A Techno-Economic Model for the Optimized Introduction of ADSL Technology in an Urban Area

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Abstract: - This paper optimizes the introduction of broadband internet service in an existing PSTN network, by the means of a techno-economical model. The proposed model determines the optimal timing of introduction of ADSL technology to an urban telephone network, as seen by the Network Access Provider perspective. The implementation strategy is determined on the basis of the maximization of the total income while keeping capital expenditures under a given budget. Costs and Incomes are predicted based on current prices of both charging rates and broadband equipment. The feasible policies concern the evolution of the Central Offices of the urban network, as well as the introduction of centralized equipment, such as routers and aggregators. The model first determines the number of feasible policies and the costs associated with each one, using inputs concerning the network status, i.e., the number, position and capacity of exchanges and links, broadband services demand predictions, technical specifications as well as pricing predictions and, by the means of a charging (revenues) model produces the alternative policies for each Central Office (CO) as well as for the introduction of routers and aggregators along with their corresponding costs and incomes. These results are then fed to the second part of the model, which, using the costs and revenues associated with each alternative policy for each CO and for each type of centralized equipment, selects the overall optimal network policy, by estimating the most profitable combination of CO policies, one for each, as well as the policies concerning the introduction of routers and aggregators, by keeping the sum of the corresponding costs under certain limits. The overall policy is determined by the means of an IP (Integer Programming) algorithm. The Integer Programming algorithm consists of an objective function maximized with respect to a number of constraints. The model was implemented in the case of the urban telephone network of Patras/ Greece, using several realistic assumptions for the estimation of the costs and revenues, as well as typical current configurations for estimating the costs involved. The results obtained proved the validity of the model.

Key-Words: - Adsl, Integer Programming, Techno-Economic Model.

1 Introduction

The needs of speech have been the main criteria of network design over the past 100 years. PSTN networks worldwide use twisted-pair copper wiring as part of the gradually constructed infrastructure in order to support speech communication. However, during the last years communication needs are changing rapidly. The growth of the internet has been phenomenal and the need for increasing bandwidth is insatiable. As vendors roll out increasingly sophisticated software based on even more powerful processors, as Web content grows in complexity, and as IP telephony and video streaming enter the mainstream, Internet users demand higher speed connectivity.

The dilemma becomes how to make use of the existing infrastructure without causing potential overwhelming of the existing switched networks. It is very difficult and expensive to replace the old infrastructure with fiber optics lines and new equipment. So, the new techniques must coexist with the old and leverage the ability to make use of the existing structures to support the new. The solution is to use the part that is the most difficult to replace and use new parts in the areas where it is more feasible. ADSL attempts to do this by utilizing the existing wiring between home/ business, and the switching network and avoiding the existing network used for making speech calls [1].

PSTN network operators use ADSL technology as a mean in order to offer broadband services to their subscribers without bearing the cost of replacing their traditional twisted copper pairs [2], [3]. However, the introduction of a new technology which implies a significant capital investment and the difficulty of changing technologies once implemented, necessitate the use of optimization tools. In the past, several optimization models have been introduced, originally to optimize the introduction of digital telephony to analogue urban networks, some involving integer programming algorithms to optimise the policy for individual Central Offices [4-6], while, others optimised the policy for the total urban network [7], [8].

Based on the previous considerations, it seems that through the introduction of ADSL technology, a Network Access Provider should be able to satisfy the demand for broadband connection and, thus, it should happen as early as possible. However, any strategic decision concerning the evolution of a telecommunication network is not only restricted within the confines of the limited budget but it also involves costs for the provision and operation/ maintenance, as well as various other costs, such as line qualification, provisioning and conditioning costs, sales and marketing costs, etc, while, in contrast, the revenues are to be expected, and not given, depending on various factors, such as the overall financial environment, the outcome of the competition between the providers of the same technology, or, even between providers supporting different technologies, e.g., DSL, BPL, cable, or satellite.

The solution to this complicated issue should thus take into account deterministic factors such as design limitations posed by technical specifications, or purchase costs based on configuration, along with non deterministic factors such as predictions for new services demand, equipment pricing, services pricing, or the financial environment. Keeping these factors under consideration, it seems logical to base the optimization of the network access provider policy on the maximization of the revenues while keeping the expenditures under a constraint representing the available budget.

The paper is organized as follows. We begin in Section 2 with a definition of the problem under consideration. All the necessary information we need in order to select the best implementation strategy for the deployment of ADSL technology in a PSTN network is obtained in Section 3. In Section 4, the best overall network policy is detected by the means of an Integer Programming algorithm consisting of an objective function maximized with respect to a number of constraints. An implementation case regarding the optimization of the introduction of ADSL Services in an urban telephone network is presented, in Section 5 that maximizes future revenues keeping expenditures under given budget constraints. In Section 6, the results proving the validity of the model are obtained. Finally, in Section 7, the conclusions and comments regarding the future work are presented.

