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METHOD OF PRESENTATION INTEGER PROBLEM FREQUENCY RESOURCE ALLOCATION IN LTE AND WiMAX NETWORKS AS NONLINEAR PROGRAMMING

In paper proposed a method of presentation integer problem frequency resource allocation in LTE and WiMAX networks in the form of nonlinear programming problems. The method is based on the fact that the integer character of control variables which are responsible for the order of frequency resource allocation in LTE and WiMAX networks is provided by the additional nonlinear constraints. The transition from the MINLP and MILP problems to nonlinear programming problem solving can significantly reduce the computational complexity of resulting solutions on frequency resource allocation in LTE and WiMAX networks. This is especially important due to the fact that these problems must be solved in real time with minimum requirements for hardware and software of LTE eNodeB or WiMAX Base Station in a permanent increase the number of users (UE and SS).

Keywords: *LTE, WiMAX, frequency resource, resource block, subchannel, method, optimization, nonlinear programming.*

Introduction

Performance of modern Metropolitan Area Networks (MAN), based on LTE (Long-Term Evolution) and IEEE 802.16 (WiMAX) technologies, mainly determined by forming the frequency resource and methods of its efficient allocation to user stations. In LTE technology such resources include the Resource Block (RB), and in WiMAX is a frequency subchannels. In the relevant standards [1, 2] clearly defined procedure of forming resource blocks and subchannels depending on the channel bandwidth and operating modes of network equipment.

For allocation of frequency subchannels and resource blocks there are a lot of different solutions proposed currently: from simple heuristic schemes [3, 4] to more complex models and methods [5-13], based on optimization formulation and solution of this problem.

From the point of view of both science and practice the future is for the second group of solutions able to optimize the allocation of frequency resources in LTE and WiMAX networks in order to provide a given level of Quality of Service (QoS).

It is important to note, that the major deterrent in practical use of optimization models and methods of allocation frequency resources in LTE and WiMAX networks in real time is their relatively high computational complexity.

This is due to the fact that the result of the allocation of frequency resources, as a rule, obtained by solving a rather complicated problem of discrete programming of high dimension, related to the class of Integer Linear Programming (ILP) [7-9], Mixed Integer Linear Programming (MILP) [13], and sometimes Mixed Integer Nonlinear Programming (MINLP) [10].

In this regard, actual is the problem associated with the reduction of computational complexity of solutions on allocation the frequency resources in LTE and WiMAX networks, based on the change of class optimization problem to be solved without loss of adequacy of final solutions.

1. Realization of Resource Blocks Allocation in LTE Downlink in the Form of Nonlinear Optimization

1.1. Presentation of Resource Blocks Allocation in LTE Downlink in the Form of MINLP Optimization

When using Resource Allocation Types (RAT) 1 the set of resource blocks is divided into several non-overlapping subsets, the number of which (N_{RB}^{DL}) is determined by Resource Block Group (RBG) size (P parameter):

$$P = \begin{cases} 1, & \text{if } N_{RB}^{DL} \le 10; \\ 2, & \text{if } N_{RB}^{DL} = 11 \div 26; \\ 3, & \text{if } N_{RB}^{DL} = 27 \div 63; \\ 4, & \text{if } N_{RB}^{DL} = 64 \div 110. \end{cases} \quad (1)$$

The number of resource blocks in subsets may vary. To determine the number of resource blocks in subsets in LTE technology the following expression is proposed [2]:

$$N_{RB}^{RBGsubset}(p)=\begin{cases}\left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2}\right\rfloor P+P, \\ \text{at } p<\left\lfloor \dfrac{N_{RB}^{DL}-1}{P}\right\rfloor \bmod P; \\ \left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2}\right\rfloor P+\left(N_{RB}^{DL}-1\right)\bmod P+1, \\ \text{at } p=\left\lfloor \dfrac{N_{RB}^{DL}-1}{P}\right\rfloor \bmod P; \\ \left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2}\right\rfloor P, \\ \text{at } p>\left\lfloor \dfrac{N_{RB}^{DL}-1}{P}\right\rfloor \bmod P, \end{cases} \quad (2)$$

where $N_{RB}^{RBGsubset}(p)$ is power of the p-th subset; p is a current number of resource blocks in subset for which calculation of power is performed ($p=\overline{0,P-1}$); N_{RB}^{DL} is the number of RBs formed during the transmission of one time slot. In LTE technology the number of RBs depends on the width of frequency channel and may be equal to 6, 15, 25, 50, 75, 100.

