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Optimization of Telecommunication Access Network

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Introduction

The process of optimization of telecommunication network is very important for the creation of a new network or for modification of the resources of an existent network. The process of network optimization is shown in Fig. 1. The smaller triangle shown in the picture represents the relationship between costs, network resources and quality of the operator network, when it is in the initial stage of operation. The optimization process allows changing the quality of the network when at the same time affecting the costs and resources of network implementation. Although the results obtained in the optimization process often allow to improve the network quality significantly when only insubstantially increasing the costs and resources of the network.

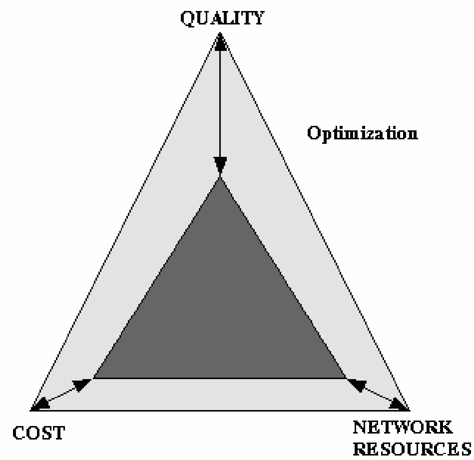

Fig. 1. The Effect of Process Optimization

Various methods and programming packages are used for optimization and planning of the network.

The supplied methods do optimization according to different criteria of optimization, so they are not universally applicable and can give an optimal solution only in respect to a single criterion. It is possible that when based on a single criterion, say, implementation costs, the result could be optimal regarding the costs but the quality parameters of the network access could be lacking. That's why in practice when solving the tasks of definition of boundary zones and their optimization it is advisable to use several criteria and methodologies. For example having calculated the access ranges according to the minimal costs we could check the technical possibility of user connection by the methods based on the quality criteria.

Optimization method analysis

When looking for optimal solution with multiple parameters and variables, multiparametric optimization methods can be used. During the analysis some specific factors e.g. quality or reliability have to be under control. These factors put a limit on the area for the search of optimal solution and are the restrictions. Since most of the variables are associated with the quality parameters through a non-linear relationship, so the multiparametric optimization method with restrictions can be reduced to a task of non-linear programming. To evaluate the degree of violation of restriction, a penal functions method can be used. According to this method, the penalty will increase in accordance with magnification of violation of restriction.

For the solution of this task various programming methods can be used: "on-coordinates descent", "heavy ball", Pearson's, "deformable polyhedron" etc [1]. Although this methodology can be used only when variables are defined by contiguous functions. In the case of the access network optimization, most of the variable values are discrete and some of them don't even have a digital expression e.g. types of modulation: QPSK, 4QAM, 16QAM and similar. In this case the gradual approach programming methods cannot be used. The values for the boundary zones and grid elements are contiguous by nature, although only the discrete value sets for these variables are traditionally used. Besides when using discrete variable sets, the complex methods of hybrid programming are not needed. What we get is an optimization task that can be solved using discrete methods. We cannot use the methods in the optimization theory directly, because of the different nature of the parameters and variables in the task involved and a substantial set of restrictions. This optimization task is solved by the aid of the elements of mathematical and telecommunication network optimization [2]:

- multiparametric optimization;
- sorting of variables and their values according to their possible effect for the goal and restriction functions;
- methodologies of minimal costs and network characteristic's (quality) evaluation.

Algorithm for access network optimization

Currently available methods for calculation of access network optimization are applicable for the search of optimal solutions only by one chosen criterion or a parameter, so using them in solving the tasks of cost and quality becomes rather problematic. Therefore we suggest using combined access optimization methods which are obtained combining the methods of minimal costs, quality and multiparametric optimization.