2 Model Description

The purpose of the model presented in this paper is the optimization of the implementation strategy of ADSL equipment in an urban area. Let us assume that there is a hypothetical urban area with a given population, and served by a certain number of Central Offices. A Traditional Telephony Provider known as Incumbent Local Exchange Carrier (ILEC) or PTT intends to offer ADSL services to the residents of this urban area, following an optimum financial strategy, whereas optimality regards the maximization of the profits over a specific time period. Since the introduction of ADSL technology enables new value added broadband services, what prevents the Telecommunication Organization from installing ADSL in all Central Offices of the area right from the very beginning of the time period under consideration is the restraint amount of available capital. This limitation arises due to a possible inadequate capital and due to the high cost of the ADSL equipment during the first years of implementation. This cost decreases as time elapses. It is self-evident, that the answer to the above optimization problem involves the knowledge of the ADSL composition and the cost of the ADSL technology. For this purpose, there was a thorough study of the ADSL technology as well as a market research as far as the ADSL components are concerned.

A decisive factor for the installation of ADSL equipment in a specific CO or not, within a particular time period, is the number of the subscribers that have to be served from the specific CO. If this number is bounded and the income of the Organization's subscriptions is not satisfying, then the installation is either postponed for a later time period (when the subscriber number will be high enough and the ADSL components cost will be reduced to a desirable price) or even recalled. Furthermore, it is necessary to know the exact population size of the urban area as well as the fraction of the citizens that will eventually be interested in adopting ADSL technology as solution for the provision of broadband services. It must also be clarified in which category group the subscribers belong to, that is whether they are domestic users (consumers) or business users (telecommuters) and therefore which is the desirable bandwidth.

Consumers that use the ADSL technology in order to connect to the Internet have rather low bandwidth demands, in contrast with the telecommuters who deal with great needs in file transfer and therefore have bigger bandwidth expectations. Moreover, telecommuters need network equipment, which protects them from external security threats (firewalling) and facilitates the connection of various external appliances. The exact knowledge of the penetration rate of the technology is also necessary, as is the number of Central Offices and the subscriber density in their surrounding areas of service. It is obvious that in central city areas, where the business buildings are located, the number of consumers will be limited, whereas in the suburbs, the number of telecommuters is relatively low or even negligible.

The model consists of two parts, Policies Estimation and Policy Optimization, as shown in the diagram of Fig.1.

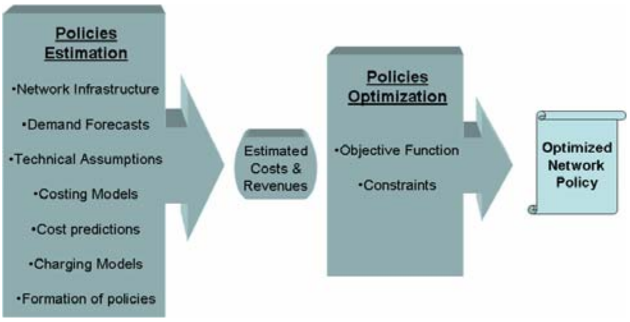

Fig.1 Structure of the Techno-Economic Model

The first uses inputs concerning the network status, i.e., the number, position and capacity of exchanges and links, broadband services demand predictions, technical specifications as well as pricing predictions and, by the means of a charging (revenues) model produces the alternative policies for each Central Office as well as for the introduction of routers and aggregators along with their corresponding costs and incomes. These results are then fed to the second part of the model, which, using the costs and revenues associated with each alternative policy for each CO and for each type of centralized equipment, selects the overall optimal network policy, by estimating the most profitable combination of CO policies, one for each, as well as the policies concerning the introduction of routers and aggregators, by keeping the sum of the corresponding costs under certain limits.

Unquestionably, a factor that determines the Organization's income and therefore its financial strategy is the subscription fee for the ADSL service (the subscription fee is paid every month or every post month). Furthermore, the Organization's income also includes the activation process of the ADSL service, as well as the sale and installation of the subscriber equipment (when this is done by the ADSL Provider and not by external stores).

All the above mentioned elements are taken under consideration for the estimation of the gain coefficients of the Telecommunication Organization's income-function deriving from every Central Office during a time period starting from a certain year *t* until the end of the time horizon *N*. The estimation of the gain coefficients is computed using a C++ algorithm. As it is already stated, the inhibitory factor for the installation of ADSL to a Central Office is the installation cost, which is also determined by the C++ application. Installation costs include all the expenses of the Telecommunication Organization concerning every single Central Office, again for the time period of year *t* to year *N*.

