Model of the Balanced Distribution of Subchannels in the Mesh-Network Using WiMAX Technology

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***Abstract*—Available approaches to solving the problem of frequency resource distribution in the wireless mesh-networks with WiMAX technology are analyzed; the requirements of the systems nature on the structure and contents of the frequency resource distribution mathematical model are stated on the basis of these approaches. The frequency resource distribution mathematical model is offered as a problem of subchannels' number balancing between radio channels formed by mesh-stations of the wireless network. The use of the offered model has made it possible to raise efficiency of the wireless mesh-network as a whole and ensure the "bottlenecks" absence. The mesh-networks efficiency increase was also substantiated by assurance that the primary and secondary interferences are absent**

***Keywords*—WiMAX; mesh-network; primary and secondary interferences; subchannels distribution**

I. Introduction

The advent of economically effective wireless mesh networks (WMN), based on the WiMAX (Worldwide Interoperability for Microwave Access) technology [1-4], modified essentially the process of setting up both wireless access networks and transport radio networks. The mesh mode use has enabled the subscriber stations (SS) to exchange messages not only through the base station (BS), but immediately to one another. As a result the SS placed at significant distance from the BS can be connected to it in several steps through other SS.

Among many requirements imposed on the wireless mesh-networks (low cost of devices, low level of energy consumption etc.), the main one is the requirement to provide a high efficiency and quality of service (QoS) of the wireless network as a whole. Researches directed to the increase in the mesh-network efficiency concern the protocol means of the technological level for the standard model of the open systems interconnection (OSI). A high level of efficiency can be provided at the cost of refinements in corresponding network protocols and mechanisms responsible for the accessible network resources distribution. Among resources of such type there are: network traffic (information resource), channel capacities (channel resource), queue (buffer resource) as well as separate frequencies and frequency channels (frequency resource), which is of particular importance for the wireless networks. Moreover, the use of the OFDMA (Orthogonal Frequency Division Multiple Access) provides the possibility of controlling frequency and time resource [5]. The subcarriers, being the primary structural unity of the orthogonal frequency-division multiplexing OFDM (Orthogonal Frequency-Division Multiplexing), can be used as an alternative to the frequency resource as well as subchannels, being the least logical structure of the OFDMA frequency domain and being formed with several subcarriers. The symbols, being the least structural unity of the OFDM in the time domain [3, 6-10], can be used as a time resource of the OFDMA technology. In this connection the need for analysis of the available and development of new approaches to the frequency resource distribution arises, which meet simultaneously the requirements for QoS and the condition of increase in efficiency of the mesh-network as a whole.

II. Analusis of Requirements for Models and Methods of Frequency Resource Distribution in Mesh-Networks of WiMAX Technologi

Analysis of the known solutions [11-18] has shown that at the moment there is rather a wide spectrum of approaches aimed at increasing efficiency and support of QoS through solution of the frequency resource distribution problems. The solutions of the problem of frequency resource distribution in the WMN with the WiMAX technology are presented in [11-18] in the form of the frequency channels distribution problem.

The disadvantage of setting up the frequency resource distribution problem as a problem of frequency channels consists in the necessity to use, first, several receivers-transmitters to avoid the primary interference in every SS and, second, sufficiently great number of the frequency channels to avoid secondary interference between the neighboring SS. The primary interference emerges in the case when the user's station realizes the information exchange simultaneously with several users' stations in the same frequency channel [12, 13].

The cause of the secondary interference is an attempt to use the same frequency resource by different pairs of the users' stations in the operation zone of the receiving consumer station [12, 13]. In this case the use of several receivers-transmitters will raise the complexity and cost of the users' stations and will require additional expenditure of electric energy. On the other hand the use of the sufficiently great number of the frequency channels is not always accessible due to overload of the frequency range used for the WiMAX technology functioning.

