On optimal design of network topology

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Abstract

This paper describes an implementation of the general flexible interactive method of optimal network topology design with simultaneous calculation of network equipment parameters which depend on the network topology. The initial information on the projected network contains the following data: single and corporate users location, the structure and the quantity of their information flows to the different corporate users (as senders-receivers) and QoS of all users. The structure and the quantity of information flows must be presented in the form of probability characteristics of these flows applied to each traffic type. The algorithm of the proposed method is based on use of two complex potential functions and a solving of flow problems. The proposed method is integrated into the complex software tool for network design. There are numerical experiments.

1. Introduction and problem formulation

1.1. Review

The optimal topology design and the topology extension of high-speed communication networks are presented in number of works with different problem formulations. One of them is considered in [1], [4], [5] and [8] (network components location are predefined). In this case, the problem is connected with traffic estimation, optimal choice of link capacities and most effective routing strategy. Another formulation considers the topology as surplus graphs, where switching nodes location is given and links have to be chosen according to different constraints [2] and [6].

Our problem formulation differs from the mentioned above in the following point: we do not know the location of switching elements and links, which connect them. User/network nodes are characterized by number of input/output ports, capacity and performance. However, in our formulation we use only nodes capacities, since we do not consider flow and congestion control constraints (such as call blocking probability, propagation delay, cell loss probability etc). Links/nodes capacities express upper bound to the total information flow in the network. Therefore, our approach can be used both as in the preliminary stage of methods from [1], [4], [5] and [8] as in independent method of topology optimization.

We use the continuous mathematics methods in order to solve the discrete mathematics problem. Potential users are given by their flow types, QoS and geographical locations. These users can be represented both by single users and by corporate ones (i.e., set of users that are connected into one LAN). We use budget and reliability constraints as optimization criterions and obtain (as results of the considered method) the number, the type and the location of user/network nodes and links as well as links and nodes capacities. Besides, we can group single hosts into corporate LAN. We assume, that links are inexpensive relative to other network components, but link cost increases significantly as far as its length grows. The proposed method provides solutions for additional sub-problems: a) one combines close hosts together, b) another shows future local networking with active information exchange between hosts and c) the third determines optimal equipment properties which are economically reasonable. In addition, basing on this method, it is possible to reduce congestion situations and increase performance of networks with unbalanced load. One practical usage of the proposed method is MANs design where LAN/MAN interconnection is based on ATM. The proposed method is based on results from [9].

1.2. Input information

Let $\mathbb{S} = \{a^{(i)} = (a_1^{(i)}; a_2^{(i)})\}_{i=1}^{I}$ be a system of corporate users located into the rectangle π on the plane in points $a^{(i)} \in \pi$ $(i = 1, 2, ..., I)$ with their "masses" $q^{(i)} = \sum_{j \in Q(i)} q_{ij}$, where q_{ij} is the information flows from the user i to the user j, $Q(i)$ means the set of all receivers or senders which associated with the user i by information flows according to all traffic types. We characterize random processes of an information transmission by means of the following characteristics: the sustainable bit rate $\bar{q}_\nu(i,j)$ and the burst size $\sigma_\nu(i,j)$ for the sender i, the receiver j by traffic type ν ($\nu = 1,2,3,4,5$) corresponding to voice, video, computer data, compressed voice and compressed video. We possess also an information on nodes in the form of the standard nodes menu $\dot{Q}$ ($\dot{Q} = (\dot{Q}_1; \dot{Q}_2; \dot{Q}_3; \dot{Q}_4; \dot{Q}_5)$, where $\dot{Q}_i$ is a capacity of an available switching device).

1.3. Problem formulation

Solving main problem three following results could be obtained: 1) the optimal choice of equipment for the projected network on account of the standard nodes menu, 2) the optimal arrangement of network and user nodes in the region of the projected network on account of dominating information flows and the "density" of information sources, 3) the optimal layout of the future information network. We take into account both the initial data about network flows and the final results of the solution per second.

2. Algorithm brief description

It is well known that the discrete mathematics problems are difficult solvable, in particular, when their dimension is sufficiency high. On the other hand, the continuous mathematics methods have big advantages in comparison with the discrete mathematics methods because we can use powerful concepts such as gradient, potential function and other. Therefore, in our problem we pass (in the solving procedure only) from the discrete formulation to the continuous one, but we preserve integral correlation between discrete and continuous concepts in the same areas $\omega \subset \pi$.

