Technology Evolution Model for Broadband Multimedia Networks

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Abstract

The rapid growth in the number of Internet users has accelerated the use of high-speed Internet access services, including broadband multimedia services. In the delivery of broadband multimedia services to end users, it is necessary to build a high-speed backbone and access network. To construct a broadband access network, several alternative technologies including xDSL, CATV and FTTx have been suggested and implemented in telecommunication networks. However, even if a technology is proven to be optimal for the current environment, it can be deteriorated by the elapse of time or the advent of new challenging technologies in the future. In this paper, we concentrate on the selection of an evolution path for broadband access networks. We developed an optimization model for selecting the best technology and evolution path with the minimum total cost. The problem can be formulated as a mixed Integer Programming model. With a scenario for demands and cost factors, we find the optimal evolution path by solving our model with the CPLEX program, and illustrate some sample paths for the broadband access network evolution plan. Once the cost and the demand are defined in detail to reflect the real-world case, our model can be useful to generate a practicable technology evolution plan for broadband access networks in real-world applications.

Keywords; broadband access network, network evolution, mixed integer programming model, multi-commodity network flow problem

1. Introduction

The advent of the Internet has had a significant impact on access networks, particularly in the provision of various communication services. The increase of Internet usage has accelerated the transformation of traditional voice-based networks to data-based networks, which are effective in delivering Internet traffic. For instance, VoIP (Voice over Internet Protocol) and e-mail have been rapidly replacing voice communication services, while numerous other services based on the Internet are penetrating various areas such as an entertainment, education, electronic commerce, etc. As the use of the Internet increases, users require high-speed network capability and seamless service provided by a convergence between fixed and mobile networks.

To provide broadband multimedia services, an access network should be evolved from the current narrowband to broadband connectivity. The evolution of broadband access networks will be accomplished by the upgrading of existing networks or the deployment of new technologies, which may change the economics of broadband services. The best way to provide broadband services in an access network is to set up an optical fiber cable to each user. However, this requires a huge investment to install the fiber transmission system. Alternatively, some broadband architectures based on upgrading the existing access network have been suggested. For broadband multimedia services, different types of technologies have arisen based on copper cable, optical transmission, wireless technologies and satellite systems. Among these innovations, there is no dominant alternative in terms of economic and technological advantages.

In this paper, we focus on the problem of optimal evolution path for a broadband multimedia network. We develop an optimization model to select the evolution path from the existing networks to a broadband network as a mixed IP Model. Since a communication network is composed of various equipment and has a complicated cost structure, it is difficult to analyze the effectiveness of technological investment on an broadband network with a simple model. Furthermore, we have to consider various technologies for broadband services. In light of these issues, there have been four types of studies on the economic analysis of investment for broadband networks: improving network capability, pricing mechanism for services, introducing new services, and analyzing costs [1-3]. Most of the existing studies only concentrate on an economic analysis for a given time period without consideration of a strategy for network evolution with various demand types and equipment costs. However, it is necessary to analyze the economic evolution path for access networks when the network requires improvement in order to provide advanced services. In Europe and the U.S., several techno-economic analysis tools have been developed and used to analyze the cost-effectiveness of investment for broadband access networks [4,5].

While there have been several studies on economic analyses for broadband access networks, most focused on a technology comparison with respect to cost-effectiveness. Only Antunes et al. [1] suggested a network evolution approach based on an optimization model for broadband services. Although they did not include the variation of facility costs and increasing demand in their model, their research is innovative in taking a new approach based on an optimization model for network evolution problems. The paper presented here can be viewed as a generalized version of the work of Antunes et al. [1]. That is, in this paper, we suggest an optimization model for the network evolution problem to provide broadband services with considerations of fluctuations in costs and growing demand.

In section 2, we analyze several alternative technologies and services for broadband networks, and develop an optimization model for selecting the evolution path among alternative technologies with minimum total cost in section 3. Further research directions and concluding remarks are described in the final section.

2. Broadband Access Network Technologies and Services

There is a wide range of alternatives for upgrading an access network to broadband, in selection of both transmission medium and system technology. At present, no single technology or network architecture seems to present a dominant choice. In this paper, we have considered wire-line systems and architectures using twisted pairs, coaxial cables and fiber optic systems. Table 1 provides a brief sketch of the alternative technologies for broadband access networks.