It should be stated that adequacy and efficiency of the frequency resource distribution problem solution with one or other method is very often defined by the mathematical model used as its basis. As a result of the known solutions [11-18] analysis and requirements presented in [8, 19-21], the requirements for the structure and contents of the mathematical model of frequency resource distribution in the mesh-network of the WiMAX technology were stated as follows:

- taking account of the modern WMN inhomogeneity, owing to the use of equipment of different modifications, series, firms-producers;
- the provision of the frequency resource efficient use;
- orientation to mostly dynamic nature of the frequency resource distribution problem solution;
- maximization of the network efficiency as a whole and support of other indices of the QoS;
- the use of the distributed or centralized mode of resources control;
- minimization of action of the primary and secondary interference between the consumers' stations of the WMN;
- consistent solution of the problems of radio channels separation between mesh-stations and assignment of subchannels to them;
- orientation to the use of simple protocols of routing;
- taking account of the network technological particularities such as communication range, intensity of the user traffic arrival into the network, volume of the used frequency and time resources, quantity of the supported receivers-transmitters in the stations of the WMN, frequency channel width, the number of subchannels etc.

It is important to understand that the efficiency of the technological solution of the problem of frequency and time resources distribution in the mesh-networks of the WiMAX technology on numerous occasions is defined by the requirements consideration completeness when constructing and functioning of the WMN described with the mathematical model. The result of their incomplete consideration in the mathematical description for the most part results in complication of the realizing protocol.

To eliminate the disadvantages inherent in solution of the frequency channels distribution problem, the frequency planning problem can be presented in the form of the problem of frequency subchannels distribution in the mesh-networks of the WiMAX technology. On the basis of the performed analysis and the stated requirements the model for the single channel subchannels distribution is offered. The offered mathematical model is aimed at increase in the mesh-network efficiency as a whole through balancing the number of subchannels singled out for separate radio channels. This, in its turn, should provide creation of wireless network without "bottlenecks", i.e. the sections with the minimal efficiency.

III. Mathematical Model for Distribution of Subchannels in Wireless Mesh-Network of WiMAX Technology

The following initial data are supposed to be known in the offered model: N – is the general number of stations in the network (base and users stations); K – is the number of the subchannels being used; M – is the general number of radio channels being formed in the network. By a radio channel is meant a set of two mesh-stations of a wireless network carrying out an information exchange without re-receptions.

With the aim to develop a mathematical model for distribution of subchannels in the WMN let us introduce a number of symbols (tab. 1) making it possible to represent graphically the WMN elements.

TABLE I. Example of Symbols of Mesh-Network Elements

Symbol	Description
● 1	Base station has the first serial number in the network
○ 4	User's station has the fourth serial number
○—○ 4 (2) 5	Users' stations №4 and №5 form radio channel №2
3-6,11 ○—○ 4 (2) 5	Subchannels from the third to the sixth as well as the eleventh subchannels are assigned to radio channel №2

The concept of radio channels is introduced into the mathematical model making it possible to perform accounting of the WMN territorial distance in the network. The radio channel matrix is a rectangular one, the number of its lines and columns corresponds to the general number of radio channels M, and it has the form

$$D = \left\| d_{m,s} \right\|, \ (s, m = \overline{1, M}),$$

where
$$d_{m,s} = \begin{cases} 1, \text{ if the common station participates in} \\ \quad \text{formation of the } m\text{-th and } s\text{-th} \\ \quad \text{radio channels;} \\ 0, \text{ otherwise} \end{cases}$$

Fig, 1 demonstrates the WMN example with the indication of the stations number ($N = 8$), as well as the radio channels being formed with these stations ($M = 11$).

The following radio channels matrix corresponds to the mesh-network, shown in fig.1:

$$D = \begin{Vmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \end{Vmatrix}.$$

Within the frameworks of the given work the notation $N|M|K$ will be used with the aim to demonstrate topological and functional parameters of the WMN possible configuration. Thus, the notation of the WMN possible configuration, shown in fig.1, will assume the form $8|11|32$.

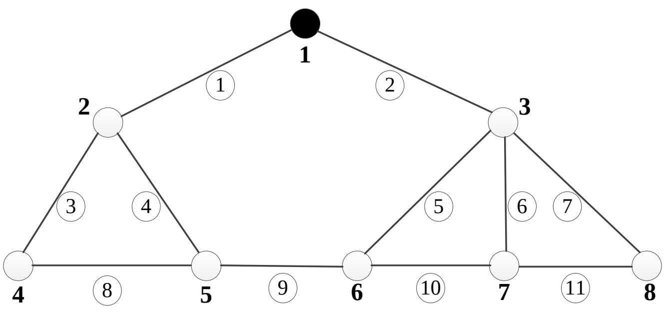


Fig.1. Example of mesh-network with indication of stations $N=8$ and radio channels $M=11$

