Slot Allocation Model and Data Burst Scheduling in Downlink WiMAX Technology

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Abstract - **A mathematical model of slots allocation and bursts data scheduling in the downlink of IEEE 802.16 standard is proposed. The proposed model is focused on the formation of one packet of downlink data for each subscriber station, that minimizes the number of overhead information sent over the used frequency communication channel.**

Keywords - **slot allocation, data burst scheduling, mathematical model, modulation and coding system.**

I. Introduction

In WiMAX technology an effective way to increase productivity and improve the basic quality of service (QoS), is to use structural and functional principles of self-organization. A high level of self-organization can be achieved through improved network of protocols and mechanisms responsible for the allocation of the available network resources. This kind of resources includes first and foremost, the network traffic (information resource), the bandwidth of communication channels (channel resource), queue (buffer resources), as well as the frequency subcarriers (frequency resource), that is especially important for wireless networks [1, 2]. IEEE 802.16 standard defines mechanisms for planning and allocation of network resources for uplink, leaving the right on choice for telecom operators and equipment manufacturers in the downlink [3].

In the framework of WiMAX, built on technology OFDMA, you can control the frequency and time resources. As the frequency resources are the subcarriers and also subchannels. Slots advocate as a temporary resource of OFDMA technology which, in the frequency domain, always occupy one logical subchannel, and in the time resource – from one to three OFDM-symbols. Slots allocated for the transmission of information to a single user and united into one area, form a burst data [4].

Thus, the problem of allocation of the frequency and time resource of WiMAX should be formulated as the problem of allocation of slots between the subscribe station (SS) of the wireless network and their respective allocation into the bursts data based on the stated rate and QoS parameters.

II. Analysis of the Known Solutions

Analysis of the known solutions [5-9] has shown that the increase of WiMAX productivity and ensuring of QoS can be achieved by a separate and coherent problems solution as to allocation of frequency and time resources. Thus, modification of the problem on allocation of frequency resources are presented in [5, 6]. The approach proposed in [7], addresses the problem of temporary resource allocation. Furthermore, in [8, 9] proposed the approaches to the solution of a joint distribution of frequency and time resource allocation problem formulated as slots allocation and data burst scheduling in the downlink. However, the approaches proposed in [8, 9] are heuristic in nature.

Based on the shortcomings of the known solutions [5-9], the following requirements to the promising solutions of slot allocation and burst data scheduling in downlink of WiMAX technology have been formulated: focus on the efficient use of the frequency and time resources; respect for the SS rate and quality of service; minimizing the number of service data transmitted over the communication channel; focus primarily on the dynamic nature of the problem of slots allocation and burst data scheduling; focus on maximizing network performance on the whole and improving the quality of other services; taking into account the technological features of the network (operating mode, bandwidth, number of subchannels, frame duration); consideration of geographically remote stations (MCS determines the choice to SS signal).

Based on the analysis, as well as the requirements set forth, it is proposed a unified model, which describes the joint distribution procedure both for frequency and time resources. The proposed model is presented in the form of the solution of the slots allocation and their scheduling into the data bursts in the downlink of WiMAX technology based on indicators of QoS (SS required rate) and geographically remote of SS network (MCS to SS signal transmission).

III. Initial Data for the Problem of the Slots Allocation and Data Burst Scheduling in the Downlink

The proposed mathematical model is designed for using in the wireless bandwidth networks with IEEE 802.16a and IEEE 802.16d, applying OFDMA scheme with a fixed "window" of fast Fourier transformation (FFT) with 2048 subcarriers and the working bandwidth channel of 20 MHz [4].

In the proposed model, the following inputs are assumed to be known:

1) N – the number of user stations in a wireless network;

2) K – the number of subchannels in the frequency channel specified by the submodes and making 32 subchannels for DL FUSC, and for DL PUSC - 60 subchannels;

3) L – the number of characters in the frame. It should be noted that under WiMAX frame duration may vary and make equal to 2, 2.5, 4, 5, 8, 10, 12.5, 20 ms. Based on the fact that the useful part of the symbol has a fixed duration T_b =89.6 ms, the number of characters in the frame will take the value of 19, 24, 39, 49, 79, 99, 124, 198 accoding, to specified duration of the frame. However, between the symbols there is a guard interval, which can take four values concerning the length of useful part of the symbol: $T_g = T_b / 4 = 22.4$ ms; $T_g = T_b / 8 = 11.2$ ms; $T_g = T_b / 16 = 5.6$ ms; $T_g = T_b / 32 = 2.8$ ms. As a result, the exact duration of the frame can be calculated as $(T_b + T_g)L$;

