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Planning the evolution to broadband access networks: A multicriteria approach [1]

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Abstract

The interplay between continuing technical innovations, development of multifaceted modes of communication and market structure, among other factors, have raised new and complex problems concerning the strategic modernisation planning of telecommunications networks, namely regarding the evolution paths towards a wide range of new service offerings to be delivered to homes by using broadband technologies. However, decisions must be made by telecommunications operating companies or administrations in a turbulent environment, full of uncertainties with respect to reliable demand forecasts (for new services for which no past data is available), production costs and time to reach the market of some equipment based on brand new technologies, development of new services, etc. Moreover, strategic decisions to be made generally involve distinct, incommensurate and conflicting aspects; that is, problems are multicriteria in nature in the sense that economical, technological, market and social aspects are at stake. Therefore, in order to make well founded decisions, models should explicitly address those different objectives, so that decision makers and planning bodies may grasp the conflicting nature of the objectives and the trade-offs to be made in order to select satisfactory evolution plans. This paper presents a multicriteria model, which extends previous work by the authors, aimed at studying the evolution scenarios to deploy new supporting technologies in the access network to deliver broadband services to individuals and small enterprises.

Keywords: Telecommunications network planning; Multicriteria models; Decision aid; Strategic modernisation planning; Broadband services

1. Introduction

The interplay between the rapid pace of technical innovations, the development of multifaceted and more sophisticated modes of communication and changing market structures (namely the

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erosion of the regulated monopoly structure including in the local access networks, and a steady transition towards liberalisation), among other factors, have raised new and complex problems concerning the strategic modernisation planning of telecommunications networks, regarding the evolution paths towards a wide range of new service offerings to be delivered using broadband technologies, in a residential and small business setting.

However, these important decisions (because of the huge investments required and their potential to induce significant economical and social changes) must be made by telecommunications operating companies in a turbulent environment. In fact, beyond some well-established trends such as the pervasiveness of digital technology, the integration between telecommunications and information processing, the emergence of competitive markets (including a role to cable TV network operators) and the need of a "reasonable" bandwidth in the local access ("the last mile") network [2], multiple sources of uncertainty persist. These are mainly related to the availability of reliable demand forecasts (for new services for which no past data is available), estimates of the production costs and time to reach the market of some equipment based on brand new technologies, need for optical fibre deployment in the local access network or progressive installation of interim technologies, development of new revenue producing services, etc.

Moreover, strategic decisions to be made generally involve distinct, incommensurate and conflicting aspects; that is, problems are multiobjective in nature in the sense that economical, technological, market and social aspects are at stake. Therefore, in order to provide more and better information which enables well founded decisions to be made, models should explicitly address those different objectives, so that decision makers and planning bodies may grasp the conflicting nature of the objectives and the trade-offs to be made in order to identify satisfactory evolution policies.

In such an environment, characterised by a fast and somewhat unpredictable pace of innovations at various levels, would it be possible to develop useful decision aid models which can capture the distinct impacts of emerging technologies, architectures and services?! It is our conviction that even in the present context characterised by so many sources of uncertainty, it is useful to develop decision aid models to make experiments, test scenarios, unveil knowledge about certain regularities and trends, and exploit sensitivity analyses to assess the robustness of conclusions. However, it must be remarked that these are outline studies aimed at aiding decision makers by providing them better quality information and enabling a better understanding of these complex problems. Thus, the results must not be taken as "ready to be implemented" prescriptions, but rather as a material basis to discover better plans and policies.

The authors have developed a multiple objective linear programming (MOLP) model aimed at supporting decision makers and/or planning engineers in evaluating modernisation policies for local telecommunications networks, regarding the introduction of new supporting technologies and service offerings (Antunes et al., 1993). This model, which is reviewed in Section 2, is based on a state transition diagram, whose nodes characterise a subscriber line in terms of service offerings and supporting technologies. A short presentation of services, media and technology architectures, that are at stake when evaluating the evolution strategies towards broadband access networks is made in Section 3. In Section 4 the previous model is extended for studying the evolution towards broadband services and some conclusions are drawn based on runs of different versions of the model, namely regarding the allowed transitions and parameter assumptions.

