A Joint Time and Frequency Domains Utility-Based Packet Scheduler for Mobile WiMAX Networks

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Abstract. Mobile WiMAX represents a broadband wireless solution that enables the convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. IEEE802.16e standard for Mobile WiMAX system is based on the Orthogonal Frequency Division Multiple Access (OFDMA) scheme and allows sub-channelization in both uplink and downlink connections. Different sub-channelization schemes were proposed and implemented for Mobile WiMAX standard. Among them, AMC allows the exploitation of multi-user diversity over frequency domain, in that sub-channels may be allocated to users according to their frequency response over each band of sub-carriers comprising each sub-channel. This multi-user diversity can provide significant gains in overall system capacity if each sub-channel is opportunistically assigned to the user resulting in the highest gain, and therefore using the most efficient modulation and coding scheme. As the frequency diversity is lost with AMC this mode of channelization is more appropriate for fixed and low-mobility applications and/or with the use of Adaptive Antenna Systems (AAS) because these scenarios are associated to better SINR ratios.This article extends the work performed in by proposing a new joint scheduling and resource allocation algorithms for Mobile WiMAX system. The scheduler is based on the two degrees of freedom which results from the definition of radio resources over both time and frequency domains in the TDD OFDMA frame standardized by IEEE802.16e.

Keywords: Mobile WiMAX, AMC sub-channelization scheme, time and frequency domains packet scheduler, utility.

1 Introduction

Mobile WiMAX [1] represents a broadband wireless solution that enables the convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. IEEE802.16e standard for Mobile WiMAX system is based on the Orthogonal Frequency Division Multiple Access (OFDMA) scheme and allows sub-channelization in both uplink and downlink connections. For each symbol in the Time Division Duplexing (TDD) frame, different sub-channels may be allocated to different users according to

J. Rodriguez, R. Tafazolli, C. Verikoukis (Eds.): MOBIMEDIA 2010, LNICST 77, pp. 178–192, 2012.

OFDMA, and sub-channels may be constituent using either contiguous sub-carriers or sub-carriers pseudo-randomly distributed across the frequency spectrum corresponding to each OFDM symbol:

- Sub-channels formed using distributed sub-carriers provide more frequency diversity [2] and this is useful for mobile applications. For distribution sub-carrier allocation channel quality is estimated from the OFDM symbol conveyed in the preamble of the TDD frame. Also, sub-channels formed using distributed sub-carriers provide more frequency diversity and this is useful for mobile applications.
- In Mobile WiMAX sub-channels may also be formed by allocating sub-carriers contiguously along the spectrum associated to each OFDMA symbol in the frame. In Mobile WiMAX this is called band adaptive modulation and coding (AMC).

Of fundamental importance in the support of applications QoS requirements is the packet scheduler. Packet schedulers must be designed properly to be reactive to changes in the channel and traffic patterns, in order to respond fast to deviations from the requested QoS of even the most delay sensitive applications. The scheduler is located inside each base station to enable rapid response to traffic requirements and channel conditions.

The use of AMC results in the loss of frequency diversity. However AMC allows the exploitation of multi-user diversity over frequency domain, in that sub-channels may be allocated to users according to their frequency response over each band of sub-carriers comprising each sub-channel. This multi-user diversity can provide significant gains in overall system capacity if each sub-channel is opportunistically assigned to the user resulting in the highest gain, and therefore using the most efficient modulation and coding scheme. As the frequency diversity is lost with AMC this mode of channelization is more appropriate for fixed and low-mobility applications and/or with the use of Adaptive Antenna Systems (AAS) because these scenarios are associated to better SINR ratios.

This article extends the work performed in [3] by proposing a new joint scheduling and resource allocation algorithms for Mobile WiMAX system. The scheduler is based on the two degrees of freedom which results from the definition of radio resources over both time and frequency domains in the TDD OFDMA frame standardized by IEEE802.16e. It is organized as follows: section 2 summarizes the state of the art available in the research literature; section 3 is about the implementation of the map of resources with AMC sub-channelization for Mobile WiMAX system level simulations; section 4 describes all the steps followed in the implementation of the proposed time-frequency domain packet scheduler; section 5 presents results from the performance evaluation of the proposed scheduler. Both VoIP and WWW traffic models from 3GPP were used in performance evaluation, for two types of channels: SISO channel with ITU PedB and a 3 Km/h mobile speed, and 2x2 MIMO channel with STBC Alamouti coding also with a 3 Km/h mobile speed [4]. Section 6 concludes the article.

