Analysis Results of WIMAX Dowlink Traffic Management Model In Congestion Conditions

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Abstract

The results of development a mathematical model for capacity allocation downlink technology WiMAX. The novelty of the proposed model is possible preventive limit transmission rate allocated to the service flows of the user stations in the downlink by using the WiMAX technology linear or linear-quadratic objective function. It is shown that the use of a linear-quadratic objective function in comparison with the linear, can produce a more equitable management of requests based on the relative priorities. The analysis of known methods for dividing the time-frequency resource WiMAX technology showed that they all focus on the distribution between the subscriber stations all bandwidth downlink. The model proposed is directed to the allocation of each user station a guaranteed bit rate in the absence of overload downlink as well as the preventive rate limiting allocated user stations under overload conditions. Using the mathematical model is directed to distribution between subscriber stations of a time-frequency resource of the downlink, which in turn improves the conditions in the electromagnetic frequency range used. The influence of the priority request rate used in the model, the nature of the possible failures.

1 Introduction

Today in modern telecommunication networks, specifically in WiMAX networks, numerical values of certain Quality of Service (QoS) indexes, one of which is guaranteed transmission rate, are mainly deciding effectiveness of traffic management task [1, 2]. Taking into consideration heterogeneity and multiprotocol nature of modern wireless technologies, especially in case of congestion, frequency and time resources constrains, enhancement of downlink bandwidth distribution coordination between Subscriber Stations (SS) and rate limiting traffic fed to network becomes primary task. At the same time possibility of MAC-sublayer QoS provisioning for each Service Flow (SF) needed to be taken into consideration. In addition, considering multiservice nature of modern wireless technologies, denial of service should apply to low-priority traffic in the first place.

As analysis shows, known methods of WiMAX downlink bandwidth distribution use Best Effort (BE) approach. Which means that quality of provided service is not guaranteed and all SS share available bandwidth [2]. However, WiMAX supports couple Classes of Service besides of BE, among those Not Real Time, Real Time, Extended Real Time, Unsolicited Grant Service, which are oriented to guaranteed bandwidth allocation.

Thereby, development and study of WiMAX downlink bandwidth distribution methods and mathematical models, which guarantee provisioning of needed bandwidth to SS and their SF, which also could be used as a basis of next-generation technological solutions is seen to be topical scientific and practical task. As a result, WiMAX downlink bandwidth distribution mathematical model was developed.

2 Initial Data

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.

In the proposed model, the following inputs are assumed to be known [1]:

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 dura-

tion 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 according, 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 [3] 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 modulation and coding system (MCS), depending on geographically remote SS;

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

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

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 [3]), 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 [3]. 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 [3]:

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

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

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 MCS of overhead information the QPSK 1/2 is used. As a result, the following settings $R_c^{\text{MAP}} = 2$ and $k_b^{\text{MAP}} = 1/2$ 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

$$Q = Q_{DL-MAP} + Q_{UL-MAP} + Q_{FCH}, \tag{4}$$

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

3 Model of time-frequency resources distribution

During solution of transmitted burst scheduling task for downlink-sending SF of all SS in framework of proposed model, calculation of Boolean management variable ($x_{k,m}^n$), which defines slot distribution order, needs to be done:

$$x_{k,m}^n = \begin{cases} 1, \text{ if } m\text{-th slot on } k\text{-th} \\ \quad \text{subchannel is allocated to } n\text{-th SS}; \\ 0, \text{ otherwise.} \end{cases} \tag{5}$$

Besides that value α^n is introduced, which simulates fraction of bandwidth allocation denials [4]. Then considering (5) vector of sought parameters is conveniently expressed as:

$$\vec{X} = \begin{bmatrix} x_{k,m}^n \\ --- \\ \alpha^n \end{bmatrix}. \tag{6}$$

Coordinates of $\vec{X}$ vector is a set of variables $x_{k,m}^n$, where $n = \overline{1,N}$, $m = \overline{1,M}$, $k = \overline{1,K}$, and a number of α^n parameters, where $n = \overline{1,N}$. In this case set of variables $x_{k,m}^n$ is defined as $N \times M \times K$.

