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RESEARCH OF IMPACT DOWNLINK PARAMETERS AND SERVICE DISCIPLINE ON BALANCING PROCESS THE SUBCHANNELS NUMBER ALLOCATED TO SUBSCRIBER STATIONS IN WIMAX

Introduction

Currently, the introduction of latest infocommunication services in terms of improving their mobility and availability is directly related to further deployment of wireless telecommunication technologies. However, the limiting factor in this case is low performance provided by wireless technologies in comparison with the wired solutions. At the same time for improving the performance of wireless technology standards such that 3G, 4G, and eventually 5G is necessary to use all available means to manage the available network resources: frequency, time, channel, buffer, and information. In this context, more and more attention of scientists, designers and developers of network equipment and appropriate standards paid to finding effective solutions of formation and optimal allocation of time-frequency resources available on the data link layer.

In WiMAX (Worldwide Interoperability for Microwave Access) technology, which surely takes one of the leading places in the market of wireless solutions, the main resource unit is a subchannel which is result of splitting the original frequency downlink. The number of such channels is entirely determined by the channel bandwidth ($1.25 \div 20$ MHz) and selected operating mode, and may vary from 2 to 32 for the DL FUSC mode, and from 3 to 60 for DL PUSC mode. It should be noted that the level of satisfaction of the Quality of Service requirement requests of a particular user station (Subscriber Station, SS) is determined by the number of subchannels allocated and modulation and coding scheme (Modulation and Coding Scheme, MCS) used.

Unfortunately, existing methods (schedulers) of time-frequency resource allocation, such as Proportional Fair Scheduling, Round Robin Scheduler, Max C/I Ratio, Best CQI Scheduling [1], do not satisfy the requirements for differentiation or guarantee quality of service (QoS). In this regard, there is an actual problem associated with improvement of frequency and time resource allocation methods in WiMAX technology. Currently there are known several approaches to optimization the process of frequency and time resource allocation in WiMAX technology [1-4]. Special attention should be paid to solutions based on balancing the number of subchannels and slots [2-4] allo-cated to particular subscriber station within generated bursts.

1. Model for Subchannel Balancing in Wireless Network of IEEE 802.16 Standard

In the method of balancing the number of subchannels allocated to subscriber station it is assumed that there are known the following inputs:
- bandwidth of used frequency channel is from the range of 1.25 MHz to 20 MHz;
- selected mode of usage of the subchannels (FUSC, PUSC, OPUSC, OFUSC, and TUSC);
- N is the total number of the SSs in the network;
- K is the number of subchannels used depending on the selected channel bandwidth (for example, using the mode of DownLink FUSC the number of subchannels can take values 2, 8, 16, 32; while for DownLink PUSC they are 3, 15, 30, 60);
- R_{req}^n is the required transmission rate for service of the n-th SS (Mbps);
- $R^{n,k}$ is the bandwidth of k-th subchannel allocated to the n-th SS.

In the WiMAX technology the duration of frame can vary and take values equal to 2, 2.5, 4, 5, 8, 10, 12.5, and 20 ms. 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 (Table 1).

Table 1

Guard Interval Values	$T_b/4$	$T_b/8$	$T_b/16$	$T_b/32$
T_g (µs)	22.4	11.2	5.6	2.8
OFDMA Symbol Duration, T_b+T_g (µs)	112	100.8	95.2	92.4

The 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 [5, 6]:

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

where $R_c^{n,k}$ is the speed of the code used at coding of a signal of the n-th SS; $K_b^{n,k}$ is the bit load of the symbol of the *n*-th SS; K_s is the number of subcarriers for the data transmission in one subchannel (for the DownLink FUSC submode $K_s = 48$ and for DownLink PUSC $K_s = 24$); $T_{RTG} = 105$ µs is the duration of the interval of switching from receiving to transmission (receive/transmit transition gap, RTG); $T_{TRG} = 60$ µs is the duration of the interval of switching from transmission to receiving (transmit/receive transition gap, TRG); *BLER* is the probability of the block error obtained at the expense of the Hybrid Automatic Repeat Request mechanism (HARQ) [1].

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

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

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

Total number of control variables depends on amount of subscriber stations in the network and used subchannels respectively defined by the expression $N \cdot K$. When calculating the required variables x_n^k, it is necessary to meet a number of important conditions limitations.