2. A MOLP model for modernisation planning of telecommunications networks

This model aims at providing decision aid in evaluating evolution plans of telecommunications

[2] The definition of local access network (or local loop) is traditionally based on the copper pair connecting the telephone subscriber's line to the operator's central office (or local exchange). It generally consists of a feeder (or primary distribution) portion, a (secondary) distribution portion and a last drop to the subscriber's premises.

networks regarding the introduction of new supporting technologies and service offerings. The model is based on a simple (aggregated) state transition diagram, whose nodes characterise a subscriber line in terms of:

Supporting technologies: analog (A) and digital (D);

Service offerings: traditional telephone service (P); enhanced service providing a narrow band data channel in addition to voice (E); wide-band integrated digital service suitable for voice, data and video communications (R).

The state transition diagram on Fig. 1 displays the allowed transitions between states at consecutive years of the planning period (the dashed lines depict the installation of new lines directly in any state). The transitions which are not permitted express the irreversibility of service enhancement (once it is upgraded it will not be downgraded) and digitisation (once a facility is digitised it will not be replaced by analog equipment).

Two categories of cash-flows associated with the evolution of a given subscriber line are considered in the model: one related to the lines which have a transition between two states, and another one related to the lines that are in a given state. The first category includes the investment cost and the salvage value after dismantling a line. The second category considers the annual operational and maintenance charges, the annual revenue and the final value of a line at the end of the planning period.

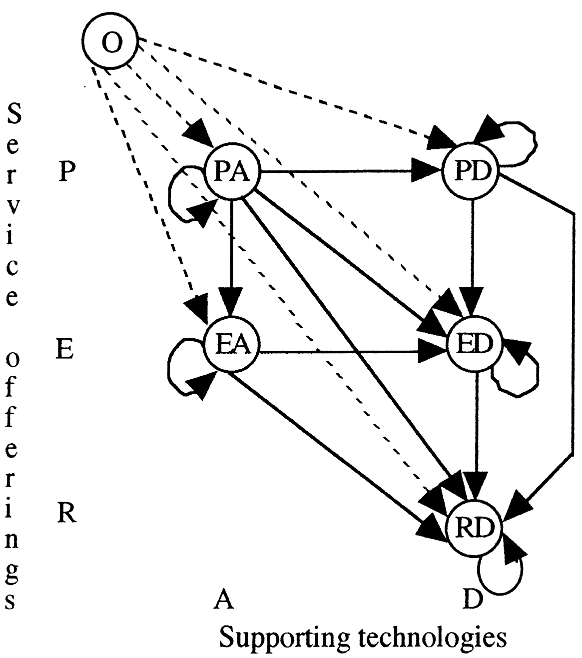

Fig. 1. State transition diagram.

The objective functions are:
- the net present value of the evolution of subscriber lines, to be maximised; it includes all types of cash-flows throughout the planning period;
- the net present cost of the external dependence associated with the evolution strategies, to be minimised; it quantifies the imported part associated with the investment costs, and operational and maintenance charges;
- the degree of modernisation associated with the availability of new services (a surrogate for the quality of service quantifying the number of lines supporting new services E and R weighted by a desirability coefficient), to be maximised.

The constraints express lower bounds for the degree of satisfaction of the estimated demand and penetration of supporting technologies, technical and budgetary limitations.

The decision variables consist of the number of lines which have a transition between two states of the diagram at a year of the planning period and the number of lines which are in a given state at the end of a year in the planning period.

Further details on the mathematical model as well as an example of its exploitation by using an interactive MOLP decision aid tool can be found in Antunes et al. (1993). This computer tool is a method base named TOMMIX (see Antunes et al., 1992), which enables advantage to be taken of the potentialities of each method or combination of interactive MOLP methods. The aim is to offer decision makers the possibility of combining the methods while guaranteeing the transfer of usable information whenever a method switch is made, in order to support a "learning" process.

