal{E}\{H_{k,c}^l (H_{k,c}^l)^H\} \quad (11)$$

that derives from temporal averaging over the duration $T_f = 5ms$ of DL frame. The idea to feedback the covariance comes from the fact that it changes slower, e.g. second order statistics have a long coherence time compared with that of fading. Also, from (4), the channel covariance is the only metric that is representative of the received SNR and is better than feeding back channel autocorrelation. Additionally, the users inform the BS only for the value of the representative subcarrier in order to achieve a feedback reduction scheme. The following two feedback strategies are proposed

A. Mean over subcarrier covariance metric (MSC)

The estimated covariance matrix from user k $R_{k,c}^l$ is indicative of gain variation in the cluster c. The representative value is obtained from averaging the covariance matrix of all subcarriers that belong to cluster c

$$R_{k,c} = \frac{1}{L} \sum_{l=1}^{L} R_{k,c}^l \quad (12)$$

B. Minimum Effective SNR covariance metric(MEC)

Each user calculates the effective SNR at each subcarrier $l \in \{1, 2 \cdots L\}$.

$$ESNR_{k,c}^l = \mathcal{E}\{SNR_{k,c}^l\} \quad (13)$$

$SNR_{k,c}^l$ is computed from equation (2) taking account that each receiver k has perfect knowledge of the channel in all subcarriers and for all antennas. In this scheme, the covariance matrix $R_{k,c}$ corresponds to subcarrier l^* with the minimum effective SNR.

$$R_{k,c} = \mathcal{E}\{H_{k,c}^{l^*} (H_{k,c}^{l^*})^H\}$$
$$l^* \leftarrow \arg\min_{\forall l \in L} \{ESNR_{k,c}^l\} \quad (14)$$

The two schemes offer a considerable reduction in the amount of feedback and complexity of the allocation process but also decrease the system throughput. The scheduling isn't done for each subcarrier individually because our scheme proposes the same value of supportable throughput for all subcarriers of the cluster. This considerably reduces the allocation complexity especially for a small number of clusters Q. It's clear that having small clusters, many users achieve their throughput target but the feedback load isn't reduced much. The choice of large clusters reduces feedback but increase the risk to achieve lower data rates that those required. If the size of clusters is of the order of the channel coherence bandwidth, no degradation in system throughput occurs. The channel variations over subcarriers are small and thus we achieve the optimum capacity. This cluster size is the optimum in the case that users move with low speeds and large amount of feedback is feasible. In order to reduce the feedback load even more in situations where the channel changes rapidly, each user sends back only the covariance matrix of the strongest cluster c_{max}. c_{max} corresponds to the cluster with the greatest minimum ESNR. Therefore

$$R_{k,c_{max}} = \mathcal{E}\{H_{k,c_{max}}^{l*} (H_{k,c_{max}}^{l*})^H\}$$
$$c_{max} \leftarrow \arg\max_{\forall c} ESNR_{k,c}^{l^*} \quad (15)$$

This approach can lead to many users not reaching their target rate. If there are few active users and they feedback information about only a cluster, there is a high probability that the BS receives no information about some clusters. The amount of feedback could be scaled for higher speeds. The users estimate the set $\{ESNR_{k,c}^{l^*}\}_{c=1,\cdots,Q}$ of the effective SNR on the weakest subcarrier at each cluster c. The clusters are sorted in increasing order. Let $C_{\pi(1)}$, $C_{\pi(2)}$, .., $C_{\pi(Q)}$ be the sorted clusters. User k sends to BS information only for $\pi(\alpha)$ clusters with $\alpha \in \{1, 2, \cdots, Q\}$. The cluster – size α is scaled according to mobility-speed classes. It takes the maximum value for the stationary users where optimum performance is required and the minimum value equal to one for the high speed users in order to ensure basic performance.

Remark: No transmission will be scheduled on the cluster that $ESNR_{k,c}^{l^*} \leq \overline{ESNR}$, where $\overline{ESNR}$ is a threshold.