Condition of fixing one subchannel only for one subscriber station is defined according to the expression

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

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

$$\sum_{k=1}^{K} R^{n,k} x_n^k \geq R_{req}^n \delta_n, \tag{4}$$

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

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

$$\frac{\sum_{k=1}^{K} R^{n,k} x_n^k}{R_{req}^n} \geq \beta, \ (n = \overline{1,N}) \tag{5}$$

where β is a control variable too, characterizing lower bound of satisfaction level of QoS requirements to access rate. In general $\beta \geq 0$.

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

$$\beta \rightarrow \max. \tag{6}$$

Thus, the model of balancing the number of subchannels allocated 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, 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.

2. Research of Balancing Process the Subchannels Number without Guarantee of Access Rate (channel bandwidth 5 MHz, number of subscriber stations is 3)

Within research considered the following input data:
- number of subscriber stations is 3 ($N = 3$);
- number of available subchannels is 8 ($K = 8$);
- access rates required for each station: $R_{req}^1 = 1 \div 5$ Mbps (step 0.5 Mbps), $R_{req}^2 = 1.5$ Mbps,

$R_{req}^3 = 1$ Mbps;
- matrix of bandwidths:

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

In further investigation two cases were considered for input data mentioned above:

1. Process of balancing the number of subchannels to subscriber stations makes no guaranties for access rate: $\delta_n = 0$, $n = \overline{1,3}$.

2. Guaranties provided just to first station: $\delta_1 = 1$, $\delta_2 = 0$, $\delta_3 = 0$.

For the first case on Fig. 1 shown how adaptively changed the lower bound of satisfaction level of QoS requirements to access rate depending on the growth requirements of the first station to

access rate. As it can be seen from Fig. 1, with $R^1_{req} \leq 2$ Mbps each SS received the required QoS level, because $\beta \geq 1$. With further growth of $R^1_{req} > 2$ considered method adaptively (but not step-wise) reduced the level of quality of service for each station in dependence on their requirements for access rate (Fig. 2 – 4).
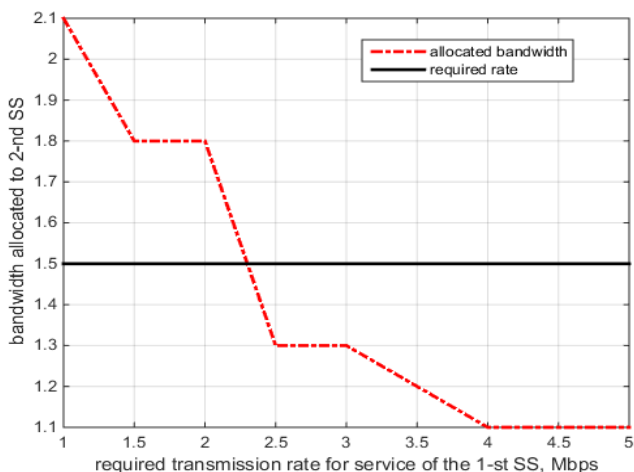