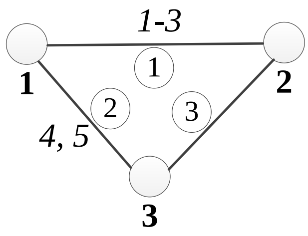
Within the framework of the offered model in the course of solving the subchannels distribution problem, the users' stations of the network should be provided with the Boolean controlling variable calculation

$$x_{m,k} = \begin{cases} 1, \text{ if } k\text{-th subchannel is singled out to } m\text{-th} \\ \quad \text{radio channel;} \\ 0, \text{ otherwise.} \end{cases} \tag{1}$$

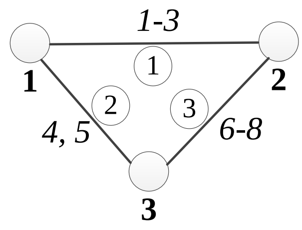
The general number of variables (1), defining the order of subchannels distribution, depends on the number of radio channels being formed in the network, subchannels being used and, respectively, will be defined by the expression $M \times K$. Subchannels assignment to radio channels should be the result of variables (1) calculation. In this connection a number of important conditions-limitations should be met when calculating the sought variables $x_{m,k}$:

1. Condition of every radio channel use (fig. 2):

$$\sum_{k=1}^{K} x_{m,k} \geq 1 \quad (m=\overline{1,M}). \tag{2}$$



a) condition (2) is not met



b) condition (2) is met

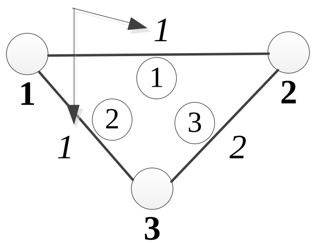
Fig.2. Example of checking the condition of every radio channel use

2. Conditions of the primary and secondary interferences prevention (fig. 3 and fig. 4):

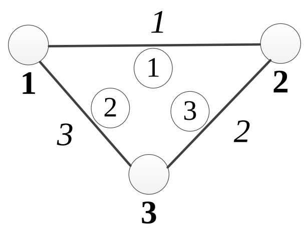
$$x_{m,k} + \sum_{s=1}^{M} d_{m,s} x_{s,k} \leq 1, \tag{3}$$

at $k=\overline{1,K}$, $m=\overline{1,M}$, $s \neq m$.

Radio channels №1 and №2 utilize a general (first) subchannels



a) condition (3) is not met



b) condition (3) is met

Fig.3. Example of checking the condition of the primary interference absence

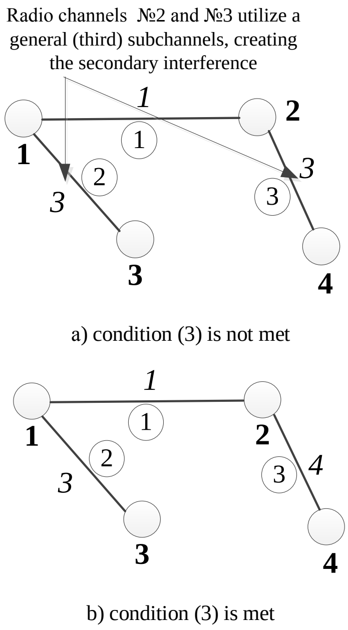


Fig.4. Example of checking the condition of the secondary interference absence

3. Condition of balancing the number of subchannels assigned to every radio channel:

$$\sum_{k=1}^{K} x_{m,k} \geq \chi \quad (m = \overline{1, M}). \tag{4}$$

where in the left-hand part of the inequality the number of subchannets assigned to the m-th radio channel is presented, χ – is the upper dynamically controlled threshold of the subchannels number assigned to the randomly chosen WMN radio channel.

Within the frameworks of the offered mathematical model (1)-(4) the optimization problem solution can be carried out with the following criterion:

$$\max_{x,\alpha} \chi, \tag{5}$$

directed to the increase in the mesh-network efficiency as a whole through the increase in efficiency of each radio channel. The use of the goal function (5) contributes to creation of the wireless network without "bottlenecks", i.e. the network where efficiencies of all junctions are balanced ones [22]. The main advantage of the solution obtained with the use of the goal function (5) consists in the possibility of the data packet routing in the mesh network using the metrics of the minimal number of re-receptions, this will significantly simplify the routing functions in the WMN.

