A Novel Adaptive Resource Allocation Scheme With QoS Support in Mobile WiMAX Release 2 Wireless Networks

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***Abstract*—This paper presents a new resource allocation algorithm in downlink Mobile WiMAX Release 2 networks. Our study considers three types of service including a real-time Polling Service (rtPS), a non-real-time Polling Service (nrtPS) and a Best Effort (BE) service. Each service type has its own QoS requirements (eg. radio bandwidth, packet loss ratio, latency delay, etc.) each type of them is stored in a global buffer in order to reduce time processing. Our proposed scheme includes three steps which are: radio resource reservation, arriving connections scheduling and adaptive resource allocation. A fourth step is introduced when a threshold for rtPS-class is defined based on the overall system capacity. Our scheduler gives the priority to rtPS service to ensure an adequate resource allocation without discriminating against nrtPS and BE services performances. The behaviour of our adaptive resource allocation algorithm is compared to other well-known methods such as MAX-CINR [1] and MPF [2]. Numerical results prove that our proposed scheme due to its adaptive and scheduling approach deals better with total system capacity, rtPS packet loss ratio and nrtPS and BE packet satisfaction ratio than MAX-CINR and MPF methods. Moreover, thresholding approach deals better with rtPS QoS requirements without disadvantaging other services performances.**

***Index Terms*— Mobile WiMAX Release 2, Scheduling, QoS, OFDMA, QoS-threshold.**

I. Introduction

RECENT wireless packet access networks including 3GPP Long Term Evolution (LTE) and Mobile Worldwide Interoperability for Microwave Access (WiMAX) employ a very large radio bandwidth to meet the rapid growth in demand for good multimedia communications quality with various Quality of Service (QoS) requirements. Scheduling prove crucial to ensure multi-services demand satisfaction per a mobile user.

Five types of Class of Service (CoS) are defined in Mobile WiMAX Forum which are [3]: Unsolicited Grant Service (UGS), extended rtPS (ertPS), real-time Polling Service (rtPS), non-real-time Polling Service (nrtPS), and Best Effort (BE). Each type of service has its own QoS sensitivity such as radio bandwidth, packet loss ratio, latency delay and jitter constraint.

In this paper, we propose an adaptive resource allocation algorithm with QoS support in downlink Mobile WiMAX networks. Firstly, sub-channels are distributed depending on proportional parameters that are computed and dynamically updated based on system resource availability. Secondly, a priority function is defined to sort arriving connections stored in the same buffer. We define a global buffer for each service type aiming to reduce processing time. Our scheduler gives high priority to rtPS-class, then nrtPS-class and finally BE class. Thirdly, an adaptive sub-channels allocation procedure is introduced, to assign to each user its best sub-channel in order to maximize the total system capacity. A fourth step is introduced only if a QoS-threshold is considered to ensure an adequate resource allocation for rtPS-class without discriminating against nrtPS and BE services performances. If the overall system capacity exceeds QoS-threshold, redistribution sub-channels stage is introduced to offer additional sub-channels to rtPS-class that are initially reserved for nrtPS or BE classes.

Our proposed algorithm is evaluated and compared to other well-known schemes which are Maximum Carrier to Interference and Noise Ratio (MAX-CINR) [1] and Modified Proportional Fairness (MPF) [2]. Simulation results demonstrate that our adaptive resource allocation scheme outperforms MAX-CINR and MPF methods in terms of total spectral efficiency, rtPS packet loss ratio, nrtPS and BE packet satisfaction ratio and computational complexity. To highlight thresholding approach performances, it is compared to a non-thresholding approach. Simulation results prove that thresholding approach deals better with total spectral efficiency and rtPS QoS requirement without disadvantaging nrtPS and BE services performances. We notice that our work is based only on simulation study, by simulating the problem described in section III of the current paper, and we suppose to develop an analytical study in the future work.

The reminder of the present paper is organized as follows. Section II analyzes related works, section III presents adopted system model and formulates optimization problem to resolve later in section VI that proposes a novel adaptive resource allocation algorithm. In section V, simulation results and performance analysis are provided.