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5 shows an example of solving the problem of subchannel allocation between the three SSs according to the following initial data: $R^1_{req} = 3$ Mbps, $R^2_{req} = 1.5$ Mbps, $R^3_{req} = 1$ Mbps (fig. 1); service discipline is best effort for all SS. Within the obtained solution provided balanced allocation ($\beta = 0.8$) of eight subchannels between the three SSs according to their QoS requirements on bandwidth. An example includes the case where the frequency channel resource and its forming subchannels is not enough to meet the needs of subscriber stations ($\beta < 1$).
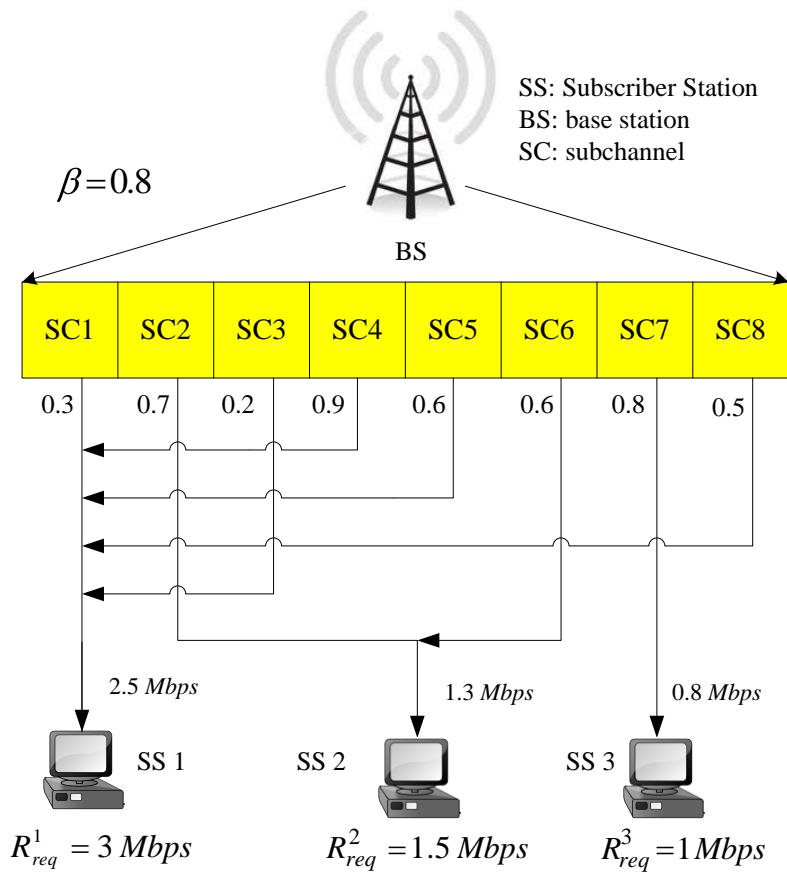
Fig. 5

3. Research of balancing process the subchannels number with guarantee of access rate for some subscriber stations (channel bandwidth 5 MHz, number of subscriber stations is 3)

For the second case, when guaranties of access rate provided just for some subscriber stations, considered the same input data as for the first. But guaranties provided only to first subscriber station: $\delta_1 = 1$, $\delta_2 = 0$, $\delta_3 = 0$. Then, on Fig. 6 shown how adaptively changed the lower bound of satisfaction level of QoS requirements to access rate depending on the growth requirements of the first station to access rate ($R_{req}^1 = 1 \div 3$, step 0.18 Mbps). As it can be seen from Fig. 5, with $R_{req}^1 \le 2$ Mbps each SS also received the required QoS level, because $\beta \ge 1$.