To illustrate the model results, a selected nondominated solution is displayed on Fig. 2, where the figures near to the arcs of the transition diagram are the number of lines which make a state

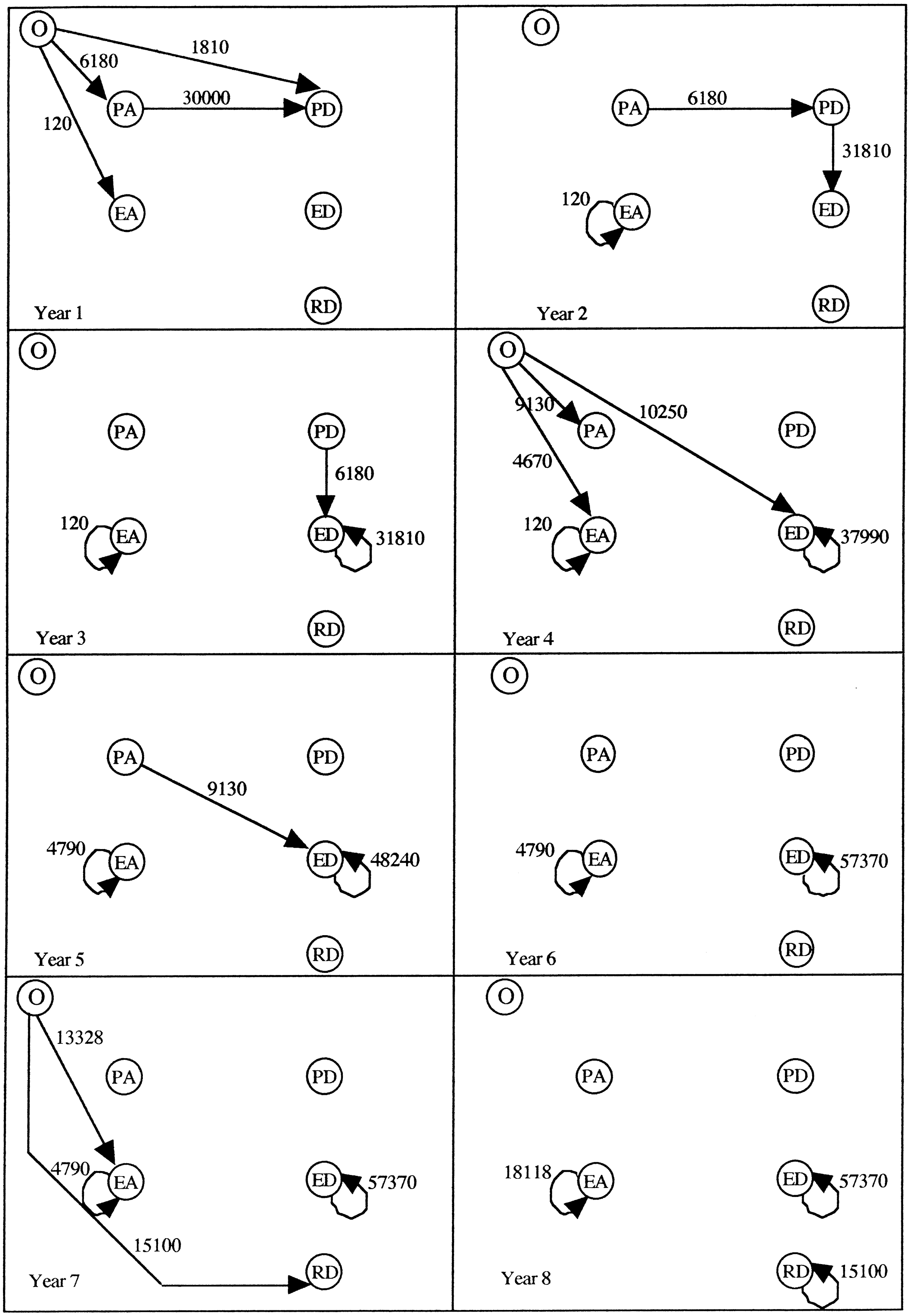

Fig. 2. A modernisation strategy corresponding to a nondominated solution.

transition. This format of result presentation has been added to the interactive package to facilitate the interpretation of the results.

3. Evolution scenarios for broadband access network

This section is devoted to exploit some paths for extending the model presented in the previous section to the evaluation of feasible broadband access network scenarios. The motivation for providing new services to customers is clear: average growth in the traditional telephone service (the bulk of today's revenues) has slowed in developed countries to less than 5% and, at the same time, the potential demand for fast data transfer, image and sound communication as well as for enhanced voice, fax and video services has been increasing with a growing market of computer and multimedia systems. Therefore, the emergence of new services based on broadband access technologies is an essential driver to generate additional revenues and support a long-term growth and financial strength of operators (Jameson, 1996; Olsen et al., 1996). However, this trend is a risky one for network providers, because of the large investments needed, uncertainty regarding specific service demand and potential to generate revenues, rapid pace of technology evolution and components mass production costs, relaxing regulations and competitive environments. Other important factors influencing decisions are dwelling distribution and conditions of the existing network (Ims et al., 1996), which may vary greatly between countries and regions within a country.