The algorithm for access network optimization is produced using and combining methods of minimal costs and boundary definition by quality parameters. We introduce a multiparametric optimization condition into the goal function i.e. we define *n* variables, according to which the optimization of access network will be carried out. In this case the access network cost minimization goal function is expressed in the following relationship:

$$C_{min}=f(A,\ T),\ A \in \mathbf{A},\ T \in \mathbf{T},$$
$$A=(B,L),\ T=(M,R,H,V,W,G), \qquad (1)$$

where C– network implementation costs; A – variables of the access network boundary: B – size of the grid element (area), km^2; L– size (area) of boundary zone, km^2; T – variables used in the network access technology: M – type of channel/transmission media; R – the speed for the data transmission, kbps; H – discipline for the data package service; V – channel access method; W – type of modulation; G – type of codec.

In the expression (1) the variable sets are defined as follows:

$$\mathbf{A} = \mathbf{B} \times \mathbf{L} \text{ and } \mathbf{T} = \mathbf{M} \times \mathbf{R} \times \mathbf{H} \times \mathbf{V} \times \mathbf{W} \times \mathbf{G}\ . \qquad (2)$$

We will formulate the optimization task: let's have a function $C=f(A,\ T)$ and conditions, which are defined by the unknown $(A,\ T)$, we have to find the values of variables $(A^*,\ T^*)$, under which the value of function becomes minimal, i.e. $C_{min}=f(A^*,\ T^*)$. N – dimensional point $C_{ls}=f(A,T)$ that satisfies the boundary system:

$$\begin{cases} Q_{1\,min} \le Q_1 \le Q_{1\,max}, \\ Q_{2\,min} \le Q_2 \le Q_{2\,max}, \\ Q_{3\,min} \le Q_3 \le Q_{3\,max}, \\ \ldots\ldots\ldots\ldots\ldots\ldots, \\ Q_{r\,min} \le Q_r \le Q_{r\,max}, \end{cases} \qquad (3)$$

we will call permissible solution. Here $Q_1, Q_2,..Q_r$ the r-th quality indicator (factor): $Q_{1min}, Q_{2min},..Q_{rmin}, Q_{1max}, Q_{2max},..Q_{rmax}$ – the minimal/maximal value for the r-th quality factor.

Since the quality indicator can be limited from the bottom as well as from the top by the values of Q_{imin}, Q_{imax}, besides their values can be the same as the extreme values of the quality norms, so the restrictions (3) are introduced not with strict equations.

In case the set of permissible (allowed) solutions is not empty, we come to the search of the optimal solution.

For the function $C=f(A,T)$ an optimal solution will be a point, for which the variable values belong to the set of permissible solutions and the value of C function is minimal:

$$C_{min}=f(A^*,\ T^*)=min. \qquad (4)$$

We will build a block diagram for the optimization stages (Fig. 2).

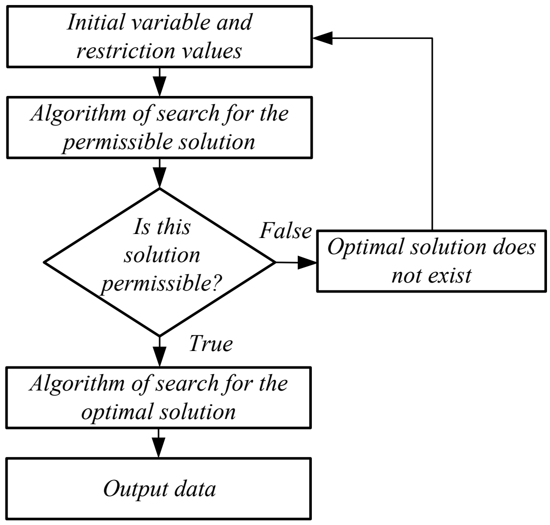

Fig. 2. Block diagram of the optimization stages

We build the access network optimization algorithm according to costs and quality parameters $Q_1,Q_2,...Q_r$ (Fig. 3). In the supplied algorithm the established quality factors for the initial access network structure calculation $Q_1, Q_2,..Q_r$ is checked whether they satisfy the defined quality norms according to the restrictions (3). In case at least one factor does not satisfy the condition, then the value of the variable which has the biggest influence to the unsatisfied quality norm factor is being changed.

