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Topology optimization of an overlay ATM network in an SDH infrastructure ☆

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Abstract

The paper presents a realistic scenario for the introduction of a public ATM network to be implemented on the Hungarian SDH infrastructure. The Hungarian SDH network was deployed in 1996 with STM-4 rings on the lower level, and an STM-16 mesh subnetwork on the higher level, while the ATM network is intended to be introduced with two hierarchical levels: the access level and the backbone level consisting of transit and regional sublevels. A network optimization model and a practical approach are proposed for the topological optimization of the ATM network. In the proposed approach the problem is decomposed into two phases, namely, the determination of the topology of the ATM backbone including the identification of access and transit sites, and the near optimal realization of ATM links in the SDH infrastructure. The planning method and the scenario are demonstrated by some numerical results. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: ATM; SDH; Network optimization; Heuristic algorithm

1. Introduction

State-of-the-art telecommunication and data services require more and more bandwidth, therefore it is a modern tendency to develop high-speed transmission capabilities that can be simultaneously and economically used as an integrated infrastructure for different applications.

ATM network development to support advanced data and reliable multimedia communications is gaining the popularity with network operators who aggressively use this technology to drive new business initiatives, since an ATM backbone provides simple and effective network management for public networks and a scalable network solution for the later introduction of new integrated services as well. One can read more information on the pilot projects for the Wide Area ATM Deployment of the European operators in [1,2] and recently the plan of the international joint venture of Deutsche Telekom, France Telecom and Sprint for the launch of a seamless Global ATM service via one of the largest and most advanced ATM-based networks

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in the world, which will be offered in 13 countries: Belgium, Canada, Denmark, France, Germany, Ireland, Israel, Japan, The Netherlands, Sweden, Switzerland, United Kingdom and the United States [3].

Moreover, an existing SDH infrastructure is often utilized as the transport network for ATM in order to decrease the initial deployment cost of the ATM network. For example, the Hungarian Telecommunication Company (HTC) has implemented a country-wide high-speed (622 Mbps–2.4 Gbps) SDH based backbone network ([9]) with several network protection capabilities, that is being used as an efficient transport layer for the ATM network to fulfill the continuously growing demands initiated towards HTC.

In this paper we present an approach for planning an ATM network which is implemented on top of the SDH infrastructure and is intended to serve high-speed advanced data communications. To design such a network we decompose the problem into the following subproblems:

1. optimize the topology of an ATM network which includes
   - select the location of ATM access switches and the assignment of users to the switches to minimize the unused SDH capacity,
   - select the location for transit switches to efficiently carry traffic for the users,
2. realize the ATM links in the SDH infrastructure (optimal routing for ATM links in the SDH).

The solutions for the above subproblems are obtained by using heuristic algorithms. Moreover, the planning system is designed in such a way that it allows the network planners to set up a complete planning process. The solution of the above subproblems is being implemented in the XPLANET tool developed for the support of the network planning activities of HTC [7], and the tool is being applied for the determination and comparison of possible network solutions based on the scenarios where the public ATM network is introduced on top of the SDH infrastructure.

The rest of this paper is organized as follows. Section 2 describes the network scenario (the ATM network hierarchy and the introduction phases), Section 3 presents the network planning approach, Section 4 focuses on a mathematical formulation and the proposed optimization procedures and Section 5 deals with some results on a realistic scenario. Finally, Section 6 concludes the paper.

2. Network scenario

2.1. Main phases of the ATM network deployment

In order to provide a smooth introduction of ATM technology in Hungary the PKI Telecommunications Development Institute distinguished the following five phases:

Phase 1. ATM Laboratory. At the beginning of 1996 an experimental ATM Laboratory was established.

Phase 2. ATM Pilot Network. In the middle of 1996 the ATM Laboratory was extended to an ATM Pilot Network which is to ensure an independent basis for development purposes. This environment is for service development and testing of new hardware and software elements. In this network several applications, like broadband video conference, MPOA, LAN emulation, and VoD are tested, but there is no live traffic.

Phase 3. Extended ATM Pilot Network. At the beginning of 1997, the Pilot Network was extended with transit and access switches.

Phase 4. ATM field-trial network. From the middle of 1997 to the beginning of 1998, a new separate network was established, the field trial ATM network. The ATM field-trial network currently consists of four nodes. The international switch and three other switches are already in service in Budapest. HP bearer and circuit emulation experimental services are available for a dedicated group of subscribers.