The gain coefficients are the terms of the equation we wish to optimize, whereas cost coefficients comprise the constraints equation. In order to solve this equation, another optimization algorithm for Integer Programming (IP) problems, has been used. In an IP problem, some or all the variables have to be positive integers. In the specific method, Boolean variables (1-0 IP) have been used. These variables refer to every single Central Office of the urban area and to the *t* year of the *N*-year time period.

Based on the above model, on the prices of the ADSL service that have been published in 2008 by the main Internet Service Providers in Greece and the penetrations rates (the data have been taken from the Observatory for the Greek Information Society, as seen in Fig.2) for a 9-year time period, an optimum strategy has been determined that an

ADSL Provider should follow for an urban area of 200.000 people.

In conclusion, the proposed model can be used, by the Network Access Provider, as a strategic planning evaluation tool offering the advantage of determining the optimal timing of introduction of ADSL technology to an urban PSTN network, and at the same time maximizing total income while keeping capital expenditures under a given budget.

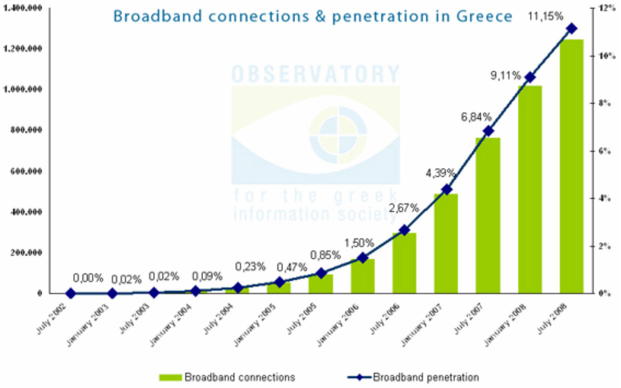

Fig.2 Broadband penetration trend

3 Policies Estimation

An ADSL network can be divided into three functional segments: the Customers Premises Equipment (CPE), the Network Access Provider (NAP), and the Network Service Provider (NSP), as shown in Fig.3.

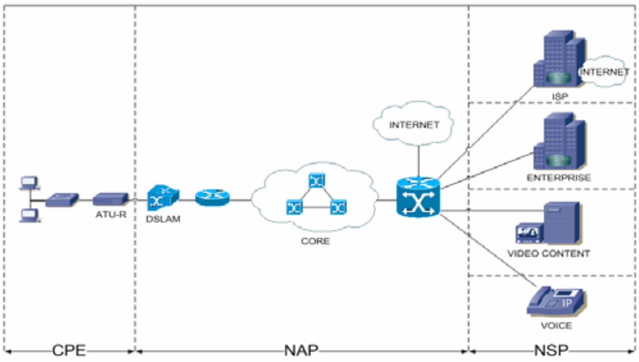

Fig.3 ADSL - Functional Segment Diagram

CPE refers to the equipment required on the subscriber premises to encapsulate the subscriber IP traffic over the DSL loop and includes an ADSL transmission unit-remote (ADSL-R). Subscribers are separated into two general types, consumers, and telecommuters, the difference being that the latter, using the ADSL connection for professional reasons and having their corporations paying their service, make heavier use of the services, and are, thus, charged accordingly. The NSP is usually an Internet Service Provider (ISP) to which the end customer is subscribed to.

The NAP portion of the network consists of mainly three components, the DSLAM, an aggregation component, and a core, or edge, network for transport [2]. The ISP router accepts the aggregated traffic, terminates the ATM VCCs, PPP sessions or L2TP tunnels and forwards the resulting traffic. Digital Subscriber Line Access Multiplexer (DSLAM) is a network device that connects multiple customer Digital Subscriber Lines (DSLs) to a high-speed Internet backbone line using multiplexing techniques.

Our goal is to determine the network strategy that maximizes total income while keeping capital expenditures under a given budget. The optimal overall network policy determines the time of introduction of ADSL technology at each CO, as seen by the Network Access Provider perspective. The method consists in dividing the time horizon into time periods and to assign for each CO one policy for the introduction of ADSL services at the beginning of each time period. In addition, the cost of the centralized equipment of the core network (routers, aggregators, and links) is to be taken into account and thus, one policy is assigned to introducing each type of these devices at each time period, while separate policies are assigned to installing additional devices when the demand makes it necessary. The length of the study time horizon along with the number of the periods and their lengths are crucial factors for the validity of the results of the model. A large number of periods give a more detailed solution with finer resolution, but the nature of Integer Programming means the computational burden varies exponentially with the number of the periods. Predictions about the general technical, financial and social context in which the broadband services will be introduced can be used to produce an optimal number of periods; however, such analysis was beyond the scope of this study. In the implementation of the model, a 9 years study time horizon consists of 9 one-year periods. For each CO, a number of policies equal to the periods of the Time Horizon are determined, corresponding to the introduction of ADSL services in that CO in each period.

