Dynamic Resource Allocation for IEEE802.16e

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ABSTRACT

Mobile communications has witnessed an exponential increase in the amount of users, services and applications. While 2G cellular networks were mainly optimized to support voice services, effective delivery of broadband multimedia applications will drive the requirements for Next Generation Networks (NGNs). WiMAX targets to provide broadband connectivity to wide area coverage, and thus introduces significant design challenges in the MAC (Medium access Control) to provide the seamless transport of heterogeneous traffic in a cost-effective manner. This paper proposes a Dynamic Resource Allocation (DRA) strategy that can provide operators the flexibility to deliver broadband traffic with high spectral efficiency. The DRA unit constitutes a scheduler, Link Adaptation (LA), Resources Allocation (RA) and Hybrid Automated Repeat Request (HARQ) components inter-working seamlessly. The potential for the DRA to deliver QoS is achieved through service classification lists, where higher priority is given towards retransmitted packets, and subsequently to first-time transmitters with packet delay. The simulation results show that the proposed DRA scheme has the capacity to provide enhanced coverage for NRTV (Near Real Time Video) services in wide area networks (WANs)

Keywords

Dynamic Resource Allocation, Max C/I, WiMAX, OFDM.

1. INTRODUCTION

The emergence of WiMax [1] will reflect a significant step towards a wireless networking ambient, it will bring data services to the subscriber on the move, and provide a step closer to a fully data driven environment. Initially designed as a system for the provision of wireless broadband internet access for small business and residential fixed access users IEEE802.16-2004 [2], the requirement for wireless mobility has led to the IEEE802.16e [3]. Two of the most promising attributes offered by WiMAX is the potential for OFDM to overcome the restrictions of the radio channel due to multipath propagation, namely in non-line of sight (NLOS) scenarios Furthermore, the use of Orthogonal Frequency Division Multiple Access (OFDMA) provides an effective multiple access scheme for the efficient use of radio spectrum. This latter issue is particularly suitable for adaptive transmission and resource allocation due to the existence of parallel subchannels in the frequency domain. A key principle of adaptive resource allocation is to exploit the inherent systems diversities in various domains through the intelligent management of the allocation and access of users to the resources available. In particular mobile WiMAX can provide three distinct types of resources/degrees of freedom: frequency sub-channels in the frequency domain, OFDM symbols in the time domain, and additionally spatial beams in the space domain facilitated through MIMO (Multiple Input Multiple Output) antennas. It is the intention of this paper to address the Adaptive Resource Allocation policies envisioned for this standard and to propose a flexible Dynamic Resource Allocation (DRA) policy that can exploit the inherent features in WiMAX to deliver the seamless transport of heterogeneous traffic in a cost-effective manner.

This paper is organized as follows: Section 2 describes the WiMAX system level model; Section 3 presents the proposed DRA architecture; Section 4 presents the simulation results; and the conclusions are given in Section 5.

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2. WiMAX System Level Modelling

2.1 WiMAX Frame Structure

Figure 1 illustrates the IEEE802.16e TDD frame structure.

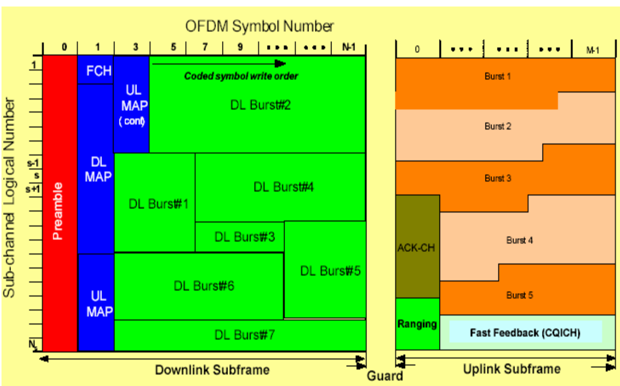

Figure 1. WIMAX Frame Structure

Although mobile WiMAX standard support both frequency division duplexing (FDD) and time division duplexing (TDD), only the TDD mode is being supported by the system profiles designed by the WiMAX forum for equipment compliance and interoperability. Also TDD offers some advantages over the FDD mode such as the support of asymmetrical data rates in UL and DL and also the fast estimation of the downlink channel in the UL transmission.

