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Review Article

Priority-Based Model of Subchannel Allocation in WiMAX Downlink

Oleksandr V. Lemeshko[1], Haider D. Al-Janabi[2], Hussam D. Al-Janabi[3]
[1]Telecommunication Systems Department, Odesa National Academy of Telecommunications named after O.S. Popov, Ukraine, 65029, Odesa, Kovalska St. 1
[2]Telecommunication Systems Department, Odesa National Academy of Telecommunications named after O.S. Popov, Ukraine, 65029, Odesa, Kovalska St. 1
[3]Department of Software Engineering, Imam Jaafar Al-Sadiq University, Baghdad, IRAQ

***Corresponding author**
Haider D. Al-Janabi
Email: avlem@ukr.net

Abstract: Priority-based model of subchannel allocation in WiMAX downlink is presented, which is based on solution of the optimization problem associated with maximizing the lower weighted bound of allocated bandwidth for each subscriber station according to its quality of service requirements for access rate and priority. Numerical research of model showed that increasing of the bandwidth requirements of the stations with higher priority significantly affect the resource allocation to other stations than the requirements of lower priority stations. The adequacy and effectiveness of solutions in terms of providing different types of service level to subscriber stations depending on the priority is confirmed.

Keywords: WiMAX; QoS; subchannel; priority; allocation; subscriber station.

INTRODUCTION

Nowadays WiMAX (Worldwide Interoperability for Microwave Access) telecommunication networks take an important place in the information infrastructure of modern society. It reliably serves large geographical areas and provides scalable high-speed solutions. The effectiveness of WiMAX deployment depends on the quality of solving problem that is concerned with allocation of time and frequency resources (timeslots, channels/subchannels), and bursts formed due to the processes of physical and data link OSI layers. It is important to take into account the priority of service requests in resource allocation, because modern networks are multiservice, and flows generated by different applications have different bandwidth requirements. In connection with this the priority-based model of subchannel allocation in WiMAX downlink taking into account the user (Subscriber Station, SS) requests priority is proposed [1].

QUALITY OF SERVICE LEVELS IN WIMAX

WiMAX networks support different types of QoS (Fig. 1). While IEEE 802.16 defines the following five types of service flow (Table 1) with distinct QoS requirements [2]:

- Unsolicited Grant Services (UGS): designed to support Constant Bit Rate (CBR) services such as voice applications;
- Real-Time Polling Services (rtPS): designed to support real-time services that generate variable size data packets on a periodic basis, such as MPEG video;
- Extended Real-Time Polling Services (ErtPS): designed to support voice applications with activity detection (VoIP);
- Non-Real-Time Polling Services (nrtPS): designed to support non-real-time and delay tolerant services that require variable size data grant burst types on a regular basis such as FTP;
- Best Effort (BE): designed to support data streams that do not require any guarantee in QoS such as HTTP.

The standard IEEE 802.16 supports different flow classes for QoS, but does not define a slot allocation criterion or scheduling architecture for any type of service. Thus a scheduling module is necessary to provide QoS for each class.

In practice, belonging of the flow to a particular QoS level is carried out by marking transmitted data through the recording priority of the frame (packet) to the Data Link or Network Layer header.

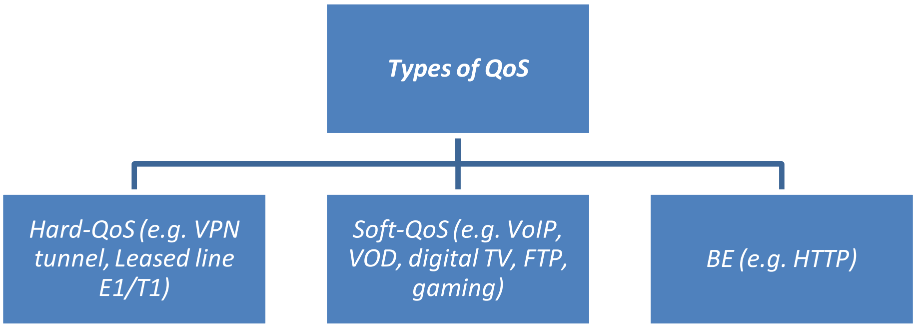

Fig-1: Types of QoS in 802.16

Table 1: QoS Categories

QoS Category	Applications
UGS	VoIP
rtPS	Streaming audio/video
ErtPS	Voice with activity detection (VoIP)
nrtPS	FTP
BE	Data transfer, Web browsing, etc.