According to variables calculations results (6) sub-channel fixing and slots distribution for SS service flow, which will be used for downlink data transmission. In addition, during calculations of sought parameters vector $\vec{X}$, couple important criteria-constraints need to be satisfied:

1) Criterion of k-th channel fixing not more than for single SF during m-th slot transmission:

$$\sum_{n=1}^{N} x_{k,m}^n \le 1 \ (k = \overline{1,K}; m = \overline{1,M}). \tag{7}$$

2) Criterion of slot quantity fixing for n-th SF, which provides needed bandwidth considering modulation and coding techniques used on certain SS:

$$R_S^n \sum_{m=1}^{M} \sum_{k=1}^{K} x_{k,m}^n \ge R_{req}^n \quad (n = \overline{1,N}), \tag{8}$$

where $R_S^n = \dfrac{SR_c^n k_b^n K_s}{(T_b + T_g)L + T_{RTG} + T_{TTG}}$ 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); 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) Criteria of single burst forming for n-th SF of certain SS, which allows minimization of slots used for service traffic transmission:

$$x_{k,i}^n x_{k,z}^n (i - z + 1) - \sum_{u=z}^{i} x_{k,u}^n \le 0\,, \qquad (9)$$

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

$$x_{j,m}^n x_{r,m}^n (j - r + 1) - \sum_{s=r}^{j} x_{s,m}^n \le 0\,, \qquad (10)$$

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

4) Criterion of "square shape" burst forming with accordance to technological aspects of IEEE 802.16 standards family utilizing OFDMA:

$$x_{k,m}^n \sum_{d=1}^{M} x_{k,d}^n \sum_{b=1}^{K} x_{b,m}^n = x_{k,m}^n \sum_{g=1}^{K} \sum_{h=1}^{M} x_{g,h}^n\,, \qquad (11)$$

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

5) Criteria of needed slots used for service traffic transmission reservation:

$$\sum_{k=1}^{K} \sum_{n=1}^{N} x_{k,m}^n = 0\,,\ (m = \overline{1, m_{oh} - 1}, \lceil Q/K \rceil \ge 1); \qquad (12)$$

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

$$\sum_{n=1}^{N} x_{k,1}^n = 0\,,\ (k = \overline{1, k_{oh}}, \lceil Q/K \rceil < 1), \qquad (14)$$

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 (12) and (13) 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 $\lceil Q/K \rceil \ge 1$. Besides, condition (12) allows to make a reservation all subchannels for transmission of the number of slots equal to m_{oh}. Conditions (13) and (14) reserve a part of subchannels (k_{oh}) for the duration of one slot.

According to physics of task being solved coordinates α^n of vector $\vec{X}$ are subject to following constraints [4]:

$0 \le \alpha^n \le 1$ (15) or $\alpha^n \in \{0{,}1\}$, (16)

if based on Service Level Agreement (SLA) partial transmission rate limiting is permitted (15) or not permitted (16).

Calculation of sought variables (6) according to criteria-constraints is reasonable to perform during solving optimization task, providing minimum of linear (17) or linear-quadratic (18) target functions [4]:

$$\min_X C^t \vec{X} = \min_X \sum_{k=1}^{K} \sum_{m=1}^{M} \Big(\sum_{n=1}^{N} c_{k,m}^n x_{k,m}^n + \sum_{n=1}^{N} c^n \alpha^n \Big)\,, \qquad (17)$$

$$\min_X \left[\frac{1}{2} \vec{X}^t H \vec{X} + C^t \vec{X} \right], \qquad (18)$$

which characterize relative cost of bandwidth distribution during data burst scheduling. Coordinates of vector $\vec{C}$ and matrix H can be expressed as:

$$\vec{C} = \begin{bmatrix} c_{k,m}^n \\ --- \\ c^n \end{bmatrix} \quad (k = \overline{1, K}\,;\ m = \overline{1, M}\,;\ n = \overline{1, N}), \qquad (19)$$

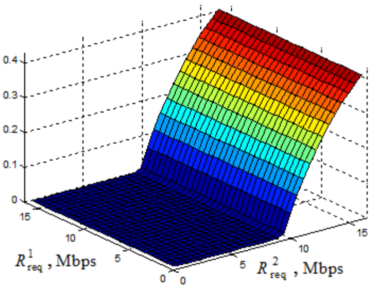
$$H = \begin{Vmatrix} \mu c_{11}^1 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mu c_{12}^1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu c_{k,m}^n & 0 & 0 \\ 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu c^n \end{Vmatrix}. \qquad (20)$$

Coordinates of vector $\vec{C}$ define relative penalty for downlink slots usage ($c_{k,m}^n$) and limitation of user traffic service (c^n), provided, that $c_{k,m}^n << c^n$, μ – coefficient defining how much coordinates of diagonal matrix H are bigger (smaller) than coordinates of vector $\vec{C}$.

