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The Improvement of a Wireless Network Performance Functioning Based on Diffusive Moving The Loads of Cells

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Abstract. *In the paper, the original method of balancing cell loads in wireless networks has been presented. It allows for diffusing the load to the area assembling cells with decreased load and, thus, improving the total network capacity. The method is highly effective in load balancing and acceptable as far as computational complexity is concerned. Its performance has been proved by experimental tests.*
Keywords: *Load balancing, cell networks, networks design, graph theory.*

1. Introduction

Lately, the computer networks have been building in a way to minimize the effect of digital exclusion. Such networks have most often a regional organization and assume their range to the area of administrative district, province or region [1, 2]. They have the hierarchic structure, made of 3-4 levels, while the lowest levels are realized by means of wireless techniques.

The qualification of the quantity and the selection of the economy-technical profiles of the hierarchic structure, just like whole process of projecting, needs to be formalized. Let's consider the maximum hierarchic structure built of all L levels, which can occur in the projected network. The problem of selecting the optimum structure of the hierarchy lies in synthesis of the cheapest tree which consists of l levels exclusively, controlling the definite class of V_0 homogeneous units of the zero level (the lowest one). The elements of the first level of the hierarchy are also homogeneous and connected with the elements of the second level etc. At last, the elements of the level $(l-1)$ of the outcome tree are connected with one only element l - of this level. The searched quantities are as follows: the number of indispensable levels l of the projected structure $(l \leq L)$ and the number of the elements $(k-1)$ of the level built of i - element and k - level.

The costs of the construction and the maintenance of i - element of k - level and the costs of connecting x_{k_i} the elements of $(k-1)$ level with them are described by non-negative results of the costs $f^k(x_{k_i})$, which value depends exclusively on the number of $(k-1)$ level elements connected with i - node. The above-mentioned mathematical model can be described by the following formula:

$$\sum_{k=1}^{l}\sum_{i=1}^{n_k} f^k(x_{k_i}) \rightarrow \min_{x_{k_i},n_k} \tag{1}$$

$$\sum_{i=1}^{n_k} x_{k_i} = n_{k-1}, \quad k = \overline{1,l} \tag{2}$$

$$1 = n_l < n_{l-1} < \ldots < n_1 < n_0 = n, \quad l \leq L \tag{3}$$

$$l, x_{k_i}, n_k \in Z^+ \tag{4}$$

With regard to the above-mentioned the problem – the algorithms of the exploration of the optimal solution are known, with the polynomial complexity, using its decomposition and based on the dynamical programming. What is characteristic for the algorithms is the computational complexity $O\left(Ln^3\right)$ and the memory $O\left(Ln^2\right)$ complexity. One can distinguish special cases which enable considerably reduce computational and memorial complexity, and are particularly helpful in finding the solution to analytical problems.

The problem of identifying the number and the types of network levels can also be described as the problem of the multi-level distribution. One can apply the method based on linear relaxation and the solution of dual problem with the local improvement of the solution to his approximate solution. If the exact solution of the problem is indispensable, one can apply the method of branch and border

Table 1. Composition of technology on the levels of the hierarchic network for individual topologies

Variants	**A**	**B**	**C**	**D**	**E**
The type of the core	Centralized	Centralized	The ring	Related rings	Related rings
The level I	Central switch	Central switch	Optical fibre	Optical fibre	Optical fibre
The level II	Optical fibre	Optical fibre	Optical fibre	Optical fibre	Optical fibre
The level III	Wireless	Wireless	Wireless	Optical /Wireless	Optical /Wireless
The level IV		Wireless			Wireless

and bounds. If additional limitations are imposed on the structure of the projected network, one can apply the following methods: searching the unbuttoning tree with the limited ray; building the optimal Steiner's tree with the limited lengths of paths and the limited quantity of Steiner's points and searching the rectangular Steiner's tree with the paths of the equal length. Unfortunately, all the above mentioned methods belong to the group of NP-complete algorithms.

The research was carried out with use of the original method based on solving the problem of searching the optimal tree by the analysis of nontrivial division of the group with set power on the subgroups. The costs are defined on the basis of the parameters of accessible communication technologies and topological organizations [2]. The variants of the hierarchy under evaluation have been shown in chart 1.