II. RELATED WORKS

Several researches have addressed resource allocation problems in recent packet access networks with QoS support. In [3], scheduler located at the BS schedules connections, at Medium Access Control (MAC) layer, according to a defined priority function and then allocates available radio resources to only one connection at each time slot at the physical layer, so it cannot reach the maximum total system capacity. Authors in [4] perform a two-steps resource allocation scheme. Firstly, it computes connections priority of each user on each sub-channel to sort users in descending order. Secondly, it allocates for each user its best sub-channel to serve scheduled connections which leads to an unfair resource allocation because a lower priority connection may be scheduled before higher priority one in this case. To resolve such problem, authors in [5], used a proportional fair scheduling algorithm to guarantee fairness among active users and then the proposed scheme cannot support a huge traffic, because it satisfies a minimum number of users in a frame to support better fairness criterion. In [6], authors employ a priority function at MAC layer and a slot allocation scheme at physical layer. The main idea is to redistribute slots from the most satisfied user to the most unsatisfied one, which may cause total system capacity degradation. A new cross layer scheduling algorithm is presented in [7] to schedule arriving packets. Packet scheduling requires more processing time especially in a heavy traffic environment and then the system performances deterioration. In the same context, authors in [8] propose a joint packet scheduling and resource allocation procedure. The idea here is to define a distinct scheduling priority for each packet on each sub-channel based on QoS requirements and channel information. Designing a buffer for connection of each user leads to an important processing time. In [9], a finite queue for each user is defined to store arriving packets. Firstly, a scheduling priority is defined for each packet on each sub-channel to schedule packets. Secondly, a Mean square Error Criterion (MMEC) scheme is employed to allocate sub-carriers to users. However, using a finite queue to store arriving packets causes a packet rejection probability. Authors in [1] use two scheduling factors, the urgency of scheduling and the efficiency of radio resource management, depending on wireless environment characteristic and traffic QoS requirements. The time-utility function is used to represent the urgency factor and the channel state is used to indicate radio resource management efficiency. Proposed scheduler transmits real time and non-real time packets depending on defined scheduling priorities obtained from the urgency and the efficiency factors. The proposed scheduler overlooks the packets burst nature and cannot take advantage of the statistical multiplexing gain.

In this paper, we propose a novel adaptive resource allocation scheme with QoS support in downlink OFDMA based system aiming to maximize the total system capacity. Simulation results prove that our proposed scheme satisfies QoS requirements and uses efficiently radio resources while enjoying a low computational complexity.

III. SYSTEM MODEL AND PROBLEM FORMULATION

For our work, we adopt a single cell system including a single BS that servers K users, and N represents the number of sub-channels composed by a group of M adjacent subcarriers in each sub-channel with $N=L/M$ and L is the total number of sub-carriers. The sub-channel gain $h_{k,n}$ of user k on sub channel n is defined based on a sub-channel gain computation method well described in [10]. The downlink quality can be measured by the Signal-to- Interference plus Noise Ratio SINR and expressed as:

$$SINR_{e,k} = \frac{P_e}{(I_{e,k} + N_0 \Delta f)} \left| h_{k,n} \right|^2 . \qquad (1)$$

where P_e and Δf represent respectively the transmit power and sub-channel spacing. N_0 is the Additive White Gaussian Noise (AWGN) variance. The average downlink interference per sub-channel $I_{e,k}$ by the MS k served by BS e [11] is expressed as follows:

$$I_{e,k} = \sum_{s \neq e} \Lambda(e,s)\, \chi_s \left(\frac{P_s G_{s,k}}{L_{s,k}} \right) . \qquad (2)$$

where P_s, $L_{s,k}$ and $G_{s,k}$ represent respectively the downlink transmit power of the BS s, the path loss between BS s and the MS k, and the antenna gain. χ_s is the probability that the same sub-channel used by the mobile k is used in the same time by another MS served by the BS s and $\Lambda_{(e,k)}$ denotes the interference matrix, where the coefficient $\Lambda_{(e,k)}$ equals to 1 if cells e and s use the same band and zero otherwise.

Let $N_{AMC_{k,n}}$ and $N_{sym/SF}$ represent respectively, the number of bits per symbol and the number of symbols per sub-frame, depending on the AMC level defined according to SINR value that is computed based on equation (1) and (2). $\alpha_{k,n}$ is equal to 1 if the sub-channel n is allocated to user k and zero otherwise.

Having the target to maximize the system capacity, the objective function is formulated as follows:

$$\textbf{Maximize} \quad C_{syst} = \sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{n=1}^{N} \alpha_{k,n} . M . N_{AMC_{k,u}} . N_{sym/SF} . \qquad (3)$$

$$\textbf{Subject to} \quad \textbf{C1:} \ \alpha_{k,n} \in \{0,1\}, \forall k \in \psi, \forall n \in \Gamma. \qquad (4)$$

$$\textbf{C2:} \ \sum_{k=1}^{K} \alpha_{k,n} = 1, \forall n \in \Gamma. \qquad (5)$$

$$\textbf{C3:} \ \sum_{n=1}^{N} \alpha_{k,n} \leq 1, \forall k \in \psi. \qquad (6)$$

The two constraints C1 and C2 ensure that each sub-channel is assigned to only one user where notations ψ and Γ denote respectively, the set of active users and available sub-channels in the cell. The constraint C3 denotes that one MS could have only one sub-channel in the same time.