In the frame, resources are available in two domains: frequency (sub-carriers) and time (OFDM symbols). The OFDM symbols available for data transmission and the subcarriers constitute distinct logical slots. Different types of logical channels are available, depending of the type of channel model used. The standard defines two basic types of generic channel modes: channel modes that are intrinsically diverse in frequency called diversity sub-carrier permutation modes and the channel modes that make use of the frequency selective nature of the radio channel. In this paper we focus primarily on the so-called Full Usage Subcarrier Channelization (FUSC) channel mode. In FUSC mode, every subchannel is available for allocation in the cell. The data subcarriers are randomly allocated along the whole spectrum of the FFT. In the FUSC mode the small unit of allocation is the slot. A group of slots defines a burst in the radio frame. A burst can be assigned to more than one user provided the same modulation and coding scheme is followed in the transmission of all packets allocated to it.

2.2 Scheduling

Although the signalling messages and control channels that are required for resource allocation are defined by the standard, the design of the resource allocation policy and scheduling mechanisms are intellectual property, leaving it for manufacturers as a means for equipment differentiation. Nevertheless both scheduling and optimization of radio resource usage are two fundamental aspects that operators need to address so as to maximize network utility in an era where spectral resources are at a premium. The scheduling is a fundamental element of the proposed DRA architecture, and in order to address the throughput maximization potential in the proposed DRA design, we have used the Max C/I scheduler [4]. The Max C/I scheduler opportunistically assigns resources to the user with the highest channel gain in the following way. At the beginning of each radio frame *n,* the mobile with the best channel quality indicator (CQI) is scheduled for transmission. The user is chosen according to the following rule:

$$k(n) = \arg \max_{i \in \{1,\dots,K\}} R_i(n); \quad n = 0,1,2,... \tag{1}$$

The max C/I scheduler is very effective in resources allocation in terms of capacity maximization, but is totally unfair and completely blind towards user QoS requirements. Thus the DRA potential to deliver QoS to the system users will be addressed by incorporating priority lists based on packet delay, and retransmissions; refer to section III for further details.

2.3 Link Adaptation

The proper transmission mode (modulation and code scheme used – MCS) is defined by the link adaptation method. We have considered 10 MCS schemes encompassing QPSK, 16QAM and 64QAM modulation schemes and the Convolutional encoder, according to the profiles envisioned by the WiMAX forum. For each selected user in each allocated resource the MCS scheme to be used is chosen according to the following method:

$$i = \max_{i \in MCS_{set}} \left[\left(R_i (1 - BLER_i) \right) \right] \tag{2}$$

where MCS_{set} is the set of modulation and coding schemes, R_i is the throughput achieved for the MCS scheme, and $BLER_i$ is the predicted BLER for the MCS scheme.

2.4 SINR Modelling

In the simulations a wideband SISO channel model is implemented by a six tapped delay model, according to the Ped B 3Km/h channel model from [5]. The narrowband fading channel is generated by a Jake's model where the carrier frequency and the speed are used to define the statistics of the fading [6]. Slow fading is modeled according to a log normal distribution. Spatial shadowing correlation between mobiles and base stations is implemented. The shadowing $SH_j(x,y)$ in dB between one MS at position *(x,y)* and BS *j* is given by:

$$SH_j(x, y) = \sqrt{0.5} \left[\left(F_o(x, y) + F_j(x, y) \right) \right] \tag{3}$$

Where $F_o(x,y)$ and $F_j(x,y)$ are spatial functions with a Gaussian distribution with zero mean and standard deviation (σ) in dB, generated using the method described in [7].They have a spatial correlation given by:

$$R(d) = \exp^{\left[-\ln(2) \frac{d}{DecorreLength} \right]} \tag{4}$$

Where *d* is the distance between two points in the network layout and DecorrLength is the shadowing de-correlation length in meters.