Phase 5. Public ATM network. Starting in 1999 the public ATM network offers public ATM-based B-ISDN services. The main services are the ATM bearer service and high-speed LAN interconnection service. The country-wide ATM network was constructed with the help of the results presented in this paper.

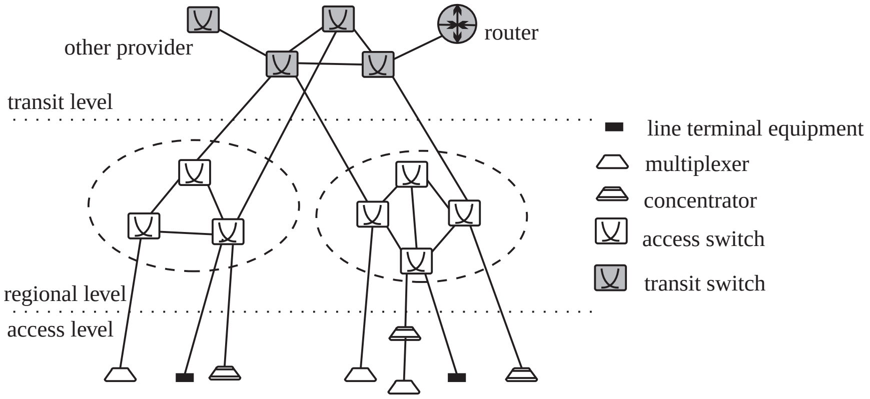

Fig. 1. The considered ATM network hierarchy.

2.2. Network architecture

The target network is partitioned into two levels: the access and backbone levels. In more detail, both in the access and in the backbone subnetworks further network sublevels can be identified. The access network provides the access of users to the access switches. It is composed of line terminators, multiplexers and concentrators, and normally has a tree topology. The backbone network with a two-level hierarchical architecture is currently under consideration (Fig. 1). The higher level consists of transit switches and interconnects the access switches of the regional subnetworks. For data communication services (such as LAN/MAN interworking) multiprotocol routers are used. The multiprotocol routers are usually connected to the transit nodes.

The network provides point-to-point and point-to-multipoint connections which can be flexibly allocated, maintained and reallocated by the management system. The transit and access ATM switches are sophisticated multiservice devices and can be easily extended as the user demand grows.

2.3. Realization of the ATM network in the SDH infrastructure

In this paper, we consider the case when the ATM network is built on top of an SDH infrastructure. The following assumptions are made:

- The public ATM access and transit switches are placed into the nodes of the SDH network, thus all the ATM links are realized and routed in the SDH infrastructure.
- The ATM network service will be required by business subscribers with an ATM interface. These users are not located in the nodes of the SDH network, therefore, the access of users to the SDH infrastructure must be provided. The ATM link between a specific user and its first ATM access switch is realized with two consecutive sections. For the first section new optical cable will be deployed between the site of the user and the nearest SDH ADM (Add and Drop Multiplexer) point in the SDH infrastructure. [2]

The cost of deploying access cables is fixed and depends only on the location of users. Therefore, this part of the network can not be optimized. The second section will be realized only in the SDH infrastructure. Since the physical capacity of the second section in the SDH infrastructure is not shared with other users in the ATM layer, [3] the physical capacity of the second section is not efficiently used if the bandwidth requirement is below the port rate.

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[2] If it has been already implemented, the cost for the user is decreased.

[3] In contrast with the SDH physical capacity interconnecting the ATM switches.

3. Planning method

3.1. Modelling the cost of the SDH usage

The following function is introduced to model the cost for the SDH usage of the ATM network on the SDH infrastructure:

$$f(i,j,C) = g_1(C)(n_{ij}\gamma + d_{ij}\lambda) + g_2(C), \qquad (1)$$

where C denotes the required speed of an ATM link whose endpoints are i and j, to be realized in the SDH infrastructure, $g_1(C)$ and $g_2(C)$ the stepwise functions to take into account the fact that in ATM networks link capacities are of discrete value, n_{ij} the number of SDH hops (number of ADMs) and d_{ij} the length of the ATM link between node i and j in the SDH infrastructure, γ and λ are the cost coefficients.