There are the following steps of the optimization algorithm:

Step 1. Initial data is entered: a digital GIS map is prepared, the area of the territory concerned is calculated, and the number of users is forecasted.

Step 2. The boundaries for the r quality factors $Q_{1min}, Q_{2min},...Q_{rmin}, Q_{1max}, Q_{2max},...Q_{rmax}$ are defined, which have to be ensured by the optimized access network.

Step 3. Sorting of variables B, L, M, R, H, V, W, G according to their possible effect on the goal and introduced restriction functions.

Step 4. In the optimization algorithm the area of the territory depending on the technology of the selected access network can be classified as follows:

a) ***In the case of wired network:*** by the rectangular grid elements, of which *L* size boundary zones are formed. The size of the grid elements is chosen 100 to 600 m. The main assumptions:

- optimization is started with the smallest element in the grid (from 100 m);
- the users in the grid element are evenly distributed, so the connection lines have to reach to the center of the grid element.

The number of grid elements is calculated as following:

$$N_B = \frac{S_{n.t.}}{B} = \frac{N_L \cdot L}{b_x \cdot b_y}\,; \tag{5}$$

where $S_{n.t.}$ – the area of the territory; N_L – the number of range zones; *L* – area of the range zone; *B* – the area of the grid element; b_x, b_y – the side of the grid element.

b) ***In wireless access case:*** size of tetragon or hexagon shaped cells is selected according to biggest boundary radius. Consequently, the number of tetragon shaped elements shall be calculated as follows:

$$N_{kv.e} = \frac{S_{n.t.}}{L_{kv.e}} = \frac{S_{n.t.}}{S_{sekt.}\cdot 4} = \frac{S_{n.t.}}{\left(\frac{d}{\sqrt{2}}\right)^2 \cdot 4} = \frac{S_{n.t.}}{2\cdot d^2}\,, \tag{6}$$

where $S_{sekt.}$ – base station sector space; *d* – biggest boundary radius.

In case of hexagon shape:

$$N_{šeš.e} = \frac{S_{n.t.}}{L_{šeš.e}} = \frac{S_{n.t.}}{\frac{3\cdot\sqrt{3}}{2}\cdot d^2}\,. \tag{7}$$

Depending on access type, algorithm operates in two ways. Wire access station allocation place is detected in conformity with minimum expenses method. In wireless access case it is agreed that the station is allocated in