Using the aforementioned channel models, the SINR (Signal-to-Noise-Interference Ratio) of each OFDM subcarrier is computed according to the following expression [8]:

$$\gamma_k = \frac{I_{or}}{I_{oc} + N_o} . \frac{N_{used}}{N_d + PDR.N_p} .H_k \tag{5}$$

Where N_{used} is the total number of subcarriers, *PDR* is the pilot-to-data subcarrier power ration, N_d is the number of data subcarriers per OFDM symbol, N_p is the number of pilot subcarriers per OFDM symbol, N_o is the receiver thermal noise power and I_{oc} is the other-cell noise power density (assumed spatially and temporally uncorrelated). The gain of the H_k^{th} subcarrier is given by [9]:

$$H_k = \left| \sum_{p=1}^{N_{paths}} M_p A_p e^{j\theta_p} e^{-2\pi f_k T_p} \right|^2 \tag{6}$$

Where *p* represents the multi-path path index, A_k is the amplitude value corresponding to the long-term average power for the p^{th} path, f_k is the relative frequency offset of the k^{th} subcarrier, and T_p is the relative time delay of the p^{th} .

2.5 Link Level Interface

The transmission of a coded block over different sets of sub-carriers results in a number of SINR measures that equals the number of sub-carriers sets, which can be quite high. Hence, data compression is mandatory. The coded symbol SINR can be given by:

$$SINR_p = G_{actual}\left(\sum_{m=0}^{L-1}\left|h_{m,P}\right|^2\right)/L \tag{7}$$

Where G_{actual} is the actual geometry; $h_{m,P}$, is the complex amplitude of the m^{th} sub-carrier in the p^{th} subcarrier set; and L is the spreading factor. The set of coded symbols SINRs are mapped to a single value named the Effective SINR value. This value can be used to match AWGN LUTs. The EESM [9] expression determines how the Effective SINR is obtained from the multiple SINR's on the different subcarriers:

$$SINR_{eff} = -\beta \ln\left(\frac{1}{P}\sum_{p=1}^{P} e^{-\frac{SINR_p}{\beta}}\right) \tag{8}$$

Where β is to be optimized for every link mode (MCS) based on link level simulation results. Figure 2 shows that the EESM approach results in BLER points very close to the ones obtained by simulation over an AWGN channel.

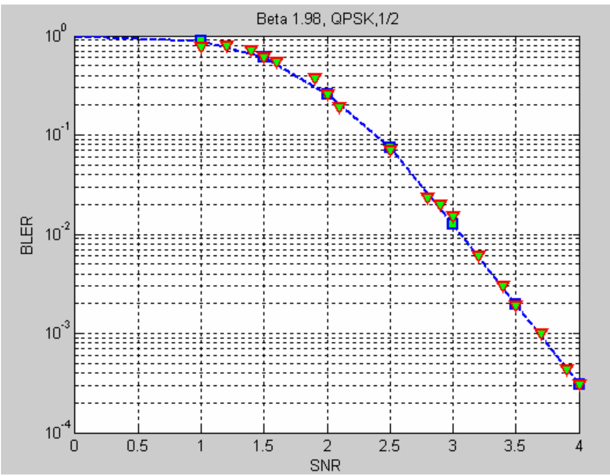

Figure 2. BLER vs. SNR (-- =AWGM; ∇= EESM)

3. DRA Architecture

3.1 Resource Map Definition

A schematic description of the Resource Allocation Map (RA) in the WiMAX System Level Simulator is given by **Figure 3**. The Resource Allocation Space is a matrix of sub-channels per OFDM symbols. The minimum granularity in the map is composed of a FEC (Forward Error Correction) block which is defined by one sub-channel and four OFDM symbols, where one time slot maps to two OFDM symbols. Each FEC block is defined as a RAU (Radio Access Unit).

