Results of Development of Sub-Channels Scalable Scheduling Model in WiMAX Network

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***Abstract*—Based on the detected disadvantages of the known mechanisms of the frequency resources scheduling in the downward channel the mathematical model introduced by a number of linear and nonlinear conditions-limitations is offered. The novelty of this model consists in the statement of the sub-channels scheduling task as the tasks of rescheduling of the accessible capacity of the downward channel of the WiMAX technology for the information transmission in the direction of users stations, taking into account their territorial remoteness (type of the system of modulation and coding).**

***Keywords*—WiMAX, IEEE 802.16, wireless network, allocation of sub-channels, self-organizing, mathematical model, scaling**

I. INTRODUCTION

The use of structural and functional self-organization principles is one of effective paths to rise performance and improve the main indices of quality of service (Quality of Service, QoS) for the systems using the WiMAX (Worldwide Interoperability for Microwave Access) technology, based on the IEEE 802.16 standard [1, 2]. The use of self-organization solutions makes it possible to respond effectively to variations of the state and conditions of the wireless network operation, which can be dictated, for example, by a failure or overload of the network elements, oscillations of traffic, arriving into the network, by dynamics of change in the signal-to-noise conditions etc. [3, 4]

A high level of self-organization can be reached through refinement of the network protocols and mechanisms responsible for scheduling of accessible network resources. It should be noted, that the IEEE 802.16 standard does not define mechanisms of the network planning and resource scheduling, leaving the choice with the operators of link and equipment manufacturers (vendors). Such resources include, first of all, the network traffic (information resource), the communication channels capacity (channel resource), queues (buffer resource), and also frequency subcarriers (frequency resource), that is especially important for wireless networks [3, 4].

Frequency subcarrier is the primary structural unit of the OFDM, which logical association forms a unit of frequency resource called a sub-channel. The group of sub-channels in turn forms a frequency channel [5].

The majority of known solutions on allocation of frequency resource are aimed at solving the task of subcarriers' scheduling. Thus the number of subcarriers forming one frequency channel can be different and it is defined with the width of the frequency channel. The choice of this or that width of a frequency channel makes it possible to define the number of sub-channels formed by equal sets of subcarriers. As a result of it the task of the frequency resource scheduling, concerning the fixed subcarrier referring to the sub-channels, should be reduced to the task of the sub-channels scheduling between subscrieber's stations (SS) of the network.

Thereupon, the mathematical model of the sub-channels scheduling in the networks with application of a scalable version of the OFDMA is offered in this paper. The accounting of characteristics of the scalable version of the OFDMA, in comparison with the known solutions, will make it possible to sample the needed width of the frequency channel. Also it will make it possible to use the given model in the IEEE 802.16e standard. In its turn, the task of structural self-organization is considered in the offered model as the task of sub-channels scheduling; that has allowed making account of technological features of the wireless network as compared to the known solutions, in which the task of subcarrier scheduling is solved.

II. EASE OF USE ANALYSIS OF KNOWN SOLUTIONS

The methods for scheduling of the accessible resources using the Round Robin Scheduler algorithm were analyzed in [6]. The use of the Round Robin Scheduler algorithm assumes selection of equally accessible resource for every US. In its base implementation, the Round Robin Scheduler selects a time interval for every US, within the framework of which this US gains an exclusive access to the channel. In this case the data transmission rate of the US is limited by the actual value of a signal-to-noise ratio (SNR). The methods where the Max

C/I Ratio algorithm had been used [7] were also analyzed; this algorithm presents an accessible resource of the user's station with the best values of the signal-to-noise ratio (SNR), not providing a validity of this resource scheduling between the US. Moreover, the methods of accessible resources scheduling, using the algorithm of proportional fair scheduling of service (Proportional Fair Scheduling) [8], are analyzed. The performed analysis has shown that the Proportional Fair Scheduling algorithm promotes the US, which has a high SNR value, simultaneously providing a sufficient number of accessible resources for US with the worst SNR value.

The analysis has shown that the most reasonable mechanism for scheduling of the access to radio resources of the WiMAX technology would be the mechanism including features of the Round Robin and Max C/I Ratio algorithms. The choice of the algorithm depends on the load category and value. The exact choice of the algorithm for the access scheduling is especially important at a great load.

