A Mathematical Model of Channel Distribution in Multichannel Mesh Networks 802.11

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Abstract – **This paper focuses on mathematical models of distribution channels in the multi-mesh-networks, the 802.11 standard by which the balancing of mesh-stations on domains conflicts with their territorial remoteness and activity that can improve the performance of multichannel mesh network as a whole.**

Keywords - **Mesh Network, Modelling, Mathematical Model, the distribution channels, transmission range.**

I. Introduction

At this stage of development of telecommunication systems, wireless networks find their increasing use. However, the main limiting factor in their development is the low productivity. An analysis of existing ways to improve performance of wireless networks should be noted that the most promising avenue is the use of multichannel mesh networking standard, IEEE 802.11, which compared to other methods (spread spectrum signal, link aggregation, the use of MIMO-systems, etc.) has significant advantages. Established that the efficiency of multichannel mesh networks is largely determined by the used models and methods of distribution channels between the air interfaces mesh stations.

II. Model of Disribution Channel

A mathematical model of the distribution channels in the multichannel mesh networks. In the proposed model are assumed to know the following data: $\{R_i,\ i=\overline{1,N}\}$ - the set of mesh-stations, where N - their total number in the network, m_i- the number of radio interfaces on the mesh-station, R_i; K - the number of non-overlapping channels in the mesh-network. For example, in technology IEEE 802.11 b/g channels of 3÷4, and the technology of IEEE 802.11 and - 12 non-overlapping channels.

Let $\{G_z, z=\overline{1,Z}\}$ - a number of zones for sustainable reception - clusters (Transmission Range, TR), which form a geographically remote mesh-station, where Z - their total number in the network.

Moreover, in this paper agree that the transmission range of sustainable forms a set of mesh-station maximum power, in which stations can transmit information to each other.

To account for the territorial remoteness network mesh-stations in the mathematical model introduced the concept of the transmission range matrix or TR-matrix. The matrix is a rectangular with the number of rows corresponding to the number of the transmission range use (Z), and the number of columns corresponding to the total number of mesh-stations (N) in the network, i.e.

$$D=\left\|d_{i,j}\right\|,\ \ i=\overline{1,Z}\ ;\ \ j=\overline{1,N}\ ,$$

where $d_{i,j}=\begin{cases}1, & \text{if the j-th station is located in the i-th TR;}\\ 0, & \text{otherwise.}\end{cases}$

In the proposed model in solving the problem of distribution channels for radio interface network mesh-stations necessary to provide the calculation of a boolean variable

$$x_{i,j}^{k}\in\{0,1\}\quad(\,i=\overline{1,N};\ \ j=\overline{1,m_i}\ ;\ k=\overline{1,K}\,),\tag{1}$$

where $x_{i,j}^{k}=\begin{cases}1, & \text{if j-th radiointerface i-th station operates on the k-th frequency channel;}\\ 0, & \text{otherwise.}\end{cases}$

The total number of variables (1), which determine the order of distribution channels, depending on the number of stations in the network, the radio interface used channels and, accordingly, will be determined by the expression $N\times m\times K$. The result of the calculation variables (1) must be a partition of mesh-network as a whole and each transmission range separately connected to each other collision domains in which the mesh-station operating on the same channel. In this regard, when calculating the unknown variables $x_{i,j}^{k}$ in each individual G_z must perform a number of important conditions-limitations:

1. Conditions for the i-th station in the network:

$$\sum_{k=1}^{K}\sum_{j=1}^{m_i}x_{i,j}^{k}\geq m^{*}\quad(\,i=\overline{1,N}\,),\tag{2}$$

where $1\leq m^{*}\leq m_i$ - integer parameter that characterizes the minimum required number of included radio interface on an arbitrarily chosen mesh-station;

$\sum_{k=1}^{K}\sum_{j=1}^{m_i}x_{i,j}^{k}$ - the number of active radio interface in one station. Typically, the number of supported radio interfaces at the station as well.

2. The condition of separation j-th radio interface mesh-station no more than one channel:

$$\sum_{k=1}^{K}x_{i,j}^{k}\leq 1\quad(\,i=\overline{1,N};\ \ j=\overline{1,m_i}\,).\tag{3}$$

3. The condition of securing the k-th channel to the i-th mesh-station for no more than one radio interface:

$$\sum_{j=1}^{m_i}x_{i,j}^{k}\leq 1\quad(\,i=\overline{1,N};\ \ k=\overline{1,K}\,),\tag{4}$$

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Conditions (3) and (4) are complementary and define the order of consolidation as a channel for the radio interface mesh-station and backwards. They are linear.