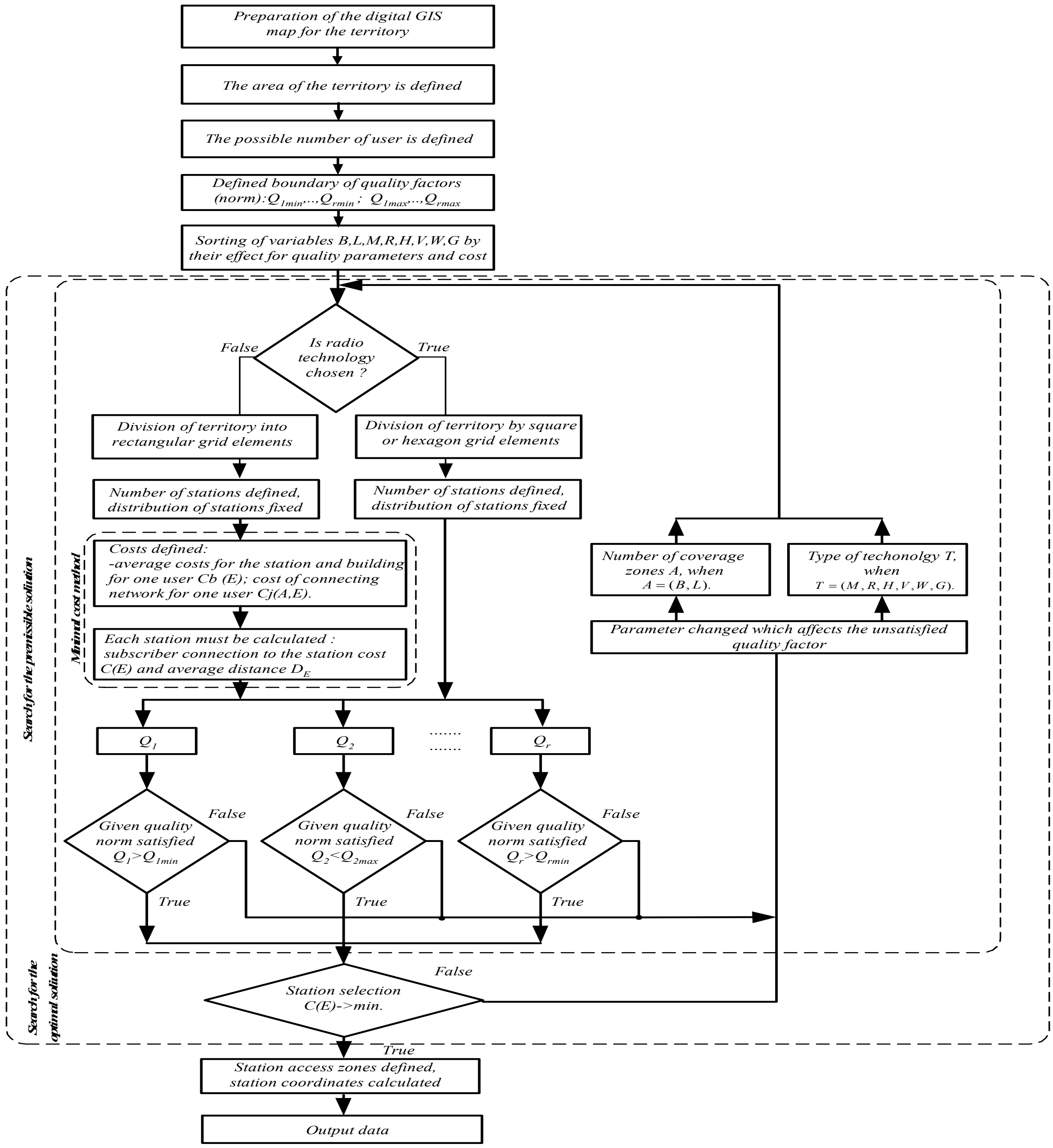

Fig. 3. Optimization algorithm for access network, by costs and *r* quality parameters

the center of tetragon or hexagon because in this case expenses much less depend on distance between base station and subscriber station.

Step 5. The number of station n is indicated here. Dislocation places of stations are calculated and their distribution is temporary fixed.

Then the column (line) K can be found. Calculation:

$$S_j = \sum_{i=1}^{n} ab(i,j) \cdot C_C(D_E), \quad (8)$$

where $(i,j) \in E, \; S = \sum_{j=1}^{m} S_j$.

Then column (line) K can be found.

$$\sum_{j=1}^{K} S_j < \frac{S}{2} \quad ir \quad \sum_{j=1}^{K} S_j \geq \frac{S}{2}. \quad (9)$$

Then the center, or the point of importance, can be found where the number of subscribers on the left side, on the right side, at the top and at the bottom is the same.

Step 6. The station boundaries will be determined here. The expenses of subscriber's connection to the station will be counted as well as the average distance between i-network element and station D_{Ei}.

Subscriber's, located in place at *(x,y)* and attached to traffic zone A, connection to the station E located (X_E, Y_E) can be expressed as:

$$C(E)=C_j(A,E)+C_b(E)+D_E*C_s(D_E)+C_f. \quad (10)$$

In case of wire communication with rectangular network elements distance between station, located at (X_E, Y_E) and certain point located at *(x,y)* can be calculated according to the

$$D(X_E, Y_E, x, y) = | X_E - x | \cdot b_x + | Y_E - y | \cdot b_y. \quad (11)$$

Step 7. Research for permissible solution.