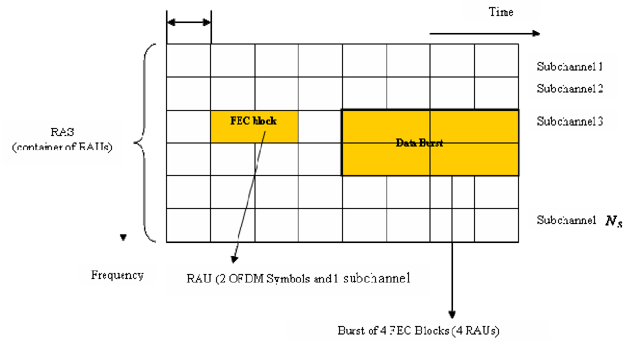

Figure 3. WiMAX Resource Allocation Map (RAM)

A data burst is composed of a group of continuous RAUs which are mapped onto the resources space. If there are a total of 20 OFDM symbols for data transmission in the DL and 10 sub-channels available in the DL-FUSC sub-channelization mode, then we have a total of 10*10= 100 RAUs per frame. Each RAU represents one Resource Unit RAU*(i,j)*, where *i* is the sub-channel index and *j* is the time slot index. Each RAU will store information regarding the assignment of mobile station and Modulation and Coding Scheme (MCS) used. Subsequent to scheduling and mapping of the IP packets to the available RAUs, the base station broadcasts the RAM information to the network via the broadcast channel. Each mobile utilizes this information to anticipate packet transmission and demodulation using the appropriate MCS scheme. The Resource Allocation Map is updated every frame by the base station. The base station allocates resources according to a four frames cycle mechanism:

- Phase A1: The base station computes the Resource Allocation Map to be used for data transmission during the Phase C1 that follows.
- Phase B1: The base station broadcasts the Resource Allocation Map determined during Phase A1, so that all users in the cell have the information required to demodulate the packets they will receive during Phase C1.
- Phase C1: The base station sends data according to the Resource Allocation Map determined in Phase A1.
- Phase D1: The base station receives ACK messages from users which have received their packets successfully during Phase C1, and likewise receives NACK messages from users which have received their packets un-successfully during Phase C1.

The mobile station receives packets according to the same four frames cycle mechanism:

- Phase A2: The mobile station receives the broadcasted Resource Allocation Map from the base station.
- Phase B2: The mobile station receives one packet mapped onto a set of slots according to the Resource Allocation Map received in Phase A2.
- Phase C2: The mobile station processes the received packet. If the received packet is only another version of a first packet transmission the mobile station performs Chase Combining on the different replicas of the same packet.
- Phase D2: After decoding the received packet the mobile station sends an ACK/NACK message according to the quality of the received packet: this is to inform the base station about the future status of the H-ARQ transmission buffer.

As only one frame (corresponding to the Phase C1) over four is used for data transmission, there is a loss of efficiency. In order to achieve continuous data transmission four different HARQ processes are considered (from 0 to 3) per user. Each HARQ channel is mapped onto one of a total of four TDD frames. Each HARQ process of each mobile station handles only one packet mapped onto one or more slots of the resources map. Once a radio packet is allocated a H-ARQ process, it remains active until the packet has been received correctly at the mobile station, or the packet has been dropped due to retransmission time-out.