4) R_{req}^n – the required data rate for serving the n-th SS (Mbps);

5) S – the number of symbols that form a slot. The size of the slot depends on the submode [4] and can be set for DL FUSC - one OFDMA-symbol in one subchannel; DL PUSC - two OFDMA-symbols in one subchannel; UL PUSC - three OFDMA-symbols on one subchannel, AMC - 6, 3 or 2 OFDMA-symbols in one subchannel;

6) the types of MCS, depending on geographically remote SS;

7) the number of slots in one subchannel of the downlink to transmit useful information:

$$M = \left\lfloor \frac{UL - L_{pr}}{S} \right\rfloor, \qquad (1)$$

where $\lfloor \ \rfloor$ – operation of rounding to the nearest integer in the lower side, U is a ratio of the number of characters in the downlink to the total number of characters in the frame (the ratio of the number of characters in the downlink to the number of characters in the uplink varies from 3:1 to 1:1 to support different traffic profiles [4]), L_{pr} – the number of symbol to transmit preamble (equal to unity).

The mathematical model records the useful information transmitted in a single frame, and consisting of a fixed and a variable part. The fixed part consists of a preamble and Frame Control Header (FCH). The variable part includes DL-MAP and UL-MAP, which contain downlink MAP information element (DL-MAP_IE) and uplink MAP information element (UL-MAP_IE) respectively. To each data burst in the downlink corresponds one DL-MAP_IE, and to each burst in the uplink - one UL-MAP_IE. Fixed and variable parts have the following dimensions:

- DL-MAP – 88 bits;
- DL-MAP_IE – 60 bits;
- UL-MAP – 48 bits;
- UL-MAP_IE – 52 bits.

In order to better recover overhead data at the receiver's side under WiMAX technology the number of repetitions of fixed and variable parts can have the following values: w =2, w =4 and w =6. As a result, the number of slots needed used for transmission of the overhead information will be calculated as follows:

$$Q_{DL-MAP} = \left\lceil \frac{88 + 60N}{SR_c^{\mathrm{MAP}} k_b^{\mathrm{MAP}} K_s} \right\rceil w; \qquad (2)$$

$$Q_{UL-MAP} = \left\lceil \frac{48 + 52N}{SR_c^{\mathrm{MAP}} k_b^{\mathrm{MAP}} K_s} \right\rceil w, \qquad (3)$$

where in the numerator there is the total number of bits of the overhead information, in the denominator there is the number bits of the overhead information transmitted in a single slot, $\lceil \ \rceil$ – operation of rounding to the nearest larger integer; R_c^{MAP} – coding rate used for encoding the signal of overhead information; k_b^{MAP} – bit loading symbol used for encoding a signal of overhead information; K_s – the number of subcarriers for data transmission in a single subchannel (for sending the overhead information DL PUSC submode is used, resulting in K_s =24). It should be borne in mind that WiMAX technology for the modulation and coding system (MCS) of overhead information the QPSK 1/2 is used. As a result, the following settings $R_c^{\mathrm{MAP}} = 2$ and $k_b^{\mathrm{MAP}} = 1/2$ shall be used for the expression (2) and (3).

The total number of slots for the overhead information transmission can be calculated from the expression

$$Q = Q_{DL-MAP} + Q_{UL-MAP} + Q_{FCH}, \qquad (4)$$

where Q_{FCH} =4 – the number of slots to transmit frame control header.

IV. A Mathematical Model of Slots Allocation for the Data Bursts in the Downlink

In the course of solving the problem of slots allocation and of data bursts scheduling for transmission of useful information in the downlink by each SS of the network, it is necessary to determine a boolean control variable ($x_{k,m}^n$) in the framework of the proposed model, ensuring the allocation of slots:

$$x_{k,m}^n = \begin{cases} 1, \text{ if the } m\text{-th slot is used in the } k\text{-th} \\ \quad \text{subchannel allocated by the } n\text{-th SS;} \\ 0, \text{ otherwise.} \end{cases} \qquad (5)$$

The total number of control variables depends on the number of SS in the network, the number of used subchannels, and the number of slots in one downlink subchannel that will be determined by the expression $N \times K \times M$. The calculation of the variables (5) results in binding of SS subchannels and allocation of slots which will be used to transfer the data in the downlink. In addition, the calculation of the variables $x_{k,m}^n$ must be performed tacking into accounting a number of important conditions/constrains:

1) Fixing the k-th subchannel for the m-th slot transmission for no more than one SS

$$\sum_{n=1}^{N} x_{k,m}^n \le 1 \ (k = \overline{1,K} ; m = \overline{1,M}); \qquad (6)$$