IV. PROPOSED RESOURCE ALLOCATION SCHEME

In this work, we consider only three types of Class of Service (CoS) which are: rtPS, nrtPS and BE. In this work, we propose two contributions: the first one is without resource redistribution phase and the second one is an adaptive resource allocation procedure based QoS-threshold. Our proposed algorithm consists of three steps: sub-channels distribution, calculation of each connection's priority and sub-channels allocation procedure.

A. Sub-channels Reservation

We assume that N_{rtPS}, N_{nrtPS} and N_{BE} represent respectively the number of sub-channels reserved to rtPSclass, nrtPS-class and BE-class determined by the following equations: $N_{rtPS} = \alpha N$, $N_{nrtPS} = \beta N$ and $N_{BE} = \gamma N$ where α, β and γ are proportional parameters and $\alpha + \beta + \gamma = 1$. Assuming that NC_i and NC denote respectively connections number in class *i*, $i = \{rtPS, nrtPS, BE\}$ and the total connections number, proportional parameters values α, β and γ are initially determined, respectively, by $\alpha = \left(\frac{NC_{rtPS}}{NC}\right)$, $\beta = \left(\frac{NC_{nrtPS}}{NC}\right)$ and $\gamma = \left(\frac{NC_{BE}}{NC}\right) = 1 - (\alpha + \beta)$.
These proportional parameters values are not static. They are dynamically updated each sub-frame time in the first contribution as is depicted in figure 1.

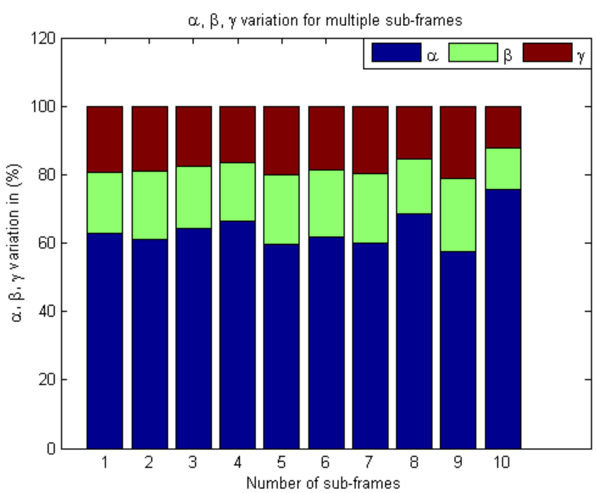

Fig.1. proportional parameters α, β and γ for multiple sub-frames

In QoS-threshold contribution, referred in this paper as contribution 2, proportional parameters values, α, β and γ change dynamically depending on the system availability and a defined threshold *thresh* introduced based on the maximum system capacity. We define $thresh_{\max}$ representing the maximum number of rtPS connections accepted by the network operator where $thresh_u = \min(thresh, thresh_{\max})$. Assuming that NU_{nrtPS} and NU_{BE} denote the used sub-channels number for nrtPS and BE services and *VRT* represents sorted rtPS connections vector, the redistribution sub-channels phase is well described by the following algorithm. Here, we use the same notation as described above.