With growth of R_{req}^1 presented method due to limited volume of available channel resource adaptively reduced level of quality of service for each station in dependence on their requirements for access rate (Fig. 6). However, the first station always got required level of service for access rate (Fig. 7), and for second (Fig. 8) and third (Fig. 9) stations as expected QoS requirements were not satisfied with $R_{req}^1 > 2$.
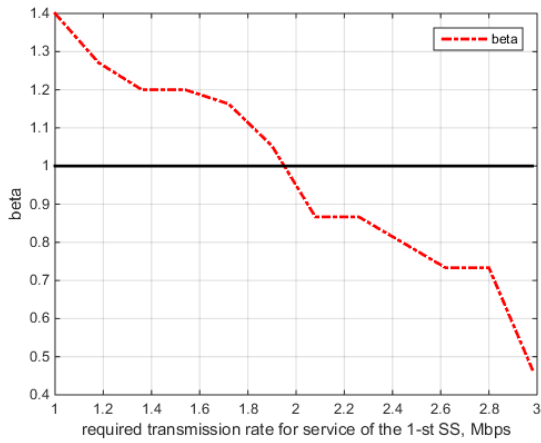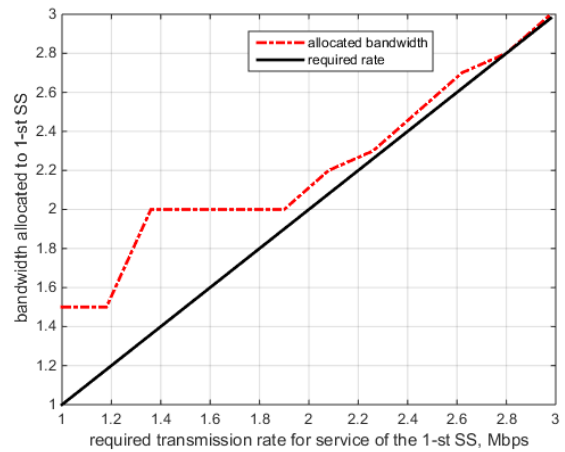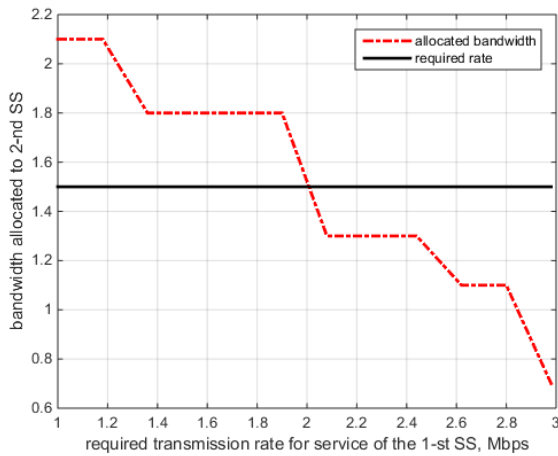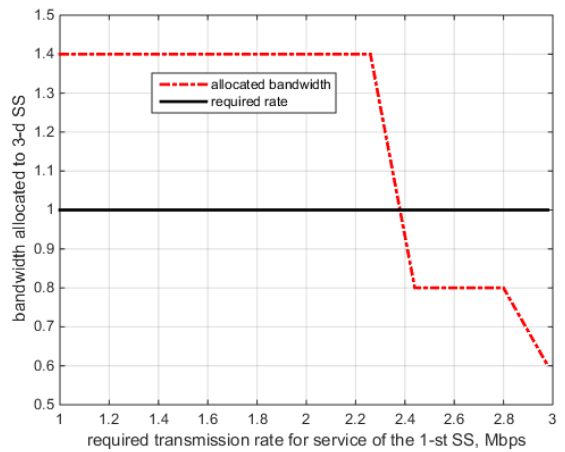
Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10 shows an example of solving the problem of subchannel allocation between the three SSs during the next initial data: $R_{req}^1 = 2.8$ Mbps, $R_{req}^2 = 1.5$ Mbps, $R_{req}^3 = 1$ Mbps (fig. 6); service disciplines are with guaranties for 1-st SS, and best effort service for 2-nd and 3-d SSs. Within the whole solution it was provided a balanced allocation ($\beta = 0.7333$) of eight subchannels between the three SSs, while the first station provides guaranties with respect to the increasing demands of bandwidth (fig. 7).

Analyzing the obtained results (fig. 1 – fig. 9), it can be concluded that a small bandwidth of the downlink (5 MHz) and related limited number of available subchannels ($K = 8$) affect the quality of balancing the use of channel resources. This was revealed in the fact that in some cases of initial data (QoS-requirements) not to all stations provided fair allocation of subchannels and downlink bandwidth. For example, with the use of best effort service discipline with $R_{req}^1 = 2.5$ Mbps, $R_{req}^2 = 1.5$ Mbps, $R_{req}^3 = 1$ Mbps (fig. 1 – fig. 4) third SS received 1.4 Mbps (instead of required 1 Mbps), while the first and second stations received respectively 2.3 Mbps and 1.3 Mbps, which was slightly below the stated requirements.