The range of application services that can be provided over subscriber broadband networks can be broadly categorised in entertainment (e.g., video on demand, interactive video games), information (e.g., distance learning, transaction services, internet access) and communication services (personal communications). The planning horizon to deploy broadband access networks and make all these services available is necessarily a medium-term one (at least), because of technical and economical reasons. Besides making forecasting an even more difficult task, this suggests the consideration of incremental upgrade strategies as more adequate since they offer service providers a revenue basis to make the investments more attractive. According to European surveys, video on demand and simple home office working will be the application services with higher demand, followed by videotelephone, distance learning and interactive video games (Stordahl and Murphy, 1995). The patterns of forecasted service demand show a strong dependence on disposable income.

The alternative media for delivering the set of services are optical fibre, coaxial cable and twisted pair copper. Optical fibre deployment can have distinct alternative configurations: – fibre to the building/home (FTTB/FTTH) [3], that is fibre from the central office to the subscriber premises equipment; – fibre to the curb (FTTC), in which the last drop to reach the subscribers' equipment is twisted pair copper (for basic telephony, generally called plain old telephone service (POTS)) or coaxial cable (for narrowband integrated digital service network (N-ISDN) or cable TV (CATV)). The first alternative has more evolutionary potential at the expense of a higher cost. Recently, copper-based technologies such as asymmetric digital subscriber line (ADSL) capable of realising transmission rates up to 6Mb/s over around 500 m (downstream, that is towards the subscriber) arose as a promising (interim?!) technology to provide broadband access without the need to deploy optical fibre. ADSL needs high-speed modems, located in the central office and at the subscriber's premises, which need to be added only on a new subscriber basis, being also possible to re-use them at a new location. ADSL offers also a much lower rate upstream (that is, away from the subscriber) capability suitable for asymmetric services such as video on demand or internet access. While some authors consider that ADSL will be the dominant technology to broadband access in the next years, driven by the huge quantity of copper lines presently

[3] The introduction of optical fibre solutions in the access network is known as fibre in the loop (FITL). The terms fibre to the curb/building/home (FTTC/B/H) denote the FITL architectural solutions where the optical network unit is placed closer and closer to the subscriber premises equipment (e.g. telephone, modem, etc.).

installed (“an interim technology for the next forty years”!...; see Maxwell, 1996), granting simultaneously a full compatibility with the telephone service, other authors stress the increase of capital costs related to technological issues which need to be addressed beyond the introduction of high-speed modems (Pugh and Boyer, 1995). Coaxial cable is mainly used by CATV operators to distribute analog TV channels within a neighbourhood (that is, one-way communications), in the framework of hybrid fibre coaxial (HFC) networks. Communication of digital data over an HFC network will require cable modems to be installed (similarly to voice-grade modems presently used for data transmission over telephone lines) and the provision of an upstream channel for (asymmetric) bi-directional services. Meanwhile, the advantages of N-ISDN over copper lines could become undermined as soon as 56 kb/s modems enter the market.

It is apparent from this brief presentation of services, media and architectures (see also Dyke and Waters, 1994, for further details), that the evaluation of modernisation strategies towards broadband access networks is an extremely complex task. Most technical papers almost invariably conclude for the “clear superiority” of one solution over another alternative (see, for instance Bisdikian et al., 1996, Verbiest et al., 1993, Maxwell, 1996, for whom HFC networks, optical fibre and copper-based ADSL, respectively, will emerge – by using sound arguments, it must said! – as the dominant broadband access technology). Nevertheless, an attempt is made herein to extend the work described in Section 2 to accommodate the evaluation of alternative policies of evolution to broadband access networks capable of supporting a full range of new and more sophisticated services.