Algorithm 1: Redistribution Sub-channel Phase

BEGIN
  if $NC_{rtPS} > thresh_u$ **then** verify the system availability
    if the system is available **then**
      $NF_{nrtPS} = N_{nrtPS} - NU_{nrtPS}$ ***%compute free sub-channels reserved to nrtPS class***
      $NF_{BE} = N_{BE} - NU_{BE}$
      if $NC_{nrtPS} > NC_{BE}$ **then**
    $N_{rtPS} \leftarrow NF_{BE}$ ***%add free sub-channels reserved to BE class to rtPS class.***
  for $i = N_{rtPS} + 1$ **to** length (VRT) **do**
    $j = N - NF_{BE}$; alloue =0;
    while (alloue=0) **AND** (j ≤ N) **do**
      if $\alpha_{1 \to K, j} = 0$ **then**
        $\alpha_{k,j} \leftarrow 1$; $\Gamma \leftarrow \Gamma - \{n\}$; ***%allocate sub-channel***
        $alloue \leftarrow 1$; Update rate;
      else $j \leftarrow j + 1$ ***% find the next free sub-channel***
      end if
    end while
  end for
else
    $N_{rtPS} \leftarrow NF_{nrtPS}$ ***%add free sub-channels reserved to nrtPS class to rtPS class.***
  for $i = N_{rtPS} + 1$ **to** length(VRT) **do**
    $j = N_{rtPS} + NF_{nrtPS}$; alloue =0;
    while (alloue=0) **AND** ($j \le N - N_{BE}$) **do**
      if $\alpha_{1 \to K, j} = 0$ **then**
        $\alpha_{k,j} \leftarrow 1$; $\Gamma \leftarrow \Gamma - \{n\}$; $alloue \leftarrow 1$; Update rate;
      else $j \leftarrow j + 1$
      end if
    end while
  end for
 end if
end if
END

B. Arriving Connections Ordering

For each service's type rtPS, nrtPS and BE, we define a global queue used for buffering arrival packets in the proposed BS scheduler at MAC layer as it is presented by figure 1.

1) *Real Time Polling Service Class:*

For rtPS connection *j* of user *k*, on sub-channel *n*, the scheduling priority $PRT^{n}_{k,j}$ is defined as [13]:

$$PRT^{n}_{k,j}=\begin{cases}\left(\frac{R_{kn}}{R_{\max}}\right)\left(\frac{W_k}{T_k-2T_F}\right) & \text{if } T_k-2T_F>W_k.\\ \left(\frac{R_{kn}}{R_{\max}}\right) & \text{if } T_k-2T_F\le W_k.\\ 0 & \text{if } R_{kn}=0.\end{cases} \quad (7)$$

where R_{kn} is the information bits that can be carried by user *k* on the sub-channel *n*, using Adaptive Modulation Coding (AMC) scheme and $R_{\max}$ is equal to six in this work. We choose this value, based on the principle of the AMC coding scheme, that specifies 6bit/symbol for the 64-QAM modulation (for more details, see [12]). W_k, T_k and T_F denote respectively, the longest packet waiting time of user k, the maximum packet latency of user *k* and the frame duration. The rtPS packet should be immediately sent if its deadline expires before the next frame is totally served. If $W_k \ge T_k - 2T_F$ we set the highest priority to the corresponding packet. When $R_{kn}=0$, the channel is in deep fade and the capacity is zero, so this connection should not be served. After calculating the rtPS connection's priority of each user *k* on each sub-channel *n*, we define a priority function PRT_j that represents the highest rtPS connection's priority and described as:

$$PRT_j = \max \mathrm{PRT}^{n}_{k,j}, \forall n \in \Gamma, \forall k \in \psi. \quad (8)$$

2) *Non Real Time Polling Service Class:*

For nrtPS connection *j* of user *k* on sub-channel *n*, the scheduling priority is defined as [3]:

$$PRT^{n}_{k,j}=\begin{cases}\left(\frac{R_{kn}}{R_{\max}}\right)\left(\frac{\overline{r_k}}{r_k}\right) & \text{if } r_k\le \overline{r_k}.\\ \left(\frac{R_{kn}}{R_{\max}}\right) & \text{if } r_k>\overline{r_k}.\\ 0 & \text{if } R_{kn}=0.\end{cases} \quad (9)$$

where $\overline{r_k}$ and r_k represent respectively, the average transmission rate and minimum reserved rate. If $r_k \le \overline{r_k}$ the rate requirement is satisfied. If $r_k > \overline{r_k}$, representing the case within the queue will be full, packets of user *k* should be then sent as soon as possible.

After calculating the nrtPS connection's priority of each user *k* on each sub-channel *n*, we define a priority function $PNRT_j$ that represents the highest nrtPS connection's priority and described as:

$$PNRT_j = \max \mathrm{PNRT}^{n}_{k,j}, \forall n \in \Gamma, \forall k \in \psi. \quad (10)$$

3) *Best Effort Class*

For BE connection j of user *k* on sub-channel n, the scheduling priority depends only on the channel quality and is defined as [4]:

$$PBE^{n}_{k,j}=\left(\frac{R_{kn}}{R_{\max}}\right) \quad (11)$$

After calculating the BE connection's priority of each user *k* on each sub-channel *n*, we define a priority function that represents the highest BE connection's priority PBE_j and described as:

$$PBE_j = \max \mathrm{PBE}^{n}_{k,j}, \forall n \in \Gamma, \forall k \in \psi. \quad (12)$$

After scheduling rtPS, nrtPS and BE connections according to respectively PRT_j, $PNRT_j$ and PBE_j the scheduler gives the priority sequentially, to rtPS-class, nrtPS-class and finally BE-class as it is presented by the following figure. 2.