The analytical research has proved the relevance of applying three- and four-level architectures. The first two of them should be realized on the basis of optical fibres, and the third one (and the fourth, alternatively) with use of the wireless broadcast (D variant). The comparison of the evaluation of various hierarchy structures created with use of methods of the functional analysis of costs has been presented in Fig. 1. Looking at this chart we can see the relative evaluation of the solution which can even show the optimum 100% in the chart. High efficiency is also characteristic for the network of related rings (the variant E), in which two leveled wireless access is used.

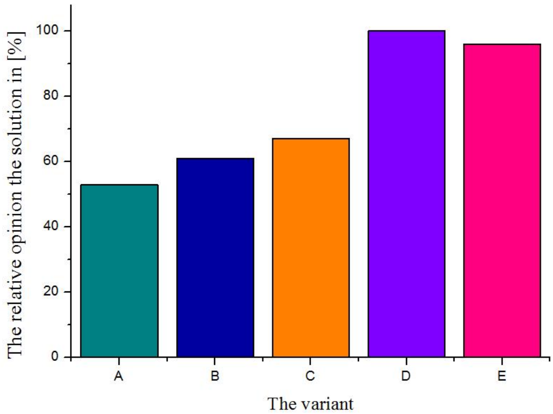

Figure 1. Comparison of the relative opinion of the variants of the hierarchy of the physical topologye

The realisation of the bottom levels of the network on the base of wireless techniques results from the properties of those technologies. First of all, they assure the access to the network without any obstacles. Moreover, the elastic modification of network users is easier to access. However, the use of wireless networks may lead to new threats, sometimes trivial and not occurring in wire networks. Except from the problem of security and the system on its own, the biggest problems are overloads in the networks and their consequences. The communicative parameters of the overloaded wireless networks are degraded to considerably higher extent than in case of wired networks. The complexity of the above mentioned problem results from the restricted capacity of communication channels and the type of broadcast transmission in the networks of this class MIN.

Enlargement of the capacity of nodal devices or communication channels is response to the overloads wire networks. Such a solution is not always possible because of the limited possibilities of the accessible communication technologies of this class in the case of wireless networks. The alternative, and in many cases, the only possible solution of the problem of overloads is the correct efficiency with use of available sources [4]. That is why it is necessary to create new effective methods of maximising the level of utilization of devices and communication channels, especially by means of balancing the load of individual cells in the wireless networks.

2. The problem of projecting cellular networks

Minimization of the influence of the overloads of individual cells on functioning the whole network is basic problem solved in this paper. It is said that only the network which is not overburdened assures the correct realization of communication tasks which are ordered by users. The struggle with potential overloads should begin with dividing the network into cells. Such a division should take into the account both the communication parameters of the basic station and the minimization of the intercellular traffic requiring service on the level of the core of the network. To project the covering of the cells we assume that the diameter of the cell can be adapted to its size and to the thickness of the users' distribution. Let's consider i- cell of the wireless network. We can present it with use of the coherent graph which is not directed $G_i = (V_i, E_i)$, where: V_i– is the set of nodes ($V_i = \{v_{i_1}, \ldots, v_{i_n}\},\ n > 0$); E_i – the set of the edges ($E_i = \{e_{i_1}, \ldots, e_{i_m}\},\ m > 0$), whereas for every k; e_{i_k} is the pair of elements from the set V_i. The movement in i - matrix of interstitial flows defines this cell $L = [\lambda_{kl}]_{n\times n}$, where: λ_{kl}– the informative stream among nodes: k-this and l-this, $k, l \in V_i$. We define the bearings of client nodes using the board of $W = [\alpha_k, \phi_k]_{n\times 2}$ geographical co-ordinates, where: α_k, ϕ_k– suitably length and the geographical width of the node. We define the length of the d_{kl} wireless communication channel using the example on the length of the orthodrome [7]:

$$d_{kl} = \arccos\left[\sin(\phi_k)\sin(\phi_l) + \cos(\phi_k)\cos(\phi_l)\cos(\alpha_k - \alpha_l)\right], \tag{5}$$

where: (α_k, ϕ_k), (α_l, ϕ_l) – are the geographical co-ordinate nodes k, l; α, ϕ – suitably length and geographical width. However, the length of the channel calculated with use of the expression (5) is affected with considerable error which can be reduced by transforming it into the following formula [7]:

$$d_{kl} = 2\arcsin\left[\sqrt{\sin\left[\frac{(\phi_k - \phi_l)}{2}\right]^2 + \cos(\phi_k)\cos(\phi_l)\sin\left[\frac{(\alpha_k - \alpha_l)}{2}\right]^2}\right] \tag{6}$$