$\beta = 0.7333$

SS: Subscriber Station
BS: base station
SC: sub-channel

BS

| SC1 | SC2 | SC3 | SC4 | SC5 | SC6 | SC7 | SC8 |

0.3   0.5   0.5   0.9   0.6   0.6   0.8   0.5

2.8 *Mbps*

1.1 *Mbps*

0.8 *Mbps*

SS 1

SS 2

SS 3

$R_{req}^1 = 2.8\,Mbps$
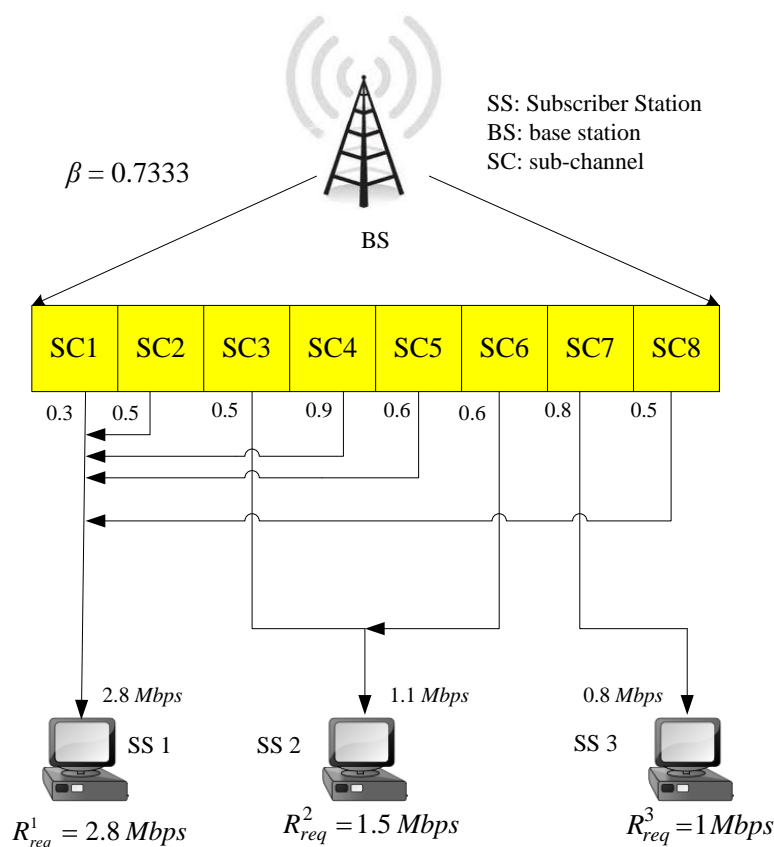
$R_{req}^2 = 1.5\,Mbps$

$R_{req}^3 = 1\,Mbps$

Fig. 10

A similar result was typical for the combined use of best effort service and guaranteed service disciplines (fig. 6 – fig. 9). Thus, with $R_{req}^1 = 2.2$ Mbps, $R_{req}^2 = 1.5$ Mbps, $R_{req}^3 = 1$ Mbps third station requirements were met (1.4 Mbps), while for the second station demands were not satisfied (1.3 Mbps). The results of numerous calculations showed that the cause of these problems is the fact that with a relatively small number of subchannels, which are provided the discrete allocated bandwidth for each SS, ensuring the ideal fair balancing of resources is difficult. This is especially true for the case where the number of subscriber stations or QoS-demands grow, and channel bandwidth and number of formed subchannels remain unchanged or even reduced.

4. Research of Balancing Process the Subchannels Number without Guarantee of Access Rate (channel bandwidth 10 MHz, number of subscriber stations is 3)

Within research considered the following input data:
- number of subscriber stations is 3 ($N = 3$);

- number of available subchannels is 16 ($K = 16$);

- access rates required for each station: $R_{req}^1 = 1 \div 7$ Mbps (step 0.45 Mbps), $R_{req}^2 = 2.5$ Mbps, $R_{req}^3 = 3$ Mbps;

- matrix of bandwidths:

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

As an example, consider the case when the process of balancing the number of subchannels to subscriber stations makes no guaranties for access rate: $\delta_n = 0$, $n = \overline{1,3}$. In analogy with Fig. 1 ÷ 4 on Fig. 11 ÷ 14 it was shown the effect on the process of balancing channel resource use with increasing QoS demands on the bandwidth, for example, of the first subscriber station. As was shown on Fig. 11÷14, with $R_{req}^1 \leq 4.3$ all stations have received a satisfactory quality of service ($\beta \geq 1$), while with further increase of QoS demands of the first station available network resources are allocated in accordance with the requirements of the stations to their allocated downlink bandwidth. Increasing the amount of available for allocation frequency subchannels (8 to 13), while maintaining the same number of subscriber stations ($N = 3$), it is possible to achieve almost ideal balancing of the frequency resource (Fig. 11) which in the limit should be a linear dependence [5, 6].
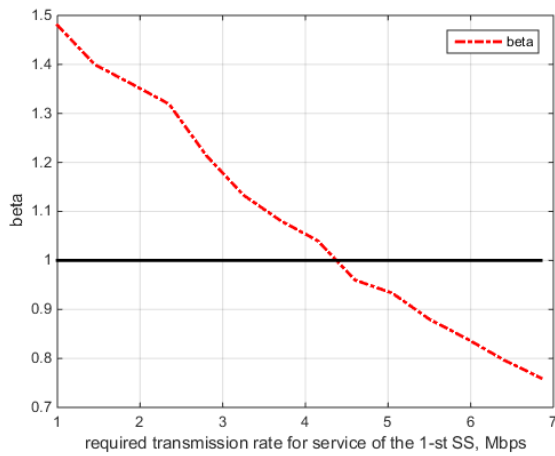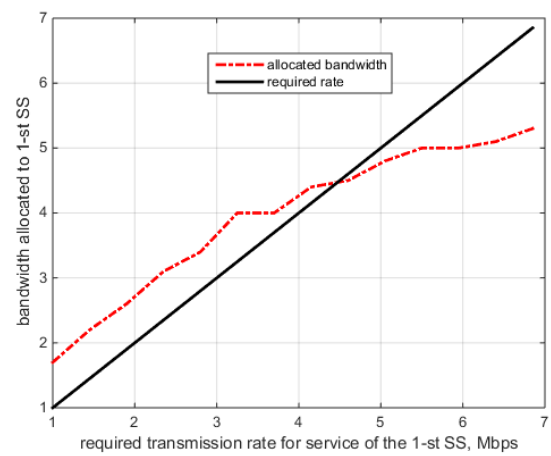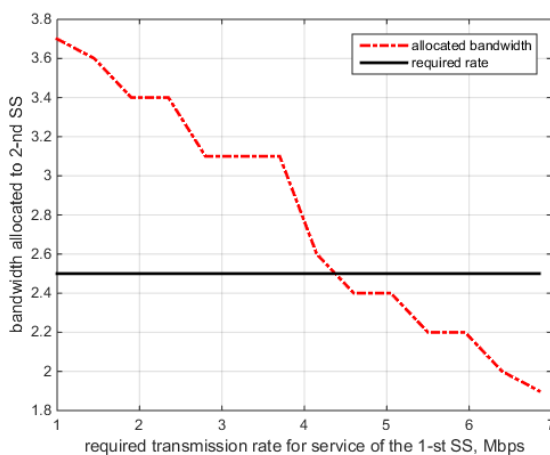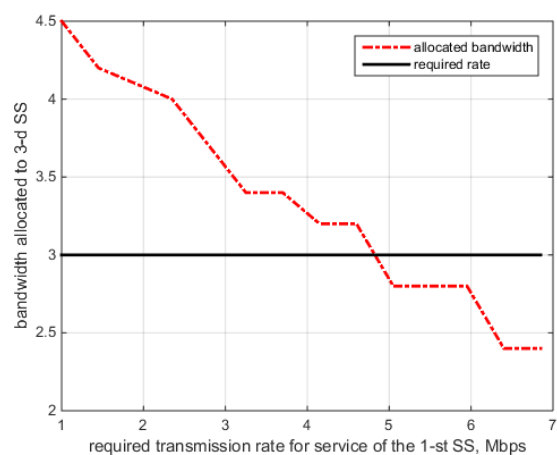

Fig. 11

Fig. 12

Fig. 13

Fig. 14

On the Fig. 15 it was shown an example of solving the problem of subchannels allocation between the three SSs according to following initial data: $R_{req}^1 = 5.05$ Mbps, $R_{req}^2 = 2.5$ Mbps,