Also as a result of the analysis it has been established, that the use of the Proportional Fair Scheduling is aimed at application to the interactive “best effort” class of data to prevent a situation, at which some US will never receive an access to the radio resource. The use of the indicated class of service (CoS) provides delivery of the user's stations data in accordance with the possibilities without the transmission rate warrants. The improvement of the quality of service, when planning the radio resource of each US, should be aimed at support of the guaranteed speed of transmission with the possibility of access to an additional (not guaranteed) bandwidth. But none of the mechanisms, which have been analyzed, is capable to provide a similar CoS.

As a result of the performed analysis the decision has been made on necessity of developing a mathematical model for the frequency resource planning in the downward communication channel of the WiMAX technology, formulated as the sub-channels scheduling tasks to support the guaranteed transmission speed of user's stations.

III. MATHEMATICAL MODEL FOR SUB-CHANNELS SCHEDULING IN WIRELESS NETWORK OF THE IEEE 802.16 STANDARD

In the IEEE 802.16a and IEEE 802.16d standards the OFDMA scheme with a fixed "window" of fast Fourier transform (FFT) of 2048 subcarriers size is utilized with an operating bandwidth of the channel of 20 MHz. In the IEEE 802.16e standard the scalable OFDMA version is used, which is realized at the expense of the FFT “window" change, that makes it possible to vary an operating bandwidth of the channel in the limits from 1,25 MHz up to 20 MHz [5]. But it should be noted, that the choice of the frequency channel width is performed by an operator of link, when designing the wireless network, and cannot be changed during its functioning. Therefore, the OFDMA scalable version, used in the IEEE 802.16e standard, will be considered further in the given paper with the aim to develop solutions by preliminary selecting of the frequency channel width.

In view of above mentioned, the following input data are assumed to be known in offered model:

1) N – is the total number of the US in the network;

2) L – is the number of sub-channels used depending on the selected width of the frequency channel. For the mode of the full usage of the subcarriers (Full Usage of Subcarriers, DL FUSC) the amount of sub-channels can accept values 2, 8, 16, 32, and for the “partial” mode of subcarriers usage (Partial Usage of Subcarriers, DL PUSC) - 3, 15, 30, 60;

3) R_{req}^{n} – the required transmission rate for service of the n-th SS (Mbps).

4) R^{n} – capacity of one sub-channel scheduled by the n-th SS.

In the WiMAX technology the duration of a frame can vary and accept the values equal to 2; 2.5; 4; 5; 8; 10; 12.5; 20 ms. Recognizing that the useful part of the character has a fixed duration T_b=89,6 ms, the number of characters in the frame will accept the values 19, 24, 39, 49, 79, 99, 124, 198, according to the indicated durations of the frame. Moreover, between the characters there is a guard interval, which can accept four values concerning duration of the useful part of the character: $T_g = T_b / 4 = 22.4$ 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.

The capacity of the sub-channel of the n-th SS (R^{n}) represents the number of the transmitted bit per a time unit (second) and can be calculated according to the formula [9, 10]:

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

where R_c^{n} – is the speed of the code used at coding of a signal of the n-th SS (for example, for modulation 16-QAM 1/2 parameters R_c^{n} =1/2 [5]); k_b^{n} – is the bit load of the character of the n-th SS (for example, for modulation 16-QAM the parameter k_b^{n}=4) [5]; K_s – is the number subcarriers for the data transmission on one sub-channel (for the DL FUSC sub-mode K_s =48, and for DL PUSC K_s =24); T_{RTG}= 105.7 μs – is the duration of the interval of switching from reception to transmission (receive/transmit transition gap, RTG); $T_{TRG} = 60$ μs – is the duration of an interval of switching from transmission to reception (transmit/receive transition gap, TRG) [1]; $BLER$ – is the probability of the block error obtained at the expense of the HARQ mechanism (Hybrid automatic repeat request) [1];