1. Variables and their values shall be settled in according to the influence on expenses and quality criteria:

$$\left(X_1^{k,l_1}, X_2^{k,l_2}, \cdots, X_n^{k,l_n}\right), \quad (12)$$

where k – variables X influence order index, $k = 0$ – on expenses, $k = \overline{1,r}$ – on quality criteria Q_k, r – on quality criteria (restrictions) number, $l_s \in \{1,2,\cdots,n\}$ – location of variable in original list of variables, n – number of variables.

Ordered set of $X_i^{k,l}$ values

$$\left\{x_{i,1}^{k,l_i,t_1}, x_{i,2}^{k,l_i,t_2}, \cdots, x_{i,m_i}^{k,l_i,t_{m_i}}\right\}, \quad (13)$$

where $t_j \in \{1,2,\cdots,m_i\}$ variable $X_i^{k,l}$ place of j–value in original list of variables.

2. There shall be original selected set of variable values $(x_1, x_2, \cdots, x_n)$ (indexes of variables and their values in conformity with original lists).

3. In conformity with the selected variable values, the quality rates $Q_1, Q_2, ..Q_r$ will be calculated.

4. The restriction breach vector will be determined there $P = (p_1, p_2, \cdots, p_r)$:

$$p_k = \begin{cases} 0, if \;\; Q_{k\,min} \leq Q_k \leq Q_{k\,max} \\ -1, if \;\; Q_k < Q_{k\,min} \\ 1, if \;\; Q_{k\,max} < Q_k \end{cases}, \; k = \overline{1,r} \quad (14)$$

If $P = (0, \cdots, 0)$, that means that permissible solution is determined and we can move to the optimum solution search.

Vector P, with all element values equal to 0 will be marked as P_0 and called as zero $P_0 = (0, \cdots, 0)$.

If new breaches appear in breach vector after variable exchange, in other words if breach vector elements turn from 0 to -1 or 1, or if breach type changes in other words if 1 appears in place of -1 or -1 in place of 1, exchange of this variable shall be cancelled and new variable shall be found. If there is no possibility to select new variable (if there are no more variables) then the conflict of restrictions shall be fixed.

5. In sequence order shall be selected variable that lowers breaches and its value shall be examined. Suppose that k_p selected criteria, whereat $p_{k_p} = -1$ or $p_{k_p} = 1$. Consequently quested variable, whereat:

$$\begin{cases} p_{k_p} = -1, then \;\; Q_{k_p}\left(x_{i,j}^{k_p,l_i,t_j}\right) < Q_{k_p}\left(x_{i,j+1}^{k_p,l_i,t_{j+1}}\right), \\ p_{k_p} = 1, then \;\; Q_{k_p}\left(x_{i,j}^{k_p,l_i,t_j}\right) > Q_{k_p}\left(x_{i,j-1}^{k_p,l_i,t_{j-1}}\right), \end{cases} \quad (15)$$

and at all other $k = \overline{1,r}, k \neq k_p$, shall meet condition:

$$\begin{cases} p_k = -1, then \;\; Q_k\left(x_{u,v}^{k,l_u,t_v}\right) \leq Q_k\left(x_{u,v+v_u}^{k,l_u,t_{v+v_u}}\right), \\ p_k = 1, then \;\; Q_k\left(x_{u,v}^{k,l_u,t_v}\right) \geq Q_k\left(x_{u,v-v_u}^{k,l_u,t_{v-v_u}}\right); \end{cases} \quad (16)$$

here $l_i = l_u$, $t_j = t_v$, $t_{j+1} = t_{v+v_u}$ or $t_{j+1} = t_{v-v_u}$, or $t_{j-1} = t_{v+v_u}$, or $t_{j-1} = t_{v-v_u}$, $v_u \geq 1$.

When such variable is selected clause 2 shall be repeated. In case such variable can not be selected permissible solution set is empty.

Step 8. Research for optimal solutions.