4. The condition of the two mesh-stations with each other by not more than one channel (for a single transmission range):

$$\sum_{k=1}^{K}\left[\sum_{j=1}^{m_i} x_{i,j}^k \cdot \sum_{l=1}^{m_i} x_{s,l}^k\right] \le 1,\ (i,s=\overline{1,N};\ i\ne s), \quad (5)$$

which is introduced to eliminate the undesirable structural redundancy, and is a quadratic character.

5. The condition that an arbitrary mesh- station on its air radio interface and assigned to it the channel works with at least one station of transmission range:

$$x_{ij}^k \le \sum_{\substack{u\in G_z,\\ u\ne i}} \sum_{r=1}^{m_r} x_{ur}^k \ \ (i\in G_z,\ z=\overline{1,Z},\ j=\overline{1,m_i},\ k=\overline{1,K}), \quad (6)$$

where $\sum_{u\in G_z}\sum_{r=1}^{m_r} x_{ur}^k$ - number of stations in the transmission range G_z that work on k-th channel.

6. The condition of absence of the effect of the "hidden station", then there is a station that belongs to multiple transmission range should not be run on the same channel, with stations in various transmission range:

$$\sum_{j=1}^{m_j} x_{sj}^k \sum_{i\in G_p}\sum_{r=1}^{m_r} x_{ir}^k = \sum_{j=1}^{m_j} x_{sj}^k \sum_{i\in G_*^s}\sum_{r=1}^{m_r} x_{ir}^k \ \ (s=\overline{1,N},\ k=\overline{1,K}), \quad (7)$$

where $G_p \in G_*^s$, G_*^s many then there is a station that belongs to multiple transmission range, to which belongs the s-th station.

7. The condition of the network connection (connection created by collisions of domain mesh-stations):

$$p=\sum_{i=1}^{N}\sum_{j=1}^{m_i}\sum_{k=1}^{K} x_{i,j}^k \ge N+K^*-1, \quad (8)$$

where K^* - amount included in the frequency channel mesh-network. Execution constraints (8) together with (5) the shortage of channels ($K^* \le N-1$) ensures that the number of radio interfaces are included (p), taking into account the number of mesh-stations and are supported by wireless technology will provide a connection channels of the multichannel mesh-network.

Two domain mesh- network connected, if there is a mesh-station operating simultaneously on the channels of these two domains, i.e., radio interface first station operates on a single channel, and the second of its radio interface is working on another channel. Two mesh-station connected, if they are in a transmission range and in the same domain of collisions, i.e. running on the same channel.

It is advisable that the number of mesh-stations in the domains were similar, i.e., there was a balancing of mesh-stations in the domain. To this end, we introduce the balancing condition mesh-stations in the domain of collisions.

8. Balancing condition of mesh-stations collision domains, depending on the territorial remoteness, activity stations and the number of transmission range, will have several interpretations.

8.1. If all the stations are in the same transmission range, the balancing condition of mesh-stations on domains conflicts will be as follows:

$$\sum_{i=1}^{N}\sum_{j=1}^{m_i} x_{i,j}^k \le \alpha \quad (k=\overline{1,K}), \quad (9)$$

where $\sum_{i=1}^{N}\sum_{j=1}^{m_i} x_{i,j}^k$ - the number of mesh-stations in the network, working on k-th channel;

α - the upper threshold is dynamically controlled by the number of mesh-stations in an arbitrarily selected domain of collisions in a multichannel mesh-network.

8.2. When account is taken of the territorial remote stations, i.e. in finding the stations in different transmission range, the balancing condition will be as follows:

$$\sum_{i=1}^{N} d_{z,i}\sum_{j=1}^{m_i} x_{i,j}^k \le \alpha \ \ (i=\overline{1,N};\ k=\overline{1,K}), \quad (10)$$

where the left-hand side shows the number of mesh-stations in the z-th transmission range.

8.3. An important factor in balancing the number of mesh-stations on domains conflicts is their activity, under which, in this case we mean the output frequency the radio station, the duration of sessions and the intensity of the traffic. Active mesh-station affects the choice of route data, energy consumption, etc. In this context, the balancing condition mesh-stations collision domains can adopt the following expression:

$$\sum_{i=1}^{N} d_{z,i}\cdot\beta_i\sum_{j=1}^{m_i} x_{i,j}^k \le \alpha \ \text{(for each } (z,k)\text{-couple)}, \quad (11)$$

where $z=\overline{1,Z}$, $k=\overline{1,K}$;

β_i – activity coefficient of the i-th station, which depends on the number of connected users, the intensity of the incoming and outgoing traffic, traffic type (voice, video, data).