4. A MOLP model for evaluating the evolution alternatives towards broadband access network

In this section a multiple objective linear programming (MOLP) model is presented, which extends the approach presented in Section 2 having in mind the issues mentioned in Section 3. The model is based on the extended state transition table depicted on Fig. 3. The table displays the states of the system as the feasible combinations of service categories and technology architectures for the access network. We opted not to display the arcs representing the transitions, because for a given state almost all transitions rightwards and downwards (including to the same state, that is an access line which is not upgraded) are theoretically possible. Besides this would jeopardise the readability of the table, some of those transitions have not been considered as feasible in some of the experiments mentioned below. In fact, some evolution scenarios not deemed plausible were a priori eliminated (for instance, implementing FTTC architecture to support POTS only, although this is technically possible).

In the extended state transition table (Fig. 3) the set of service categories (S) is classified in the following way:

POTS – plain old telephone service, inherently a narrowband symmetric service;

ES – enhanced services, such as those presently offered by narrowband basic rate ISDN;

ASB – asymmetric switched broadband services, capable of providing at least 2 Mb/s downstream and 16 Kb/s upstream;

SSB – symmetric switched broadband services, capable of providing at least 2 Mb/s bi-directional;

CATV – broadcast (distributive) broadband services typically nonswitched, such as cable TV;

AS – switched broadband advanced services, generally asymmetric.

The set of technology architectures (T) for access alternatives is:

copper pairs;

enhanced copper pairs (namely ADSL);

hybrid fibre coaxial (HFC);

fibre to the curb (FTTC).

These service categories provide distinct service applications, such as POTS, facsimile, videotext, data transfer, video telephony, internet access, desktop multimedia, distance learning, video on demand, shopping/home ordering systems, interactive video games, telecommuting (at simple and advanced levels), enhanced pay-per-view and broadcast TV. The relationships between these

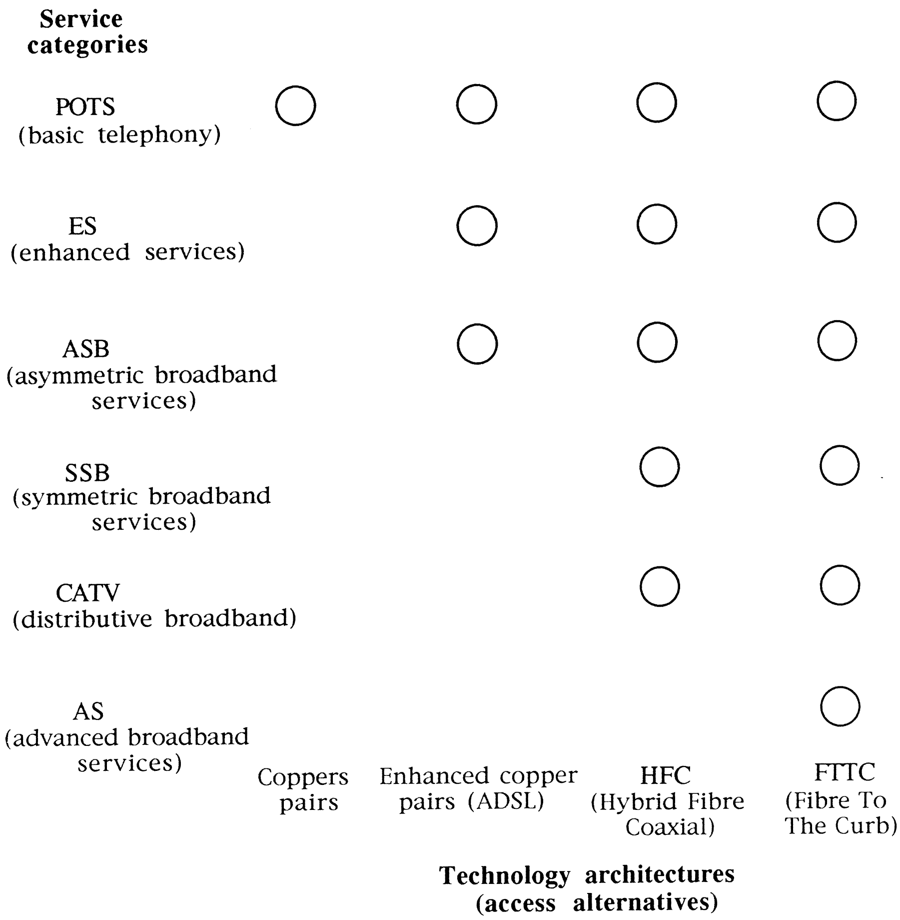

Fig. 3. State transition table to evaluate broadband access strategies.

application services and the service categories defined in the diagram are relatively simple to establish. For instance, video telephone belongs to the category SSB which can be supported by HFC or FTTC architectures.