1. In sequence shall be selected variable that lowers objective function value C.

$$C\left(x_{i,j}^{0,l_i,t_j}\right) > C\left(x_{i,j-1}^{0,l_i,t_{j-1}}\right). \quad (17)$$

2. In conformity with selected variable values quality rates shall be calculated $Q_1, Q_2, ..Q_r$.

3. Such variable value exchange shall be tested if that does not breach restrictions in other words if inequalities obtain

$$Q_{k\,min} \leq Q_k\left(x_{u,v}^{k,l_u,t_v}\right) \leq Q_{k\,max}, \; k = \overline{1,r}, \; l_i = l_u, \; t_{j-1} = t_v. \quad (18)$$

4. If restrictions are breached variable shall be selected according in sequence to the influence on restriction Q_{kp}, but objective function value shall be independent from this variable. If such variable does not exist, then clause 1 shall be repeated (*index i=i+1*).

5. If restrictions are not breached then selected variable value shall be changed (index $j = j-1$) and clause 2

shall be repeated. If restrictions are breached that clause 1 shall be repeated (index $i = i + 1$).

6. If variable, which that exchange would lower objective function value, is not found, then optimal solution is found.

7. At optimal solutions research moment expenses shall be calculated in conformity with linear expense calculation methodology. Then total solution research expenses are as follows:

a) in case of wire communication $C_{L.R.}$:

$$C_{L.R.} = (a_l + b_l \cdot x) \cdot l_l + (a_d + b_d \cdot x) + k_d \cdot c \cdot l_d + (a_s + b_s \cdot x) + k_s \cdot s \cdot l_s + (a_k + b_k \cdot x) + \sum_{j=1}^{K} S_0(i,j) \cdot n_0(j) + \sum_{j=1}^{K} S_i(i,j) \cdot n_i(j); \quad (19)$$

b) in case of wireless access network $C_{R.R}$:

$$C_{R.R.} = a_r + (b_{br} + b_{ab}) \cdot x_{bs} + (b_{ar} + b_{aa}) \cdot x_{as} + b_k \cdot x_k + (a_s + b_s \cdot x) + k_s \cdot s \cdot l_s + (a_k + b_k \cdot x) + \sum_{j=1}^{K} S_0(i,j) \cdot n_0(j) + \sum_{j=1}^{K} S_i(i,j) \cdot n_i(j). \quad (20)$$

Each network element subscribers are attached to concrete base station in conformity with minimal connection expense criteria:

$$C(E) \to min. \quad (21)$$

Thus we find optimal access network structure in conformity with expenses and quality.

Strategy of algorithm operation reduction

Many variables are used for access network optimization. In the simplest case, while searching for permissible and optimal solution, all variable values and their combinations have to be reselected. Full variable reselection may take a lot of time and calculations resources. Suppose n is a number of variable and n_k is a number of their possible variations, then total reselection number Np is calculated as follows:

$$Np = \prod_{i=1}^{n} n_k . \quad (22)$$

Access network optimization is not polynomial time problem because number of variables and their possible values can change. Seeking to decrease number of possible variations (reselections) we suggest using variable string strategy which is theoretically substantiated in simple optimization problems (such as backpack, work setout for one device problems [3]). In case of access network optimization valuable string shall be performed separately in conformity with their influence on object functions and on introduced restriction function. On purpose to determine end evaluate this influence there shall be performed analyzes of object function (expense), restriction functions (quality rates) and algorithm variables dependences.

Broadband wireless access network optimization

Hereby we set up broadband wireless access optimization according data in Table 1.

Searching for optimal solution is performed until we get minimal cost and do not breach quality restriction (vector P). Fig. 4 and 5 presents graphical illustration of searching optimal solution in two cases: a) $Q_{2\ min}$ =13,54 dB b) $Q_{2\ min}$ =20,68 dB.