3.2. Problem description

Formally, the design problem for an ATM network topology built on top of an SDH infrastructure can be stated as follows:

Given

- the SDH infrastructure,
- the list of users and their access points to the SDH infrastructure,
- users' requirement (port speed, bandwidth and QoS requirement),
- cost and characteristics (e.g., capacity) of switches, routers, the usage of SDH infrastructure,
- the potential location of switches (it is assumed that the ATM switches are realized in the node of the SDH infrastructure).

Objective: is to find an ATM network topology in order to minimize the network cost and the SDH usage.

3.3. Practical approach

Since the problem described in the previous subsection is complex and very impractical to solve in a single step, the following approach is used in this paper.

First, we decompose the planning task into two main subtasks:

1. optimize the topology of an ATM network which includes
   - select the location of ATM access switches and the assignment of users to the switches to minimize the unused SDH capacity,
   - select the location for transit switches to efficiently carry traffic among the users,
2. realize the ATM links in the SDH infrastructure (optimal routing for ATM links in the SDH).

The decomposition is carried out in a way that allows reuse of the code of the optimization algorithms (see Section 4) applied to problems in this paper. Moreover, the input interfaces of the program modules for each subproblem are designed in order to allow the network planners to build a complete planning process for this problem.

Secondly, due to the fact that the two subtasks are interrelated the solution for the planning problems can only be obtained by carrying out the appropriate subtasks iteratively.

The solution to the above problems is implemented in the framework of the XPLANET software package by using the generic network model, and therefore, both the optimization library of XPLANET and its graphical user interface are directly applied to this planning problem.

4. Models and heuristic algorithms for the components of the planning approach

4.1. Topology optimization

Notation for input data is introduced as follows:

- $U = \{1, \ldots, |U|\}$ denotes the set of users.
- $T = \{T_{hi}\}$ $(h, i \in U)$ is the traffic matrix.
- G_i is the speed of a line connecting user i to the network (specified by the user and may depend on the interface required by the user).
- S is the set of potential sites.
- μ_{ij} $(i \in U, j \in S)$ is the cost of connecting user i to site j.
- v_{kj} $(k, j \in S)$ is the cost of connecting sites k and j.

Both μ_{ij} and v_{kj} have the form of (1).

- Without loss of generality we assume that W is the switching capacity of a switch used in the network (it limits the maximal number of the switch ports).
- α is the installation cost of a switch.

Binary decision variables are defined as follows:

- $u_j = 1$ $(j \in S)$ if a switch is installed in site j, otherwise $u_j = 0$

  $\boldsymbol{u} = \{u_j : j \in S\}$.
- $x_{ij} = 1$ $(i \in U, j \in S)$ if a switch is implemented in site j and user i is connected to a switch in site j; otherwise $x_{ij} = 0$

  $\boldsymbol{X} = \{x_{ij} : (i \in U, j \in S)\}$.
- $y_{kj} = 1$ $(k, j \in S)$ if sites k and j are interconnected with a link of capacity C_{kj}; otherwise $y_{kj} = 0$

  $\boldsymbol{Y} = \{y_{kj} : (k \in S, j \in S)\}$.
- $z_{hikl} = 1$ $(h, i \in U), (k, l \in S)$ if traffic T_{hi} between user h and i is routed in a link between sites k and l; otherwise $z_{hikl} = 0$

  $\boldsymbol{Z} = \{z_{hikl} : h, i \in U, k, l \in S\}$.

A model for an integer programming problem is formulated as follows:

Model-A

$$\min_{(\boldsymbol{u},\boldsymbol{X},\boldsymbol{Y},\boldsymbol{Z})} \sum_{j\in S} u_j\alpha + \sum_{i\in U}\sum_{j\in S}\mu_{ij}x_{ij} + \sum_{k\in S}\sum_{j\in S} v_{kj}y_{kj}, \tag{A1}$$

subject to

$$\sum_{j\in S} x_{ij} = 1 \quad (i \in U), \tag{A2}$$

$$x_{ij} \leqslant u_j, \tag{A3}$$

$$y_{kj} \leqslant u_j \quad \text{and} \quad y_{kj} \leqslant u_k \quad (k \in S, j \in S), \tag{A4}$$

$$\sum_{i\in U} x_{ij}G_i + \sum_{k\in S} y_{kj}u_jC_{kj} \leqslant u_jW \quad (j \in S), \tag{A5}$$

$$z_{hikl} \leqslant y_{kl} \quad (h, i \in U),\ (k, l \in S), \tag{A6}$$

$$\sum_{h,i\in U} z_{hikl}T_{hi} \leqslant y_{kl}C_{kl} \quad (k, l \in S). \tag{A7}$$

In Model-A, expression (A1) refers to the total cost of the network. Constraints (A2) and (A3) enforce that a user should be connected to a switch. Constraint (A4) expresses that a link can be only established between sites of switches. Constraint (A5) represents that the processing capacity of the switch is limited. Constraints (A6) and (A7) implicitly include the PVC routing problem.