In the course of solving the task of sub-channels scheduling within the framework of the offered model it is necessary to provide calculation of the control variable ($x_{n,l}$), defining the order of the sub-channels scheduling. According to the solved task physics the following limitation is superimposed on the control variable:

$$0 \le x_{n,l}\ ,\ (\ n=\overline{1,N}\ ,\ l=\overline{1,L}\ ) \qquad (2)$$

The total number of the control variables depends on an amount of user's servers in the network, used sub-channels and, accordingly, it will be defined by the expression $N \times L$. When calculating the required variables $x_{n,l}$ it is necessary to meet a number of the important conditions - limitations:

The condition of scheduling the transmission speed for the *n*-th suscriber's station on the *l*-th sub-channel not exceeding the capacity of the sub-channel:

$$x_{n,l} \le \frac{R_c^n k_b^n K_s \left(1-BLER\right)}{\left(T_b + T_d + T_{RTG} + T_{TRG}\right) R_{req}^n} \quad (\ n=\overline{1,N}\ ,\ l=\overline{1,L}\ ), \ (3)$$

The condition of meeting requirements on the transmission speed for each subscriber's station in the downward communication channel with the used scheme of modulation and coding (Modulation and Coding Scheme, MCS):

$$\sum_{l=1}^{L} x_{n,l} \ge 1 \quad (\ n=\overline{1,N}\ ). \qquad (4)$$

Condition of the sub-channel fixing only for one subscriber's station:

$$\sum_{l=1}^{L} x_{n,l} x_{s,l} = 0 \quad (\ n,s=\overline{1,N}\ ,\ n \ne s\ ) \qquad (5)$$

The required variables (2) calculation according to conditions – limitations (3)-(5) is expedient for realizing during solution of the optimization task, providing a minimum or maximum previously selected criterion of quality of the sub-channels scheduling task solution. The task of sub-channels scheduling can be solved using the optimality criterion aimed at maximization of overall performance of the downward communication channel. Thus, the optimality criterion will take the form:

$$\max \sum_{l=1}^{L} \sum_{n=1}^{N} x_{n,l} \qquad (6)$$

taking into account the conditions – limitations (3)-(5). The use of the optimality criterion (6) together with the conditions – limitations (3)-(5) is aimed at supporting the guaranteed speed of transmission with the possibility of access to an additional (not guaranteed) transmission channel bandwidth, in CoS that corresponds to B subclass

From the mathematical point of view the formulated task is the task of nonlinear programming – NLP (NonLinear Programming). The variable used in the optimality criterion (6), is a non-integral one, the limitations on the required variables (3) and (4) are of the linear nature, and limitation (5) – is of nonlinear nature.

IV. EXAMPLE OF THE SUB-CHANNELS SCHEDULING TASK SOLUTION

To analyze the solutions on the sub-channels scheduling in the downward communication channels obtained with the known methods and also with the offered model (2)-(6) let us consider an example, where the following were used as the input data for the sub-channels scheduling in the downward communication channel:

- the number of subscrieber's stations – $N=5$;
- the number of sub-channels formed in the downward communication channel – $L=15$;
- the number of subcarriers for data transmission on one sub-channel – $K_s = 12$;
- the code speed used at enciphering a signal by the first SS – $R_c^1 = 2$ (QPSK), the second SS – $R_c^2 = 3$ (8-PSK), the third SS – $R_c^3 = 5$ (32-QAM), the fourth SS – $R_c^4 = 2$ (QPSK), the fifth SS – $R_c^5 = 5$ (32-QAM);
- the bit loading of the character of the first SS – $k_b^1 = 1/2$, the second SS – $k_b^2 = 1/2$, the third SS – $k_b^3 = 1/4$, the fourth SS – $k_b^4 = 3/4$, the fifth SS – $k_b^5 = 1/2$.

As an example the optimization task, set in this work, was solved with the use of the MatLab R2012b system. In this case the program fmincon of the optimization package – Optimization ToolBox – was used. As an example the identical required transmission speed, its value was equal to $R_{req}^n = 0 \div 1.9$ Mbps, was installed into all user's stations. Fig. 1 shows how the overall performance of the downward communication channel varies depending on the required transmission speed.