IV. BEAMFORMING WEIGHTS AMONG CLUSTERS

A downlink beamforming method is proposed that uses a common transmission weight vector for each cluster. This technique utilizes feedback information and assumes a flat-fading or narrowband cluster with a modified covariance channel matrix $R_{k,c}$ derived from section III. Our proposed scheme consists of simultaneously designing downlink beamformers to multiple clusters in order to maximize the total throughput or minimize the transmit power, under the constraints on providing at least a specified received SNR to each intended receiver keeping also the total BS transmit power (sum power) upper bounded. In this section, we first give a formal description of the optimization problem studied in [9]. We extended this multicast scenario with full CSI available at the transmitter to a multi-cluster, where the transmitter receives second order statistics from the receiver. In the following, we transform the transmit power optimization problem into a throughput maximization. Given the covariance matrix $R_{k,c}$ calculated from user k, γ_k the guaranteed specified SNR for user k at each cluster c and considering that the low rate feedback channel is error and delay free, the optimization problem can be described as

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

The above problem is NP-hard but it can be relaxed to a convex optimization problem. Towards this end, we define $U_c = V_c V_c^H$ of size M_t x M_t and we note that $V_c^H R_{k,c} V_c = trace(R_{k,c} V_c V_c^H) = trace(R_{k,c} U_c)$. Then problem $\mathcal{C}$ can be reformulated as

$$\begin{aligned} &\mathcal{C}' && \min trace U_c \\ &s.t. && trace(R_{k,c} U_c) \geq \gamma_k \\ &&& U_c = U_c^H \quad (a) \\ &&& U_c \geq 0 \quad (b) \\ &&& rank U_c = 1 \quad (c) \\ &\forall k \in \{1, 2, \cdots K\} && \forall c \in \{1, 2, \cdots Q\} \end{aligned}$$

The constraints (a) and (b) are applied from the fact that U_c is a symmetric, positive, semidefined matrix. The rank-one constraint derives from the definition of matrix U_c and is not convex. Dropping the constraint (c), the original problem is relaxed to a Semi Definite Programming (SDP) which can be solved by any SDP solver such SeDuMi [10], based on the interior point method. In optimization problem $\mathcal{C}'$, we have removed one of the problem constraints. Therefore, the solution $traceU_c^{opt}$ gives a lower power bound. We generate candidate beamforming vectors V_c with negligible cost by utilizing a randomization procedure described as following: The computed matrix U_c^{opt} is analyzed in $U_c^{opt} = U \Sigma U^H$ with the Singular Value Decomposition (SVD) technique. Feasible weight vectors can be found from equation $V_c = U \Sigma w_g$. w_g is a Gaussian variable with w_g ~ N(0,1) in order to achieve $U_c^{opt} = \mathcal{E}\{V_c V_c^H\}$. From the calculated beamforming vectors V_c , the vector with minimum $\|V_c\|^2$ is selected. In case that our goal is to maximize the total throughput under the transmit power constraint P_{max} , we introduce a transmit vector for each cluster $V_c' = \sqrt{P_c} V_c$. P_c denotes the power boost factor for cluster c . The boost factor changes only the gain of the antenna weights. If the transmit power is distributed equally at all clusters then

$$\|V_c\|^2 P_c = \frac{P_{max}}{Q} \Rightarrow P_c = \frac{P_{max}}{\|V_c\|^2 Q} \quad (16)$$

V. OPTIMAL TIME-SHARING

OFDMA has emerged as a promising technology for the next generation BWA networks. OFDMA provides scheduling flexibility of resource units in frequency domain (subcarriers) and in time domain (time slots). After the subcarrier allocation and optimal beams construction, we treat the problem of time slot assignment. This problem is especially crucial if the target rates of the users are predetermined. In [11], the authors develop a joint multiuser time –sharing and power allocation problem assuming that the transmitter knows only the statistical information about the channel. The initial problem isn't convex and is modified into a sub-optimal convex optimization problem.

The WiMAX standard divides all services into four classes. Each class is associated with a set of QoS parameters. These service classes support constant bit rate (VoIP), real time data streams (MPEG video), variable-size data packets (FTP) and best effort allocation (e-mail). Thus, the minimum rate required R_{min}^k in bits per second and the maximum BER ϵ are related differently in the different classes of services for each user k. The exact order of time slots allocation isn't important because only channel statistics are known at the transmitter. Therefore, we are interested in the number of slots assigned to users at each cluster. In addition, each subcarrier of the same cluster supports the same modulation level. Therefore, we could use LS timeslots and not require subcarriers for each cluster. Equations (6), (9) and (10) can be written

$$\sum_{k=1}^{K} S_{k,c} \leq LS \quad \forall c \in \{1, 2, \cdots, Q\} \quad (17)$$

$$R_k = \frac{S_{OFDM}\sum_{c=1}^{Q} b_{k,c}S_{k,c}}{T_f} \quad \forall k \in \{1,2,\cdots K\} \quad (18)$$

$$P_c = \frac{\sum_{k=1}^{K}\|V_c\|_2^2 S_{k,c}}{LS} \quad \forall c \in \{1,2,\cdots,Q\} \quad (19)$$