To estimate the costs and revenues assigned to each policy, the policies generator is fed with inputs regarding the existing network infrastructure, technology aspects, demand forecasts and charging fees. The costing and charging models then produce the costs and revenues associated with each alternative policy. The outputs consist of the feasible policies along with their costs and revenues. Inputs consist of:

- information concerning the network topology, such as the number of Central Offices, their distances, the type of existing equipment and the number of subscribers,
- demand forecasts for broadband services and the percentage of subscribers (residential/ business) per exchange,
- technical considerations regarding DSLAM configuration, Router characteristics, Aggregator specifications and fiber connections,
- price equipment forecasts thorough the time horizon concerning the costs of CPE, DSLAM, Router, Aggregator components, fiber cables as well as the prices of services such as connections to Internet Service Providers.

Costs can be divided into the ones which can be attributed to a single CO (like CPEs, DSLAMs and DSLAM connections, i.e., to ATM access switch) and into those referred to the core network (like Routers, Aggregators and Connections of the ATM Access Switch to the Aggregator and the Aggregator to the Router). Other parts of the core network infrastructure such as the ATM Access Switches and their connections to the core network were assumed existing and not included as costs in the optimization model.

The costing models used are based on the engineering method in that each policy was broken down to type and quantity of equipment [9]. This is performed by the means of a dimensionalization model that takes into account the typical configuration and the specifications of each type of equipment as well as the predictions for the demand in broadband services. The material list was then transformed to cash outflows by the means of another – prediction – model based on typical current prices and learning curves. All costs referred in this paper include purchasing the equipment in question and operating and maintaining it from the time of introduction till the end of the time horizon.

All equipment purchased was assumed to have zero net recovery value at the end of the time horizon.

It is assumed that the demand at time period *n* is the accumulated demand from the beginning of the time horizon until time period *n*, i.e., no subscribers waiting for ADSL services are missed when ADSL is introduced at a later time period.

A detailed analysis of the DSLAM cost is required since it is one of the major expenses for ADSL providers, the other being aggregators and circuits, analyzed below. Mini DSLAMs that can be introduced in cabinets (ONUs) were not considered.

The modem sharing configuration type was assumed in the implementation of this paper. In this case, the typical DSLAM configuration was assumed to consist of Multiplexer Chassis, POTS Splitter Chassis, Line Interface Multiplexer Chassis and of various cards such as: ATU-C cards, POTS Splitter Cards, subtending cards, Control cards, Network cards and Interface cards.

It was assumed that the aggregator was placed in the ADSL Provider premises to aggregate various access mediums operating as an access point that permits multiple service providers to have access to terminal users. Furthermore, a router in the NAP premises was assumed to operate as a LAC (L2TP Access Concentrator) and another router in the ISP premises was supposed to operate as LNS (L2TP Network Server). It should be noted that, however, for the purposes of our implementation, the cost of the former was included, only, since the optimization concerned only the ADSL Services Provider.

The various links costs attributed to introducing ADSL services include connections between the following devices:

- DSLAM splitters to the voice switches.
- The output of the DSLAMs to the ATM switches.
- ATM switches to the overlying ATM switch.
- Overlying ATM switch to the Aggregator.
- The Aggregator to the ISP router.

The first two types can be attributed to each CO and are thus included in the relative costs. The next three types of links serve all the COs of an urban network, so they must be attributed additional variables in the optimization process. In the case study used in the implementation of the model, all COs were assumed to be connected to the ATM network, so the cost for the third type of connections was not taken into account.

The links taken into account in this study were assumed to be introduced with the capacity needed to serve the accumulated demand until the end of the study horizon and were calculated based on the total traffic to the subscriber side. For a total downstream traffic exceeding 45 Mbps, optical fibers were introduced, while for total traffic less than this, a coaxial cable was assumed to suffice.

Revenues for the ADSL provider were assumed to consist of two elements, a start up charge for the conditioning, procurement, installation, and activation of the connection for new subscribers, and a monthly subscription for all active subscribers. This applies to both type of subscribers mentioned above.

4 Policy Optimization

In the previous part, we obtained all information necessary in order to select the best implementation strategy for the deployment of ADSL technology in a PSTN network. In this section, the best overall network policy is selected by the means of an Integer Programming algorithm consisting of an objective function maximized with respect to a number of constraints.