2 Related Work

To the best of the author's knowledge there are up to now no publications available in the literature regarding proposals for schedulers in realistic systems, combining both time and frequency domains, associated to the OFDMA multiple access in Mobile WiMAX. The approach most closely related to this work is the one presented in [5]. However, the authors do not consider realistic traffic models. The proposed DRA assigns each resource in the map to the user with the highest priority, resulting from a modified Proportional Fairness algorithm. Users are assumed as always backlogged, i.e., full queue traffic model is used. This is because the authors compare the gains achieved with AMC sub-channelization scheme over PUSC sub-channelization scheme, in terms of capacity. No QoS requests are considered, also because no traffic model is simulated. System level simulations are performed for both modes and for different types of channel models, under a SISO channel.

Most proposals for packet schedulers which consider the multi-user diversity gain over frequency are based on simplistic scenarios, mainly considering one cell, with no traffic models and/or realistic traffic channels. Invariably these proposals formulate an optimization problem in which sub-carriers are provided to the user which maximizes a given performance metric (for example, a minimum data rate which must be provided to each user) whilst satisfying some simple constraints, such as the maximum power available for data transmission in the cell.

In [8] another channel dependent scheduler in both time and frequency domains is proposed for 3GPP UTRAN LTE network. The scheduler is divided into a time-domain and a frequency-domain part and both schedulers work independently and different algorithms can be applied in each scheduler part. Schedulers in time domain provide a list of mobiles to the schedulers in the frequency domain. Authors claim that a gain of 35% can be achieved in throughput and coverage over the basic opportunistic time-domain scheduler.

In [9] the same principle is used with the definition of a metric that decouples time and frequency domain schedulers. Two types of traffic models are considered: Best Effort and (BE) and Constant Bit Rate (CBR). Authors claim that this decoupled metric results in a coverage gain of up to 60% for a cell throughput loss of 5% over the time-frequency domain proportional fairness scheduler. The same approach for scheduling in time and frequency independently is followed in [10].

In [11] a frequency domain packet scheduler is considered for the analysis of a downlink OFDMA system using three different forms of CQI reporting schemes. Other proposals for time-domain schedulers are [12,13]. The work in [14] extends the original time-domain scheduler for MIMO channels.

3 Resource Space for Time-Frequency Domain Scheduler

With band AMC each burst can be allocated to a resource spanning 64 data sub-carriers in frequency domain and 21 OFDM symbols in time domain. In AMC mode pilot and data sub-carriers are organized in bins and each bin comprises 8 data sub-carriers and 1 pilot sub-carrier, which amounts to 12 resources available in the map of resources. Assuming each slot is made-up of 2 bins per 3 OFDM symbols there are in total 7*(8/2) = 28 slots per resource.

Differently from the PUSC mode, in which channel quality estimation is derived from the symbol conveyed in the frame's preamble, in band AMC channel quality must be estimated from the pilot sub-carriers for the bins assigned to each radio resource in the frame. In the simulations the quality of each resource is estimated from the 8 pilot sub-carriers, corresponding to each one of the 8 bins comprising each resource. As the pilots are activated only for those resources which are conveying information, the Channel Quality Indication (CQI) associated to each burst mapped into a resource will depend on the amount of load in the system: a system close to full load will result in more interfered bins and, therefore, in the need to use a more robust MCS scheme; a system under-loaded will result in bursts less interfered and in more efficient MCS schemes. The amount of interference will depend on the position of the mobile in the cell and this negative effect will be somehow compensated by the opportunistic nature of allocating resources with better SINRs for each user. Figure 1 depicts the map of resources for the band AMC-based DRA.