Our goal is to maximize total throughput while ensuring the users' individual QoS by optimizing the time-sharing S_k^c for all users. Mathematically, this optimization problem can be presented as

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

A simple approach is to schedule equal time slots at each cluster. If F_c is the number of users which send back information for cluster c then the number of time slots allocated to each user is

$$S_{k,c} = \lfloor \frac{SL}{F_c} \rfloor \quad (20)$$

$\lfloor x \rfloor$ denotes the biggest integer that does not exceeds x. Finally, we consider the problem of minimizing the overall transmit power guaranteeing a specified QoS by optimizing the time-sharing $S_{k,c}$

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

Problems $\mathcal{T}$ and $\mathcal{P}$ are Linear Programming (LP) problems and they could be solved optimally by using SeDuMi [10].

VI. SIMULATION RESULTS

A network deployment with one cell radius R=500m and one BS at the center of the cell is considered. The number of BS and MS antennas is four. Uniform Linear Arrays (ULA) with half wave length spacing are used at both ends. The network is assumed to operate at 5.25 GHz and OFDM with 800 sub-carriers is used within the 10 MHz transmission bandwidth. All simulation, throughput and transmit power estimation was generated in Matlab system. A summary of system parameters is provided in Table I. The channel model related to C2 Metropolitan area for typical urban macro-cell scenario from WINNER II channel model was used [12].

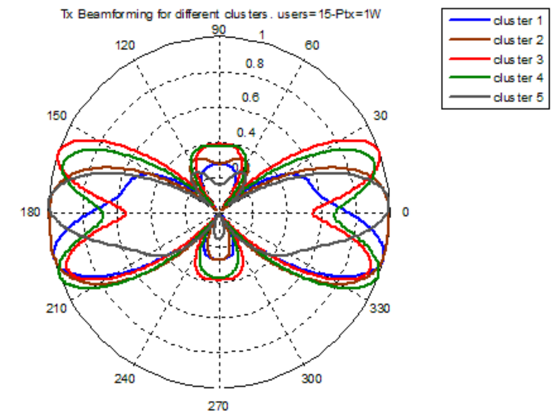

Figure 1. Transmit beams for different clusters

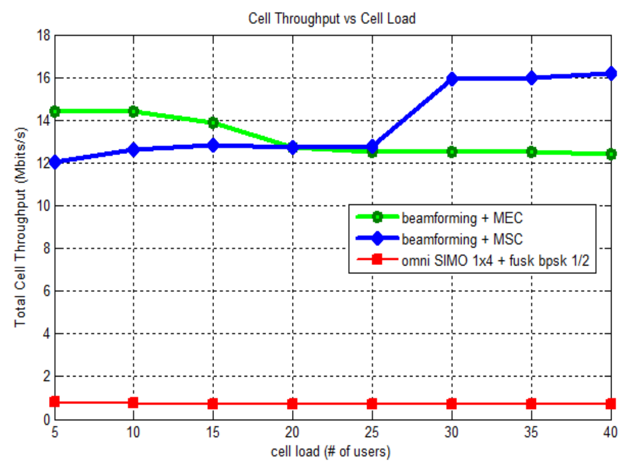

Figure 2. Cell throughput versus cell load

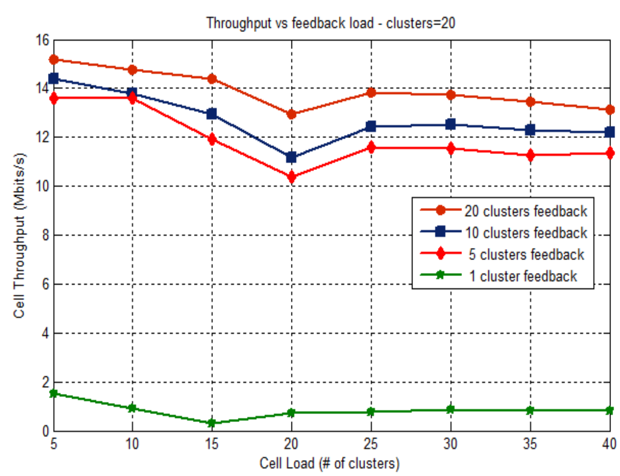

Figure 3. Total cell thrpughput versus feedback load

The model is applicable for mobiles located in an outdoor environment at street level communicating with fixed BSs installed above rooftops. Non Line Of Sight (NLOS) propagation is the typical case scenario. Table II demonstrates the type of modulation and coding rate which is selected in relation to received SNR and compliant to IEEE 802.16e standard. In the following, the performance of optimization problem $\mathcal{C}$ is evaluated. The feedback scenario with 5-clusters is used. All clusters are sent as feedback information from the 15 mobiles to the BS. Furthermore, the total throughput of an omnidirectional transmit system at BS with four antennas at the receiver – Single Input Multiple Output – is also given to serve as a lower bound. This SIMO 1x4 system could be compliant to an IEEE 802.16e in case of high mobility, where no CSI is available at the BS.