Table 1. Initial data

Parameter/variable	***Value***
Area size/ number of customers	*100 km²/220*
BWA parameter:Ps, Gs, Gi, f.	*19 dBm,15 dB,28 dB, 24,5 GHz*
M	*radio*
d_1, ... d_{20}; Δd*	*0,18 ...3,5; 0,175 km*
R_1, ... R_{16}; ΔR	*64 ...1024; 64 kbps*
H, V	*M/M/1/S, TDMA*
W, link availability	*a) 4QAM, 99,999%* *b) 16QAM, 99,997%*
G_1,...G_6	*G.711, G.722, G.723, G.726, G.728, G.729*
$Q_1\{t\}$ *– data packet delay* $Q_2\{S/Tr\}$*– signal to noise ratio*	Q_{1max}=30 ms a) $Q_{2\ min}$ =13,54 dB b) $Q_{2\ min}$ =20,68 dB

* *In case of hexagon grid elements:* $d=\sqrt{L \cdot \frac{2}{3 \cdot \sqrt{3}}}$

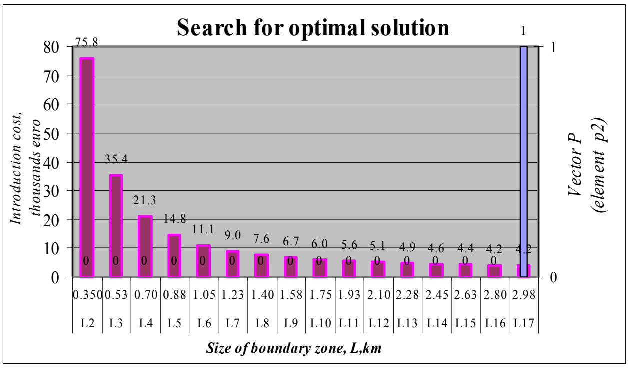

Fig.4. Results of BWA optimization: $Q_1\{t\}$=30ms, $Q_2\{S/Tr\}$=13,54 dB, W=4QAM, R=R_{13}, L=L_{16}, G=G_1

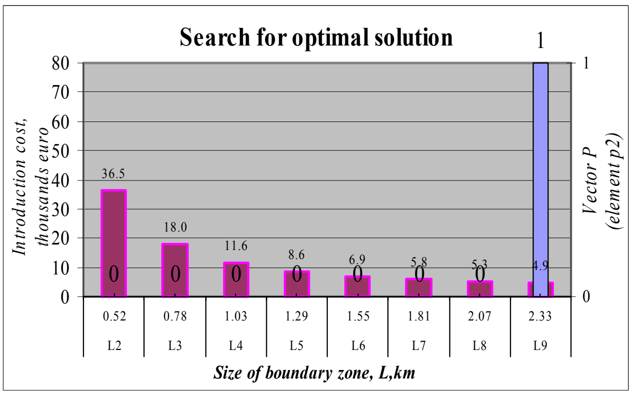

Fig.5. Results of BWA optimization: $Q_1\{t\}$=30ms, $Q_2\{S/Tr\}$=20,68dB, W=16QAM, R= R_{13}, L=L_8, G=G_1

Fig. 6 and 7 presents optimal broadband wireless access network structures in respect to the cost with assurance of set level of quality of service. Fig. 7 shows that using 16QAM modulation for the coverage in theoretical level as well as for the assurance of set quality values there is needed twice bigger number of base stations, then in case of 4QAM modulation (Fig.5) because base station coverage declines two times.

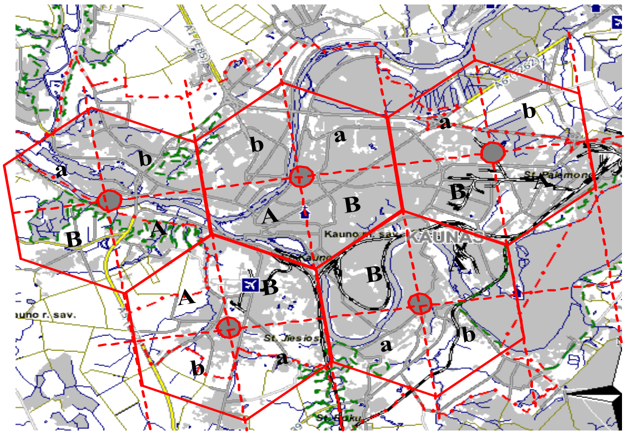

Fig. 6. Territory coverage when $Q_1\{t\}$ *and* $Q_2\{S/Tr\}$ restrictions are unimpaired*. Network parameters: 4QAM modulation,* $N_s=5$*, maximum radius 2,8 km, availability 99,999%*