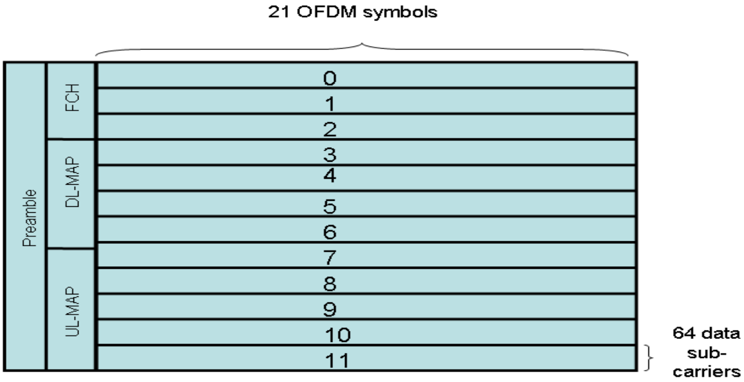


Fig. 1. Map of resources for Mobile WiMAX TDD frame with AMC sub-channelization Scheme implemented

4 Proposed Scheduler

The proposed time-frequency packet scheduler encompasses 4 steps:

1. Computation of the list of active users eligible for scheduling. Users are inserted into the active list if they comply with any one of the following constraints: (i) the user has an active HARQ process waiting for transmission; (ii) the user has new packets waiting in the buffer.
2. Perform scheduling in time domain by means of the utility-based packet scheduling algorithm. Only new packets in the user's buffer are considered.

The output from step (1) is a list of priorities for the users in the active list. Only QoS requirements, in terms of the maximum allowable packet delay, are considered. Channel quality is not included in the computation of the user's priority, as it would depend on the resource being considered.

3. Perform scheduling in frequency domain. A priority metric is computed for each resource in the map according to a scheduling algorithm which takes into account the combined gain of the set of sub-channels into which each resource is mapped. Different algorithms can be considered such as: the Maximum C/I (CI), Proportional Fairness (PF) or the Maximum C/I over the Average C/I (AvgCI).
4. Combine the outputs from both schedulers, in time and frequency, and compose a list of priorities, one for each resource in the map of resources. The user with the highest priority is selected for transmission.

4.1 Time Domain Packet Scheduler

The scheduling algorithm used in time domain is a small modification of the basic utility-based packet scheduler proposed in [3], as the algorithm does not consider the channel quality in the estimation of the utility to be transferred. This is because the computation of the user's transferred utility according to the channel state would depend on the position of the resource in the map of resources. And at this stage one does not know in advance in which resource to map the user's packets. One possible solution would be to perform the scheduling for each resource independently. But this would result in an increase in the simulation complexity and execution time. In order to circumvent this all packets in the user's buffer are used in the computation of the transferred utility. If the user does not have any channel with quality good enough to perform data transmission the scheduler in frequency domain will reflect this fact by forbidding channel access to the user, no matter its position in the list of priorities outputted from the time-domain scheduler. The steps followed in the time-domain scheduler are the following:

Step 1. At the beginning of frame period n compute the total amount of potential utility $U_p(n)$ in the cell. This is given by equation (1):

$$U_p(n) = \sum_{i=1}^{N} \sum_{l=0}^{L_i} U_i(\tau_i^{(l)}) \tag{1}$$

Where $U_i(\tau_i^{(l)})$ is the utility of the l^{th} packet with delay $\tau_i^{(l)}$ in the buffer of the i^{th} user, assuming there are L_i packets in the buffer of user i and a total of N active users in the cell.

Step 2. For a given user, $j \in \{1,\ldots,N\}$, compute the amount of utility that will be transferred to the network if the user is scheduled for transmission. All packets stored in the user's buffer are considered in this computation. This is given by equation (2):

$$U_j^T(n) = U_j(\mathbf{Q}_j(n)) = \sum_{k=1}^{L_j} U\left(\tau_j^{(k)}\right) \tag{2}$$

Where $\mathbf{Q}_j(n) = \left\{\tau_j^{(0)}, \tau_j^{(1)}, \cdots, \tau_j^{(L_j-1)}\right\}$ is a vector representing the delay of each packet from the buffer of user *j*. $\tau_j^{(0)}$ is the delay of the Head of Line (HOL) packet in the user's *j* buffer.