To solve this optimization problem we decompose Model-A into two submodels. The solution of the planning task can be obtained by applying the appropriate combination of two well-known heuristic algorithms.

For example, the following procedure can be set up for planning a network with a two-level hierarchical architecture. First, we select the location of ATM access switches and the assignment of users to the switches to minimize the unused SDH capacity. Second, we optimize the topology of the regional subnetwork. Third, we identify the location for transit switches to efficiently carry traffic among the users. Fourth, we design the topology of the transit network. We can observe that the first and the third planning task can be carried out with the same algorithm. This is also true for the second and the fourth task.

The submodels and heuristic algorithms are presented in the next section.

4.1.1. Switch location and assignment

A model for an integer programming problem is formulated as follows:

Model-B

$$\text{Min} \quad \sum_{j\in S} u_j\alpha + \sum_{i\in U}\sum_{j\in S}\mu_{ij}x_{ij}, \tag{B1}$$

subject to

$$\sum_{j\in S} x_{ij} = 1 \quad (i \in U), \tag{B2}$$

$$x_{ij} \leqslant u_j, \tag{B3}$$

$$\sum_{i\in U} x_{ij}G_i + KCu_j \leqslant u_jW \quad (j \in S), \tag{B4}$$

where we assumed that each switch is connected to at least K other switches with capacity C.

At first glance, one can observe that this is similar to the concentrator location problem which can be solved with heuristic algorithms (for example the Center of Mass, the Add, Drop algorithm). [4] However, there are some differences between the concentrator location problem and this problem. Namely, in the concentrator location problem there is a center and the capacity of the center is assumed to be infinite. In this paper we modified the Add algorithm for our problem. The applied algorithm is of greedy nature. The algorithm evaluates the savings obtainable by adding a switch at each site. Then it greedily selects the switch which saves the most money. After each switch is selected, the savings by adding an additional switch is changed so all the potential savings are reevaluated. Moreover, whether the capacity of switch is exceeded because of directly attached users is also checked.

In order to decrease the search space we can determine the minimum number ($N = \sum_{i\in S} u_i$) of necessary switches in what follows. From (B4) one obtains

$$\sum_{j\in S}\sum_{i\in U} x_{ij}G_i + KCn \leqslant NW, \tag{2}$$

and it follows:

$$\frac{\sum_{i\in U} G_i}{W - KC} \leqslant N. \tag{3}$$

4.1.2. Topology optimization

The formal formulation of this problem is as follows:

Given

- the SDH infrastructure and the cost model,
- a set of the switches' locations denoted by S' ($S' \subseteq S$),
- the "traffic matrix" between the switches.

Design objective:

- is to find a topology of the backbone network in order to efficiently serve the user demands.

A model for an integer programming problem is formulated as follows:

Model-C

$$\text{Min} \quad \sum_{k\in S'}\sum_{j\in S'} v_{kj}y_{kj}, \tag{C1}$$

subject to

$$\sum_{i\in U} x_{ij}G_i + \sum_{k\in S'} y_{kj}u_jC_{kj} \leqslant u_jW \quad (j \in S'), \tag{C2}$$

$$z_{hikl} \leqslant y_{kl}(h, i \in U) \quad (k, l \in S'), \tag{C3}$$

$$\sum_{h,i\in U} z_{hikl}T_{hi} \leqslant y_{kl}C_{kl} \quad (k, l \in S'). \tag{C4}$$

The routing is implicitly included in this problem, therefore it seems that this problem can not be solved as a linear programming problem. Moreover, for practical size a heuristic technique must be used. For our purposes we use the MENTOR algorithm, which is able to create a low cost, effective network [5].