8.4. In connection with the non-uniform load radio interface mesh-station and in view of their work in various fields, to obtain more precise formalization of the condition (11) is recommended to use a normalized activity coefficient of the mesh-stations

$$\sum_{i=1}^{N} d_{z,i}\cdot\left(\beta_i \Big/ \sum_{k=1}^{K}\sum_{j=1}^{m_i} x_{i,j}^k\right)\sum_{j=1}^{m_i} x_{i,j}^k \le \alpha \ \text{(for } (z,k)\text{-couple)}, \quad (12)$$

where $z=\overline{1,Z}$, $k=\overline{1,K}$;

$\beta_i / \sum_{k=1}^{K}\sum_{j=1}^{m_i} x_{i,j}^k$ - normalized activity coefficient of the station, which takes into account the traffic distribution to the i-th station for plug-in radio interface, i.e. related mesh- stations.

Calculation of the unknown variables (1) and setting in accordance with the terms, formalized by (2) - (12), it is advisable to carry out in the course of solving an optimization problem by providing a minimum or maximum pre-selected quality criterion for solving the problem of distribution channels in a multichannel mesh-network. The main requirements for the optimality criterion is necessary to carry on the one hand, compliance with the physics of the problem, i.e. the problem of distribution channels in the mesh-network, on the other hand, the possibility of obtaining on its basis is practically workable solutions (results). Thus, the formulation of the problem should not be unnecessarily complicated, but its solution must be known or developed an effective method.

Due to the fact that the number of stations in geographically distributed mesh-networks significantly prevails over the number of channels and there is a need to address issues such as interference and the effect of "hidden" stations, as this criterion was chosen as the minimum number of work mesh-stations to create a domain collisions, which is known, enhances the overall performance of the multichannel mesh-network. Then, in the framework of the proposed mathematical model (1) - (12), the problem of distribution channels in the mesh-network takes the form of optimization, in which the solutions necessary to ensure that the following criteria

$$\min_{x,\alpha} \alpha \qquad (13)$$

taking into account the conditions (1) - (12).

The problem formulated in terms of the physics of processes occurring in multichannel mesh-networks, refers to the class of balancing network resources - weighted number of mesh-stations in the domains of conflict with respect to their territorial remoteness of activity, and from a mathematical point of view - this is the problem of mixed integer nonlinear programming - MINLP (Mixed-Integer NonLinear Programming). The model variables $x_{i,j}^{k}$ are unknown (1) are boolean, minimized variable α is an integer (when the conditions (7) - (10)), or the real (under conditions (11) - (12)), and restrictions on the unknown variables are both linear (1) - (4), (6) - (11) and nonlinear (5), (12) character.

Consider the example of the distribution of frequency channels in a multichannel mesh-network.An example of mesh-network with an indication of areas of sustainable use (*z*=4) is shown in Fig. 1.

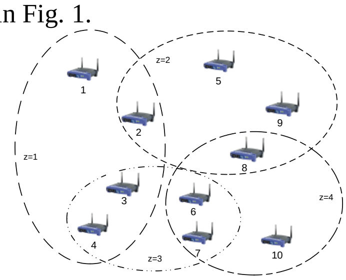

Fig.1. An example of mesh-network with an indication of the transmission range

Shown in Fig. 1 mesh-network corresponds to the following transmission range matrix:

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

As is evident from the results obtained (Fig. 2), *k*=3, all mesh-network was divided into three domains of collisions on four stations in each. With an increasing number of channels used (Fig. 3); for *k*=4 network is «falling apart» already on the five domains of collisions in which the maximum number of stations did not exceed three. In this case, the network has already distribution two domains conflicts station, which worked on one channel (*k*=1), but these domains are located in different areas of stable reception, so do not merge into a single domain of larger dimension.

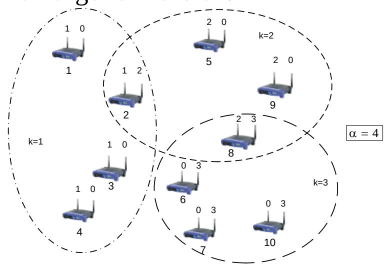

Fig.2. Example of distribution channels in the mesh-network with *K*=3

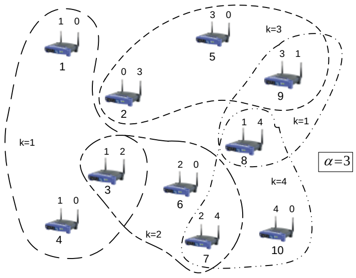

Fig.3. Example of distribution channels in the mesh-network with *K*=4

III. Conclusion

As a result of the proposed mathematical model was created a connected structure of the collision domain, thus allowing for information exchange between any pair of stations, multichannel mesh network. Also, the use of the model of distribution channels not only improves performance of multichannel mesh network, but also due to the conditions imposed, eliminating the effect of "hidden" stations to reduce interference, etc.

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