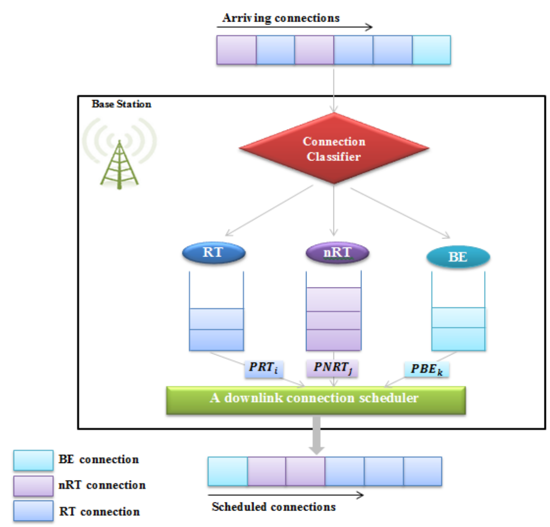

Fig.2. Average nrtPS Packet Satisfaction Ratio versus the number of connections

C. *Adaptive Sub-channel Allocation Procedure*

Aiming to maximize the total system capacity, proposed scheme allocates to each user its best sub-channel. If two or more connections have the same order, we should consider the channel quality of each one. On one hand, if connections have the same order on the same best sub-channel, we select the user with the minimum second best sub-channel as it has a low chance to get a good sub-channel. On the other hand, if connections with the same order do not require the same best sub-channel, we assign to each user its best sub-channel if it is not yet allocated. Our proposed sub-channel allocation procedure is well described in the following algorithm.

Algorithm 2: Adaptive Sub-channel Allocation Scheme

BEGIN

(i) Initialization

Equal power is allocated to sub-channels.

$\Gamma = \{1,2,\ldots,K\}$; $\psi = \{1,2,\ldots,N\}$;

$\alpha_{kn} = 0, \forall k \in \Gamma, \forall n \in \psi$;

(ii) Sub-channel Reservation

Calculate sub-channels' number N_{rtPS} , N_{nrtPS} and N_{BE} reserved respectively to rtPS, nrtPS and BE classes.

(iii) Connections Ordering

VRT=Sort rtPS connections based on PRT_j

VnRT=Sort nrtPS connections based on $PNRT_j$

VBE=Sort BE connections according to PBE_j

(iv) Sub-channels Allocation

Sort sub-channels in decreasing order.

% allocate sub-channels to rtPS connections

for i=1 **to** length (VRT) **do**
  j=1; alloue $\leftarrow 0$;
  while (alloue=0) **AND** ($j \le N_{rtPS}$) **do**
    if $\alpha_{1\rightarrow K,j} = 0$ **then**
      $\alpha_{k,j} \leftarrow 1$; $\Gamma \leftarrow \Gamma - \{n\}$; $alloue \leftarrow 1$; Update rate;
    else $j \leftarrow j+1$
    end if
  end while
end for

% allocate sub-channels to nrtPS connections

for i=1 **to** length (VnRT) **do**
  $j \leftarrow N_{rtPS}+1$; alloue $\leftarrow 0$;
  while (alloue=0) **AND** ($j \le N_{rtPS} + N_{nrtPS}$) **do**
    if $\alpha_{1\rightarrow K,j} = 0$ **then**
      $\alpha_{k,j} \leftarrow 1$; $\Gamma \leftarrow \Gamma - \{n\}$; $alloue \leftarrow 1$; Update rate;
    else $j \leftarrow j+1$
    end if
  end while
end for

% allocate sub-channels to BE connections

for i=1 **to** length (VBE) **do**
  $j \leftarrow N_{rtPS} + N_{nrtPS}+1$; alloue $\leftarrow 0$;
  while (alloue=0) **AND** ($j \le N$) **do**
    if $\alpha_{1\rightarrow K,j} = 0$ **then**
      $\alpha_{k,j} \leftarrow 1$; $\Gamma \leftarrow \Gamma - \{n\}$; $alloue \leftarrow 1$; Update rate;
    else $j \leftarrow j+1$
    end if
  end while
end for
Return rate
END

V. Simulation Results

In this section, we present numerical results in order to show the performance of proposed schemes compared to other existing methods. The simulated system consists of a single cell that uses 1024 sub-carriers for communications and serves 150 mobile users. In order to consider the mobility, we assume that the channel state changes every sub-Frame delay. Simulation parameters are described in Table I.