4.2. ATM link routing in the SDH infrastructure

The formal formulation of this problem is stated as follows:

Given

- ATM physical link demands between ATM switches and between users and switches,
- the underlying SDH infrastructure,

Design objective:

- determine the optimal routing of ATM links in the SDH infrastructure.

This problem can be formulized as a multicommodity flow model and can be solved by standard linear programming techniques [4].

4.3. Assessment of the planning approach

Some general assessments of the planning approach and algorithms are as follows:

- Note that no constraint is imposed on the number of users in the network optimization model and algorithms. However, the number of the users does affect the running time of the algorithms.
- It should be mentioned that the planning approach can also be used for another scenario where an ATM network is not realized on the

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[4] The interested reader may finds more detail on these algorithms in [8].

SDH infrastructure (e.g., on a pure fiber optic infrastructure). In that case we need only to change the cost function.

5. Numerical results

In this section we demonstrate the proposed planning approach with some numerical results obtained for a specific ATM network to be implemented on top of the Budapest and core SDH networks. We present some preliminary results concerning the regional ATM network in the first scenario and some results concerning the hypothetical transit ATM network for Hungary in the second scenario.

5.1. Budapest metropolitan network

In this scenario the infrastructure is supposed to be the SDH network implemented in Budapest. The network structure consists of two levels: STM-4 rings and STM-16 mesh are deployed on the lower level and higher level, respectively, and it is depicted in Fig. 2.

For the numerical study we suppose that a network is implemented with ATM switches of 2.5 Gbps capacity. The cost of a switch (hardware cost, implementation) is fixed (and is represented by the average cost of the ATM switches available in the market).

We also assume that the number of users is 42 which reflects the number of potential business users of the Hungarian Telecommunications Company at the beginning of the introduction of the public ATM network. All of the business users require the STM-1 access interface to the ATM network. The traffic from the users is described by a two-state ON–OFF model where it is either in a busy (ON) state sending packets back-to-back at peak rate or in an idle (OFF) state sending no packets at all.

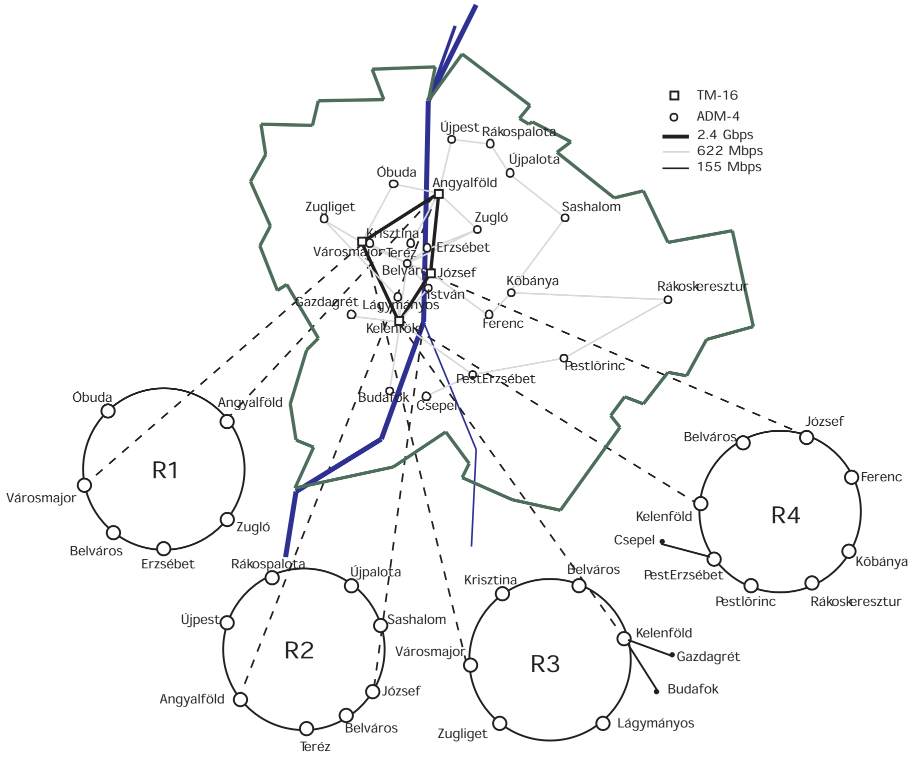

Fig. 2. The structure of the Budapest SDH network.