2) Fixing the number of slots for the n-th SS providing the necessary transmission rate when using MCS

$$R_S^n \sum_{m=1}^{M} \sum_{k=1}^{K} x_{k,m}^n \geq R_{req}^n \quad (n=\overline{1,N}), \tag{7}$$

where $R_S^n = \frac{S R_c^n k_b^n K_s}{(T_b + T_g)L + T_{RTG} + T_{TTG}}$ is the slots bandwidth assigned to the n-th SS, that depends on the MCS determining the number of bits transmitted in a time equal to the length of the slot; R_c^n – code rate used when encoding the signal of the n-th SS (for example, for 16-QAM 1/2 modulation the parameter is R_c =2 [4]); k_b^n is a bit loading symbol of the n-th SS (for example, for 16-QAM 1/2 modulation the parameter is k_b^n=1/2); K_s – the number of subcarriers for data transmission in a single subchannel (for DL FUSC submodes K_s =48, and for DL PUSC K_s =24); $\Delta f \approx 11{,}16$ KHz – frequency separation between subcarriers; $T_{TTG} = 105{,}7$ μs – transmit/receive transition gap (TTG) interval time; $T_{RTG} = 60$ μs – receive/transmit transition gap (RTG) interval time [1].

3) Scheduling conditions of a single burst for the n-th SS

$$x_{k,i}^n x_{k,z}^n (i - z + 1) - \sum_{u=z}^{i} x_{k,u}^n \leq 0, \tag{8}$$

at ($z=\overline{1,M-1}$; $i=\overline{2,M}$; $n=\overline{1,N}$; $k=\overline{1,K}$; $i>z$);

$$x_{j,m}^n x_{r,m}^n (j - r + 1) - \sum_{s=r}^{j} x_{s,m}^n \leq 0, \tag{9}$$

at ($r=\overline{1,K-1}$; $j=\overline{2,K}$; $n=\overline{1,N}$; $m=\overline{1,M}$; $j>r$).

4) Scheduling condition for the "rectangular" bursts

$$x_{k,m}^n \sum_{d=1}^{M} x_{k,d}^n \sum_{b=1}^{K} x_{b,m}^n = x_{k,m}^n \sum_{g=1}^{K} \sum_{h=1}^{M} x_{g,h}^n, \tag{10}$$

at ($n=\overline{1,N}$; $k=\overline{1,K}$; $m=\overline{1,M}$).

5) Conditions for the required number of slots reservation for the overhead transmission

$$\sum_{k=1}^{K} \sum_{n=1}^{N} x_{k,m}^n = 0, \; (m=\overline{1,m_{oh}-1}, \lceil Q/K \rceil \geq 1); \tag{11}$$

$$\sum_{n=1}^{N} x_{k,m_{oh}}^n = 0, \; (k=\overline{1,k_{oh}}, \lceil Q/K \rceil \geq 1); \tag{12}$$

$$\sum_{n=1}^{N} x_{k,1}^n = 0, \; (k=\overline{1,k_{oh}}, \lceil Q/K \rceil < 1), \tag{13}$$

where $m_{oh} = \lceil Q/K \rceil$ – the number of slots allocated for the overhead information transmission, occupying the entire width of the frequency channel (available after preamble);
$k_{oh} = Q - K(m_{oh} - 1)$ – the number of slots allocated for the overhead information transmission, occupying only part of the width of the frequency channel.

Conditions (11) and (12) are used, if the number of slots needed to transmit overhead data is greater than or equal to the number of subchannels in the frequency channel $\lceil Q/K \rceil \geq 1$. Besides, condition (11) allows to make a reservation all subchannels for transmission of the number of slots equal to m_{oh}. Conditions (12) and (13) reserve a part of subchannels (k_{oh}) for the duration of one slot.

Calculation of the variables (5), in accordance with the conditions/constraints (6)-(13) is advisable to carry out in the course of solving the optimization problem by selecting minimum or maximum quality criteria to decide the problem of slots allocation and bursts scheduling for data transmission by the SS wireless network of IEEE 802.16a and IEEE 802.16d standards.

The problem of SS slots allocation and bursts data scheduling can be solved by using the optimality criterion, aimed at saving the frequency and time resources, and reducing the time spent by SS in the active state, that will reduce power for SS. Thus, the optimality criterion becomes:

$$\min \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m}^n, \tag{14}$$

taking into account the conditions/constraints (6) - (13).