3.2 Resource Allocation Procedures

In what follows, the proposed Resource Allocation Map computation is described for the H-ARQ process channel 0, but is applicable for all other H-ARQ processes. Here, we define the resource allocation procedures to encompass the methodologies for packet scheduling, resource map allocation, and link adaptation. We propose the following four step process:

3.2.1 Determining mobile stations lists

Two lists of mobile stations are computed: the initial transmission and retransmission list. The first transmission list is filled in with any mobile station *k* that has its HARQ process number 0 inactive and that has bits waiting to be transmitted by the base station. The retransmission list is filled in with any mobile station *k* that has its HARQ process 0 active and waiting for a retransmission. It is assumed that the base station hosts a waiting queue for each mobile station

3.2.2 Scheduling re-transmissions

Symbol	Quantity	Value
f_c	carrier frequency	2.5 GHz
B_s	system bandwidth	10 MHz
P_{max}	BS max. tx. Power	43dBm
N_o	Thermal Noise density	-174 dBm/Hz
NF_m	MS Noise figure	7 dB
CT	cell type	tri-sectored
d_{is}	inter-Site Distance	2.7Km
G_{bs}	BS Antenna Gain	15 dBi
σ_s	shadowing standard deviation	8 dB
d_{sh}	shadowing de-correlation length	20 m
PL	Path Loss in dB for Urban Environment	$128.1+37.6\log_{10}(d_m)$

For each RAU, the base station initially checks the re-transmission list. If the slot is not allocated to a mobile station of the re-transmission list, then the slot in temporarily not allocated. The current total data transmission power P_{max} is computed. It is the sum of the transmit power allocated to each slot. The remaining transmission power P_{budget} is updated according to the following expression: $P_{budget} = P_{max} - P_{data}$, where P_{max} is the maximum base station transmission power available for data. The re-transmissions are allocated the same slots, MCS scheme and transmit power as for the first transmission.

3.2.3 Scheduling new transmissions and link adaptation

The first transmission list is split into two sub-lists: one list of high priority mobile stations and the other is the low priority list.

- High Priority List

Mobile stations with packets waiting in the queue for a period of time longer than a specific threshold are placed into the high-priority list. The delay threshold is service specific: for real-time services such as voice services or near-real time video, the delay threshold is zero; for web services, the delay threshold can be larger.

- Low Priority List

The remaining users are put into the low priority list.

Both lists are then re-ordered by the user Channel Quality Indicator (CQI) value, the CQI is an implicit measure of the mobile signal strength and obtained by taking into consideration the SINR measured from the preamble of the frame. The mobiles are assorted in descending order with high CQI users being allocated highest priority. The base station selects the mobiles with highest priority in each list, where mobiles from the high priority list have preference.

Once a mobile is assigned to the RAU, the link adaptation mechanism selects the appropriate MCS scheme according to the predicted $SINR_{pred}$,. The MCS allocation criteria is given by eqn. (2).

3.2.4 Interaction with the physical layer.

Finally the following inputs are sent to the physical layer for data transmission:

- RAM: that provides the MS, and ARQ process scheduled for transmission on the current sub frame.
- *HARQ table* that gives the selected MCS, and the data block.

4. Simulation Results

4.1 Simulation Scenario

The system level simulation methodology was based using a combined dynamic snapshot approach. In one simulation run, the users were uniformly distributed across the cell, and the path loss values, user positions and random shadowing values were drawn and held constant throughout the whole run whilst fast fading was simulated on a TTI basis; the user positions were updated on every run. A simulation run was 1000 TTI long, with 50 snapshots (runs). In each TTI we prioritized the users according to the proposed DRA architecture considered. In Table 1, we provide the main simulation parameters for the WiMAX system level.

Table 1 WiMAX System Level Simulation Parameters

4.2 Results

This section provide the simulation results obtained for the urban deployment model, i.e. assuming tri-sectored cells at mobile speeds of 3km/h, using the proposed DRA architecture For the simulations, the following evaluation metrics were utilised:

- Geometry (GFactor) defined as:

$$G(MS) = \frac{antG(Cell_0, MS)x\frac{1}{PL(Cell_o, MS)xSH(Cell_0, MS)}}{\sum_{k=1}^{N} antG(Cell_k, MS)x\frac{1}{PL(Cell_k, MS)xSH(Cell_k, MS)}} \quad (9)$$

Where $Cell_o$ *and* $Cell_k$ is the respective serving sector and interfering sector of mobile MS; *antG(cell*$_o$*,MS)* is the antenna gain between the serving sector and the MS ; *PL(cell*$_o$*,MS) and SH(cell*$_o$*,MS)* are the path-loss and shadowing loss in linear scale between the base station of the serving sector and the MS respectively; and *N* is the number of interfering sectors.