As a result of performed analysis there was made a decision to develop a mathematical model for bandwidth management in LTE downlink using RAT 1, and it is formulated as a problem of resource blocks allocation for providing required bandwidth for each user equipment (UE). In [7] proposed linear model of bandwidth allocation in LTE downlink with RAT 1 reduced to task of mixed integer linear programming. In this paper proposed an approach helps to reduce the computational complexity of the solution of initial problem, which is based on the modification of model proposed in [8-10].

In chosen model assumed that the following initial data is known:

- N is the number of UEs;
- K_s is the number of subcarriers for data transmission in a single RB. This parameter depends on the frequency diversion between subcarriers Δf, and it must satisfy the term $K_s\Delta f=180$ KHz. K_s can be equal to 12 and 24, that already corresponds to the frequency diversion between subcarriers Δf as 15 KHz and 7.5 KHz;
- N_{symb}^{RB} is the number of symbols that form a single resource block. Parameter N_{symb}^{RB} =7 in case of using normal cyclic prefix (CP). Duration of the normal CP of the first OFDM symbol is T_{CP}^{1} =5.2 μs, from second to sixth OFDM symbol it is T_{CP}^{2-6} =4.7 μs. When using the extended CP (T_{CP} =16.7 μs) RB consists of six OFDM symbols (N_{symb}^{RB} =6);
- T_{RB} =0.5 ms is time of one RB transmission;
- T_{SF} =1 ms is time of one subframe transmission;
- N_{SF}^{RB} =2 is the number of RBs that are formed on the identical subcarriers and are allocated to UE during the transmission of one subframe;
- R_c^n is the rate of code used in signal coding of the n-th UE;
- k_b^n is bit symbol load of the n-th UE;
- type of channel division (FDD or TDD), and frame configuration used;
- R_{req}^n is the required data transmission rate for n-th UE;
- K is the number of subframes used to transmit information in the downlink. When using FDD the number of downlink subframes is equal to the total number of subframes per frame (K =10). When using TDD the number of downlink subframes must be used according to the frame configuration;
- $M=\max(N_{RB}^{RBGsubset})$ is the largest number of resource blocks belonging to any subset.

For solving the problem of bandwidth allocation in LTE downlink with RAT 1 within the proposed model it is needed to provide the calculation of Boolean control variable ($x_n^{m,p}$), that determines the order of resource block allocation:

$$x_n^{m,p}=\begin{cases}1, \text{ if the } m-\text{th resource block on} \\ \text{the } p-\text{th subset allocated to the } n-\text{th UE;} \\ 0, \text{ otherwise,}\end{cases} \quad (3)$$

where $m=\overline{0,M-1}$; $p=\overline{0,P-1}$; $n=\overline{1,N}$.

When calculating the desired variables $x_n^{m,p}$ several important terms-limitations should be fulfilled:

1) The term of allocating each resource block to only one user equipment:

$$\sum_{n=1}^{N} x_n^{m,p}\le 1, \; (m=\overline{0,M-1}; p=\overline{0,P-1}). \quad (4)$$

2) The term of allocating number of resource blocks to n-th user equipment that provide the required bandwidth in the downlink using modulation and coding scheme (MCS):

$$\sum_{m=0}^{M-1}\sum_{p=0}^{P-1} x_n^{m,p}\frac{N_{symb}^{RB}N_{SF}^{RB}K_S R_c^n k_b^n K}{10T_{SF}}\ge R_{req}^n, \; n=\overline{1,N}. \quad (5)$$

3) The term of allocating n-th user equipment a number of resource blocks of only one subset, which is introduced to satisfy the specifics of designing the LTE downlink that uses RAT 1 [10]:

$$\sum_{s=0}^{P-2}\left[\prod_{p=s+1}^{P-1}\sum_{m=0}^{M-1} x_n^{m,p}\right]=0\,, \quad n=\overline{1,N}\,. \qquad (6)$$

4) The term of allocating n-th user equipment a number of resource blocks that satisfy sizes of subsets determined using the expression (1):

$$\sum_{n=1}^{N}\sum_{m=N_{RB}^{RBGsubset}(p)}^{M-1} x_n^{m,p}=0\,, \qquad (7)$$

at $p=\overline{0,P-1}$; $N_{RB}^{RBGsubset}(p)<M$.

Use of the term (7) is directed to allocate a number of resource blocks, corresponding to the power of the p-th subset and determined with the expression (1), to UEs. Introduction of this term into the mathematical model is caused by the fact that during the calculation of control variables (3) for taking into account the number of resource blocks we use a variable m, that takes values from 0 to $M-1$ ($m=\overline{0,M-1}$). Thus, fulfillment of the terms (6), (7) guarantees that resource blocks which do not belong to the p-th subset ($m=\overline{N_{RB}^{RBGsubset}(p),M-1}$), will not be allocated to UEs in conditions when the power of this subset is less than maximum value ($N_{RB}^{RBGsubset}(p)<M$).