Table 1 Broadband Access Network Alternatives

<table>
<tr><th colspan="2">Type</th><th>Speed</th><th>Media</th><th>Applications</th></tr>
<tr><td colspan="2">HFC</td><td>128Kbps ~ 10Mbps</td><td>Coaxial/Optical Cable</td><td>High Speed Internet, VOD, CATV</td></tr>
<tr><td rowspan="5">xDSL</td><td>ADSL</td><td>~ 8Mbps</td><td rowspan="5">Twisted Copper Cable</td><td>High Speed Internet, Multimedia Service</td></tr>
<tr><td>HDSL</td><td>1.5Mbps / 2Mbps</td><td>T1/E1 Services Only</td></tr>
<tr><td>SDSL</td><td>1.5Mbps / 2Mbps</td><td>HDSL with a Single Line</td></tr>
<tr><td>VDSL</td><td>~ 52Mbps</td><td rowspan="2">High Speed Internet, VOD, Multimedia Service</td></tr>
<tr><td>SHDSL</td><td>~ 23Mbps</td></tr>
<tr><td rowspan="3">FTTx</td><td>FTTO</td><td>155Mbps</td><td rowspan="3">Optical Fiber</td><td rowspan="3">High Speed Internet, VOD
Personal Internet Line</td></tr>
<tr><td>FTTC</td><td>~ 8Mbps</td></tr>
<tr><td>FTTH</td><td>155Mbps</td></tr>
</table>

xDSL is an enhanced copper system technology including ADSL, HDSL (high-bit-rate DSL), SDSL Single line DSL), VDSL and SHDSL (symmetric high-bit-rate DSL). In DSL options, there is a trade-off between distance and transmission capacity (speed). ADSL uses one twisted cooper cable for asymmetric transmission, while HDSL offers cost-effective T1 or E1 services on existing copper wire [4]. SDSL is a single line version of HDSL, and VDSL provides both symmetric and asymmetric transmission. SHDSL merges strengths from both HDSL and SDSL technologies. The HFC technology for coaxial cable networks aims to offer various services over existing CATV infrastructures. The HFC network is asymmetrical by nature, the downstream flow being much larger than the upstream. Since HFC is based on a point-to-multipoint configuration, each user has to share common sections of coaxial cable for transmitting its upstream traffic. To manage such a shared capacity system, HFC allows provision of return capacity in CATV networks. FTTx is the fiber optic technology considered the most promising alternative for broadband services provision. Some network architectures such as FTTO (Fiber To The Office), FTTH and FTTC (Fiber To the Curve) are commonly proposed, depending on the local network area conditions. FTTx enables service providers to offer bandwidth intensive communications services on demand. The choice between FTTC, FTTO and FTTH should be mitigated by the unit cost per end user of the considered configuration.

Several alternative architectures and technologies have been suggested for providing broadband services on an broadband multimedia network. One of the important factors for selecting a broadband multimedia network technology is the demand types along with their volume for broadband services. Existing copper-based networks are adequate for transmitting low-and-medium speed (narrowband) service, and CATV or optical networks are required for high-speed (broadband) service. In the real world, demand for low-and-medium speed service and demand for high-speed service co-exist, and the demand for each service has changed gradually from narrowband service to broadband by the growth of information technology. Hence, there are several alternative technologies for broadband services, and an optimization model for selecting an efficient technology in the migration process from narrowband to broadband networks needs to be developed. A broadband service can deliver massive multimedia contents such as video, images, music and text. Table 2 shows examples of available broadband home application services [9].