Transmitted beams for different clusters are highlighted in fig. 1 to show the effect of our approach. Fig. 2 compares the Mean over Subcarrier Covariance (MSC) statistical feedback strategy, the Minimum Effective SNR covariance (MEC) feedback scheme and the omnidirectional SIMO 1x4 system, where FUSC scheduling with BPSK modulation type and ½ rate coding is supported in order to provide frequency diversity for high-speed users. FUSC doesn't need feedback information. As figure 2 indicates, the performance with feedback may be significantly enhanced, e.g. total cell throughput is improved from 1 Mbits/s to more than 12 Mbits/s. The performance with MSC feedback is better when the number of mobiles grows than that with the MEC feedback scheme. Figure 3 depicts the achievable system throughput as a function of feedback load if the 800 OFDMA sub-carriers are divided into 20 clusters for a system with MEC feedback scheme. The total cell throughput increases from 1Mbits/s, when the strongest cluster is fed back to more than 10 Mbits/s in the case where the five clusters with bigger minimum ESNR are used. A degradation of the system performance of about 15% is observed if 5 clusters instead of 20 are selected as feedback.

Finally, computer simulations are conducted to evaluate the performance of the optimization problem $\mathcal{T}$ after beamforming and frequency allocation problem is solved for 5 clusters. Our proposed algorithm for optimal time – sharing is compared to equal-time method (equal number of slots is allocated to each user) in figure 4. Target rates of users are predetermined to 500 Kbits/s. When the number of users is greater than 15, our optimal strategy tends to allocate similar number of slots with the equal-time method. The total throughput versus the target rate for 10 users is plotted in figure 5. All the users have the same target rate. Results indicate that total throughput decreases from 14.5 Mbits/s when minimum rate required is 10 Kbits/s to 11 Mbits/s when minimum rate is 1 Mbits/s. In figure 6, the total throughput versus the number of time slots allocated at each cluster (S) is illustrated. We assume that the minimum required rate is

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

1Mbits/s while the number of users is 10. As we can see, from S=8 to S=32, the performance is independent of the number of time slots. The value S=4 gives the maximum throughput, equal to 13 Mbits/s.

VII. CONCLUSIONS

This paper has addressed the multiuser MIMO/OFDM problem of beamforming and scheduling in the frequency and the time domain when the transmitter has only the knowledge of channel statistics of the users. We proposed and developed two new, flexible and scalable low rate feedback schemes in a network with rapidly time-varying channels. Our results indicated that the proposed algorithms can meet the requirements of the promising IEEE 802.16m standard technology.

REFERENCES

[1] IEEE standard for Local metropolitan area networks "part 16: Air interface for Fixed and Mobile Broadband Wireless Access Systems; Amendment 2: Physical and Medium Access Control Layers for combined Fixed and Mobile Operation in Licensed Bands and Corrigendum", 28 February 2006.

[2] IEEE 802.16 Broadband Wireless Access Working Group, IEEE 802.16m system Requirements 2007-10-19.

[3] Jafar, S.A.; Goldsmith, A,"Transmitter Optimization and Optimality of Beam forming for Multiple Antenna Systems". Wireless Communications, IEEE Transactions on Volume 3, Issue 4, July 2004.

[4] Jorswieck E.A, Boche, H, "Channel Capacity and Capacity-Range of Beam forming in MIMO wireless systems under Correlated Fading with Covariance Feedback". Wireless Communications, IEEE Transactions onVolume 3, Issue 5, Sept. 2004

[5] Hung-Ta Pai, "Limited feedback for Antenna selection in MIMO-OFDM system", Consumer Communications and Networking Conference, 2006. CCNC 2006. 3rd IEEE,Volume 2, Issue , 8-10 Jan. 2006.

[6] Cimini, L.J., Jr.; Babak Daneshrad; Sollenberger, N.R.,“Clustered OFDM with transmitter diversity and coding”, Global Telecommunications Conference, 1996.

[7] J.G. Proakis, “Digital Communications”, 3rd ed.,New York, Mc-Graw-Hill 1995

[8] Xiaoxin Qiu; Chawla, K., “On the performance of adaptive modulation in cellular systems”, Communications, IEEE Transactions onVolume 47, Issue 6, Jun 1999

[9] Papathanasiou C., Tassiulas L.,“Multicast Transmission over IEEE 802.11n WLAN”, ICC 2008.