The main idea of our approach is based on following principles: 1) A transformation of point-wise information sources and drains on the plane to the "spread" form of these sources and drains, i.e., to their density function on the plane (in our consideration, those are potential functions, or simply potentials $P_i(x)$ $i = 4,5$ $x \in \pi$). 2) The similar transformation of one dimensional information flows on the plane into the "spread" form of these flows on the plane, but now in the vector form (the potential $P_i(x)$ $i = 1,2,3$, $x \in \pi$). 3) We use so-called operator of kernel smoothing with-well known kernel function in order to obtain a transmission from the discrete given data to the transformed data (now in the continuous form i.e., in the form of a density). Integral correlation is preserved (for example, for any given circle $\sum_{i \in s} q^{(i)} = \int_s P_5(x)ds$). 4) We consider two "layers" of information flows: local flows and transit ones (see the potential function $P_4(x,y)$), correspondingly, for design of the planar network graph part and transit links of this network.

In the following we use two abbreviations: (CS) - a computer solution, if a corresponding parameter is obtained by a computer calculations and (DS) - a designer solution, if this solution is set by designer.

Our algorithm is interactive; it consists of initial stage **(i)** and three additional stages **(ii)-(iv)** which are realized in the certain recursive process.

(i). In the initial stage we define the approximate number of network nodes and user nodes, which are necessary to provide prescribed information flow. In this stage we obtain the initial number of nodes (which may be changed in following iterations) with their characteristics (selecting these nodes from the standard nodes menu) and so-called the radius of "attachment" ρ. Later on we use this radius for two purposes: in order to smooth certain given functions out and to create the virtual user nodes system for the next recursive process. The initial stage is to be realized in the form of (CS)+(DS).

In each following recursion we improve both the location of network and users nodes in the area π and the network topology (connections of information origins by means of links).

(ii). The first stage aim is to create a refined information for designer regarding information flows and information origins location. For this purpose, we construct five continuous functions defined at all points $x \in \pi$: $P_1(x)$ (the indicator of the horizontal flow projection), $P_2(x)$ (the indicator of the vertical flow projection), $P_3(x)$ (the flows potential), $P_4(x;y)$ (the indicator of so-called transit flows; this function is defined on pair of points sender-receiver, receiver-sender) and $P_5(x)$ (the origins potential). The calculation of $P_i(\cdot)$ for $i = 1,...,5$ is performed by (CS).

(iii). Designer (DS) performs the second stage. The main target of designer is to locate nodes (for the chosen number of nodes) by using the functions $P_i(\cdot)$ $i = 1,...,5$ which were obtained earlier on the first stage. After that, a designer must connect selected nodes by links and distribute all corporate users to different user nodes using also these functions P_i for $i = 1,...,5$. In addition, two supplementary procedures (also by (CS)) may be used by designer for the calculation: 1) virtual nodes load variation which is depended on those virtual nodes displacements and the chosen radius ρ, 2) virtual links load variation under conditions of fixed parameters of the virtual network. In the second stage endpoint, a designer obtains the certain network topology with current parameters which were fixed for this iteration.

(iv). The third stage solves the flow problem for obtained network with respect to corporate users $q^{(i)}$ $i = 1,...,I$ which work as random senders or random receivers. This stage is performed by (CS). In view of solution obtained on the third stage, a designer can introduce the network topology variation or nodes location, then he can begin the new recursion, i.e., pass to the first **(ii)** stage but with new parameters.

3. Preliminary stage of nodes number obtaining

We assume that a corporate user is realized in the form of a local network or a servers system, which are connected with one of user nodes. In addition, the users number in the local network or in the servers system is sufficiently large. Using the limit theorems of the probability theory, we obtain probabilistic characteristics of flows from each corporate user. Summing these characteristics over all information origins and taking into account statistical distributions of paths lengths in similar networks, we obtain the general flow Q per second in the projected network as the random vector of known characteristics. Hence, using the standard nodes menu (i.e., $\dot{Q} = (\dot{Q}_1; \dot{Q}_2; \dot{Q}_3; \dot{Q}_4; \dot{Q}_5)$), we can define the minimal nodes number allowing the future network functioning. This choice is realized by (DS) in the form $\tilde{N} = \frac{\kappa_1 \hat{Q}}{\dot{Q}_i}$, where $i \in \{1; 2; 3; 4; 5\}$, $\hat{Q}$ is the mathematical expectation of Q and κ_1 is the coefficient which is depended on the Q characteristics.