Table 2 Broadband Services for Home [9]

Area	Broadband Applications Services
Education, Learning	Remote Education, Video on Demand, Multimedia Library
Newspaper, Broadcasting	News on Demand, E-newspapers, e-Books
Entertainment, Leisure	Movies on Demand, Remote Games, Karaoke on Demand
Remote Medical Care	Remote Medical Treatment, Medical Information
Remote Public Service	Get Public Services from Home, Accessing Government Data
Shopping, Banking	Home shopping, Home Banking
Living Information	Remote Reservation, Remote Home Networking, Home Security, Living & Local Information

The key factor in the network planning process for employing a broadband multimedia network is the volume of traffic being carried on the network for accommodating various broadband services. To estimate traffic volume, we need to categorize services by the required bandwidth for their effective transmission. In this paper, broadband services are divided into four groups, as classified by Auntunes et al. [1]: Enhanced Service (ES), Asymmetric Switched Broadband Service (ASB), Symmetric Switched Broadband Service (SSB), and Switched Broadband Advanced Service (AS). ES includes “plain old telephone services” (POTs), fax delivery, and the transmission of short images. As such, it is inherently a narrowband service offered by low-and-medium rates (typically up to 384Kbps). ASB represents asymmetric services, at least 2Mbps downstream and 16Kbps upstream, which include VoD, file downloads and high-speed Internet access. SSB is a symmetric switched broadband service, capable of providing at least 2Mbps symmetrically. On-line education, large-sized file transfer and remote medical services may be included in SSB service. AS is an advanced service having the capability to offer more bandwidth than ASB or SSB. Interactive TV, HDTV and CATV are typical services for AS. Table 3 shows the service types, characteristics and some typical examples of broadband services.

Table 3 Types of Broadband Access Services

Type	Characteristics	Examples
ES	• Medium/low speed access service as standard narrowband ISDN • Text, image and voice transmission	• Text based internet service • Reservation and financial transaction service
ASB	• Connection between existing web servers and end users using asymmetric data traffic • Asymmetric broadband services including video, image, text and audio transmission using 2Mbps download speed	• VOD on Internet • Multimedia service
SSB	• 2-way 2Mbps service for high speed data exchange	• High speed 2-way multimedia service • High-speed person-to-person data transmission. • High speed services of remote education and remote medical care
AS	• 2-way interactive service faster than 2Mbps • Mainly for broadband video transmission	• Multimedia Tele-conference, Broadcast • Video Distribution (CATV etc.)

3. Optimal technology selection model for broadband multimedia network evolution

There are several alternative technology architectures for broadband multimedia networks accommodating various services. Table 4 shows a feasible combination of available service types and technology architectures for an broadband network. In Table 4, we see, for example, the services of ES or ASB can be provided by any technology, but the employment of an advanced technology or an upgrade of the existing network to offer SSB or AS services is necessary. The existing copper-based network may be upgraded to ADSL, SDSL, VDSL and SHDSL to accommodate the growth of demand for broadband services. Alternatively, a new technology such as FTTC or FTTH may be introduced to save the total network re-structuring cost induced by the removal of existing facilities and the investment of new systems for broadband services.

Table 4 Service Types and Access Network Alternatives

Type	ADSL	CATV	FTTC/ADSL	SDSL	VDSL	SHDSL	FTTH/PON
ES	○	○	○	○	○	○	○
ASB	○	○	○	○	○	○	○
SSB	X	X	X	X	○	○	○
AS	X	X	X	X	X	○	○

Notes: ○ indicates that each technology is good for service, and X indicates that each technology is unavailable.

For the forecast of demand for broadband services, we must consider that the best network architecture and technology at the moment may not necessarily be cost-effective in the future as a result of change in the facility cost and fluctuation of demand for broadband services. Maintenance costs tend to gradually increase for existing facilities over time, while facility costs generally fall with development of new technologies. For these reasons, it is extremely difficult to select the best architecture and technology for an access network in terms of accommodating broadband service among several competitive alternatives. For this problem, difficult decisions must be made, including selection of architecture and a technology alternative, optimal investment time and a transition plan from the existing network to the new one.

If there is only small demand for services based on SSB and AS, it may be better to delay offering the service because a vast investment is required. Hence, some demands for SSB and/or AS based services may be delayed; subsequently unsatisfied requests should be compensated in order to retain them until the services are available. Therefore, we have to consider the trade-off between the investment cost for accommodating a few broadband demands and the compensation cost for unsatisfied demands in the network evolution plan.

For providing broadband services cost-effectively, the appropriate architecture and technology for the access network should be selected. The existing technology will be upgraded to and replaced with new technologies according to the cost reduction of facilities and the growth of demand for various broadband services. When considering the conversion of an existing network to a new one, we should take into account the investment of new technology and all of the various kinds of conversion costs including the removal cost, replacement cost and restructuring cost.