The minimization of the cost of the building of the network is the basic criterion of projecting, achieved for the smallest number of cells and base stations covering the cluster. We should now find such a location of the base stations and attribution of client nodes, so the number of cells is minimum and all the nodes have the ensured suitable quality of the service. If we allow projecting multi-criterial designing, then we can use such standard projecting nets as: the mineralization of communication delays, the maximization of total transfer function, the minimization of the maximum load of the communication channel and other. The maximum admissible diameter of the cell and the admissible capacity of the base station [1, 2] are the most important limitations which are projected.

The most often used are those algorithms of the division which take into account the limitations of the stream intensity and the minimum value of the stream among cells. Those algorithms are based on the methods of the quickest fall and minimum section. The primary data are most often such algorithms as: the type of the schedule of streams; maximum and minimum of their intensity; the admissible value of intensity; the maximum ray of the cell; the maximum diameter of the cell; the maximum number of client‘s nodes. The algorithms are often realised in two steps. In the first step, the section without the regard to the intensity of streams is realised. In the second step, we consider the frequency of the streams and create cells with smaller or bigger diameter [2, 4].

However, the effective solution of the problem regarding decomposition of the network on cells is insufficient for waltzes with overloads. The traffic generated by users changes dynamically, and its profiles in the neighboring cells can be opposing. That is why the right move is to guarantee the possibility of exchange in the network of the load, at least among neighboring cells. The solution of the above mentioned problem can be application of numerous well-known methods, especially the method of the recursive section for co-ordinates, inert and spectral division, algorithms of Kernigan-Lin's, Fiduccio-Mettheyess's, or Diechmann's [2].

The two-stage process of decomposition is found in the majority of well-known algorithms. Rough decomposition can be also carried out with use of any algorithms of the section including the algorithm of full searching, because the number of nodes rough graph is usually limited. However, qualitative indicators of such decomposition are comparatively low, because they depend directly on equableness of the action of processing (rounding off) the graph. During the rough section, there are created cells with different weights, because the weights grouped nodes are usually characterised by large dispersion. To sum up, it is necessary to specify local borders of the cells which allows to level their weights and reduces the number of the edges which go out from their borders. The algorithms which are most often used for this aim are those of Kernighan-Lin or Fiduccio-Matheyess. The algorithms are characterized by the low computational complexity [2].

As the experience shows, purposeful use of additional criteria of decomposition, such as: the minimization of the maximum stage of the cell and the assurance of connectivity of every subgraph which describes it. However, the majority of well-known algorithms is not used for establishing connectivity and the maximum stage of the cell, which requires the studies on the new algorithm of decomposition. The algorithm of spectral halving is one of the interesting algorithms which assure obtaining the initial approximation of high quality. If the algorithm of spectral halving is used recursively, one can divide the graph into number of parts. The Graph decomposition into two parts can be executed through its arrangement according to the value of the components of the Fiedler's vector - the vector corresponding to the smallest non- zero value of the spectral matrix subgraph (Laplace's matrix). The subgraph's division into more parts, on the basis of the components of the Fiedler's vector, can be used to create cells with small number of neighbors. The essential defect of the method , which limits the number of the decomposed graph, is the complexity of the qualification of the components of the Fiedler's vector nonsingular of the spectral matrix subgraph is an essential defect of the method, what limits the number of nodes of the decomposed subgraph [2].