Step 3. Compute the average of the utility already transferred from user $j \in \{1,\ldots,N\}$, according to equation (3)

$$\overline{U_j^T}(n) = \lambda.\overline{U_j^T}(n-1) + (1-\lambda).U_j^T(n) \tag{3}$$

Where:

- $\overline{U_j^T}(n)$ is the updated value of the average utility transferred from user *j* in frame period *n*. It stores the state of the previous transmissions from this user.
- λ is the forgetting factor. It should be longer than the coherence time in order to average out the influence of fast fading in the radio channel.

Step 4. Estimate the potential utility that will remain for frame period *n*+1 if user *j* is selected for transmission in frame period *n*. This is given by equation (4):

$$U_p(n+1 \mid j) = \sum_{i=1, i\neq j}^{N} \sum_{l=0}^{L_i} U_i(\tau_i^{(l)}) \tag{4}$$

Step 5. Compute the priority metric for each user. The selected user is the one which results in the maximization of the difference between the transferred utility, $U_j^T(n)$, and the loss, $Loss_j(n)$, of utility incurred in this selection, as given by equation (5):

$$M_i(n) = \frac{U_i^T(n)}{\overline{U_i^T}} - Loss_i(n), \quad i \in \{1,\ldots,N\} \tag{5}$$

Where: $Loss_i(n) = U_p(n) - U_p(n+1 \mid i) - U_i^T(\mathbf{Q}_i(n))$.

Step 6. Normalize the priority metric $M_i(n)$ for each user $i \in \{1,\ldots,N\}$, according to equation (6):

$$\begin{array}{lll} \text{if } M_i(n) \geq 0 & M_i^{norm}(n) = M_i(n)/\max(M_i(n)) \\ \text{else} & M_i^{norm}(n) = M_i(n)/\min(M_i(n)) \end{array} \tag{6}$$

The purpose of this normalization is to force the final priority to be in the range: [1,1].

4.2 Frequency Domain Packet Scheduler

The scheduling algorithm used in frequency domain is the Proportional Fairness (PF), although other scheduling algorithms could be considered as well. The PF metric is computed for each resource in the map of resources, with channel quality strong enough to guarantee the transmission with a high probability of success. To this effect an *admission threshold* parameter is considered:

- If the channel quality is not good enough to support transmission, with at least the most robust MCS scheme, a new value for the CQI is computed, by assuming the most robust MCS scheme is used in the transmission.
- If the new value of the CQI is equal to or greater than the Admission Threshold the PF metric is computed for the given resource and user.
- Otherwise the user is not considered in the list of priorities for this specific resource.

This strategy is followed in order to avoid transmissions with a CQI level which could result in transmission errors with high probability and, therefore, would decrease resource utilization efficiency.

The PF scheduler computes the priority metric for each user and for each resource in the map of resources according to equations (7-9).

$$F_i(n) = \frac{DRC_i^k(n)}{T_i^{avg}(n)}, \quad i \in \{1,\ldots,N\}; k = \{1,\ldots,K\} \tag{7}$$

$$DRC_i^k(n) = \frac{N_i^k}{T_{frame}}(1 - BLER_i^k) \tag{8}$$

$$T_i^{avg}(n+1) = \lambda.T_i^{avg}(n) + (1-\lambda).R_i(n) \tag{9}$$

Where:

- $DRC_i^k(n)$ is the estimated data rate for user *i* on resource *k*.
- N_i^k is the size of the transport block that can be transmitted in resource *k*. It depends on the MCS scheme used.
- $BLER_i^k$ is the estimated Block Error Rate for user *i* on resource *k*.
- T_{frame} is the duration of the radio frame.
- *N* is the number of active users in the active set.
- *K* is the number of resources in the map of resources.

- T_i^{avg} is the average throughput from user i.
- $R_i(n)$ is the amount of information transmitted by user i in previous transmission cycle over all resources assigned to it.
- λ is the filter length. It must be higher than the coherence time associated to the Doppler frequency and lower than the period of time corresponding to the de-correlation length. It was defined as 1.5 seconds.

4.3 Computation of Final Priority

It is important to mention that resources are first assigned to HARQ processes which are active and waiting for a new transmission opportunity. This is because the same resource must be assigned to the HARQ process for re-transmission, in order to be consistent with the MCS scheme used in the first transmission attempt. Only those resources in the map of resources which remain free for allocation are considered in the computation of the final priority.