Restricting oneself, for example, $N = \tilde{N} + N^*$ nodes in the network (where N^* depends on the network topology and flows), a designer can change this number in accordance with given nodes menu in the following iterations.

4. Algorithm for the potentials $P_i(\cdot) \quad i = 1, 2, 3.$

The potential flow function helps to localize the best switching nodes installation place.

Let D_1 and D_2 be projections of the area π on the axes x and y, and $\pi = D_1 \bigotimes D_2$ is the rectangle containing all users. Fixing sufficiently small number δ, we partition D_1 and D_2 by means of a mesh so that $r = 1, ..., R$; $s = 1, ..., S$ and $\pi_{rs} = \{x = (x_1; x_2) \in \pi : r\delta \leq x_1 \leq (r+1)\delta; s\delta \leq x_2 \leq (s+1)\delta\}$; then it is clear, that $\pi = \bigcup\limits_{r=1}^{R} \bigcup\limits_{s=1}^{S} \pi_{rs}$. Introduce the following notations for the oriented pair i and j (sender-receiver): $\alpha(i,j) = (a^{(i)}; a^{(j)})$ is the shortest connection of users i and j, i.e., the segment on the plane with ends $a^{(i)}$ and $a^{(j)}$, $e^{(1)} = (1; 0)$, $e^{(2)} = (0; 1)$, $G(r,s) = \{(i,j) : \alpha(i;j) \cap \pi_{rs} \neq \emptyset\}$. Then the functions $P_i(x)$ for $i = 1, 2, 3$ can be calculated in the following form:

$$P_1(\xi_{rs}) = c_1 \sum_{(i,j) \in G(r,s)} \frac{|\langle \alpha(i,j); e^{(1)} \rangle|}{\|\alpha(i,j)\|} q_{ij}$$
$$and \tag{1}$$
$$P_2(\xi_{rs}) = c_1 \sum_{(i,j) \in G(r,s)} \frac{|\langle \alpha(i,j); e^{(2)} \rangle|}{\|\alpha(i,j)\|} q_{ij}$$

where $\langle \cdot ; \cdot \rangle$ is a scalar product, $\|x\| = \|x\|_{\mathbb{R}^2} = \sqrt{x_1^2 + x_2^2}$ is a norm of the vector x;

$$P_3(\xi_{rs}) = c_1 \sqrt{P_1^2(\xi_{rs}) + P_2^2(\xi_{rs})} \tag{2}$$

where $q_{ij} = \sum\limits_{\nu=1}^{5} [\bar{q}_\nu(i,j) + \mu_\nu(i,j) \cdot \sigma_\nu(i,j)]$; $\mu_\nu(i,j)$ is the reliability weight coefficient for delivery of information flow of the type ν from i to j: $\nu = 1, ..., 5$; $i, j = 1, ..., I$; c_1 is a normalizing multiplier. Recall in this point that ν is a traffic type and I is the number of all users and we do not consider $i = j$. These weight coefficients are connected with QoS and data characteristics of the sender "i" and the greater coefficient $\mu_\nu(i,j)$ corresponds to the greater value of QoS by other coinciding conditions.

Remark 1. In view of approximation of the potential $P_i(x)$ for $i = 1, 2, 3$ by linear splines, the level lines of this potential are direct. Therefore, each of them is represented in the form of a piecewise linear line and, hence, its position is defined by finite sequence of points.

Consider all directions e_{rs} from the point-knot $x_{rs} \in \pi$ and select the direction e^*_{rs} such that the variation of $P_i(\cdot)$ for $i = 1, 2, 3$ is minimal (in essence, this direction coincides with the level line from the point x_{rs}).

Remark 2. In view of the same causes that are mentioned by us in Remark 1, there exists the class of piecewise linear splines on π (which is generated by segments-edges of the given mesh) such that the variation of P_i for $i = 1, 2, 3$ is minimal along these lines. We shall call similar lines the piecewise splines of the minimal gradient.

5. Algorithm for the potential functions $P_4(\cdot)$ and $P_5(\cdot)$

The transit flows indicator $P_4(x; y)$ is defined on $\pi^2 \subset \mathbb{R}^2 \bigotimes \mathbb{R}^2 = \mathbb{R}^4$ by means of the averaging with the kernel function $f(x) \quad (x \in \mathbb{R}^1)$ depending on the following factors: installation conditions of servers to the user nodes, cost of user and network nodes. Recall that the user i is located in the point $a^{(i)} \in \pi$.