The analysis of predispositions which occur while projecting a network shows that the best project effects can be reached with use of the Diechmann's bubble algorithm. That is why, through its modification, the new group of algorithms which better applied to the needs was created. The new approach is based on the observation that cells including incoherent groups of tops are created on the stage of initial decomposition and the process of local specification among themselves. That is why the paper suggests [2] changing the so far used methods of preliminary decomposition into the method assuring connectivity of cells. The input function the sanctity of their cohesion was postulated in turn for the stage of local specifying in this work. Analyzing the sets of internal and external nodes and defining the depth of every one of them, the notions of the core of the definite level of domain and its layer were introduced as minimum distance from the file of border nodes. The sub graph created by the nodes with depth not smaller than k- and incidental edges of these nodes was determined as the core of k- level. The notion of the layer was connected with the sub graph created through the set of nodes with the depth k and set of edges which are exclusively incidental to them . The proposed algorithm was steered to create the set of connected cells of the core, which is even more demanding than the need of connectivity of every one of them. One can show that the cohesion of the suitable core results from what lets build the effective algorithm of the control of their connectivity from the connectivity of the layer [2].

3. Balancing cells' load

Proposed in the work, the algorithms of the division of the network on cells, solve partly the problem of effective utilization of accessible communication supplies [2]. One can accept in some sense that those supplies assure the static balance of the load of domains, just as they aim to the situation, when the informative streams of every cell is approximately even. However, such a solution is used during the stage of projecting the network and so does not take into account any changes coming up while it is functioning. One could obviously prognose the changes of the traffic in the network, but as experience of such prognosis show, they are not very credible. The basic advantage of this class of algorithms is the high quality of sections made in the conditions of the stability of the movement and the acceptable time of their realization.

In the systems of dynamic alignment of cells, during the functioning of the system with the change of the load in cells, the excessive, unacceptable load is transferred from the overburdened cells to those which are not that burdened. Dynamic balancing of load is also called an additional division of cells‘ load [4]. The majority of well-known methods prove that the excessive load will be transferred among neighboring cells exclusively. Usually, the following actions are taken:

1. After the division of the net into cells, during it is functioning, after the essential change of the load, the cell with the largest load is selected , as the best product to the dislocation of the load.

2. One analyses the level of the load of the neighbouring cells, which aims to assign the possibility of transferring an excessive traffic to them.

3. If the dislocation of the load is possible, than client nodes are transferred to neighboring cells those nodes have to fulfill the following conditions:

   (a) They are in the range of the base station of the neighboring cell;

   (b) They generate the maximum external traffic, especially the one which is addressed to the cell which can accept an excessive traffic.

4. If the dislocation of the traffic is not possible (because all neighboring cells are ballasted), the streams of the overburdened cell and/or cells which are neighboring and the previous steps of the procedure of the division are repeated for the new schedule of cells.