$R_{req}^3 = 3$ Mbps (fig. 11); service discipline for this example is best effort service for all SSs. Within the obtained solution provided balanced allocation ($\beta = 0.9333$) of sixteen subchannels between three SSs according to their QoS requirements on bandwidth.
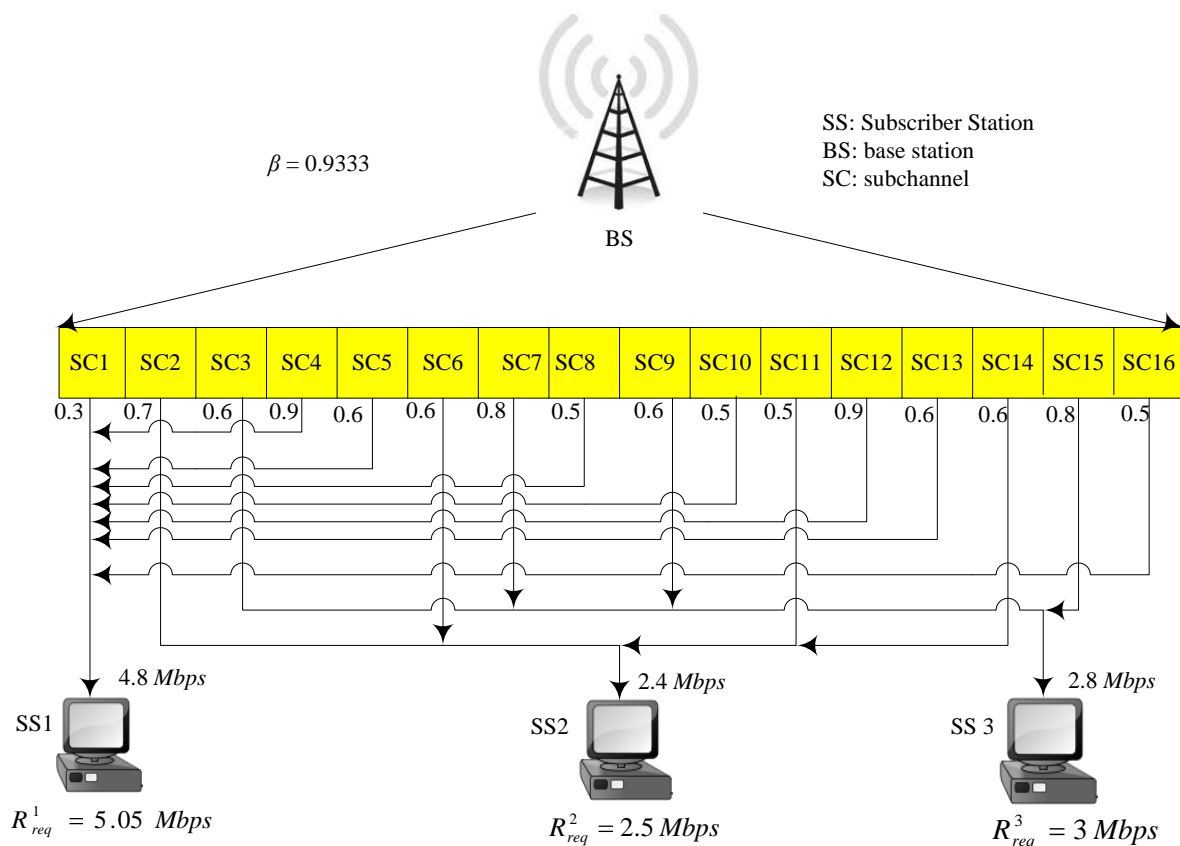

Fig. 15

Conclusion

The tasks of ensuring the quality of service in WiMAX networks are very important with the basic QoS indicator access rate. Depending on the type of provided service the required access rate can differentiate and in some cases even be guaranteed. Ensuring required access rate is mainly determined by the quality of solving problems at the data link layer OSI, in particular, the problem of allocation the set of subchannels to separate subscriber station. It is important to note, that the same subchannel will provide a different rate for various SSs (depending on the SNR, selected modulation and coding scheme), while the amount of total available resource depends on the channel bandwidth (the number of subcarriers and subchannels).

To solve this problem proposed the model for subchannel balancing in wireless network of IEEE 802.16 standard (1)-(6). Thus, the method of balancing the number of subchannels allocated to subscriber station in WiMAX network based on solution of optimization problem associated with maximizing the lower level allocated bandwidth for 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, 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.

Research of proposed model confirmed the adequacy of the model (1)-(5) and effectiveness of solutions as a whole in terms of providing different types of service level (with and without guaran-

ties) to subscriber stations. Results showed that in balancing the number of subchannels allocated to SSs with a deficit of network resource adaptive reduction of provided level of quality of service performed dependently on the type of possible guaranties and requirements regarding the access rate.

Furthermore, as shown by the results of calculations quality of balancing depends on the available for allocation frequency subchannels and the number of subscriber stations. If the minimum number of available subchannels, for example, eight, with the use of represented model (1)-(6) is not always possible to ensure a fair allocation of subchannels between subscriber stations (Fig. 1-4 and Fig. 6-9). This is especially true for the case where the number of subscriber stations or QoS demands increase, while the channel bandwidth and number of formed subchannels remain unchanged or even reduced. Increasing the amount available for allocation frequency subchannels (from 8 to 13), while maintaining the same number of subscriber stations ($N = 3$), it is possible to achieve almost ideal balancing of the frequency resource (Fig. 11) which in the limit should be a linear dependence.

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