In order to decide which user should transmit in each resource a list of priorities must be computed for each one. The user with highest priority is assigned the respective resource for transmission, according to equation (10).

$$u^k(n) = \arg \max_{i \in \{1,\ldots,N\}} \left(M_i.(n) F_i^k(n)\right), \quad k = 1,\ldots,K \tag{10}$$

Where:

- $M_i(n)$ is the priority returned from the time domain scheduler.
- $F_i^k(n)$ is the priority for resource $k \in \{1,\ldots,K\}$ returned from the frequency domain scheduler.

5 Results

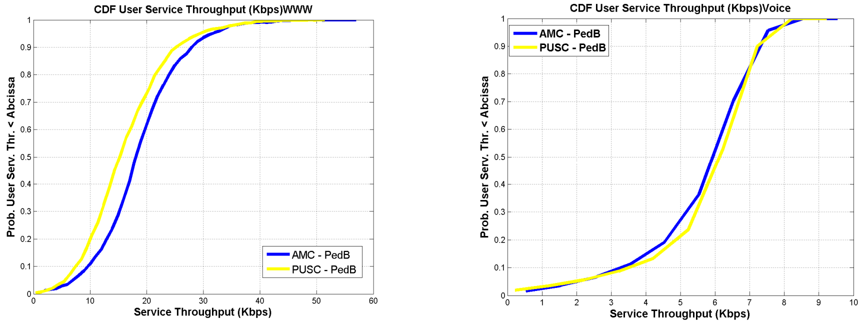
This section presents the results obtained from system level simulations conducted for both AMC and PUSC sub-channelization modes with the utility-based packet scheduling algorithm. All simulations were conducted for a total amount of 200 active users in the network and for two types of traffic models: WWW and VoIP. Simulations were also performed for two types of channels: SISO channel, with ITU PedB 3 Km/h mobile speed and 2x2 MIMO channel, with STBC Alamouti coding also with 3 Km/h mobile speed. The *admission threshold* was set to -5 dB.

Table 1 lists the parameters used in the setup of the scenario used in the system level simulations.

Table 1. A Simulation Scenario and Setup

Cell Layout	Hexagonal Grid, 19 cell sites, 3 sector BSs, 1 cell reuse in a cloverleaf layout with wraparound to simulate interference to edge cells
Number of Users	200 (Traffic Model Used); 72 (Full Queue Used)
BS Antenna Model for Horizontal Pattern	$A(\theta)=-\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$, Antenna Gain: 15dBi
BS Antenna Pattern in non-SDMA zone and SDMA-zone, θ_{edB}, A_m	θ_{dB} =70°, A_m =20 dB;
MS Antenna Gain	Omni-directional with 0dBi
BS Maximum Transmission Power	43dBm
Propagation model	$L=128,1+37.6\log_{10}(R)$, R in km
Log-Normal and Shadowing Correlation	Standard Deviation = 8dB; 0.5 for sectors of different BSs and 1 for sectors of the same BS
Channel Mode	ITU PedB and PedA with 3km/h; ITU VehA with 30km/h
Mobile Station Receiver	MRC
Moving average filter length	1.5s
T_{CQI} (CQI feedback delay)	1 frame period in CQICH UL control channel
$T_{ACK,}$NACK (feedback)	1 frame period in ACK/NACK control channel
Discard Timer and Priority	15 and 3 frame periods respectively
N_{ret} (Maximum Number of Retransmissions)	4
Number of HARQ processes	4

Figure 2 is the plot of the CDF of the average service throughput per user for WWW and VoIP traffic models respectively and for both types of sub-channelization modes.