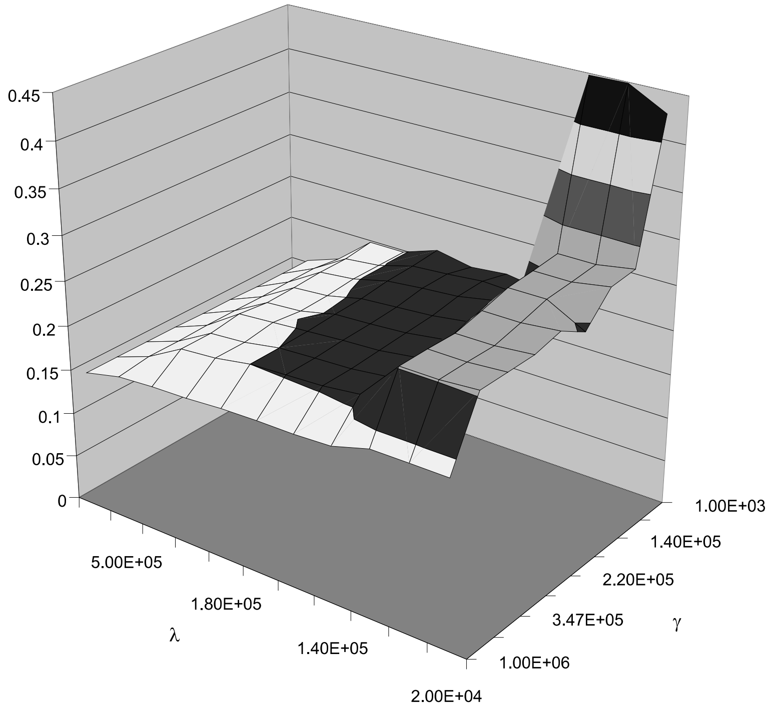

Fig. 3. Ratio of total costs between the effective bandwidth and the peak rate allocation schemes.

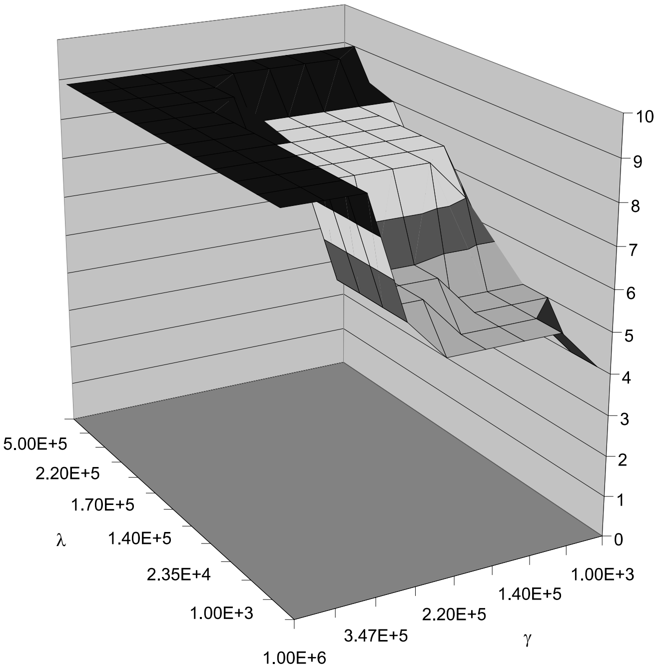

Fig. 4. Number of backbone switches vs λ and γ in Budapest.