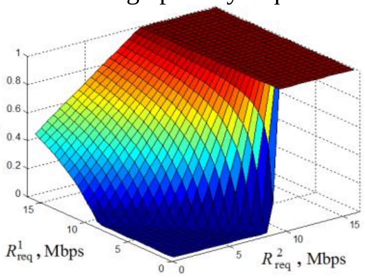
4 Analysis the received decisions

There was also conducted analysis of downlink data burst scheduling process at joint maintenance of two SFs by guides of one SS with different priorities driven by changing relations meaning $\Delta C = c_{k,m}^n / c^n$. During the research we found out that the character of possible refusals at the suggested model using depends, first of all, on number of subscribers stations and MCS use by the stations. Secondly the character of possible refusals depends of relation of costs for loading the downlink ($c_{k,m}^n$) to costs for service limitation subscribers traffic (c^n).

Below at the fig.1 and fig.2 presented dependences of refusals share at allocation necessary bandwidth of high priority (α^1) and low priority (α^2) services flows for linear and linear-quadratic objects functions. The results of the analysis showed that within suggested model service of SSs requirements is realized on the base of absolute priorities. So, using linear objective function in case when sum of requirements for demanded transmission rate exceeds bandwidth of downlink so preventive limitation gets requirement from low priority SS up to full refusal of access (fig. 1 b). Requirement for transmission rate from service flow with higher priority won't be jammed until there is possibility of refusal to low priority requirement (fig. 1 a).



a) refusals of high priority requirement



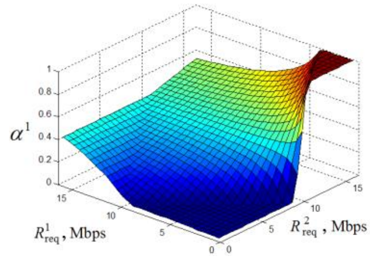
b) refusals of low priority requirement

Figure 1. Dependence of refusals share from their requirements for demanded transmission rate at linear objective function.

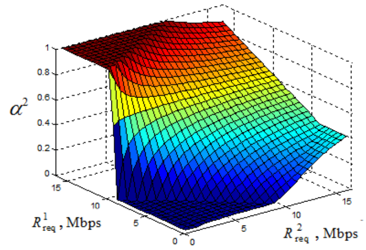
Using linear-quadratic objective function there is organized more fair management at the basis of relative priorities than when using linear objective function. I.e. in case of possible overload service refusals touch upon all the services flows at this high priority has less degree (fig. 2 a) and low priority has bigger degree (fig. 2 b). Under this model has possibility to adjust preventively of traffic limitation, going into the network by changing weight coefficients also by degree of percent correlation of possible refusals magnitude when serving high priority traffic relatively to low priority by changing meaning of μ of diagonal matrix H.

5 Conclusion

Ascertain, that one of the main tasks in WiMAX networks is the task of demanded QoS provision, which relies on guaranteed downlink bandwidth allocation for SS. Provisioning of such guaranteed bandwidth in WiMAX can be achieved by solving a downlink bandwidth distribution task. Considering this, existing approaches for wireless network downlink band-width distribution of WiMAX technology were analyzed. As a result it was specified, that all of them are using BE principle.



a) refusals of high priority requirement



b) refusals of low priority requirement

Figure 2 Dependence of refusals share from their requirements for demanded transmission rate at linear-quadratic objective function.

Mathematical model was proposed, novelty of which consists in ability to preventively limit transmission rate which is allocated for subscriber station's SF in WiMAX downlink by using linear or linear-quadratic target function, which provides inquiries management using relative priorities. Besides that, proposed mathematical model treats solving a distribution of slots between data bursts as an available WiMAX downlink bandwidth balancing for sending data toward SS considering type of modulation and coding system.

6 Literature

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