In order to evaluate the performance of various QoS services, we define length of rtPS packets 1024bits, nrtPS 2048bits, BE 4096bits. For rtPS connection, the minimum reserved rate and maximum latency of each connection are set to 500kbps and 20ms respectively. For nrtPS connection, the minimum reserved rate is set 1Mbps. For BE connection, the buffer size is 5000 packets with 512bytes each [4].

The performances of our proposed scheduling schemes are compared to two other well-known scheduling algorithms in terms of total spectral efficiency, rtPS average Packet Loss Ratio (PLR) and nrtPS and BE Packet Satisfaction Ratio (PSR). Firstly, Maximum Carrier to Interference and Noise Ratio (MAX-CINR) scheme[1] allocates resources to the user with the maximum receiver CINR and then only the users' link qualities are concerned while QoS requirements are totally ignored. On the other hand, Modified Proportional Fair (MPF) scheduling algorithm proposed in [2] to guarantee fairness among users. Moreover, in this section, we compare our two proposed schemes to highlight redistribution phase efficiency.

TABLE I
OFDMA PARAMETERS FOR IEEE 802.16 M

Parameters	Symbol	Value
Sub-carrier number	L	1024
Sub-channels number	N	48
Sub-carriers number per sub-channel	M	18
Sub-channels spacing	Δf	7.813 KHz
Frame delay	T_F	5 ms
Sub-Frame Delay		714,286

The spectral efficiency is computed based on the equation (3), presented in section III of the present paper.

In Figure 3, total spectral efficiency under MAX-CINR, MPF and proposed scheduling schemes is investigated.

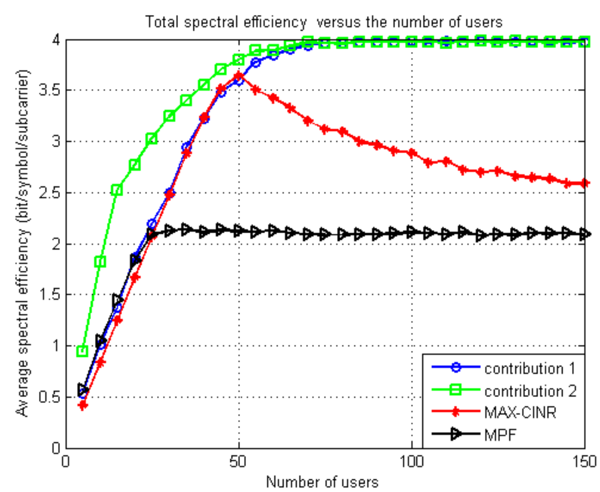

Fig.3 Total spectral efficiency versus the number of users

TABLE II
VARIATION INTERVALS IN TERMS OF RTPS PACKET LOSS RATIO

	]30,50[	[50,75[	[75,100[	[100,125[	[125,150]
LVI_{P1P2}	6,64	3,47	2,08	1,17	0,65
LVI_{P1MCI}	-43.68	-24.61	-17.21	-13.50	-10.78
LVI_{P1MPF}	-46.38	-26.23	-18.33	-14.37	-11.52
LVI_{P2MCI}	-50,24	-28,06	-19,29	-14,67	-11,23
LVI_{P2MPF}	-52.94	-30.31	-18.40	-15,42	-12.06

Table II shows variation intervals in terms of total spectral efficiency. Let $SEVI_{P1P2}$, $SEVI_{P1MCI}$, $SEVI_{P1MPF}$, $SEVI_{P2MCI}$, and $SEVI_{P2MPF}$ denote the average total Spectral Efficiency in different Variation users Intervals]0,48[, [48,75[, [75,100[,[100,125[and [125,150] in a multi-service system. These values are computed based on, respectively, the mean difference between the two proposed contributions, the mean difference between the first contribution and MAXCINR method, the mean difference between the first contribution and MPF method, the mean difference between the second contribution and MAX-CINR method and the mean difference between the second contribution and MPF method.