Let $s = s(x; \rho) = \{\xi \in \pi : \|\xi - x\|_B \leq \rho\}$ be a "ball" centered in the point x of the radius ρ, where $\|x\|_B = \max\{|x_1|; |x_2|\}$ for $x = (x_1; x_2)$, and let $H_{(rs),(kl)}(\rho) =$

$\{(i;j) : a^{(i)} \in s(x_{rs};\rho); a^{(j)} \in s(y_{kl};\rho); s(x_{rs};\rho) \cap s(y_{kl};\rho) = \emptyset; q_{ij} > 0\}$ be a set of nonempty connections between $s(x_{rs};\rho)$ and $s(y_{kl};\rho)$. At first we define the function $P_4(x;y)$ (where $x, y \in \mathbb{R}^2$) only in the points-knots of the mesh $\{(x_{rs};y_{kl})\}_{(r=1;s=1),(k=1;l=1)}^{R;S} \in \pi^2 \subset \mathbb{R}^4$ by means of the following operator which symmetric with respect to the different knots $x_{rs} \neq y_{kl}$ (links resources are shared by both flow directions):

$$P_4(x_{rs};y_{kl}) = \frac{c_2}{16\rho^4} \sum_{(i;j)\in H_{(rs),(kl)}(\rho)} q_{ij} \cdot \cdot f(\|a^{(i)} - x_{rs}\|) f(\|a^{(j)} - y_{kl}\|) \tag{3}$$

where $f(\cdot)$ means the kernel function used by us for averaging in order to construct the continuous analogy of discretely distributed origins, $\|\cdot\|$ means the usual eucledian norm in the finite-dimensional space $\mathbb{R}^4$ and c_2 is a normalizing multiplier.

Now we pass to construction of $P_5(\cdot)$. Noting by $q = \{q^{(i)}\}_{i=1}^{I}$, we introduce the measure $\tilde{\mu}$ generated by means of the pair $(\mathbb{S}, q)$. This measure is Stilt'es's measure with the support $\mathbb{S}$. In order to construct the continuous function $P_5(\cdot)$ (the user potential) from the measure $\tilde{\mu}$ defined in the discrete form, we use the following smoothing operator $P_5(x) = \int_{s(x;\rho)} \mu dt$, where the integral is the Stilt'es's integral (i.e. as a sum), $s = s(x;\rho) = \{t \in \pi : \|t - x\| \leq \rho\}$ and $\|t - x\| = \max\{|t_1 - x_1|; |t_2 - x_2|\}$. By using this operator in the points-knots $\{x_{rs}\}_{r=1;s=1}^{R;S}$ of the mesh mentioned in Sect. 4, we obtain the values of the function P_5

$$P_5(\xi_{rs}) = \frac{c_3}{4\rho^2} \sum_{i\in s(x_{rs};\rho)} q^{(i)} \tag{4}$$

in these points-knots, where c_3 is a normalizing multiplier. Further we extend the function P_5 from these nodal points up to the function P_5 defined on the whole rectangle π in the same way that was mentioned in Sect. 4 (i.e., by means of the linear-spline interpolation). In the case, when the number of corporate users is very big, the function P_5 shows the real density of information flows origins.

Remark 3. Similarly to the conclusions mentioned in Remarks 1 and 2, the level lines of $P_4(x)$ and $P_5(x)$ consist of direct lines segments, hence, their positions are defined by finite sequences of points. Besides, there exists the class of piecewise linear splines on π (which is generated by segments-edges of the given mesh) such that the variations of $P_4(x)$ and $P_5(x)$ are minimal along these lines.

The potential functions $P_3(\cdot)$ and $P_5(\cdot)$ must be normed so that the classical "Kirchhoff conditions" for the network hold (see Principle 4, Sect. 2), i.e.

$$|\sum_{k=1}^{\tilde{K}} \int_{\tilde{s}_k} P_5(x)dx - \int_{\pi} P_3(x)dx| \leq \varepsilon\tilde{Q}, \tag{5}$$

where $\tilde{Q} = \int_{\pi} P_5(x)dx$ is all the user generated information. Constants c_1 and c_3 can be obtained approximately from conditions (5) and (6) for $\varepsilon = 0$ (this is flow balance).

6. Design steps and regulation criterions

Design process is recursive (every next iteration has been directed to an improvement of the general state of the considered network, i.e., to a lowering of the total (summarized) flow across all nodes - Criterion C^*). Designer also uses several options-procedures allowing to calculate the average of information flows across the "circle" $s = s(x;\rho)$ as a function of the point-center x and the radius ρ (see Sect. 5).