[10] J.F. Sturm, “Using SeDuMi 1.02 , a MATLAB Toolbox for optimization over symmetric cones “, Optimization Methods and Software, vol 11-12, pp 625-653,1999

[11] Kai-Kit Wong,Jia Chen , “Time-division multiuser MIMO with statistical feedback”, EURASIP Journal on Advances in Signal Processing,Volume 8 , Issue 1 January 2008.

[12] IST-4-027756 WINNER II Deliverable 6.13.14 “Winner II system concept Description” v.1.1, 172 pages, January 2008.

TABLE II. TYPE OF MODULATION AND CODING RATE ACCORDING TO SNR

Modulation	Coding	SNR (dB)
BPSK	1/2	3
QPSK	1/2	6
QPSK	3/4	8.5
16 QAM	1/2	11.5
16 QAM	3/4	15
64 QAM	2/3	19
64 QAM	3/4	21

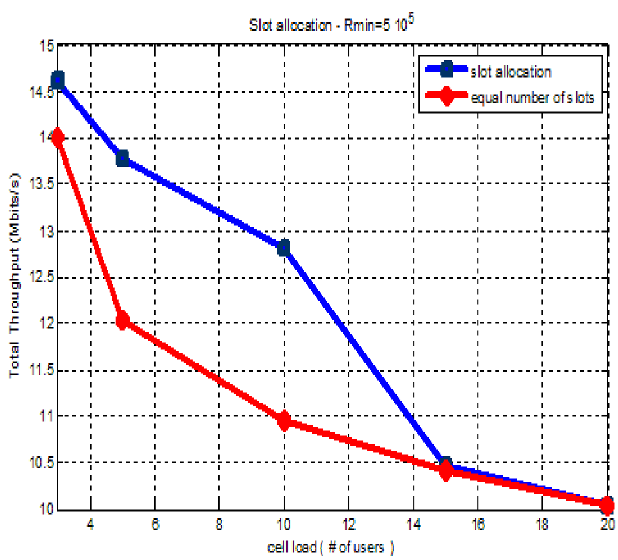

Figure 4. Total throughput versus cell load for the sharing-time problem

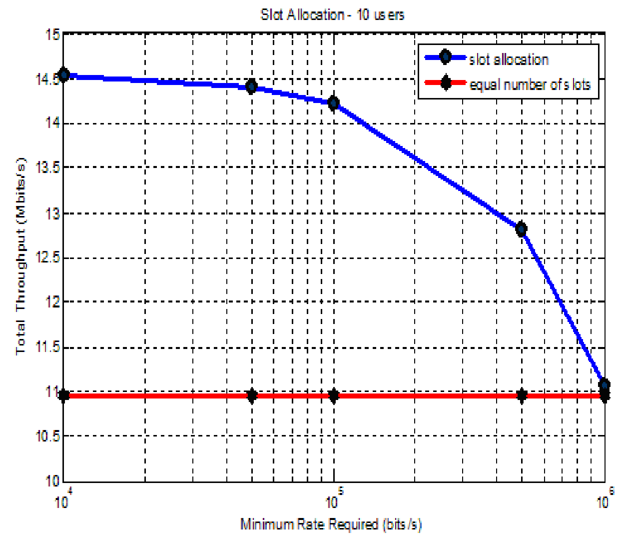

Figure 5. Total Throughput against the target rate

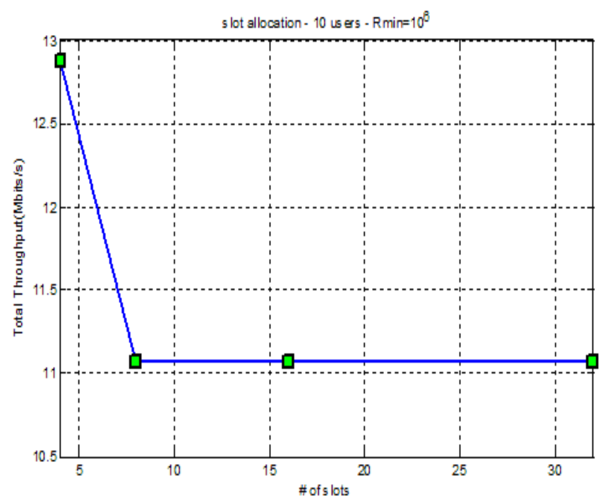

Figure 6. Total Throughput versus number of slots