As $SEVI_{P1MCI} > 0$ and $SEVI_{P2MCI} > 0$, for all intervals, it is obvious that the proposed methods provide greater spectral efficiency than the MAX-CINR method when the number of users is high important which proves clearly the contribution of our proposed algorithms that operate well with multi-users diversity. Moreover, proposed methods provide better performance than MPF method in terms of total spectral efficiency as $SEVI_{P1MPF} > 0$ and $SEVI_{P2MPF} > 0$. In addition to that, we may conclude that our contribution with thresholding approach, referred in Fig. 2 as contribution 2, provides greater data rate than contribution 1, when the number of users is less than 50, explained by the proportional parameters redistribution phase introduced in this contribution.

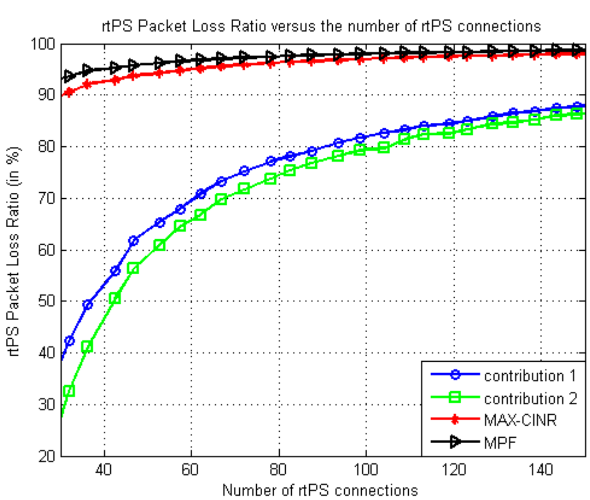

Fig.4. Average rtPS Packet Loss Ratio versus the number of rtPS connections

Figure 4 shows the average Packet Loss Ratio (PLR) of the rtPS connection across different number of connections. The average PLR is defined as the ratio of the number of the lost rtPS packets to the total packets' number. We should notice in this simulation that the average number of connections per user is equal to 3.

TABLE III
VARIATION INTERVALS IN TERMS OF NRTPS PACKET SATISFACTION RATIO

	[30,50[	[50,75[	[75,100[	[100,125[	[125,150]
SVI_{P1P2}	0.08	0.01	0	0	0
SVI_{P1MCI}	43.53	24.84	17.42	13.50	10.75
SVI_{P1MPF}	46.39	26.44	18.55	14.37	11.46

Table III shows variation intervals in terms of rtPS Packet Loss Ratio. As $LVI_{P1MCI} < 0$ and $LVI_{P1MPF} < 0$, for all intervals, it is obvious that proposed methods provide lower PLR than the MAX-CINR and MPF methods. Moreover, as $LVI_{P1P2} > 0$, for all intervals, we conclude that the second contribution provides greater performances than the first one in terms of PLR for rtPS connections due to the sub-channels redistribution phase that reserve free sub-channels of nrtPSclass and BE-class for the benefit of rtPS-class.

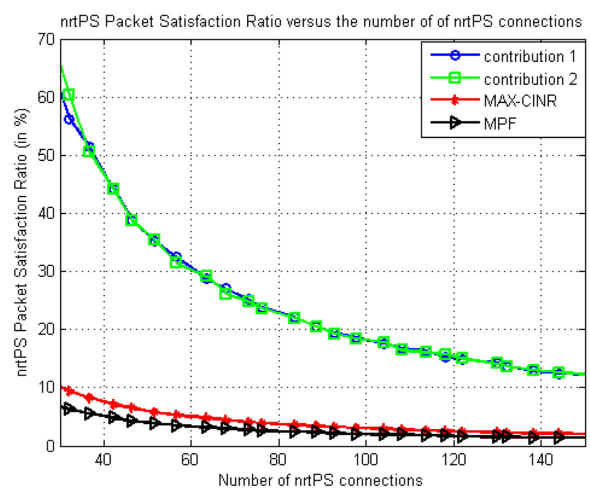

Fig.5. Average nrtPS Packet Satisfaction Ratio versus the number of nrtPS connections

In Figure 5, we investigate the average nrtPS Packet Satisfaction Ratio (PSR) which is defined as the ratio of the number of the nrtPS connections guaranteeing the minimum reserved rate to the total connections number.

Table IV shows variation intervals in terms of nrtPS Packet Satisfaction Ratio. As $SVI_{P1MCI} > 0$ and $SVI_{P1MPF} > 0$ for all intervals, it is obvious that the proposed method satisfies more nrtPS connections than other existing methods. As $SVI_{P1P2} \approx 0$, for all intervals, meaning that curve of contribution 1 and curve of contribution 2 are almost the same, which illustrates that sub-channels redistribution phase does not influence badly on the resource allocation performances for nrtPS connections classes.