The optimal policy will maximize the profits given by the following objective function:

$$\max\left\{\begin{array}{l}\sum_{i=1}^{I}\sum_{n=1}^{N}x_{in}R_{in}-\sum_{n=2}^{N}d_n-\sum_{n=1}^{N}p_n-\sum_{p=1}^{P}\sum_{n=2}^{N}r_{pn}\\ -\sum_{p=1}^{P}\sum_{n=1}^{N}s_{pn}-\sum_{q=1}^{Q}\sum_{n=2}^{N}a_{qn}-\sum_{q=1}^{Q}\sum_{n=1}^{N}t_{qn}\end{array}\right\} \tag{1}$$

Where I is the number of Central Offices, N is the study time horizon, P is the maximum possible number of additional routers, and Q is the maximum possible number of additional aggregators. The variables are defined as follows: $x_{in} = 1$ when ADSL equipment is introduced at Central Office i at time period n, $d_n = 1$ when router, aggregator and links are needed at time period n, $p_n = 1$ when router, aggregator and links are introduced at time period n, $r_{pn} = 1$ when there is a need for additional p^{th} router at time period n, $s_{pn} = 1$ when an additional p^{th} router is installed at time period n, $a_{pn} = 1$ when there is a need for additional p^{th} Aggregator at time period n, and $t_{qn} = 1$ when an additional p^{th} Aggregator is installed at time period n. Coefficient R_{in} represents the revenues collected till the end of the study period due to provision of ADSL services at Central Office i from time period n. All variables except x_{in} are included in the objective function with minus signs, and without coefficients, to keep them from unnecessarily taking on the value of 1.

The maximization must be carried out under the following constraints:

$$\sum_{n=1}^{N}x_{in}\leq 1, \qquad for \qquad i=1,2,\ldots,\mathrm{I} \tag{2}$$

One policy concerning the introduction of ADSL equipment can be selected for each Central Office of the urban network.

$$\begin{array}{l}\sum_{i=1}^{I}\sum_{n=1}^{N}x_{in}C_{in}+\sum_{n=1}^{N}p_n\left(R_n+A_n+L_n\right)\\ +\sum_{p=1}^{P}\sum_{n=1}^{N}s_{pn}R_n+\sum_{q=1}^{Q}\sum_{n=1}^{N}t_{qn}A_n\leq K\end{array} \tag{3}$$

Total costs must not exceed available capital, where K is the Capital available for the introduction of ADSL equipment in the urban network under study for the duration of the time horizon, R_n is the Router Cost at time period n, A_n is Aggregator Cost at time period n, L_n is the Links Cost at time period n, and C_{in} the cost of introducing ADSL equipment in Central Office i at time period n. This cost includes subscriber premises equipment, DSLAMs and the necessary additional cabling to establish connections between the DSLAMs and the ISP.

$$\sum_{i=1}^{I}x_{i1}-p_1M\leq 0 \tag{4}$$

$$\sum_{i=1}^{I}x_{in}-d_nM\leq 0 \quad for \quad n=2,\ldots,N \tag{5}$$

$$p_1+\sum_{l=2}^{n}d_l-d_{n+1}+p_{n+1}\geq 0 \;\; for\, n=1,\ldots,N-1 \tag{6}$$

where M is a very big number. These three inequalities ensure that router, aggregator and links, are first installed when ADSL services are first introduced in any Central Office of the urban network.

$$\sum_{i=1}^{I}x_{i1}D_{i1}-S_1*s_{p1}\leq F_p \tag{7}$$

$$\sum_{i=1}^{I}\left(\left(\sum_{l=1}^{t}x_{il}\right)D_{it}\right)-S_t*r_{pt}\leq F_p,\ \forall p\ ,\ t=2,\ldots,N \tag{8}$$

$$\sum_{i=1}^{I}x_{i1}D_{i1}-S_1*t_{q1}\leq B_q \tag{9}$$

$$\sum_{i=1}^{I}((\sum_{l=1}^{t} x_{il})D_{mt}) - S_t * a_{qt} \leq B_q \text{ , } \forall q \text{ , } t = 2,...,N \qquad (10)$$

These constraints ensure that any additional, p^{th}, router will be installed when the number of subscribers exceeds the installed routers' capacity.

D_{mt} is the forecasted demand at Central Office m, at time period t, S_t is a number bigger than the total number of subscribers of all the Central Offices at time period t. When the total number of the subscribers of the urban network is greater than F_p, one additional router is needed. In our case, it was assumed that $F_p = pF_1$, where F_1 is the number of subscribers supported by a typical router. Also, when the total number of the subscribers of the urban network is greater than B_q, one additional aggregator is needed. It was assumed that $B_q = qB_1$, where B_1 is the number of subscribers supported by a typical aggregator.

$$s_{p1} + \sum_{l=2}^{t} r_{pl} - r_{p(t+1)} + s_{p(t+1)} \geq 0, \forall p \text{ , } t = 2,..., N \qquad (11)$$

$$t_{q1} + \sum_{l=2}^{t} a_{ql} - a_{q(t+1)} + t_{q(t+1)} \geq 0, \forall q \text{ , } t = 2,..., N \qquad (12)$$

5 Implementation

The model was implemented in the case of the urban PSTN network of Patras in Greece, using several realistic assumptions for the estimation of the costs and revenues, as well as typical current configurations for estimating the costs involved.