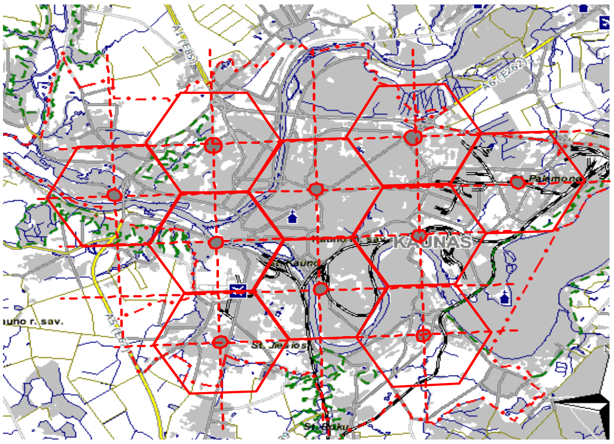

Fig.7. Territory coverage when $Q_1\{t\}$ *and* $Q_2\{S/Tr\}$ restrictions are unimpaired*. Network parameters: 16QAM modulation,* $N_s=10$*, maximum radius 2,07 km, availability 99,997%*

Conclusions

There was developed multiparametric access network optimization method with following advantages:

- it allows to perform access network optimization with minimum expenses and at the same time ensures set quality level, according *r* – number of quality rates;
- access network quality description indexes in model are optional and that allows optimizing access networks with different purpose, oriented to voice, data and other communication services;
- method is for network accesses based on wire, xDSL, fiber optic and radio technologies;
- method can be used to solve some other optimization problem with discrete variables and can be settled in conformity with their influence on objective function and restrictions.

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Telecommunication network optimization is performing with modern multicriteria, combinatorial optimization based on genetic algorithm, dynamic programming etc. methods. So they are not universally applicable and most used for solution very “narrow” optimization tasks and it used for limited application. The multiparametric method that was developed for the network access optimization allows choosing the optimal access structure and the technology in respect to the costs with assurance of sufficient quality of service.Ill. 7, bibl. 3 (in English; summaries in English, Russian and Lithuanian).

В. Гримайла, Н. Листопадскис. Оптимизация телекоммуникационной сети доступа // Электроника и электротехника. – Каунас: Технология, 2006. – № 8(72). – С. 25–30.

Сегодня для оптимизации сети доступа применяется современные методы многокритериальной, комбинаторной оптимизации на базе генетических алгоритмов, динамического программирования и др. Но множество из этих методов из-за своей специфики часто применяется для решений очень “узких” задач по оптимизации сети доступа. В статье предложен новый метод, основан на мультипараметричной оптимизации, позволяет найти оптимальную структуру и технологию сети учитывая не только расходы, но и достаточное качество услуг. Ил. 7, библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

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Telekomunikacijų tinklams optimizuoti pradedami naudoti šiuolaikiniai daugiakriteriniai, kombinatorinio optimizavimo, pagrįsto genetiniais algoritmais, dinaminio programavimo ir kt. metodai. Tačiau šie metodai nėra universalūs, dažniausiai taikomi gana siauriems tinklo optimizavimo klausimams spręsti, taigi gana ribotai. Sukurtas naujas daugiaparametris prieigos tinklo optimizavimo metodas leidžia parinkti optimalią prieigos struktūrą bei technologiją pagal kaštus, užtikrinant pakankamai gerą paslaugų kokybę. Il.7, bibl.3 (anglų kalba; santraukos anglų, rusų, lietuvių k.).