The calculation of variables (3) according to the terms (4) – (7) is reasonable to make in solving the optimization problem using next optimality criterion [9]:

$$\min_x \sum_{n=1}^{N}\sum_{m=0}^{M-1}\sum_{p=0}^{P-1}\left[x_n^{m,p} r_{n,m}+x_n^{m,p}\right], \qquad (8)$$

where $r_{n,m}=\dfrac{N_{symb}^{RB}N_{SF}^{RB}K_S R_c^n k_b^n K}{10T_{SF}}$ is a bandwidth allocated by m-th RB to n-th UE.

The task formulated from the mathematical point of view is the task of mixed integer nonlinear programming (MINLP). In the model the desired variables $x_n^{m,p}$ (3) are Boolean, and restrictions for the desired variables (6) are nonlinear.

1.2. Transformation MINLP of Resource Blocks Allocation in LTE network to a Nonlinear Programming Problem

Solution of the mixed integer nonlinear programming problem with the increase of control variables (3) number caused by increase of UEs and RBs number can be much more complicated from a computational point of view. Therefore, it is proposed to formulate the problem of RBs allocation in the form of nonlinear programming problem by dropping the fact that control variables ($x_n^{m,p}$) are Boolean. For this purpose, the expression (3) is replaced by the conditions

$$0\le x_n^{m,p}\le 1\,, \ (m=\overline{0,M-1}\,;\ p=\overline{0,P-1}\,;\ n=\overline{1,N}\,), \qquad (9)$$

i.e. introduced additional control variable $x_0^{m,p}$ that should be set to "1" in case when m-th RB is not allocated to any UE, and "0" otherwise.

In order to preserve the physical meaning of the model (4)-(7), which is in allocating the m-th RB of p-th subset to the n-th UE, it is necessary to ensure that the control variables $x_n^{m,p}$ assumed to have "0" and "1" values. For this purpose into model of RBs allocation introduced additional restrictions on the control variables:

$$\sum_{m=0}^{M-1}\sum_{p=0}^{P-1} x_n^{m,p}x_s^{m,p}=0\,, \ (n,s=\overline{0,N}\,,\ n\ne s\,), \qquad (10)$$

aimed to ensure that the m-th resource block is not allocated to two or more UEs at the same time. Also, to mathematical model was introduced restriction which together with (10) provides allocation of m-th RB to not more than one UE

$$\sum_{n=0}^{N} x_n^{m,p}=1\,, \ (m=\overline{0,M-1}\,;\ p=\overline{0,P-1}\,). \qquad (11)$$

Thus, despite the replacement of condition $x_n^{m,p}=\{0,1\}$ by (9) using (10) and (11) kept the physical meaning of control variables ensuring allocation of the m-th RB of p-th subset to the n-th UE. Application of improved model, implemented by noninteger control variable, made it easier to find an optimal solution of the problem and promoted the resource blocks allocation of downlink on practice in real time without losing its description adequacy.

Besides, as has been shown by analysis of existing solutions, in addition to solving problem of allocation of frequency and time resources can also be solved the problem of their joint allocation, which allows more accurately meet the requirements for bandwidth in the downlink of LTE technology.

2. Realization of Subchannel Allocation in WiMAX Downlink in the Form of Nonlinear Optimization

2.1. Presentation of Subchannel Allocation in WiMAX Downlink in the Form of MILP Optimization

In the model of subchannel allocation to subscriber station (SS) 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 [1, 12, 13]:

$$R^{n,k} = \frac{R_c^{n,k} K_b^{n,k} K_s (1 - BLER)}{T_b + T_g + T_{RTG} + T_{TRG}}, \qquad (12)$$

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); $T_{TRG} = 60\,\mu s$ 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 [13]:

$$x_n^k \in \{0,1\}, \ (n = \overline{1,N}, \ k = \overline{1,K}), \qquad (13)$$

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

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

$$\sum_{n=1}^{N} x_n^k \le 1, \ (k = \overline{1,K}), \qquad (14)$$

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

$$\sum_{k=1}^{K} R^{n,k} x_n^k \ge R_{req}^n \delta_n, \qquad (15)$$

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

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

$$R_{all}^n \big/ R_{req}^n \ge \beta, \ (n = \overline{1,N}), \qquad (16)$$

where $R_{all}^n = \sum_{k=1}^{K} R^{n,k} x_n^k$ is bandwidth allocated to the n-th SS; β is a control variable too, characterizing lower bound of satisfaction level of QoS requirements to access rate. In general $\beta \ge 0$.