The urban network of Patras/ Greece consists of 8 Central Offices, with a total population of 200,000 while ADSL penetration was assumed 0.005. The ratio of consumers to telecommuters was taken 7/3, and the cost of money 5%, while the Time Study Horizon was 9 time periods of one year each. The forecasted demand is depicted in Fig.4.

For the estimation of the policies costs it was assumed that the demand is covered completely and the equipment needed at each time period for the implementation of each policy is purchased at the beginning of that period. The estimated costs corresponding to the policies associated with each CO are depicted in Fig.5.

As stated in equations (7-10) a router should be introduced as soon as ADSL services are provided anywhere in the urban network, and an additional router should be added at the beginning of any period that new subscribers added exceed F_1, the capacity of the typical router. In our case it was assumed F_1 = 8,000. The same approach was followed concerning the aggregator with the difference that, in this case, the number of ADSL users that can be serviced by an aggregator, B_1, was supposed to be a fraction of the capacity of a typical aggregator, since a typical aggregator is capable of serving multiple urban networks of the type used in our application. In this case, B_1 was supposed to be 9600, or one tenth of a 96,000 subscribers aggregator. This was based on the assumption that the number of potential ADSL subscribers in the city of Patras is one tenth of the total number of subscribers on a national level. Still, the first aggregator is installed as soon as ADSL services are introduced.

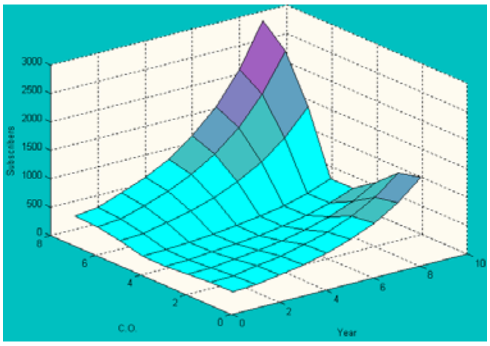

Fig.4 Forecasted ADSL services demand in the Urban Network of Patras/ Greece for a 9-year Horizon.

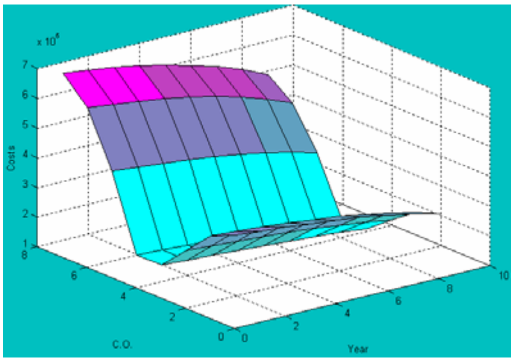

Fig.5 Costs estimated for each Policy for each CO.

The ATM network connecting the COs to the Access Switches and the Access Switches to the overlying ATM Switch were supposed to be already established. However, an additional links' cost was taken into account corresponding to the connection between the ATM overlying Switch and the aggregator as well as the aggregator and the router. Analytical costs used represent typical values as of 2008 based on data assembled by an Internet search.

The cost for each item for each type of centralized equipment depending on the time period of introduction is shown in Fig.6.

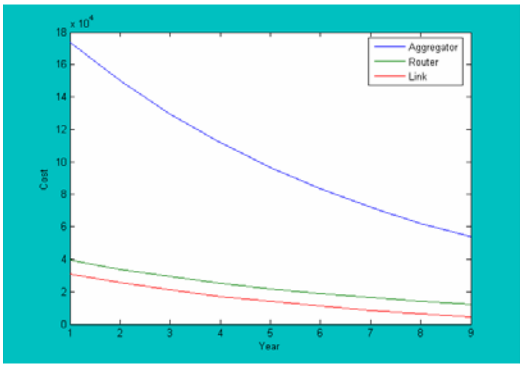

Fig.6 Estimated costs for centralized equipment.

Revenues estimated based on these prices are shown in Fig.7.