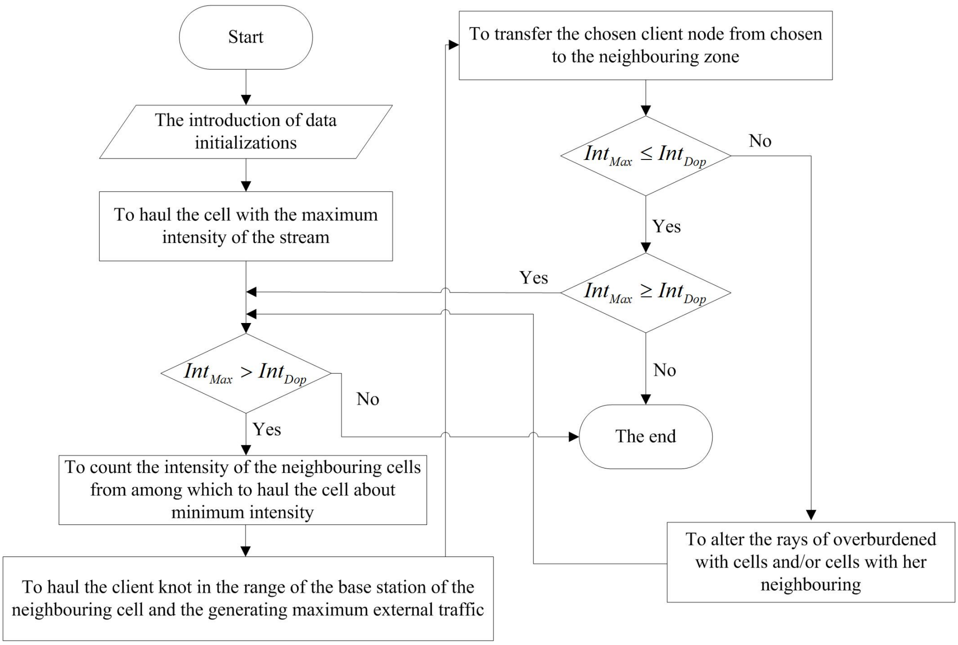

Figure 2. The method of leveling the loads of cells

5. If the change of the size of the cell does not give the assumed result, the next cell of about the largest level of the overload is chosen.

The simplified block diagram of the above mentioned method was introduced in Fig. 2.

The abovementioned method of leveling the loads of cells is simple in its realization and it does not enlarge the computational complexity of the task of the fusion of the structural wireless network. However, the efficiency of an additional division of the load is limited, mainly because of the transfer of the excessive movement exclusively to the neighboring cells. The original method proposed below does not have this defect.

4. Diffusive leveling of the loads of cells

Let's notice that cellular access networks possess, similarly as the whole regional network, the hierarchic structure. Usually, the base stations are joined using

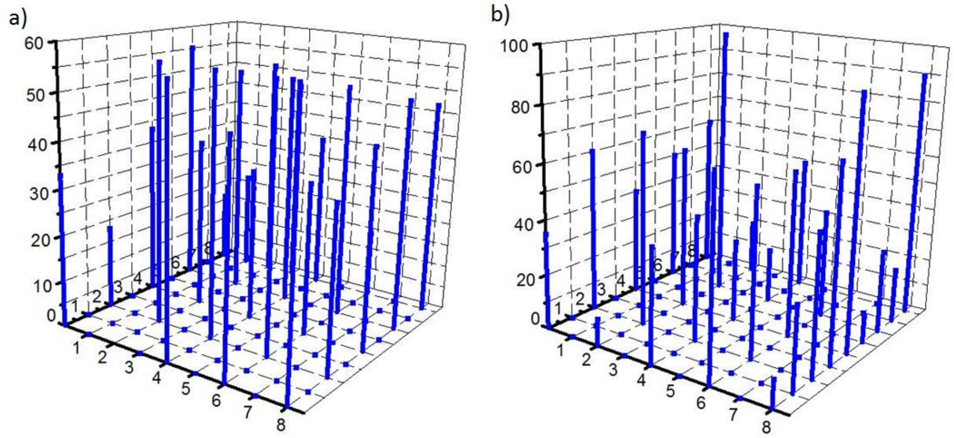

Figure 3. The graph of the source schedule was introduced on Fig. a, and on the drawing b the graph of the schedule of the intensity of stream after their additional division

the wired or two-point wireless network with the central dispatcher of the network. The dispatcher can now be a perfect tool for the management of the load level of individual cells. The dispatcher a table describing the load of individual cells in the classic solution creates in the real time. On the basis of its analysis the most loaded base stations are defined and informed about the necessity of transferring the part of its load to chosen cells with the lower level of utilization of communication supplies. Similar information is also sent out to strikers stations of the load. Obviously, the load can be exclusively exchanged among neighboring cells.

The load diffusion with the net in the direction of cells or areas about the lower load in the aim of the improvement of the efficiency of utilization of accessible in the net communication resources, in the proposed method. The general conception of the method consists of the following assumptions:

1. One can define the value L_{max} of the maximum level of the load, the load of cells will be moved after crossing and the value of L_{min} minimum load of the cells below which the cell will be weighted;

2. The strategy of the initialization will be applied by the sender in systems with the average level of the load, and in systems with the high load - the initialization by recipient;

3. In the process of leveling, only those cells will be considered for which the load L_i fulfill the condition $L_i > L_{\max}$ or $L_i < L_{\min}$(depending on used strategy);

4. For the strategy of the initialization by the sender , the following steps should be made:

   (a) The cell of the maximum load is searched;

   (b) The cell of the minimum load is searched;

   (c) By means of one of well- known algorithms (eg. on Floyd's or Danzig's), all paths are joined which connect all the above-mentioned cells, taking into account the possibilities of moving the load among neighboring cells;

   (d) Using the definite function of the aim from the set of particular paths, the path which fulfills best the requirements of load balancing in the cells of the wireless network is chosen. One can apply eg. simplex method for this aim;

   (e) Consecutively, for each next cells of the chosen paths, the procedure of moving the load is executed starting from the cell striker and finishing on the passing cell.