Let a number $\varepsilon > 0$ be the small prescribed number which defines the part of information flows located sufficiently inconveniently with respect to nodes. We call the circles family $\{s_k = s(x^{(k)};\rho_k)\}_{k=1}^{K}$ the covering Σ_ε if the following inequality holds

$$|\sum_{k=1}^{K} \int_{s_k} P_3(x)dx - \int_{D} P_3(x)dx| \leq \varepsilon Q, \tag{6}$$

where $Q = \int_D P_3(x)dx = \sum_{i=1}^{I} q^{(i)}$ is the general flow in the considered network. Generally speaking, partition of all nodes into two groups (users nodes and network nodes) is sufficiently conditional, since, in most cases, the nodes are realized as both user nodes and network nodes in the same time. Therefore we partition all nodes into two groups virtually. Designer actions are consisted of the following steps:

Step 1 (Virtual network nodes arrangement of the planar network layer). Using Remarks 1,2 and the function $P_3(\cdot)$ under condition of restriction on the switching nodes number, a designer defines the virtual network nodes location (DS). We select a network node location criterion in the following way.

a) The network node must be located in the points of the local maximum of the function $P_3(\cdot)$. It is motivated by an easy cause - the density of data processing is maximal in this point and in its certain neighborhood (of course, under condition that the function values in these points are sufficiently large).

b) If the local maximum points number n^* is large, i.e. $n^* \geq N$, then a designer defines the location of network nodes in order to reach the maximal value of the total flow in the covering $\Sigma_\varepsilon = \{\bar{s}_k = s(\bar{x}_k;\bar{\rho})\}_{k=1}^{\bar{K}}$ (DS). Here a designer uses integration procedures of the function $P_3(\cdot)$ on this covering which satisfies conditions (5) and (6) on the account of the potential functions P_1 and P_2 (CS). The users $\tilde{i} \notin \Sigma_\varepsilon$ can be connected with any selected nodes in the network using other criterions.

Step 2 (Virtual user nodes arrangement of the planar network layer). Using Remark 3 and the function $P_5(\cdot)$ under condition of a restriction on the switching nodes number, a designer defines the location of virtual user nodes (DS). In this case, he uses also options-procedures allowing to calculate the integral of the information generation "density" from origins on the circle $s(x;\rho)$.

The user node must be located in the area with the high information generation density $P_5(\cdot)$ because of all connections between this user node and servers of close users will be short. Then, in this case, it is possible to reach the easiest service.

Step 3 (Coordination of virtual network and user nodes to real nodes) This step is the most important in the design. On the first and second steps we obtained the location of virtual nodes only (network and user nodes separately), but this situation is not real. The virtual nodes location is the only desired one and now a designer must agree on the real nodes location. In this process a designer can reduce two neighboring nodes (network node and user node) to one node on account of (1),(2) and the standard nodes menu (DS). In the end of the process a designer must obtain the system of nodes so that the following requirements are satisfied: 1) The general nodes number n located by designer is such that $n \le N$, where N is the nodes number accepted by designer on the design beginning. 2) All nodes can be represented by two groups (the first of them contains network nodes only, the second group consists of nodes functioning as user and network nodes at the same time). 3) Nodes power must correspond to the general information flow density in the circles around node location points (CS).

To reach the stated target, a designer uses the Lebesgue sets of functions $P_i(\cdot)$ for $i = 3, 5$, i.e., $L_3(h_3) = \{x \in \pi : P_3(x) \ge h_3\}$ and $L_5(h_5) = \{x \in \pi : P_5(x) \ge h_5\}$ correspondingly, where h_3 and h_5 are prescribed (sufficiently high) levels which may be defined from earlier calculated P_3 and P_5. It is useful to construct and to use the intersection $L_{35}(h_3; h_5) = L_3(h_3) \cap L_5(h_5)$ (CS). High data processing density of the information flow and high density of the information generation characterize this set.

The location of all nodes must be correlated with the functions $P_1(\cdot)$ and $P_2(\cdot)$ (CS), as well.