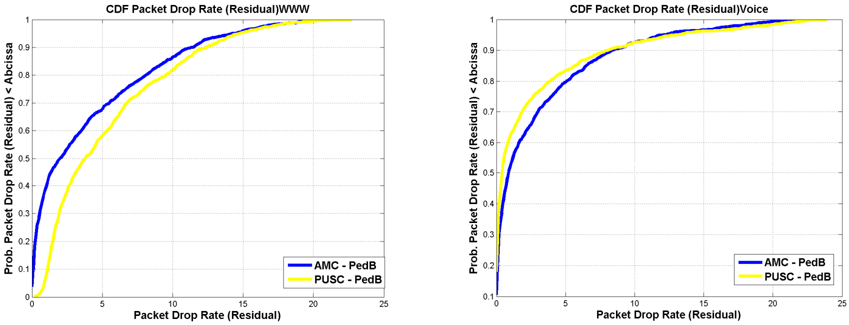
a **b**

Fig. 2. A CDF of user service throughput (a) WWW users; (b) VoIP users System throughput: SDMA and non SDMA-based DRA, for full queue and with 72 users load

As the system is overloaded for WWW, the AMC sub-channelization mode is more efficient in the utilization of the available radio resources. This efficiency results from the multi-user diversity gain over frequency, associated to this sub-channelization mode. We could expect to see an even higher gain in system capacity with the use of the full queue traffic model in conjunction with an opportunistic packet scheduler, such as the maximum C/I, which does not take into account QoS requirements, as the utility algorithm does. As the system is under-loaded for VoIP users there is no resulting multi-user diversity gain over frequency, even with the AMC sub-channelization mode and both sub-channelization modes result into similar behavior.

It is important to mention that the AMC sub-channelization mode is more sensitive to errors in channel quality reporting and also to inter-cell interference, as there is no randomization in the interference from neighboring cells over the sub-carriers composing each channel, because sub-channels are not distributed along frequency, in accordance to a random pattern. Therefore, it is to be expected that in an under-loaded scenario where all users are served, even those users with bad channel quality (as long as the admission threshold parameter condition is satisfied), the PUSC sub-channelization mode results in a better performance than AMC one.

As can be seen in the plot of the CDF of the average packet drop residual rate per user in figure 3, VoIP users present better performance for the PUSC sub-channelization mode over the AMC one. Therefore, the amount of packets dropped due to bad channel quality is smaller for the PUSC sub-channelization mode. This is because the system is under-loaded and PUSC results in better quality over transmission as mentioned above.



a **b**

Fig. 3. CDF of average packet drop rate per user (a) WWW users; (b) VoIP users

Figure 4 is the plot of the CDF of the average packet drop rate per time-out violation for WWW users. As can be seen both sub-channelization modes result in the same level of performance. This means that the gain in the performance achieved with AMC sub-channelization mode is due to the multi-use diversity gain over frequency which results into a higher amount of packets being transmitted in the system, empting user's buffer and improving transmission success probability for users with bad channel quality. Also, most of the packets are dropped due to the violation of the maximum number of transmission attempts allowed. This is because the system is overloaded for the WWW users and, therefore, most packets are dropped due to interference from users transmitting in the same resource with other spatial beams. The multi-use gain over frequency results in an increase of the available system capacity for AMC over PUSC sub-channelization schemes.

It is important to mention that the utility based scheduler behaves much like a maximum C/I for WWW users until the packet delay start to approach the packet deadline. Therefore, packets can remain in buffer while transmission opportunities are provided for users with better channel quality. This is particularly relevant for such overloaded system. On the contrary, the fact that the system is under-loaded for VoIP users and the rigid delay constraints force the scheduler to transmit packets in a much faster pace as they cannot remain in buffer for much time (otherwise they are dropped). This contributes to the level of packets dropped due to channel quality and to the insignificant amount of packets dropped due to time-out violation.

Figure 5 is the plot of the CDF of the average service throughput per user and of the average packet delay per each packet correctly received. These plots corroborate the gains achieved with AMC sub-channelization mode with WWW users over PUSC sub-channelization mode.