5. The criteria of the evaluation of the path can be:

   (a) The maximization of the number of overburdened cells in the path;

   (b) The maximization of the path length, which guarantees better diffuse of the load;

   (c) The minimization of the path length which lets minimize the time of leveling the load.

6. The paths guaranteeing import of the load the level similar to the average level in the whole net should be chosen. That is why paths can not exclusively consist only of cells which are strongly burdened;

7. Similar steps are made with regard to the strategy of the initialization by recipient.

The Algorithms of discrete mathematics are used in practical solution of the mentioned problems, which is characterized by high solutional structure [8, 9, 10, 11]. That is why the study of the new methods or the implementation of well-known methods of the solution of the partial tasks of projecting which characterizes the polynomial complexity was one of the basic aims of investigations. Utilization to this aim of the algorithms of the search of the path about sets parameters was proposed, instead of searching paths joining a pair of nodes, (ex. routing algorithms). The block pattern of the method based on the strategy of the initialization by the sender was introduced in Fig. 3.

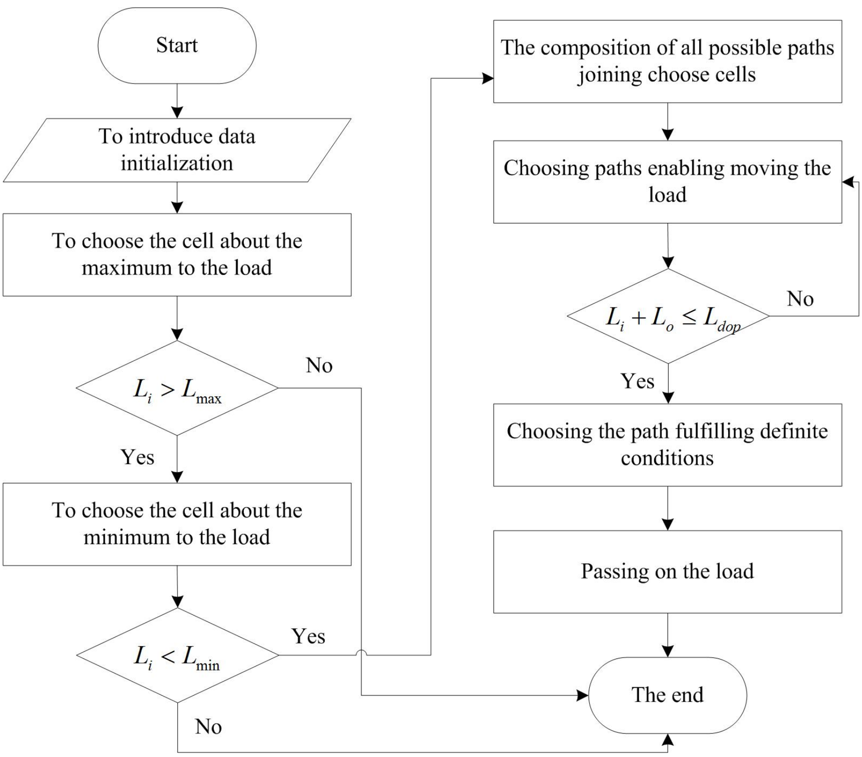

Figure 4. Block diagram of the method of leveling the loads with use of the strategy of the initialization by the sender