The reformulation of objective functions and constraints follows from the extended state transition table (Fig. 3) as briefly described in Section 2 and more deeply in Antunes et al. (1993) for the previous model.

In a new globalisation environment and competitive setting, the objective function external dependence (to be minimised in the previous model) seems to be of questionable practical interest as a fundamental point of view to assess the merit of alternative solution plans, having in mind the currently dominant paradigms of economic analysis. Therefore it was not considered in the new model. Competition is also not considered in the experiments carried out, but it could be modelled by means of appropriate market sharing by competitors.

Besides cost other aspects that appear as important, as perceived by the network operator, in face of their relevance for the evaluation of alternative solutions, are the near-term service capability (which is to some extent a surrogate for the degree of modernisation) and the compatibility with the embedded base of subscriber equipment. Another objective function, to be maximised, quantifying the number of optical fibre access lines installed was considered in the first experiments, but a strong correlation between this function and the near-term service capability has been verified, and therefore it was not included.

The decision variables x^j_{mn} are the number of lines which have a transition from state m to state n in year j of the planning period (although this number is obviously an integer, the relaxation of the integer constraints in a strategic planning model seems acceptable). The number of lines which are in state n at the end of year j is given by $y^j_n = \sum_{i\in A_n} x^j_{in} = \sum_{m\in B_n} x^{j+1}_{nm}$, where A_n is the set of states from which it is possible to reach the state n in a transition (including to the same state), and B_n is the set of states which can be reached from the state n in a transition (including to the same state).

4.1. Objective functions

The objective functions considered in the extended model are:

(i) the NPV of the total evolution cost (to be minimised)

$$f_{\text{cost}} = \sum_{j=1}^{J}\sum_{n\in N}\sum_{m\in A_n} c^j_{mn}\, x^j_{mn} + \sum_{j=1}^{J}\sum_{m\in N} c^j_m\, y^j_m,$$

where N is the set of all states, and J is the last year of the planning period.

The coefficients c^j_{mn} are related to the lines which have a transition between states m and n in year j, and the coefficients c^j_m are related to the lines that are in state m at the end of year j. c^j_{mn} is the present value of the difference between the investment costs and the salvage value associated with a transition. The salvage value is important in the case of transitions from a state supported on enhanced copper pairs technology architecture to a state supported on another architecture, due to the possibility of re-using ADSL modems. c^j_m is the present value of the difference between the operational and maintenance charges and the revenue associated with a line in a given state. The factor $(1+r)^{-j}$ is used to bring the cash-flows to its present value in year 0 of the planning period, for a given interest rate r.

(ii) The near-term service capability (to be maximised)

$$f_{\text{scap}} = \sum_{j=1}^{J}\sum_{s\in S}\sum_{m\in N_{(s)}} v^j_{(s)} y^j_m,$$

where $v^j_{(s)}$ is a weighting factor measuring the importance, as perceived by the network operator, to offer service s at year j of the planning period, and $N_{(s)}$ is the set of states which include service $s \in S$ (which can encompass less advanced services).

(iii) The compatibility with the embedded base of subscriber equipment (to be maximised)

$$f_{\text{comp}} = \sum_{j=1}^{J}\sum_{n\in N}\sum_{m\in A_n} w^j_{mn}\, x^j_{mn},$$

where w^j_{mn} is a weighting factor measuring the "compatibility" with the existing network, as perceived by the network operator, of upgrading the access line from state m to state n at year j of the planning period.

4.2. Constraints

The experiments were carried out considering three main categories of constraints (besides intrinsic model coherence constraints): – upper bound on cost and charges; – degree of satisfaction of the estimated demand; – degree of penetration of the supporting technologies.

(i) Budgetary constraint imposing an upper bound D^j on the investment costs and operational and maintenance charges at each year j of the planning period:

$$\sum_{j=1}^{J}\sum_{n\in N}\sum_{m\in A_n} g^j_{mn}\, x^j_{mn} + \sum_{j=1}^{J}\sum_{m\in N} g^j_m\, y^j_m \leqslant D^j,$$
$$j = 1,\ldots,J,$$

where g^j_{mn} and g^j_m are the present values of investment costs and operational and maintenance charges, respectively.