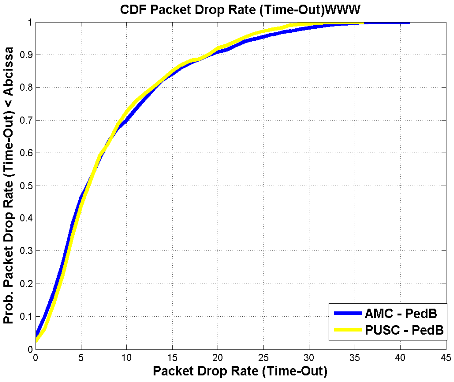
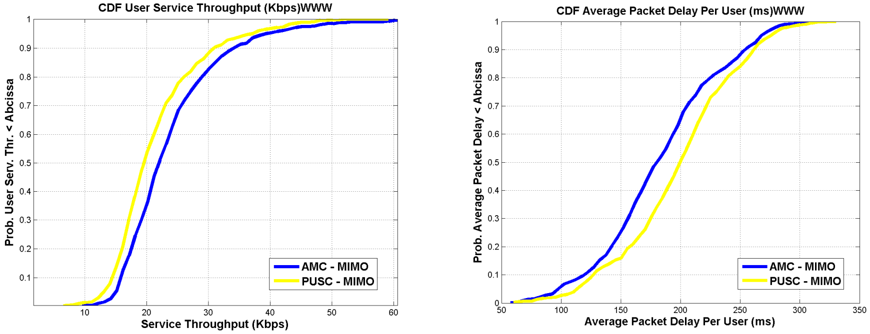


Fig. 4. CDF of average packet drop rate for WWW users



a **b**

Fig. 5. CDF of average user service throughput for WWW users; (b) CDF of average packet delay per user for WWW users – MIMO channel

Figure 6 is the CDF of the average packet residual drop rate and of the CDF of the average packet drop rate per time-out violation for WWW users. Although the MIMO channel results in a smaller percentage of packets dropped due to bad channel quality than the SISO channel, the PUSC sub-channelization still results in better performance. Both sub-channelization modes present close performance in terms of the amount of packets dropped due to time-out violation. This is because the utility-based scheduler behaves very much as a maximum C/I scheduler for WWW users, as mentioned before already.

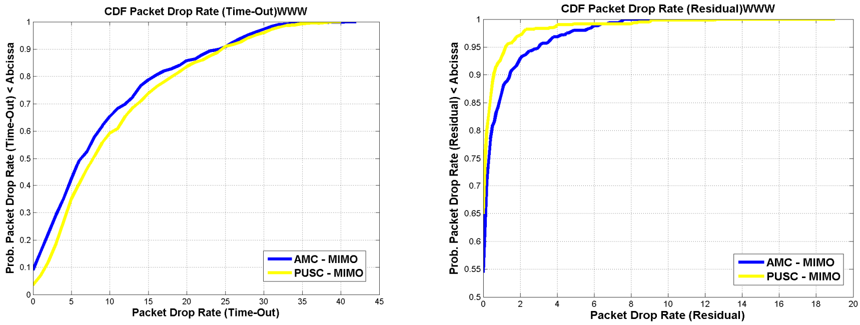


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Fig. 6. CDF of average packet drop rate per user (time-out) for WWW users; (b) CDF of average drop rate per user (residual) for WWW users – MIMO channel

Figure 7 plots the average service and average over-the air throughput per user for both sub-channelization modes, both SISO and MIMO channels and both WWW and VoIP users.

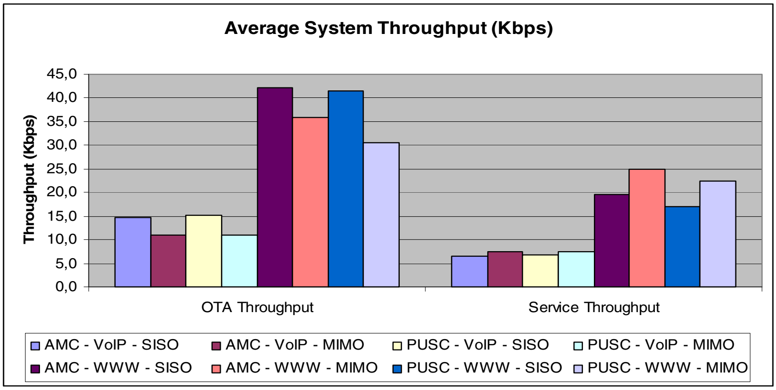

Fig. 7. System throughputs for different simulation scenarios

Some conclusions can be withdrawn from this plot.

- For both sub-channelization schemes service throughput is higher for WWW users if the MIMO channel is used than with the SISO channel.