PRIORITY-BASED MODEL OF SUBCHANNEL ALLOCATION IN WIMAX DOWNLINK

In the model of subchannel allocation to subscriber station it is assumed that there are known the following inputs: bandwidth of used frequency channel from the range of 1.25 MHz to 20 MHz; selected mode of subchannels usage (FUSC, PUSC, OPUSC, OFUSC, and TUSC); total number of the SSs in the network N; number of subchannels K used depending on the selected channel bandwidth; required transmission rate for service of the n-th SS R_{req}^{n} (Mbps); bandwidth of k-th subchannel $R^{n,k}$ allocated to the n-th SS.

Taking into account that the useful part of the symbol has a fixed duration $T_b = 89{,}6$ µs, the number of symbols in frame will take values 19, 24, 39, 49, 79, 99, 124, 198 according to the indicated size of frame. Moreover, between the symbols there is a guard interval T_g, which can take four values concerning the length of the useful part of symbol. Capacity of the k-th subchannel allocated to the n-th SS ($R^{n,k}$) represents the number of transmitted bits per time unit (second) and can be calculated according to the formula [3-5]:

$$R^{n,k} = \frac{R_c^{n,k} K_b^{n,k} K_s (1 - BLER)}{T_b + T_g + T_{RTG} + T_{TRG}}, \qquad (1)$$

where $R_c^{n,k}$ is the speed of code used at signal coding of the n-th SS; $K_b^{n,k}$ is the bit load of symbol of the n-th SS; K_s is the number of subcarriers for the data transmission in one subchannel; $T_{RTG} = 105$ µs is the duration of switching interval from receiving to transmission (receive/transmit transition gap, RTG); $T_{TRG} = 60$ µs is the duration of switching interval from transmission to receiving (transmit/receive transition gap, TRG); *BLER* is the probability of block error obtained at the expense of the Hybrid Automatic Repeat Request mechanism (HARQ) [1].

While solving a problem of subchannel allocation within the represented model it is necessary to provide calculation of the control variable (x_n^k), defining the order of subchannel allocation. According to the physics of problem the following limitation should be over the control variables:

$$x_n^k \in \{0,1\}, \; (n = \overline{1,N}, \; k = \overline{1,K}), \qquad (2)$$

$$x_n^k = \begin{cases} 1, \text{if } k-\text{th subchannel allocated to the } n-\text{th SS;} \\ 0, \text{otherwise.} \end{cases}$$

Total number of control variables depends on amount of subscriber stations in the network and used subchannels respectively, defined by the expression $\mathrm{N} \cdot \mathrm{K}$. Condition of fixing one subchannel only for one subscriber station is defined according to the expression

$$\sum_{n=1}^{N} x_n^k \le 1, \; (k = \overline{1,K}). \qquad (3)$$

Condition of scheduling the transmission rate for the n-th subscriber station on the k-th subchannel not exceeding the capacity of subchannel is defined by the expression

$$\sum_{k=1}^{K} R^{n,k} x_n^k \ge R_{req}^{n} \delta_n, \qquad (4)$$

$$\delta_n = \begin{cases} 1, \text{if for } n-\text{th SS service guarantee necessary;} \\ 0, \text{otherwise.} \end{cases}$$

For optimal balancing the number of subchannels allocated to each SS, the system introduced additional conditions limitations to the control variables x_n^k:

$$\frac{R_{all}^n}{(Pr_n + 1)R_{req}^n} \geq \beta \text{ , } (n = \overline{1, N}) \quad (5)$$

where $R_{all}^n = \sum_{k=1}^{K} R^{n,k} x_n^k$ is bandwidth allocated to the n-th SS; Pr_n is priority of service provided to n-th subscriber station; β is a control variable too, characterizing lower bound of satisfaction level of QoS requirements to access rate.

In general $\beta \geq 0$. Example of assigning priorities to services which can be provided to users (SSs) in WiMAX, in analogy to [2], shown in Table 2.

Table 2: Priority of WiMAX Service Classes

QoS Category (WiMAX Service Class)	**Priority Assigned**
ErtPS	4
UGS	3
rtPS	2
nrtPS	1
BE	0

To improve QoS in WiMAX network in solving the problem of balancing the number of subchannels allocated to SS it is needed to maximize the lower bound of satisfaction level of QoS requirements to access rate, i.e.

$$\beta \to \max \text{ .} \quad (6)$$

Thus, the model of subchannel allocation to subscriber station in WiMAX network based on solution of optimization problem associated with maximizing the lower level allocated bandwidth to each subscriber station (6) according to its QoS requirements for access rate. As the constraints stated in solving the optimization problem are conditions (1)-(5). Formulated optimization problem belongs to class of mixed-integer linear programming.