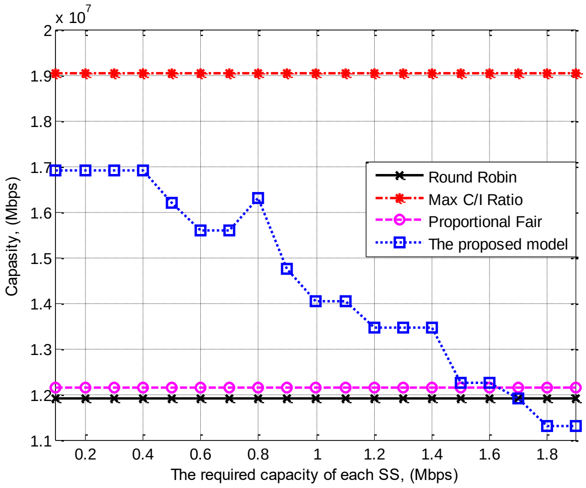

Fig. 1. Dependence of the downward communication channel common performance on the required transmission speed in view of the used way of the sub-channels scheduling

As the simulation results have shown (fig. 1) the overall performance of the downward communication channel, when using the known methods during the whole measurement interval, did not vary and was equal to 1.205 Mbps for the Round Robin method, 1.2 Mbps for the Proportional Fair method and 1.91 Mbps for the Max C/I Ratio method. The overall performance of the downward communication channel, when using the offered model (2)-(6) on the site $R_{req}^{n} = 0.1 \div 0.4$ Mbps, had the maximum value and was equal to 1.69 Mbps. On the interval $R_{req}^{n} = 0.4 \div 1.9$ Mbps the overall performance has decreased by 33 % to the value of 1.13 Mbps.

Fig. 2 demonstrates the simulation results representing the dynamics of change in the degree of balancing of the downward communication channel capacity between the user's servers. The capacity balancing degree was defined according to expression [8]

$$F^{i} = 1 - \left(\frac{\max\limits_{n} R_{n}^{i} - \min\limits_{n} R_{n}^{i}}{\sum\limits_{n=1}^{N} R_{n}^{i}} \right),$$

where R_{n}^{i} – is the transmission speed scheduled to the n-th SS on the i-th interval of measurement, $n = \overline{1, N}$.

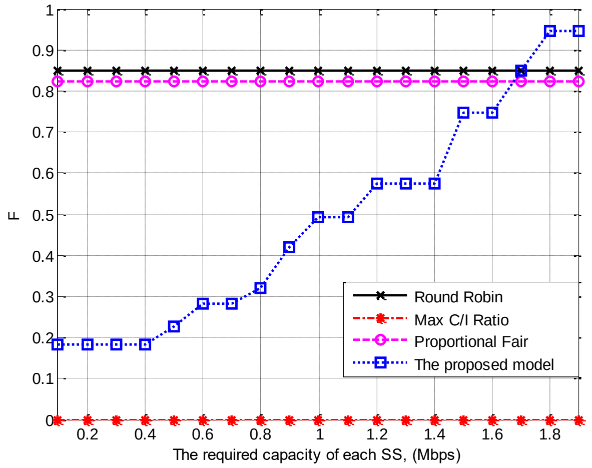

Fig.2. Dependence of the balancing degree of capacity of the downward communication channel in view of the used way of sub-channels scheduling on the required transmission rate

As the simulation results have shown (fig.2) the balancing degree of capacity of the downward communication channel, when using the known methods during the whole interval of measurement, did not vary and was equal to 0.85 for the Round Robin method 0.825, for the Proportional Fair method and 0 for the Max C/I Ratio method. The balancing degree of capacity of downward communication channel, when using the offered model (2)-(6) on the site $R_{req}^{n} = 0.1 \div 0.4$ Mbps, had the minimum value and was equal to 0.18. In the interval $R_{req}^{n} = 0.4 \div 1.9$ Mbps the balancing degree of capacity was increased up to the value of 0.94.

As the simulation results have shown the Proportional Fair method does not provide the required transmission speed for all users' stations starting with 1.4 Mbps. When using the Round Robin method the required transmission speed for the third SS is not provided starting with the value of $R_{req}^{3} = 1.8$ Mbps. The use of the Max C/I Ratio method makes it possible to provide the required transmission speed only to one (the fifth) US having the best value of product of bit loading of the character and speed of coding. The use of the offered model (2)-(6) provides selection of the required transmission speed of the SS within the whole interval of $R_{req}^{n} = 0.1 \div 1.9$ Mbps measurement.