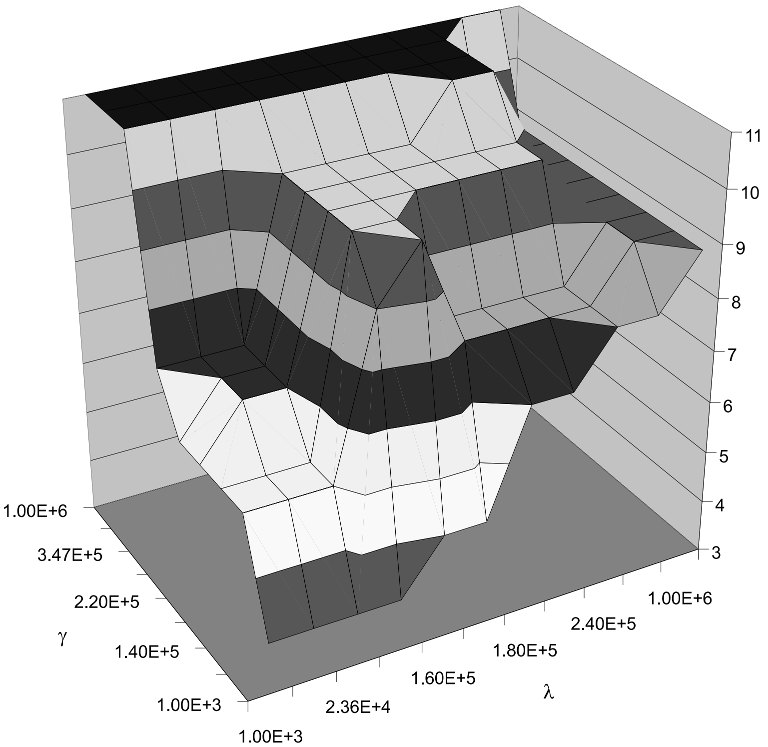

Fig. 5. Number of direct ATM links vs λ and γ in Budapest.

The bandwidth allocation schemes for connections in an ATM network also have an impact on the number of necessary link and the network cost. In Fig. 3 we illustrate the comparision of the two planning cases based on the peak cell rate and effective bandwidth scheme. The effective bandwidth of the connection is determined from the approximation derived in [6]. It is observed that in average the cost of a network based on the peak cell rate allocation is 4–5 times more than the cost of a network based on the effective bandwidth allocation scheme.

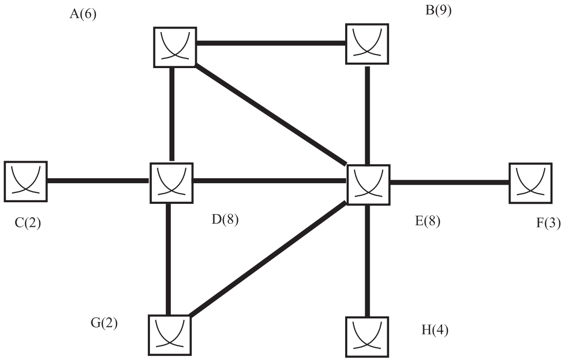

Fig. 6. ATM network topology (the number in parentheses denotes the number of connected users).

In what follows, planning results concerning the effective bandwidth allocation scheme are presented.

To investigate the impact of the policy of discouraging or encouraging the use of SDH as the infrastructure of ATM on the ATM network architecture (e.g., number of switches), we vary the cost coefficients λ and γ over a wide range while the cost of one ATM switch remains unchanged. The cost coefficients of the SDH usage reflect the range of the cost of a leased line in the SDH infrastructure. Such results are particularly useful when we have to compare the ATM implementation on top of SDH with other alternative