Our complex problem is summarized in Table 5.

Table 5 Technology Selection and Evolution Problem for Broadband Access Network

Case	Contents
Given Condition	• Technology alternatives to be considered and the cost for each technology alternative • Demand of each broadband access network service
Constraints	• To guarantee the minimum amount of the demand for each broadband access network • To compensate the unsatisfied demand • To evolve the network toward a more advanced technology than the existing one • To guarantee the minimum supply for each technology alternative
Objective	• To establish a network evolution path that can accommodate the demand for a broadband access network with minimum cost
Decisions	• The equipment capacity of each technology alternative being invested • The evolution plan including the technology being replaced, the amount of conversion demand and the equipment capacity of the new technology alternative

To formulate an optimization model for our problem, the following conditions are applied:

1) To compare the network cost under common conditions, the same network architecture for all alternatives should be considered in the model.

2) The cost reduction for each component of an alternative should be taken into account for evaluating the investment cost.

3) The planning period, the set of alternative technologies and the set of demand types are represented as T, N, and M respectively.

The demand ($D_t(s)$, demand for ‘‘s’’ service in the year ‘‘t’’) is given as the number of circuits corresponding to the number of users for the access network.

Beyond these considerations, there are additional assumptions as follows. When considering the upgrade or replacement of an existing network, the alternatives should be composed from more advanced technologies than the current one. Let $I(i)$ be the set of inferior technologies for technology i, then technology j in $I(i)$ can be evolved into technology i. Let $J(i)$ denote the set of advanced technologies for technology i. This means that technology i can evolve into one of the technologies in $J(i)$. Q_i is the capacity accommodated by technology i. Once a technology is selected as an efficient alternative, it will be used until all demands transfer to a new alternative technology. For strategic consideration of facility plans and customer service provision, we assume that the minimum amount of each alternative technology ($\xi_t(i)$) is invested each year, and the minimum amount of each demand ($\delta_t(s)$) should be satisfied each year during the planning period.

The total cost for network evolution is composed of the investment cost for the new technology, the conversion cost from the existing to the new technology, and the compensation cost for unsatisfied demand. The investment cost for employing new technology is the total cost occurring throughout the whole planning period for technology i; it can be divided into two parts, a fixed cost (F_i^t) and a variable cost. The variable cost is composed of a maintenance cost and an equipment cost. The fixed cost F_i^t denotes the sum of total fixed costs occurring during the planning period (T) when technology i is selected at year t. Let w_i^t and g_i^t be the unit cost of the capacity and the unit maintenance cost of the cumulated capacity for technology i at year t respectively.

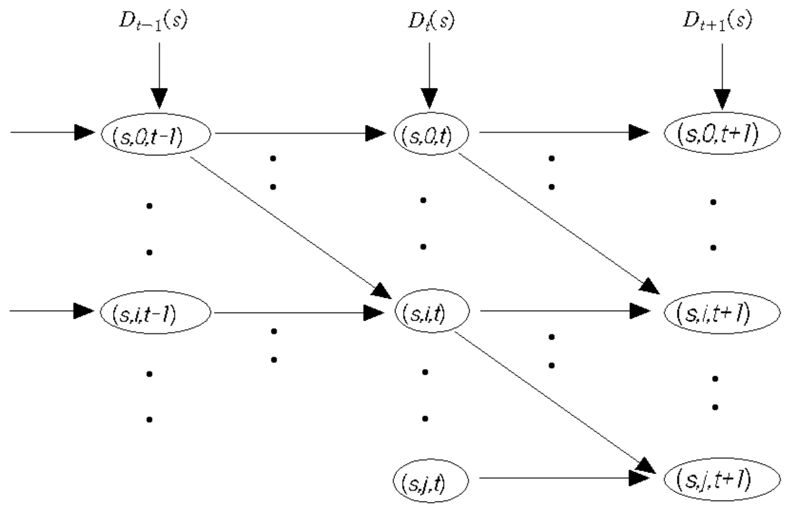
The conversion cost is also the variable cost corresponding to the technology conversion from technology i at year t to the new one at year (t+1). It includes a removal cost for existing facilities, a reconstructing cost for each user and the managing cost for effective operation of the existing and new technologies. If a single technology is running throughout the planning period, no conversion cost is required. Let $h_{ij}^t(s)$ be the unit cost of the conversion capacity from technology i to technology j at year t for service s.