RESEARCH OF SUBCHANNEL ALLOCATION WITH SS PRIORITIES

To verify the adequacy and efficiency of the proposed model with its use was obtained solution of the problem of priority subchannel allocation for different input data. In the first case investigated when the number of subchannels was equal to eight ($K = 8$), the number of stations was equal to three ($N = 3$), and capacities of subchannels available to SSs are shown in the matrix:

$$\left\| R^{n,k} \right\| = \begin{Vmatrix} 0.8 & 0.3 & 0.2 & 0.2 & 0.1 & 0.7 & 0.6 & 0.9 \\ 0.1 & 0.5 & 0.7 & 0.1 & 0.6 & 0.3 & 0.1 & 0.1 \\ 0.4 & 0.9 & 0.1 & 0.8 & 0.4 & 0.1 & 0.8 & 0.5 \end{Vmatrix} . \quad (7)$$

Table 3 shows the results of solution the problem of priority subchannel allocation for six variants (V) input data with different priorities of SSs to level of quality of service.

Table 3: Numerical Research of Priority Subchannel Allocation ($K = 8$)

V	No SS	Pr	R_{req}, Mbps	R_{all} , Mbps	No. of subchannels	β
1	1	0	0.9	1.7	1, 8	1.8889
	2	0	0.9	1.7	3, 4, 5, 6	
	3	0	0.9	1.7	2, 7	
2	1	0	2.0	1.7	1, 8	0.8500
	2	0	2.0	1.7	3, 4, 5, 6	
	3	0	2.0	1.7	2, 7	
3	1	2	2.0	3	1, 6, 7, 8	0.5000
	2	0	2.0	1.2	2, 3	
	3	0	2.0	1.2	4, 5	
4	1	2	2.0	2.4	1, 6, 8	0.4000
	2	0	2.0	1.3	3, 5	
	3	2	2.0	2.5	2, 4, 7	
5	1	0	2.0	0.8	1	0.3500
	2	2	2.0	2.1	2, 3, 5, 6	
	3	2	2.0	2.1	4, 7, 8	
6	1	2	2.0	2.4	1, 6, 8	0.4000
	2	1	2.0	1.8	2, 3, 5	
	3	0	2.0	1.6	4, 7	

First and second variants show that within the mode of the same requirements to level of QoS ($R^1_{req} = R^2_{req} = R^3_{req}$) and stations priorities ($Pr_1 = Pr_2 = Pr_3$), the amount of channel resources allocated will be approximately the same. And this is true both for under load mode (Variant 1), and for overload mode (Variant 2).

The third variant shows that with increasing priority of the request by the first station (from zero to two) the amount of resources allocated to this station has also increased (from 1.7 Mbps to 3 Mbps). The second and third stations with zero-priority request and the same QoS-requirements received the same level of service (1.2 Mbps).

Fourth variant: with equal priority requests of the first and third stations (Pr =2) they get approximately equal bandwidth (2.4 and 2.5 Mbps, respectively). The second station, which requests have zero priority allocated considerably smaller amount of channel resource 1.3 Mbps (Fig. 2).