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 meeting QoS requirements to access rate, i.e.

$$\beta \to \max. \qquad (17)$$

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 (17) according to its QoS requirements for access rate. As the constraints stated in solving the optimization problem are conditions (12)-(16). Formulated optimization problem belongs to class of mixed-integer linear programming.

2.2. Transformation MILP of Frequency Subchannel Allocation in WiMAX network to a Nonlinear Programming Problem

For the purpose of non-integer formulation (13) for a problem of frequency subchannel allocation in WiMAX network let us use the method set out in subsection 1.2. For this purpose expressions (13) are replaced by the terms of the form

$$0 \le x_n^k \le 1, \ (n = \overline{0,N}, \ k = \overline{1,K}), \qquad (18)$$

i.e. introduced additional control variable x_0^k that should be set to “1” in case when k-th subchannel is not allocated to any SS, and “0” otherwise.

Into model of subchannels allocation introduced additional restrictions on the control variables so as to one frequency channel could not be allocated to multiple SSs at the same time:

$$\sum_{k=1}^{K} x_n^k x_s^k = 0, \ (n,s = \overline{0,N}, \ n \ne s), \qquad (19)$$

$$\sum_{n=0}^{N} x_n^k = 1, \ (k = \overline{1,K}). \qquad (20)$$

Conditions (20) actually substitute expressions (14), because conditions (13) have been replaced by (18). Thus, during the use of the expressions (18)-(20) instead of (13), (14), on the one hand, we were able to abandon the integer statement of subchannel allocation problem in WiMAX network, reducing it to a nonlinear optimization problem. Using conditions (18)-(20) made it possible to maintain the adequacy of the model used, because as a result of calculation control variables x_n^k take only two values: "1" or "0".

Conclusion

In paper proposed a method of presentation integer problem frequency resource allocation in LTE and WiMAX networks in the form of nonlinear programming problems. The method is based on the fact that the integer character of control variables $x_n^{m,p}$ and x_n^k, which are responsible for the order of frequency resource allocation in LTE and WiMAX networks, is provided by the additional linear and nonlinear constraints (9) – (11) or (18) – (20).

The transition from the MINLP and MILP problems to nonlinear programming problem solving can significantly reduce the computational complexity of resulting solutions on frequency resource allocation in LTE and WiMAX networks. This is especially important due to the fact that these problems must be solved in real time with minimum requirements for hardware and software of LTE eNodeB or WiMAX Base Station in a permanent increase the number of users (UEs and SSs).

References

1. *IEEE Standard for Local and Metropolitan Area Networks: Part 16: Air Interface for Broadband Wireless Access Systems, IEEE Std 802.16-2009. – 2009. – 2094 p.*
2. *3GPP TS 36.213. 3rd Generation Partnership Project / Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) // Physical layer procedures (Release 11). – Valbonne, France: Sophia Antipolis, 2012. – 104 p.*
3. *Iosif O. On the Analysis of Packet Scheduling in Downlink 3GPP LTE System / O. Iosif, I. Banica // The Fourth International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ 2011), Budapest: IARIA. – 2011. – P. 99-102.*
4. *Puranik S.R. A Survey and Analysis on Scheduling Algorithms in IEEE 802.16e (WiMAX) Standard / S.R. Puranik, M. Vijayalakshmi, L. Kulkarni // International Journal of Computer Applications, October 2013. – P. 1-10.*
5. *Jakimovski K. Priority Based Uplink Scheduling Scheme for WiMAX Service Classes / K. Jakimovski, T. Janevski // I.J. Information Technology and Computer Science, August 2013. – P. 66-74.*
6. *Garkusha S.V. The Model of Time and Frequency Resource Scheduling in Downlink LTE / S.V. Garkusha // 2013 International Siberian Conference on Control and Communications (SIBCON). – Krasnoyarsk: Siberian Federal University, 2013. – P. 1-4.*
7. *Garkusha S. Result Research Model of Scheduling Block Allocation in Downlink LTE / S. Garkusha, A. Al-Dulaimi // International Conference Modern Problems Of Radio Engineering, Telecommunications and Computer Science (TCSET'2014), Lviv-Slavske, Ukraine, 2014. – P. 498-500.*
8. *Al-Dulaimi A.M.K. Linear Model of Bandwidth Allocation in LTE Downlink with RAT 1 / A.M.K. Al-Dulaimi // Second International IEEE Conference Problems of Infocommunications. Science and Technology, October 2015. – P. 82-85.*
9. *Lemeshko O.V. Development and analysis of bandwidth allocation linear model in LTE downlink with Resource Allocation Type 1 / O.V. Lemeshko, A.M.K. Al-Dulaimi // Телекомунікаційні та інформаційні технології. – 2015. – №4. – P. 5-11.*
10. *Al-Dulaimi M.K.H. Bandwidth Management Model in LTE Downlink with Resourse Allocation Type 1 / M.K.H. Al-Dulaimi, A.M.K. Al-Dulaimi, O.S. Yeremenko, H.D. Al-Janabi // Системи обробки інформації. – Х.: ХУ ПС, 2015. – Вип. 5(130). – С. 111-117.*
11. *Garkusha S. Result of Development of Model for Bandwidth Management in LTE Downlink with Resource Allocation Type 1 / S. Garkusha, A.M.K. Al-Dulaimi, H.D.K. Al-Janabi // XIIIth Int. conf. «The experience of designing and CAD system» (CADSM'2015), February 2015. – P. 409-413.*
12. *Lemeshko A.V. Model time-frequency resource allocation WiMAX aimed at improving the electromagnetic compatibility / A.V. Lemeshko, S.V. Garkusha // Proceedings of the 2013 IX International Conference on Antenna Theory and Techniques (ICATT), September 2013. – P. 175-177.*
13. *Lemeshko A.V. Model progress of subchannel distribution in WIMAX in antennas system / A.V. Lemeshko, H.D. Al-Janabi, A.M.K. Al-Dulaimi // X Anniversary International Conference On Antenna Theory And Techniques, ICATT'2015, April 2015. – P. 276-278.*