(ii) Lower bound on the degree of satisfaction of the estimated demand, for each type of service at each year of the planning period:

$$\sum_{m \in N_{(s)}} y_m^j \geqslant \alpha_{(s)}^j \; p_{(s)}^j, \quad j = 1, \ldots, J; \; s \in S,$$

where $p_{(s)}^j$ is the estimated demand for service $s \in S$ in year j and $\alpha_{(s)}^j$ is its minimal degree of satisfaction (which is likely to vary between services).

(iii) Lower bound on the degree of penetration of architecture technologies that must be achieved at each year of the planning period

$$\sum_{m \in N_{(t)}} y_m^j \geqslant \beta_{(t)}^j \sum_{m \in N} y_m^j, \quad j = 1, \ldots, J; \; t \in T,$$

where $\beta_{(t)}^j$ is the imposed relative penetration of architecture technology t at year j, and $N_{(t)}$ is the set of states which are supported on architecture technology $t \in T$.

Model coherence constraints guarantee that the number of lines which have a transition from state n to any other state which can be reached from n must be equal to the number of lines existing in state n at the preceding year. At the beginning of the planning period (year 0) there are y_n^0 lines already installed which are taken into account by these constraints for $j = 1$ and $n \in$ {states in which there are lines installed at year 0}.

4.3. Experiments and (preliminary) result analysis

The model has been coded in the mathematical modelling language MPL which enables changes to be easily incorporated and different versions to be analysed in a rapid and flexible manner. The objective functions are coded as macros, which are used to construct two types of scalarising functions: optimisation of a weighted-sum objective function and minimisation of a Tchebycheff distance to a reference point. This "building blocks" approach enables to implement the basic features of some well known MOLP interactive methods (such as STEM, for instance) without much extra programming effort. The model is then instantiated with a set of data, including the preference information in the scalarising functions, as an input to the CPLEX solver. An "ad-hoc" procedure has been used combining a weighted-sum scalarising function (the weights being "well-dispersed" over the weight space), the minimisation of a Tchebycheff distance to a reference point (initially the ideal solution, but which has been changed afterwards), the introduction of additional constraints on the objective function values (directly or via relaxation of the objective values obtained in previous iterations), to perform a progressive search of the nondominated solution set. We opted for this approach, rather than using dedicated multiobjective decision aid tools, because of the higher flexibility in formulating the model and performing changes on it. Thus, the "value-added" is in the multiobjective mathematical model, rather than the analysis of results due to the scarcity of real data. The aim of these experiments was not to simulate the behaviour of a "real-world" decision maker, but just to make an exploration of the nondominated solution set in order to identify feasible evolution strategies (according to the input data) for upgrading the existing access network to deliver broadband services.

Some input data sets have been used, based on the scarce information found on the literature. The planning period is the time scale 1997–2007. The annual tariffs for the services are (in ECUs; 1 ECU ≃ 1.1 USD): POTS - 160; ES - 530; CATV - 250; ASB - 600; SSB - 1000 (see also Ims et al., 1996). The model assumes that the installation of ADSL and FTTC access alternatives is not feasible (for technical and regulatory reasons) before 2000, and the same applies to CATV operators providing other services than distributive TV. Investment cost per line vary from 300 to 1000 ECU for the transitions between states of the state transition table (Fig. 3). Operational and maintenance charges are in the range 20 ECU/year per subscriber for fibre and 40 ECU/year per subscriber for copper, with annual increases between 0.5% and 1.5%, respectively. It must be remarked that these costs strongly depend on local factors such as dwelling distribution (urban or suburban areas) or conditions of the existing networks, among others. The degree of satisfaction of the estimated demand for each type of service varies from 100% for POTS to the range 50–90% for AS (depending on the year). The main features of the obtained results are described below. Detailed numerical results are not presented due to the large amount of collected data and its structural complexity, which would turn its presentation rather cumbersome.

The nondominated solution which optimises the NPV cost objective function is a very conservative strategy characterised by staged upgrades throughout the planning period as it is justified by demand: – copper pairs are used as long as possible, by integrating them with ADSL solutions to deliver enhanced (N-ISDN) and asymmetric broadband services; – optical fibre deployment is delayed because additional revenues perceived from advanced services do not justify the corresponding investment costs; – nevertheless, solutions near the optimum of f_{cost} have been obtained with early deployment of fibre when model parameters were changed to accommodate for high penetration of fibre-based services and only smooth decreasing in fibre related costs.