Step 4 (Links construction) At first we construct so-called "transit" links (i.e., sufficiently long links) by means of the function $P_4(\cdot)$ using points of its local maximums and its Lebesgue's set $L_4(h_4)$ for sufficiently big values h_4 (CS+DS). The local maximum point of the function $P_4(x, y)$ together with its certain neighborhood $s((x_0, y_0); r) = s(x_0, \rho) \bigoplus s(y_0; \rho)$ shows power transit links, definitely, under condition $s(x_0, \rho) \bigcap s(y_0; \rho) = \emptyset$ (i.e., when the distance between x_0 and y_0 is sufficiently long). A designer has a possibility to select one or several transit links in concord with nodes and links which are already in the presence. We have here $r = \sqrt{2}\rho$ in view of (2). Then we construct so-called "local" links (i.e., links connecting close nodes) taking into account two factors (DS+CS): functions $P_1(\cdot)$, $P_2(\cdot)$ and transit links obtained already. In addition, we use the certain procedure of distributed flows collection on the plane to one direction. Define the option-procedure of the join of continuously distributed flows to the united flow with discrete direction. Let θ^{k_1} and θ^{k_2} be two nodes connected with the link $[\theta^{k_1}, \theta^{k_2}]$, let two two-dimensional simplexes (two triangles) $\Delta(\theta^{k_1}, \theta^{k'}, \theta^{k_2})$ and $\Delta(\theta^{k_1}, \theta^{k''}, \theta^{k_2})$ be conjugate with the common edge $[\theta^{k_1}, \theta^{k_2}]$, let $\beta' = \frac{1}{3}(\theta^{k_1} + \theta^{k'} + \theta^{k_2})$ and $\beta'' = \frac{1}{3}(\theta^{k_1} + \theta^{k''} + \theta^{k_2})$ be centers of these simplexes.

Let $\Omega = \Omega(\theta^{k_1}, \theta^{k_2}) = \Delta(\theta^{k_1}, \theta^{k'}, \theta^{k_2}) \cup \Delta(\theta^{k_1}, \theta^{k''}, \theta^{k_2})$ be a domain that associated with the virtual link $[\theta^{k_1}, \theta^{k_2}]$; then the information flow in this link can be estimate as

$$F(\theta^{k_1}, \theta^{k_2}) = \int\limits_{\Omega(\theta^{k_1}, \theta^{k_2})} [\lambda_1 P_1(x) + \lambda_2 P_2(x)] dx, \qquad (7)$$

where $x = (x_1; x_2) \in \pi$, $a^{k_1} = (a_1^{k_1}; a_2^{k_1}) \in \pi$, $a^{k_2} = (a_1^{k_2}; a_2^{k_2}) \in \pi$, coefficients λ_1 and λ_2 depend on the ratio $\frac{a_1^{(k_2)} - a_1^{(k_1)}}{a_2^{(k_1)} - a_2^{(k_2)}}$. A designer aims to connect nodes such that: 1) the flow condensed on the area Ω has the sufficiently large value, 2) the links number is sufficiently small. In essence, the last ratio defines an angle coordinated with the direction of the considered link and integral (7) means the vector part of the whole flow that is "absorbed" by this link.

It is necessary to correct the functions $P_i(\cdot)$ for $i = 1, 2, 3$ after the construction of each real link by means of the mentioned procedure (CS).

Step 5 (Flow problem solving) In this last step of recursive process, we solve the linear problem (for the case of constant flows) with an object function according to the criterion C^*. Each iteration ends with this problem solution.

7. Numerical results

We consider the problem of network construction on geographical area π where corporate users are distributed uniformly. There are n_ν users so that each of them has traffic characteristics given by t_ν. Assuming that links cost is sufficiently low in comparison with network nodes cost, our goal is to minimize amount of network equipment (calculated as summary of switching capacities) simultaneously taking into account links length. We follow to the example considered in [3]. In our example $\nu = 2$, $n_1 = 120$, $n_2 = 40$, t_1 is an aggregated traffic from 15 standard 64