Fig. 4 demonstrates the results of calculation of the probability to meet the requirements on the transmission speed scheduled to all SS. The probability to meet the requirements on the transmission speed on the i-th interval of measurement was defined according to expression

$$P^{i} = \frac{\sum\limits_{n=1}^{N} Q_{n}^{i}}{N},$$

where $\sum\limits_{n=1}^{N} Q_{n}^{i}$ – is an amount of the SS, to which the required transmission speed on the i-th interval of measurement, i.e. $Q_{n}^{i} = \begin{cases} 0, \text{ if } R_{n}^{i} < R_{req}^{i}; \\ 1, \text{ if } R_{n}^{i} < R_{req}^{i}. \end{cases}$ is scheduled.

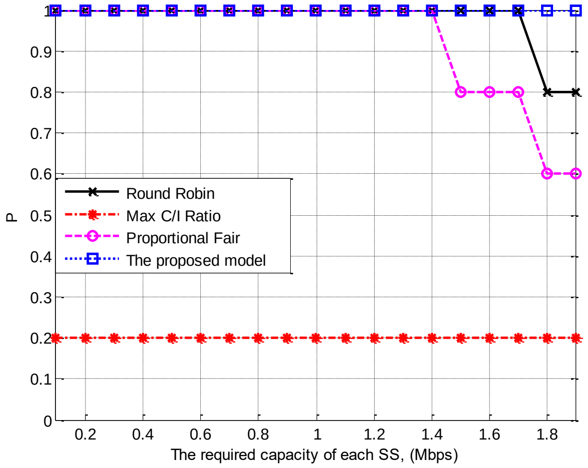

Fig.4. Dependence of probability to schedule the required transmission speed to SS in view of the used way of the sub-channels scheduling on the required transmission speed

ACKNOWLEDGMENT

It has been found out, that one of main tasks in the wireless network operating with the use of the WiMAX technology, is the task of supporting the required quality of service, which includes the need to schedule the required transmission speed in the downward communication channel to the users’ stations of the network. It has been also found out, that one of the effective ways of supporting the required transmission speed in the WiMAX technology can be reached by solving the task of the sub-channels scheduling in the downward communication channel. In this connection, the available mechanisms of the sub-channels scheduling between user's stations in the downward communication channel of the wireless network operating with the use of the WiMAX technology have been analyzed.

Based on the detected disadvantages of the known mechanisms of the frequency resources scheduling in the downward channel the mathematical model introduced by a number of linear and nonlinear conditions-limitations is offered. The novelty of this model consists in the statement of the sub-channels scheduling task as the tasks of rescheduling of the accessible capacity of the downward channel of the WiMAX technology for the information transmission in the direction of users stations, taking into account their territorial remoteness (type of the system of modulation and coding).

It has been marked, that the formulated task on the sub-channels scheduling of the downward channel from the point of view of physics of processes, taking place in the wireless network, belongs to the class of the tasks of frequency resources balancing, i.e. the number of sub-channels scheduled to the users’ stations, and from the mathematical point of view it is a task of nonlinear programming. The comparative analysis has shown that the best performance of the downward communication channel is provided with the Max C/I Ratio method, as well as the offered model (2)-(6). From the point of view of the balanced scheduling of capacity of the downward communication channel the best performance was provided with the Round Robin and Proportional Fair methods, under condition of low level requirements to the transmission speed of users’ stations. Under conditions of high level requirements to the transmission speed the most balanced scheduling of capacity of the downward communication channel was provided with the model, offered in (2)-(6).

The conducted analysis has also shown that the Max C/I Ratio, Round Robin and Proportional Fair methods were effective only under conditions of the low-level requirements to the transmission speed. Under conditions of high level requirements to the transmission speed of the users’ servers the model (2)-(6) turned out to be effective, providing to every user's station a guaranteed speed of transmission with the possibility of access to an additional (not guaranteed) transmission bandwidth, that in the service classes of the CoS corresponds to B subclass, whereas other methods do not guarantee scheduling of the required transmission speed, that in the service classes of the CoS corresponds to A subclass.

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