- For WWW, service throughput is higher if the AMC sub-channelization mode is used, compared to the PUSC one. For AMC with MIMO the average service throughput per user reaches 25 Kbps and for PUSC with MIMO it is roughly equal to 22 Kbps. For AMC with SISO the user service throughput reaches roughly 20 kbps and for PUSC with SISO the user service throughput reaches roughly 16 Kbps.
- OTA throughput is higher if SISO mode is implemented for both types of users than with MIMO. This is because the spatial diversity achieved with the 2x2 Alamouti STBC scheme decreases the degree of variation of the channel amplitude and, therefore, decreases the opportunistic gain for the utility based packet scheduling. As expected, this reduction is more significant for WWW users than for VoIP ones.
- The OTA throughput reduction is more significant for PUSC sub-channelization scheme. This is because the gain achieved with the distribution of sub-carriers according to the pseudo-random sub-carrier distribution in PUSC mode is more affected by the decrease in channel variability resulting from MIMO and Alamouti encoding. As sub-carrier gains are correlated in each sub-channel defined according to the AMC sub-channelization scheme, the decrease in channel variability affects all sub-carriers in each sub-channel by roughly the same way.

As expected, for all combinations user service, throughput performs roughly the same for VoIP users.

6 Conclusions

In this article a DRA architecture for Mobile WiMAX networks is proposed, based upon the AMC sub-channelization scheme, which results in a multi-user diversity gain over frequency. A utility-based packet scheduler is used in conjunction with the proposed DRA. A set of system level simulations was performed to infer on the gains achieved over simple scenarios where PUSC only sub-channelization mode is used.

It was verified through simulations that AMC sub-channelization mode is more efficient for WWW traffic model regarding the achieved service throughput in an overloaded scenario, and that in an under-loaded scenario, for VoIP traffic model, both sub-channelization schemes behave essentially in the same way. As the system is overloaded for WWW, the AMC sub-channelization mode is more efficient in the utilization of the available radio resources thanks to the multi-user diversity gain over frequency for AMC. As the system is under-loaded for VoIP users there is no resulting multi-user diversity gain over frequency, even with the AMC sub-channelization mode and both sub-channelization modes result into similar behavior. AMC could be even more effective in system capacity for a full queue traffic model in conjunction with an opportunistic packet scheduler, such as the maximum C/I.

However, AMC sub-channelization is more sensitive to errors in channel quality reporting and also to inter-cell interference, as there is no randomization in the interference from neighboring cells over the sub-carriers composing each channel.

Therefore, in an under-loaded scenario in which all users are served, even those users with bad channel quality, the PUSC sub-channelization mode results in a better performance than AMC.

For SINR levels between 0 dB and -5 dB, AMC results in better performance with a smaller number of packets dropped due to bad channel quality over PUSC. AMC is more effective for this range of SINR values achieved with the most robust MCS scheme, due to the contiguous allocation of sub-carriers over each sub-channel in each radio resource. For WWW users, the multi-user diversity result into a smaller amount of packets dropped due to bad channel quality if AMC sub-channelization mode is used in detriment of the PUSC.

Concerning the implementation of the AMC sub-channelization scheme it is important to reinforce that the use of an opportunistic packet scheduler such as the Maximum C/I or even the Proportional Fairness schedulers could result in better gains over the PUSC sub-channelization. This is exactly what is available in the literature up to now. The author thinks that the novelty of the work presented is related to the use of a packet scheduler for QoS provision and with realistic traffic models, something that is not available in the literature.

By means of system level simulations it was demonstrated that the AMC sub-channelization scheme can result in an increase in the system capacity provided the load is high enough, in order to make the best use of the multi-user diversity gain over the frequency domain. However, it is important to enforce that such proposal for a DRA incurs in a high complexity system, namely in the amount of computations, which must be performed for each resource in the frame and in terms of the execution time of the algorithm.

Until now there is no single proposal for such a DRA in the research literature. The work available considers mixes of simple opportunistic schedulers such as variations of the Maximum C/I and Proportional Fairness algorithms. No realistic traffic models are considered as users are assumed as fully backlogged. This is because the gains achieved with the joint time and frequency domains schedulers are more effective under such scenarios, as it was proved in the simulations conducted.

Acknowledgments. This work has been performed in the framework of the MOBILIA project (CP5-016) under the Eureka Celtic Framework, funded through the QREN Framework – PO Centro (project n. 5555).

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