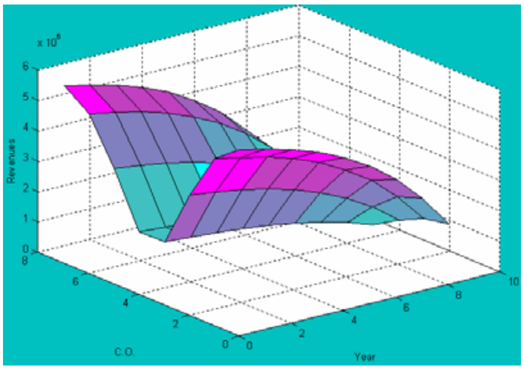

Fig.7 Estimated revenues for each Policy for each CO.

6 Results

The policies optimization was based on the branch and bound algorithm and was implemented in C++. For the implementation of the model a series of various hypothetical investment scenarios are presented. The results are shown throughout the following figures (Fig.8 – Fig.12).

In the first case we assume that the invested capital is 3,200,000€ and the result is that we need to install ADSL equipment in every CO right from the first year of operation in order to maximize the revenue which will be 30,059,600€ (Fig.8). This is also the maximum revenue that we can obtain. Thus, there is no need to make a larger investment. If we decrease the invested capital by 200,000€, and we invest a total amount of 3,000,000€ it results that the maximization of revenue requires ADSL installation in every CO at the first year, except from the 4th one which it will remain excluded for the entire time horizon of our business plan (Fig.8). In this scenario the revenue will be 28,556,620€.

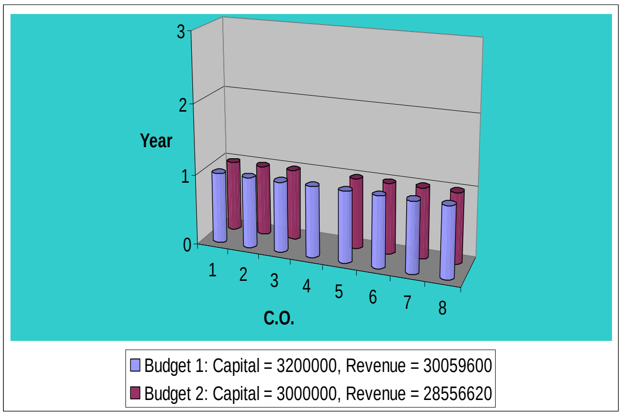

Fig.8 Invested Capital ≥ 3,000,000€

In case that the network operator decides to invest an amount between two and three million euro, we find out that for 2,850,000€ the ADSL introduction will occur at the second year of operation for the four first COs, at the third year of operation for the three last COs, and for the 5th it will never take place. This policy will provide the maximum revenue of 27,058,600€, (Fig.9).

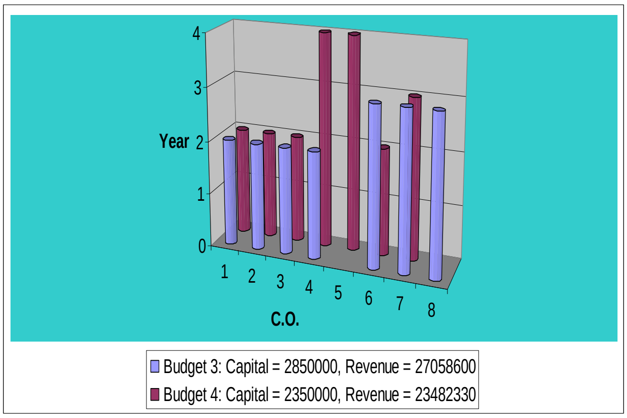

Fig.9 Invested Capital ≥ 2,000,000€

Similarly, for an investment of 2,350,000€ the optimal ADSL introduction will occur at the second year of operation for the three first COs and also for the 6th one, at the third year of operation for the 7th one, at the fourth year for the 4th and 5th CO, and for the 8th it will never happen. This policy will provide the maximum revenue of 23,482,330€, (Fig.9). Of course, this income is much lower than the previous one because the smaller amount of money invested caused the installation of the ADSL equipment to be postponed in time.

If the Network Operator has limited budget for the new investment, and intends to invest an amount of capital between one and two million euro, we find out that for 1,450,000€ the optimal ADSL introduction will occur at the first year of operation for the three first COs, at the fourth year of operation for the 4th and the 5th CO, and for the last three COs the installation will never take place. This policy will provide the maximum revenue of 16,504,370€, (Fig.10).