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МЕТОДИКА ПРЕДСТАВЛЕННЯ ЦІЛОЧИСЕЛЬНИХ ЗАДАЧ РОЗПОДІЛУ ЧАСТОТНИХ РЕСУРСІВ У МЕРЕЖАХ LTE ТА WIMAX У ФОРМІ ЗАДАЧ НЕЛІНІЙНОГО ПРОГРАМУВАННЯ

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У статті запропонована методика представлення цілочисельних задач розподілу частотних ресурсів у мережах LTE та WiMAX у вигляді задач нелінійного програмування. Методика заснована на тому, що цілочисельність керуючих змінних, що відповідають за порядок розподілу частотного ресурсу в мережах LTE та WiMAX, забезпечується в ході виконання додатково накладених лінійних і нелінійних обмежень. Перехід від задач MINLP і MILP до розв'язання задач нелінійного програмування дозволяє істотно знизити обчислювальну складність при отриманні результуючих рішень щодо розподілу частотного ресурсу в мережах LTE та WiMAX. Це особливо важливо, так як ці задачі повинні розв'язуватися в масштабі реального часу з мінімальними вимогами до програмно-апаратного забезпечення LTE eNodeB або WiMAX Base Station в умовах постійного зростання числа користувачів.

***Ключові слова**: LTE, WiMAX, частотний ресурс, ресурсний блок, підканал, метод, оптимізація, нелінійне програмування.*

МЕТОДИКА ПРЕДСТАВЛЕНИЯ ЦЕЛОЧИСЛЕННЫХ ЗАДАЧ РАСПРЕДЕЛЕНИЯ ЧАСТОТНЫХ РЕСУРСОВ В СЕТЯХ LTE И WIMAX В ФОРМЕ ЗАДАЧ НЕЛИНЕЙНОГО ПРОГРАММИРОВАНИЯ

А.В. Лемешко, А.М. Аль-Дулайми, Х.Д. Аль-Джанаби

В статье предложена методика представления целочисленных задач распределения частотных ресурсов в сетях LTE and WiMAX в виде задач нелинейного программирования. Методика основана на том, что целочисленность управляющих переменных, отвечающих за порядок распределения частотного ресурса в сетях LTE и WiMAX, обеспечивается в ходе выполнения дополнительно накладываемого множества линейных и нелинейных ограничений. Переход от задач MINLP и MILP к решению задач нелинейного программирования позволяет существенно снизить вычислительную сложность при получении результирующих решений по распределению частотного ресурса в сетях LTE и WiMAX. Это особенно важно, т.к. эти задачи должны решаться в масштабе реального времени с минимальными требованиями к программно-аппаратному обеспечению LTE eNodeB или WiMAX Base Station в условиях постоянного роста числа пользователей.

***Ключевые слова**: LTE, WiMAX, частотный ресурс, ресурсный блок, подканал, метод, оптимизация, нелинейное программирование.*