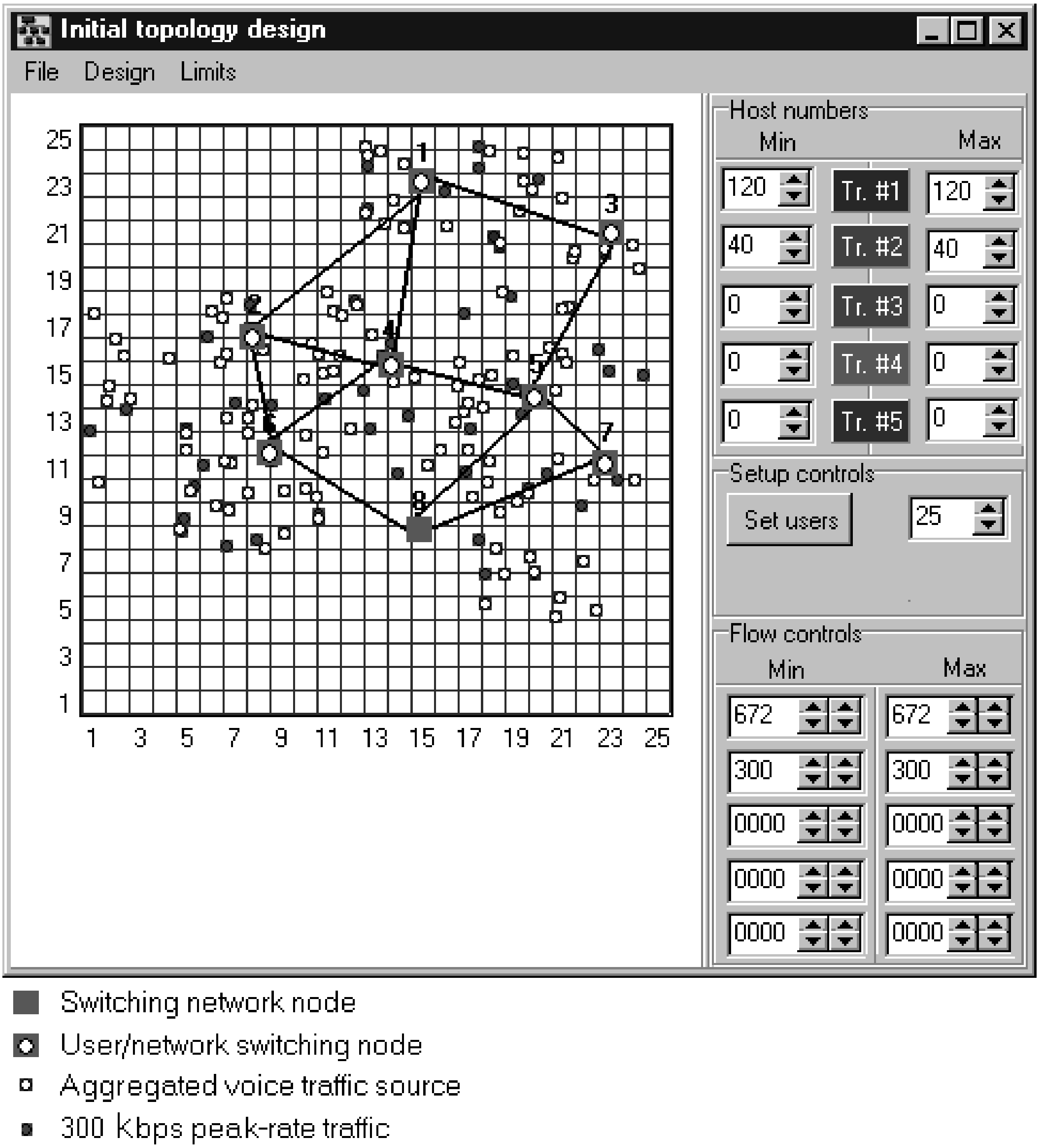

Figure 1. Result topology.