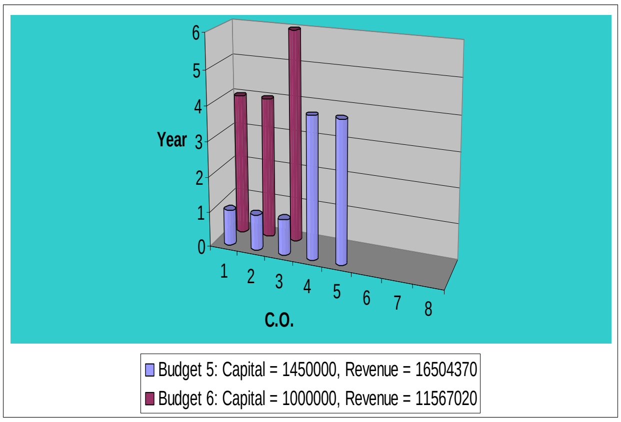

Fig.10 Invested Capital ≥ 1,000,000€

Similarly, for 1,000,000€ the ADSL introduction will occur at the fourth year of operation for the first two COs, at the sixth year of operation for the 3rd one, and for the remaining COs it will never happen. This policy will provide the maximum revenue of 11,567,020€, (Fig.10). Once again, the smaller amount of money invested causes the introduction of ADSL equipment to be postponed in time, and also the diminution of the revenue.

For a risk averse Network Operator who does not intend to invest more than 1 million euro in the broadband project, we assume that the invested capital is 750,000€. The result is that we need to install ADSL equipment in the first CO at the 3rd year of operation, and in the third CO at the 4th year. This is necessary in order to maximize the revenue which is equal to 8,110,377€ (Fig.11).

Finally, if the invested capital decreases down to the point of 500,000€, then it results that the maximization of revenue requires ADSL installation only in the first CO at the 4th year (Fig.11). In this scenario the implementation policy will provide the maximum revenue of 4,851,818€.

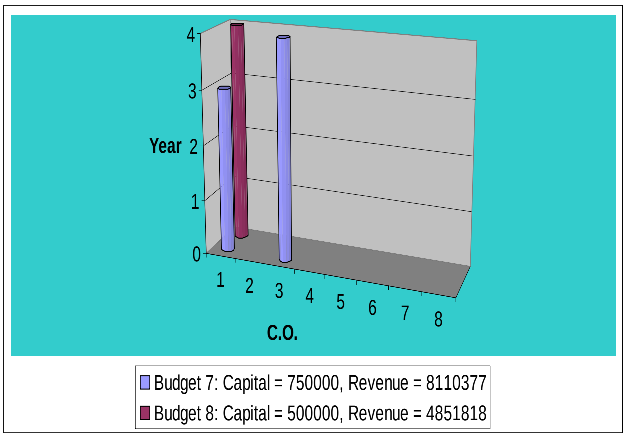

Fig.11 Invested Capital ≤ 1,000,000€

In Fig.12 we reassume and compare previous mentioned optimal overall policies for different budgets. Each scenario corresponds to a different budget, with no ADSL introduction feasible when less than 500,000€ is available, while every CO can be equipped with ADSL services with 3,200,000€.

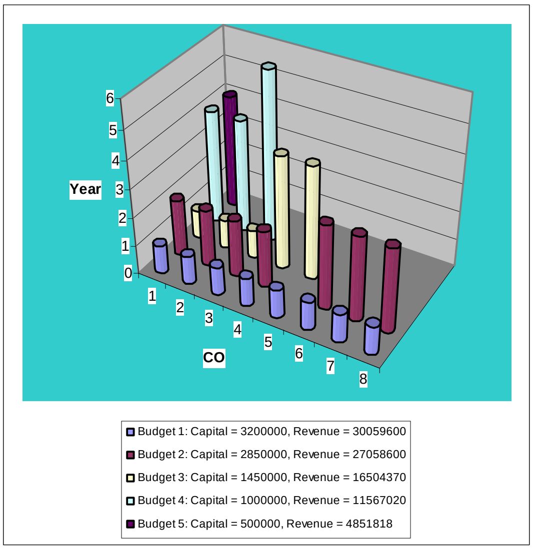

Fig.12 Optimal overall policies for different budgets.

In all solutions, a router, an aggregator and the necessary links are established in the first time period, since there is always at least one CO where ADSL is already introduced in the first time period.

The Network Operator can run easily many additional investment scenarios in order to evaluate the impact of every variable and to determine the best policies that much his business plan objectives.

7 Conclusion

A model for the optimization of the introduction of ADSL Services in an urban telephone network was presented, that maximizes future revenues keeping expenditures under given budget constraints. The model was tested in the urban telephone network of Patras/ Greece and the results proved the validity of the model.

The proposed model achieves minimum times of execution and at the same time records all the essential information in order to perform network studies. It can be applied to any kind of PSTN access network.

An improvement of the proposed model could be to expand it in order to accommodate alternative broadband network access technologies like Cable, Fiber, and Broadband over Power Line. A similar tool can perform a detailed comparison of the above mentioned broadband access technologies in several scenarios. The application of the model for all these network access solutions can provide useful guidelines regarding the selection of the most cost-effective access technology.

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