The stated problem, from the point of view of physics of the processes taking place in the WMN, relates to the class of the channel resources balancing problems – weighted number of subchannels assigned to the radio channels, and from the point of view of mathematics – it is the problem of the mixed integer linear programming – MILP (Mixed Integer Linear Programming). In the model the sought variables $x_{m,k}$ (1) are Boolean ones, the variable being minimized χ is an integer one and the limitations on the variables being sought bear the linear nature.

IV. Example of Subchannels Distribution in WMN of WiMAX Technology Problem Solution

To estimate the quality of the obtained solutions for distribution of channels within the frameworks of the offered model let us consider an example of the stated problem solution. The mesh-network $8|11|32$ shown in fig.1 was considered in the example. Within the frameworks of the cited example each user's station utilized the following initial data: the used subregime OFDMA – DL FUSC; the quantity of subcarriers for data transmission per one channel – K_S=48; frequency separation between the subcarriers – $\Delta f \approx 11{,}16$ KHz; modulation level (bit load of the symbol) – k_b=4; speed of the code used when ciphering the signal – R_c=1/2; type of the signal modulation – 16-QAM 1/2.

Fig.5 presents solution of the problem with indication of the initial radio channels and the subchannels distribution order 5.

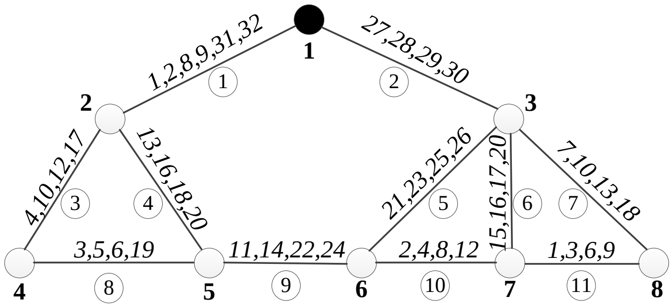


Fig.5. Example of subchannels distribution in the course of solution of the problem of structural self-organization in the mesh-network of WiMAX technology

As can be seen from the obtained result (fig.5), when solving the subchannels distribution in the mesh-network $8|11|32$ with the use of the offered model (1)-(5), no less than four subchannels ($\chi = 4$) were assigned to each radio channel, as a result the efficiency of all radio channels was no less than 4,19 Mbit/s. Moreover, six radio subchannels were assigned to the radio channel №1, this corresponds to the transmission speed 6,28 Mbit/s. As a result of the obtained solution analysis it may be concluded that the use of the model (1)-(5) is aimed at the legitimate distribution of the subchannels between radio channels of the mesh network of the WiMAX technology.

V. Conclusion

It was found that one of the main problems in the WMN in the WiMAX technology is the problem of the frequency and time resources distribution between the network stations. In this connection the available approaches to solution of the problem of frequency resource distribution in the WMN in the WiMAX technology were analyzed. The requirements to the systems nature were stated on the basis of disadvantages of the analyzed methods for frequency resource distribution in the WMN, they were directed to removal of the revealed disadvantages and development of the mathematical model for distribution of the frequency resource presented in the logical subchannels' form.

The mathematical model, presented by a number of conditions-limitations, is offered on the basis of the stated requirements put forward to prospective solutions in the field of distribution of the frequency and time resources in the WMN. The model novelty consists in the statement of the frequency resource distribution problem as the problem of balancing the quantity of subchannels between radio channels formed by mesh-stations of the wireless networks, this made it possible to raise the WMN efficiency as a whole and absence of the "bottlenecks" in the mesh-network. In its turn, this, as may be required, will make it possible to perform the data packets routing using metrics of minimal number of re-receptions. Increase in the mesh-network capacity was stipulated by assurance of absence of the primary and secondary interference, this is achieved due to the condition (3) introduced specially into the model structure.

It is noted that the stated problem, concerning the subchannels distribution in the WMN in the WiMAX technology in terms of physics' processes taking place in the wireless network, belongs to the class of the frequency resources balancing problems – the number of the subchannels used by the radio channel, and from the mathematical point of view this is the problem of the mixed integer linear programming. MatLab R2012b system was used as the instrumental means, when solving the optimization problem stated in work, the milpassign packet for the TOMLAB optimization was utilized in the frameworks of this system.

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