- *Service cell throughput* is used to study the network throughput performance and is measured as:

$$R_{service} = \frac{b}{k \cdot T}. \quad (10)$$

Where *b* is the total number of correctly received data bits by all MSs in the simulated system over the whole simulated time, *k* is the number of cell/sectors in the simulation and *T* is the simulated time.

Figure 4 shows the number of scheduled transmissions vs. the Geometry factor. It can be seen that the number of transmissions increases with the geometry factor, since the scheduler is clearly providing preferential treatment to users closer to the base station. Furthermore, the transmission samples are highly populated between 2-7dB indicating the benefits of the proposed architecture. It shows that users with lower channel quality are also provided service, since users experiencing several retransmissions and consequently delayed are given higher priority, than first time transmitters.

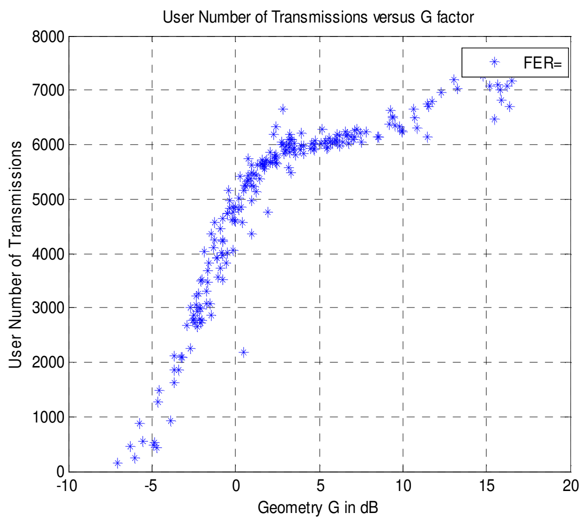

Figure 4. No. of User transmissions vs. Gfactor

The beneficial effects of the proposed DRA architecture can also be visualized from Figure 5. The graph shows the average user service throughput vs. the Gfactor (FER=0 users). It can be seen that the full source rate for NRTV can also be delivered to users closer to the cell boundary, thus enhancing the quality of service delivered by the WiMAX system.

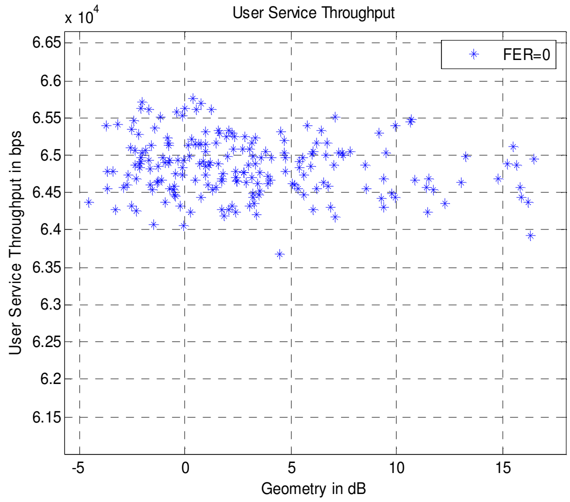

Figure 5. Average User Service Throughput vs. Gfactor

5. Conclusion

The proposed DRA architecture has been designed to provide a degree of trade-off between maximizing system capacity and user QoS. This is achieved by allocating higher priority towards retransmitted packets, and subsequently to first-time transmitters with packet delay. The simulation results show that DRA scheme has the capacity to provide enhanced coverage for NRTV services, thus increasing the possibility for WiMAx to provide broadband connectivity in rural areas. Furthermore, the DRA scheme has been designed with flexibility in mind, thus providing options for seamless inter-working with heterogeneous services.

6. Acknowledgment

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