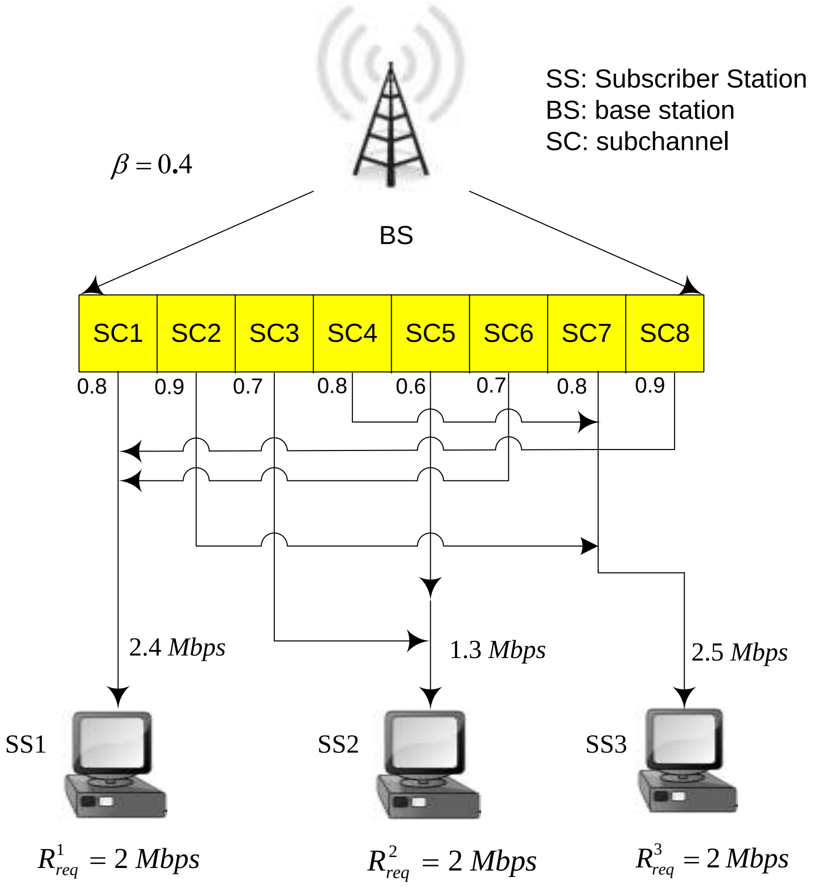

Fig-2: Result of solving (Variant 4 in Table 3)

The fifth variant shows the effect of a discrete number of subchannels and their capacities (7) on the resulting solution, causing differences in the order of channel resource allocation, for example, compared with fourth variant.

In the sixth variant requests of all stations have different priorities. This leads to the fact that amount of allocated bandwidth to stations will be different depending on the priority.

In the second case the relative impact of changes of different priority requirements of SS to pattern of channel resource allocation between SSs was estimated. As an example let us demonstrate the results with initial data, which correspond to the Variant 3 in Table 3, i.e.

- $Pr_1 = 2$; $Pr_2 = Pr_3 = 0$;
- Value R^1_{req} changed from 0 to 2 Mbps;
- Value R^2_{req} changed from 0 to 2 Mbps;
- Value R^3_{req} remained constant and equal to 2 Mbps.

It was necessary to provide differentiated and not guaranteed allocation of channel resource, i.e. $\delta_n = 0$, $n = \overline{1,3}$ (4).

Fig. 3-5 demonstrated how bandwidth (Mbps) of channel resource was allocated to each of the stations (R_{all}^{n}, $n = \overline{1,3}$).