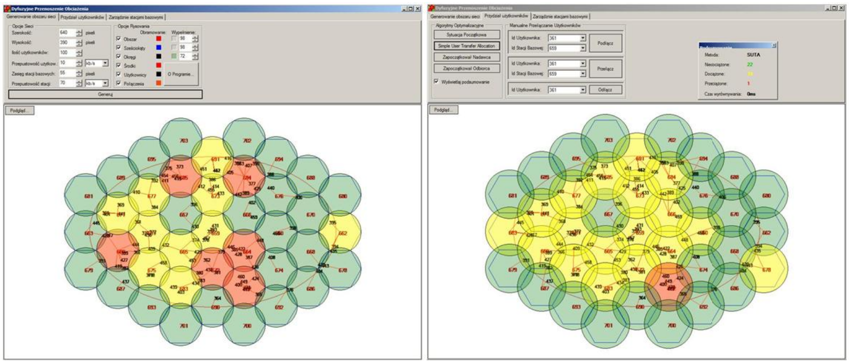

Figure 5. Two example screens of the application were introduced. The sign: CD – Central distributor of tasks; RI – Recepientinitiated; SI – Senderinitiated; G – Gradient strategy

5. Computer application

The results of the authors‘ works found their use in construction of the original computer application, designed to simulations of diffusive leveling the loads in the cellular wireless network. Not only loads of the base station in this system are defined, but also the load of the communication lines of the network core. The frequency of the dismissals appears in cells which interest us and the size of analyzed informative streams.

From the mathematical point of view, the task of leveling the cell loads is treated as the task of the imitation of b non-isomorphic coherent graphs, $b : T_m \rightarrow N_g$, where: T_m– the set of the graphs of models; N_g – the set of the graphs of the configuration of the computer network. The graph $G \in N_g$, $G = \{C, E\}$ is defined as the set of base stations C and the set of edges adequate to the communication channels of the core of the network. One can treat the set of graphs N_g as supergraph including all possible graphs G, which are his subpraph. The graph $M \in T_m$, $M = \{U, V, W\}$ describes the used model.

In the application, there are three types of leveling loads available: static B_s, dynamic automatic B_a and dynamic controlled B_d. In the case of static leveling the best solution is the subgraph $G \subset N_g$, isomorphic in relation to the graph M. However, such a subgraph not always exists, and that is why the algorithm of the search is used in the system, so called: the close subgraph. Static leveling of the cell loads is made before the beginning of the simulation of the work of the network. In the algorithm B_a of automatic dynamic leveling, the graph G and M are labeled by nodes and edges. The tops of the first graph are characterized by capacity of station of the base cell, and his edges are characterised by the capacity of the channels of the core of the network. In the second graph, the tops and the edges show characteristics of client nodes undergoing dislocation. All weights of the graph N_g are thought to be well-known.

Two screens of the application were presented on Fig. 4. Fig. 5 shows the results of the simulation of different variants of the presented method created with the produced application. The presented results got from the network built with 256 cells of the gradient load of 4,5 (Fig. 5.a) and average load of 60% (Fig. 5.b)

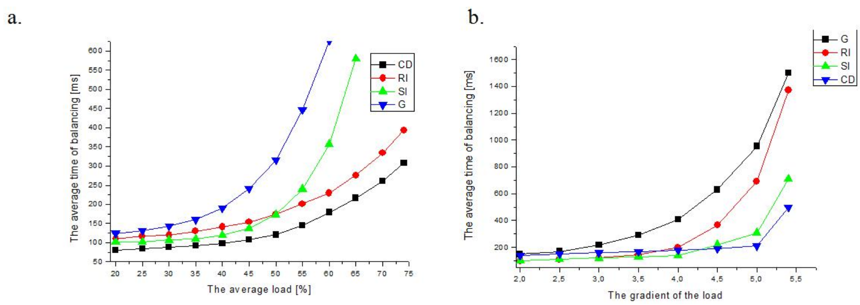

Figure 6. The results of the simulation of the different variants of the method were presented

6. Summary and further works

The thesis presented in the present work, that one of the effective way to decrease the load of the base stations in wireless networks is an additional division of client nodes among neighboring cells. The new method of the additional section of the load of cells in the wireless network was proposed to prove it. This method offers dissipation of the load along paths which join nodes with the extreme load, the highest with the lowest. As a result of applying the method, the load of the nodes show high homogeneity which has been proved by the simulation research.

Further Authors' works will focus on the study of the topology and routing organization in cellular wireless networks.

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