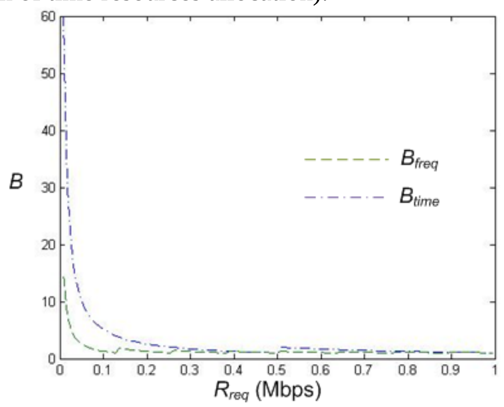
The problem formulated from the mathematical point of view is the problem of Mixed Integer Non-Linear Programming (MINLP). In the model of the variables $x_{k,m}^n$ (5) are the booling ones. Variable used in the optimality criterion (14) is integral, limits on the unknown variables (6), (7), (11)-(13) are linear, and the constraints (8)-(10) are non-linear.

As an example, to the solutions formulated in an optimization problem, MatLab R2011a system was used, in which the minlpAssign program is involved, being a part of optimization pack TOMLAB. An analysis of the solutions of the slots allocation and bursts scheduling found that increase in the required rate of transmission while using the same MCS leads to increase in direct proportion of the slots number that are a part of a data bursts. In addition, the increase in bit loading symbol and encoding rate, on the one hand, leads to a decrease in direct proportion to the number of slots that form a bursts data, but on the other hand, it reduces the communication range.

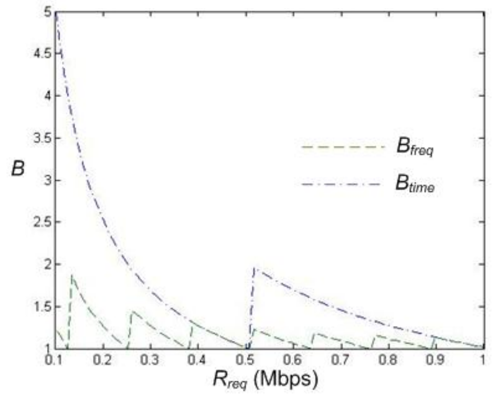
In addition, the analysis schowed that the use of (8) and (9), ensuring the scheduling of a single data bursts for each substation, enables to minimize the amount of overhead information transmitted in the downlink, since the scheduling of each additional DL-bursts leads to the DL-MAP_IE formation.

Also, the analysis found that the problem is solved more effective in case of using the joint allocation of frequency and time resource of WiMAX technologies downlink. Fig. 1 shows the number of times (B) SS slots can be reduced while solving the problem of joint frequency and time resources allocation, compared to the problems solved separately for frequency resource (B_{freq}) and time resource (B_{time}) allocation, depending on the desired SS rate transmission.

The curves shown in Fig. 1 are characterized by sharp fluctuation. The presence of fluctuation's due to the need of the next subchannel allocation (in case of solving the problem of frequency resource allocation) or a sequence of symbols, times the number of symbols in the slot (in case of solving the problem of time resources allocation).



a)



b)

Fig. 1. Effectiveness of the joint frequency and time resource allocation in the bandwidth downlink of WiMAX technology application

III. CONCLUSION

Found that one of the main challenges in the WiMAX wireless networks is the problem of ensuring the required quality of service in terms of includes the required transmission rate in the downlink for the SS network. Ensuring the necessary rate of WiMAX can be achieved by solving the problem of slots allocation between the data bursts of one frame in the downlink. In this regard, existing approaches for slot allocation between the bursts data in the downlink of wireless network under WiMAX technology have been analyzed. The analysis identified the drawbacks of the known solutions, and formulated the requirements for determining the way of solving slots allocations and data bursts scheduling problem.

On the basis of the proposed set out to solve the problem the mathematical model, presented by the linear and nonlinear conditions/constraints has been set up. The novelty of the model lies in the formulation of the problem concerning slots allocation and data bursts scheduling as a problem of balancing the available downlink bandwidth of WiMAX technology for the transmission of useful information by SS, taking into account their geographical distance (type of modulation and coding system). The growth of network productivity was caused by a decrease in overhead information transmitted in the downlink, that was achieved by allocating of a one data burst for each SS.

The formulated problem on slots allocation and data bursts scheduling in the downlink from the point of view of physics processes in the wireless network, refers to the class of balancing the time-frequency resources – the number of slots in the burst data, and from a mathematical point of view – it is a problem of Mixed Integer Non-Linear Programming (MINLP). As an example, to the solutions formulated in an optimization problem, MatLab R2011a system was used, in which the minlpAssign program is involved, being a part of optimization pack TOMLAB.

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