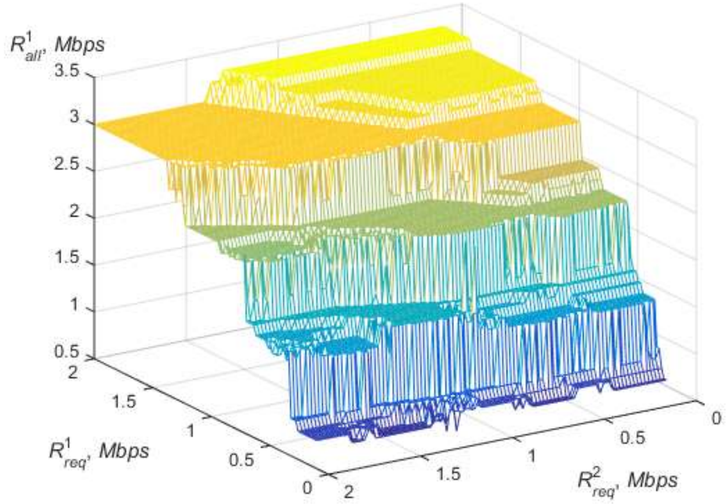

Fig-3: Bandwidth allocated to the 1-st SS

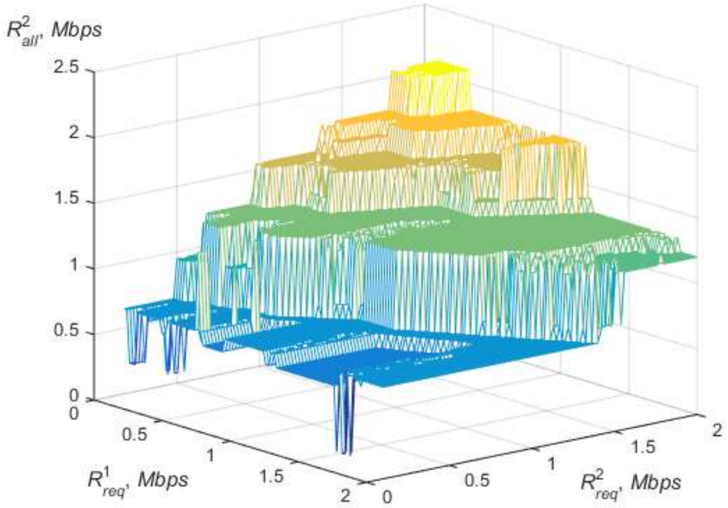

Fig-4: Bandwidth allocated to the 2-nd SS

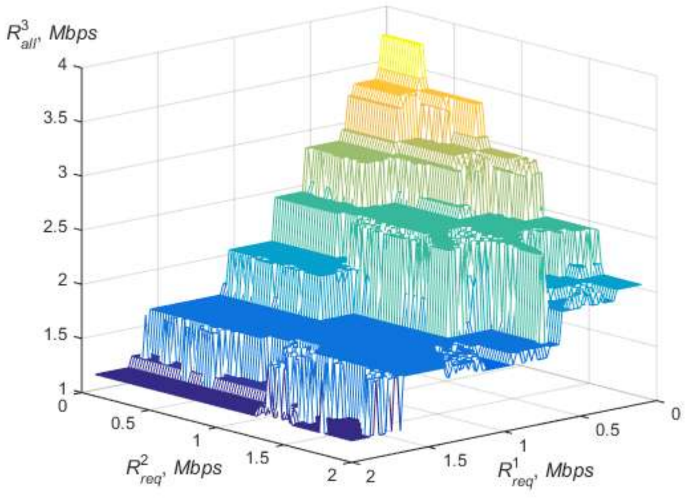

Fig-5: Bandwidth allocated to the 3-rd SS

Dependency of the lower bound of satisfaction level of QoS requirements to access rate from the required transmission rate for service of the 1-st and 2-nd SSs, which have the different priorities, is shown on the Fig. 6.

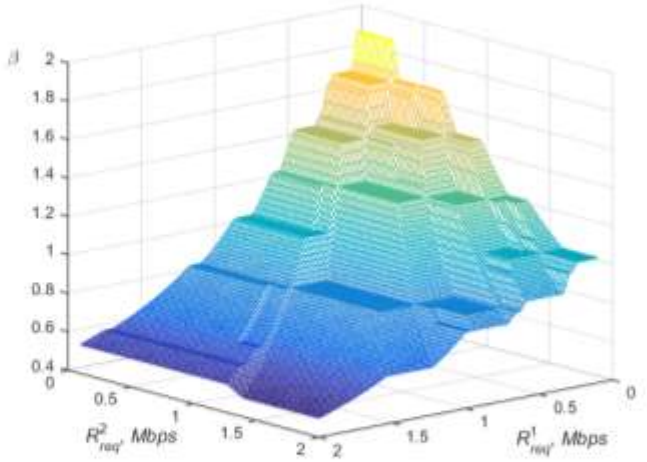

Fig-6: Dynamics of the lower bound of satisfaction level of QoS requirements to access rate

The research results demonstrated that using of the model (1)-(6) can provide an effective subchannel allocation between SSs considering the number of available subchannels and the required transmission rate for service [6], as well as service priority. For example, on Fig. 4 and 5 was clearly shown that with the increase of bandwidth requirements of the first station, which was the second priority, more critically disrupted the resource allocation to other stations than the increase in bandwidth requirements of the second station, which had a zero (lowest) service priority. A similar pattern was observed when analyzing the lower bound of satisfaction level of QoS requirements to access rate (Fig. 6).

CONCLUSION

In this paper the priority-based model of subchannel allocation in WiMAX downlink (1)-(6) was presented with optimal balancing the number of subchannels allocated to each subscriber station (5). Model based on solution the optimization problem associated with maximizing the lower weighted bound allocated bandwidth for each subscriber station (6) according to its QoS requirements for access rate and priority. Conditions (1)-(5) are stated as the constraints in solving the optimization problem, which belongs to class of mixed-integer linear programming, because some variables of (6) are Boolean, balancing variable (6) is a positive real variable, and objective function (6) and constraints (2)-(5) are linear. The research results demonstrated that using of the model (1)-(6) can provide an effective subchannel allocation between SSs considering the number of available subchannels and the required transmission rate for service as well as service priority. Moreover, it has been shown that increasing of the bandwidth requirements of the stations with higher priority significantly affect the resource allocation to other stations than the requirements of lower priority stations. Numerical research of proposed model confirmed the adequacy and effectiveness of solutions as a whole in terms of providing different types of service level (Table 3) to subscriber stations depending on the priority.

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