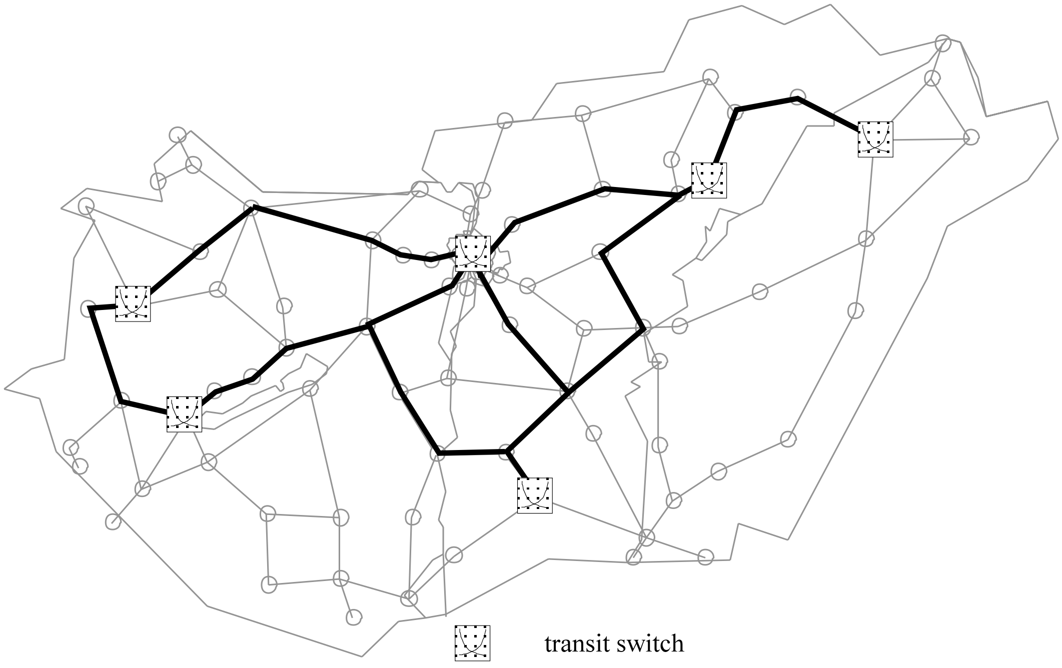

Fig. 7. A core ATM network.

implementations of ATM (e.g., fiber optics) and to make a decision whether to implement ATM on the other infrastructure in case a shortage of SDH capacity. The number of necessary switches and direct ATM links versus the cost coefficients λ and γ is illustrated in Figs. 4 and 5. It can be observed that the larger the cost of SDH usage is, the more switches are needed. For example when $\lambda = 1000, \gamma = 1000$ we need four switches, while $\lambda = 10^6, \gamma = 10^6$ we need nine switches. An intuitive argument for this result is as follows. To satisfy the capacity constraint of switches we need minimum four switches to connect the users (we have to take into account that each connection of users requires one port of a switch and each switch may need some ports to make connection to other switches). In the former case, the cost of SDH usage is not a determinant factor, so four switches are needed. Since the cost of connecting switches are is larger than the cost of a switch in the latter case, the introduction of switches can reduce the number of SDH hops between switches and therefore the total network cost.

In Fig. 6 the logical topology of an ATM network structure on top of the SDH infrastructure is plotted in a case when 8 ATM switches are allocated. The switch locations obtained with the approach show strong agreement with the SDH infrastructure since the transit nodes of the ATM network are chosen at the important points of the SDH network. Due to this fact this network is considered as one of the candidates for the very first step toward the deployment of the multilevel ATM network architecture. [5]

5.2. Core network

In the second example the ATM network with similar planning conditions to the core network is investigated. The corresponding SDH network is of two levels and consists of STM-4 rings and

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[5] The current ATM network is not different in much detail from this topology.

STM-16 mesh as in the Budapest example. The number of ATM access switches is defined 84, and the capacity of ATM switches of 2.5 Gbps as well.

The number of transit switches obtained with $\lambda = 10^3$, $\gamma = 10^3$ is 7, and the location of transit switches found by the optimization procedure can be seen in Fig. 7. However, in this case, although the sites of the nodes are also in good relation with the important nodes of the corresponding SDH network, the definition of the first phase, taking into account the long-term network architecture, needs some further investigations.

6. Conclusions

The paper presents the main phases of the ATM network deployment by the Hungarian Telecommunications Company. The target architecture of the ATM public network, which consists of two hierarchical levels: the access level and the backbone level consisting of transit and regional sublevels, is described.

We propose an optimization model and a planning approach for planning an ATM network which is built on top of the SDH infrastructure. In the approach the design problem is decomposed into subproblems and is solved in sequence. The model and the planning approach are general enough to be extended and applied to other scenarios when the ATM is directly built on other infrastructure (e.g., on the fiber infrastructure) different from SDH.

Some results concerning the application of the planning approach to a realistic scenario for the introduction of a public ATM network on top of the Hungarian SDH infrastructure are also presented. The topology of the implemented network is based on the results obtained through the planning approach. At the present, the performance of the implemented network is being evaluated to improve the planning process. Moreover, the extension of the planning approach to the consideration of a network extension and protection techniques in the planning process is also in progress.

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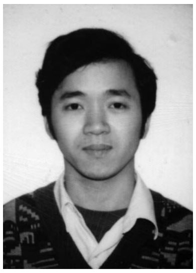

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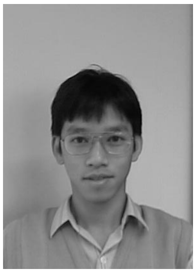

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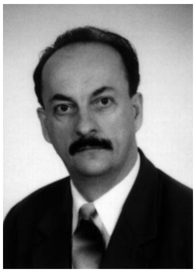

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