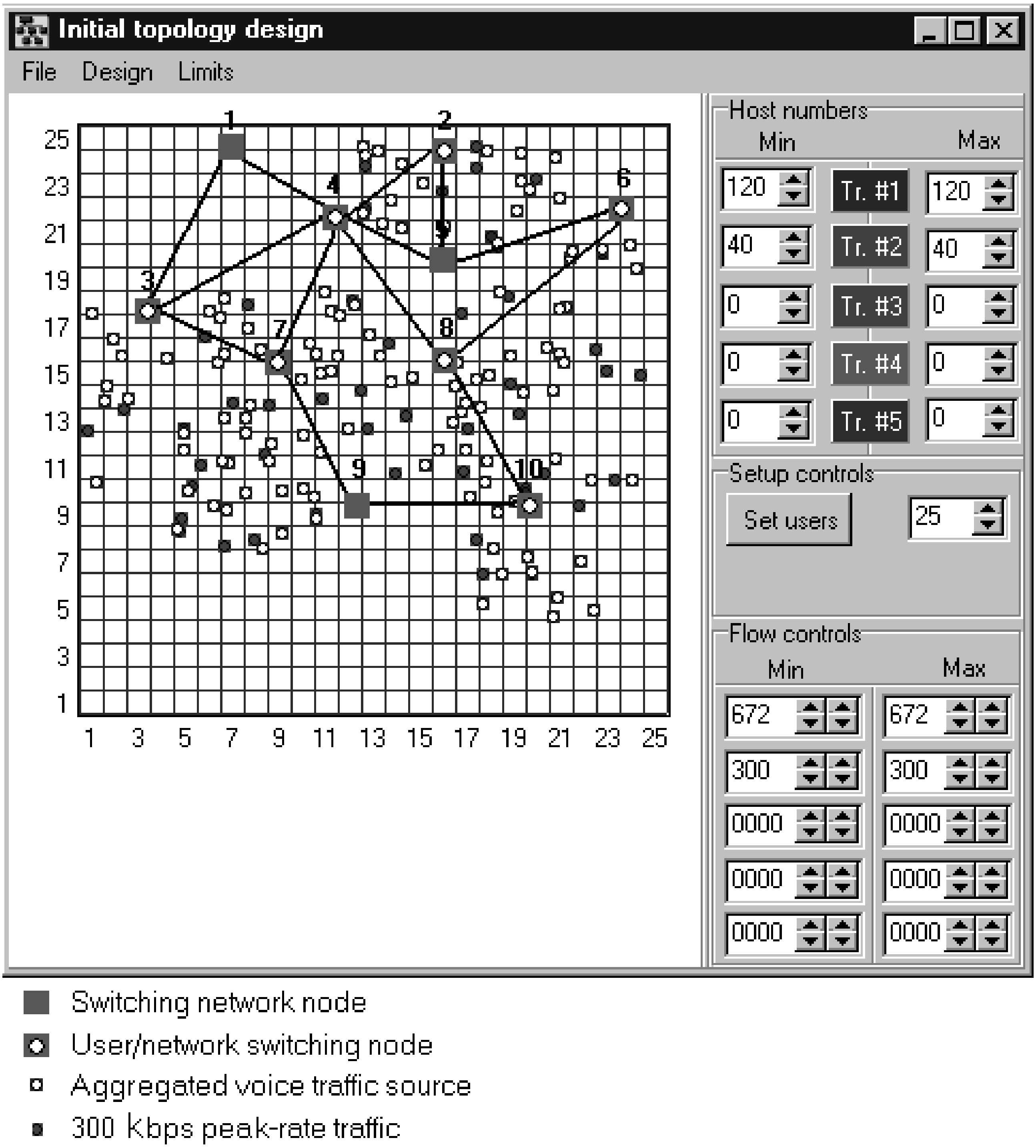

Figure 2. Topology from [3].

Table 1. Switching capacities.

Switch number	Capacities for result topology	Estimated capacities for topology from [3]
1	500	600
2	990	1560
3	766	980
4	2400	1100
5	2100	820
6	2800	740
7	900	2800
8	1100	2620
9	-	1100
10	-	2380

Table 2. Network topology information for sample networks.

	Our topology	Topology from [3]
No. of switches	8	10
No. of net. nodes	1	3
No. of links	12	14

Kbps voice channels with connection probability 0.7 and t_2 is a traffic with peak bit rate 300 Kbps and burst period 100 ms. We bound link capacity to 155 Mbps and switching capacity to sufficiently big number. In Fig.1 we show the topology constructed by proposed method comparing it to the example from [3].

Table 1 illustrates switching capacities necessary for stable network operation that were obtained by our method. In column 2 we present result values obtained by topology layout design. For adequate comparison, we use the same users distribution on the plane for the topology from [3] and our method is used for capacity estimation only. These values are presented in column 3. Table 2 summarizes the amount of network equipment used in the samples.

8. Conclusion

The correct definition of switching equipment and network layout is a first stage of network design and resource allocation problem. The proposed approach resolves the problem of switching equipment selection together with the optimal topology design. In addition, it is possible to make optimal routing precalculation with respect to congestion and performance degradation avoidance. Besides, the algorithm has the following advantages: 1) By taking into account properties of the smoothing operators that are used in construction of the potential functions $P_i(x)$ $i = 1, 2, 3, 5$ and $P_4(x, y)$ we obtain essential improvement of problem solution quality with growth of corporate users number; therefore, this approach does not meet difficulties of the scaling problem. This follows immediately from a more precise representation of the discrete formulation by the continuous one. 2) The proposed method allows to resolve network problems with non-planar graphs (by using $P_4(x, y)$) for transit links. Hence, it is possible to construct hybrid networks (with wireless links as transit ones), though any local link in the "planar" layer also can be wireless. 3) Our approach allows to take into account the resources of the already functioning network and its resources could be used for the projected network.

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