The nondominated solution which optimises the near-term service capability objective function favours the installation of fibre (FTTC architecture) as soon as possible to provide new services in advance of demand. Only a few solutions in the neighbourhood of the optimum of f_{scap} possess these characteristics.

The nondominated solution which optimises the compatibility with the embedded base of subscriber equipment objective function shows an important correlation with the cost function also favouring to extend the life of copper pairs (although in a lesser extent than in the neighbourhood of the optimum of f_{cost}).

Most nondominated solutions computed by using "central" weighted-sums [4] possess characteristics similar to the optimum of f_{cost}, that is an evolutionary upgrade strategy. The same applies to nondominated solutions obtained by minimising a Tchebycheff distance to a reference point, with "reasonable" changes in the reference point components and introduction of additional constraints on the objective functions values to reduce the scope of the search to regions of interest. This trend seems to confirm other studies reported in the literature using a unique economic indicator objective function (see also Reed and Sirbu, 1989).

[4] Objective functions are in the same order of magnitude to avoid the influence of very distinct value ranges on weighted-sums and Tchebycheff distance scalarising functions.

4.4. Some comments

The approach presented above involved a great effort of data collection to construct the coefficients of decision variables in objective functions and constraints. Because of all sources of uncertainties mentioned before (estimated demand for specific services, investment costs, operational and maintenance costs, learning curves of optical and electronic components, service potential to generate revenues, etc.) it must be questioned whether that is a worthwhile effort having in mind the significance and usability of results. We think the multiobjective mathematical programming approach is of interest to grasp certain compromises to be made and discover some trends, which can aid network operators to make decisions on whether, how and when to upgrade. The experiments have been carried out in the framework of an outline study more addressed to show the usefulness of the multiobjective model rather than putting forward "prescriptive" conclusions. More experiments with updated and more accurate data are necessary, including performing sensitivity analyses regarding model parameters and assumptions.

This type of study must, however, be complemented at a lower level of analysis with the screening of distinct alternatives to aid making some "intermediate" decisions. In this case multiple evaluation aspects are again at stake. An impact matrix stating the level of performance of each potential course of action with respect to each evaluation criterion can be developed. This is a discrete alternative multiple criteria decision problem, which can be tackled by using several methods proposed in the scientific literature. As an example for such approach, we might consider the choice between HFC or FTTC architectures using the following criteria (among other possibilities): support for full service strategy, installed first cost, incremental digital video service cost, operations savings, fit to embedded plant, and evolutionary potential (see also Pugh and Boyer, 1995, for technical details).

5. Conclusions

Telecommunications services play a crucial role in social and economic development and they are pervasive in our everyday lives. Since individuals and small enterprises are prohibited by entry costs to install their own broadband access networks they are constrained to the modes of communication provided to them. This will have strong economic and social consequences: businesses cannot be able to reach a large base of customers and individuals have further limitations regarding new forms of working, learning and entertainment. The evolution towards broadband technologies and services is beginning to take place in an environment characterised by the fast pace of technical innovations, development of multifaceted modes of communication, changing market structures, etc., so that decisions are even harder to make. Moreover, decisions to be made generally involve distinct, incommensurate and conflicting aspects. Thus, the consideration of multiple criteria models not only makes the models more realistic but also enables decision makers to better understand the compromises which need to be done in order to select satisfactory courses of action.

This paper addressed the value-added role that multicriteria models can play in aiding decision makers making better informed decisions regarding the evolution scenarios to deliver broadband services to homes and small business. It must be remarked that the main conclusions drawn in Section 4 strongly depend on the scarce and sometimes outdated information collected in the literature. As soon as new information regarding the model parameters (cost coefficients, time to reach the market of new equipments, forecasts for the yet unclear service demand, other architectural solutions such as wireless, etc.) is available and new evaluation aspects or limitations to the evolution policies become relevant, they should contribute to revise the model, including the explicit consideration of new objective functions or constraints. Moreover, sensitivity analyses regarding model parameters and assumptions must be carried out in order to assess the robustness of the conclusions.

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