TABLE IV
VARIATION INTERVALS IN TERMS OF TOTAL SPECTRAL EFFICIENCY

	]0,48[	[48,75[	[75,100[	[100,125[	[125,150]
$SEVI_{P1P2}$	0.648	0.064	0.006	0	0
$SEVI_{P1MCI}$	0.077	0.403	0.948	1.193	1.344
$SEVI_{P1MPF}$	0.725	0.467	0.955	1.192	1.342
$SEVI_{P2MCI}$	0.408	1.716	1.867	1.889	1.868
$SEVI_{P2MPF}$	1.056	1.781	1.873	1.889	1.867

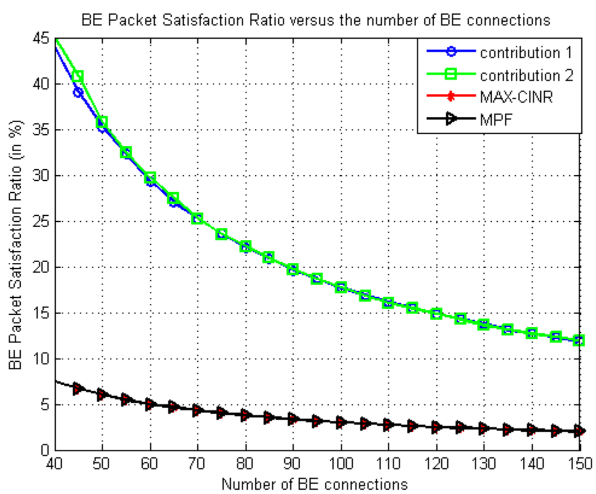

Fig.6. Average BE Packet Satisfaction Ratio versus the number of BE connections

In Figure 6, we investigate the average BE Packet Satisfaction Ratio (PSR) which is defined as the ratio of the number of the BE connections to the total connections number.

TABLE V
VARIATION INTERVALS IN TERMS OF BE PACKET SATISFACTION RATIO

	[40,50[	[50,75[	[75,100[	[100,125[	[125,150]
BVI_{P1P2}	0.34	0.02	0	0	0
BVI_{P1MCI}	43.47	24.72	17.37	13.48	10.61
BVI_{P1MPF}	46.47	26.72	17.37	13.48	10.61

Table V shows variation intervals in terms of BE Packet Satisfaction Ratio. As $BVI_{P1MCI} > 0$ and $BVI_{P1MPF} > 0$, for all intervals, it is obvious that the proposed method satisfies more BE connections than other existing methods. As $BVI_{P1P2} \approx 0$, for all intervals, meaning that curve of contribution 1 and curve of contribution 2 are almost the same when the number of users is rising, which illustrates that sub-channels redistribution phase does not disadvantage adaptive resource allocation performances for BE connections class.

Simulation results illustrate that our proposed schemes achieve provides better performances than MAX-CINR and MPF methods in terms of total system capacity. Moreover, our contributions satisfy simultaneously QoS requirements of rtPS, nrtPS and BE classes. In addition, adaptive sub-channel allocation scheme provides greater system capacity and rtPS service satisfaction, than the non-adaptive allocation scheme, referred as contribution 1, as it is shown by simulation results and numerical analysis.

VI. CONCLUSION

For this work, we propose a new adaptive resource allocation scheme with QoS support in downlink Mobile WiMAX Release 2 systems. To do so, we defined a global buffer for each type of service to store packets arrival. The main idea is to sort connections located at the same buffer in decreasing order based on a priority defined function, Then, the scheduler gives the priority to rtPS, then nrtPS and finally BE connections.

In sub-channel allocation procedure, we proposed two contributions. On one hand, sub-channels are reserved to different service types based on proportional parameters that are defined and updated each sub-frame depending on the system availability. On the other hand, a QoS-threshold is introduced based on the maximum system capacity. We proposed to imprint free nrtPS and BE sub-channels to rtPS class, if the number of rtPS connections is greater than the defined threshold. Our contributions were evaluated and compared to other existing methods considered for Mobile WiMAX Release 2 network simulation context. Numerical results demonstrate that our proposed schemes provide an efficient use of radio resources with QoS guarantees. These performances are due to an adequate scheduling strategy based on a cyclic resources allocation depending on mobile users' application requirements. In addition to that, our second contribution with QoS-threshold ensures adequate resources for the real time class without discriminating against the other classes performances. As future work we propose to extend the present contributions from a single-cell to a multi-cell system, our goal is to enhance mobility management.

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