The compensation cost for unsatisfied demand corresponds to the demand not supplied by the appropriate technology at the request time owing to the shortage of capacity. When unsatisfied demand occurs, it may negatively affect the provider's image, and result in further loss of revenue. Therefore, some compensation plans are needed to retain the unsatisfied demand until the additional capacity is available. Hence, the compensation cost may be defined by the sum of the additional revenue being considered as opportunity cost and the subsidiary for delaying services, or the strategic point of view. $\theta(s)$ denotes the unit compensation cost for the unsatisfied demand of services.

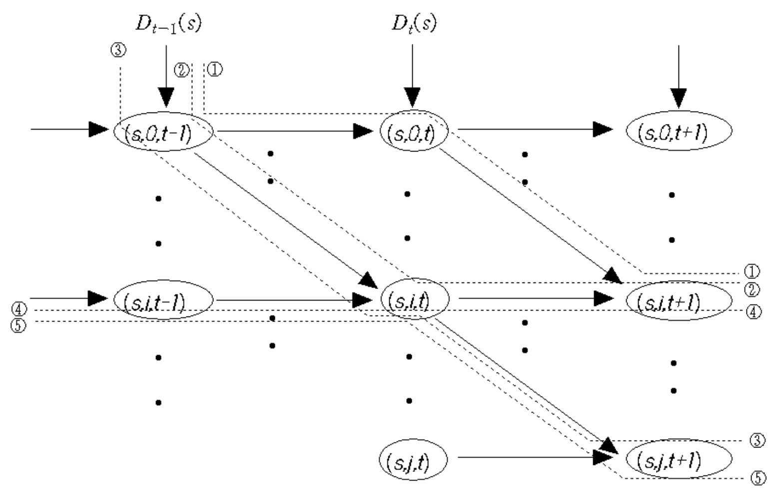
The constraints corresponding to the selection of an evolution path for the access network are given as follows:

1) The demand $D_t(s)$ for service s at year t should be accommodated by one of the alternative technologies (i); or if it is not, the remaining demand should be added to the demand for the next year $D_{t+1}(s)$. In the latter case, the compensation cost $\theta(s)$ should be considered in the model.
2) The demand for each service (s) should satisfy more than the minimum requirement at year t ($\delta_t(s)$).
3) The investment for technology i at year t should exceed the minimum capacity requirement ($\xi_t(i)$).
4) Once technology i is selected at year t, it should last for the planning period T.
5) Each technology i is indexed from an inferior technology to a superior one. In other words, technology (i +1) is more advanced than technology i.

The network evolution problem for a broadband access network is presented as a network flow problem as illustrated in Figure 1. Let (s,i,t) denote the state, where service type s is accommodated by technology i at time t. $D_t(s)$ represents the demand for service s at time t. In Figure 1, the technology alternative 0 is a dummy for accommodating the unsatisfied demand at time t. For instance, the unsatisfied demand for service s at time (t-1) remains until the next time t. The unsatisfied demand at (t-1) is added to the new demand occurring at time t and waits to be accommodated by alternative technologies. The remaining demands not accommodated by any alternative at time t should be added to the new demand at the next time (t+1).



a) Network Representation for Evolution of Broadband Access Network



b) Examples of Evolution Path of Access Network for Broadband Access Services

Figure 1. Examples for Broadband Services and Evolution Path for Broadband Access Network

Let us consider (s,i,t) in Figure 1. There are three types of incoming arcs for service s. The incoming arc from (s,0,t-1) represents the demand transferred from (s,0,t-1) at time (t-1), among the unsatisfied demand at time (t-1) and the new demand occurring at time t. This means the sum of the unsatisfied demand at time (t-1) and the new demand at time t, can be newly accommodated by technology i at time t. The incoming arc from (s,i',t-1) is the transition demand from i' technology at time (t-1) to i technology at time t. That is, the demand serviced by technology i' in I(i) at time (t-1) can be evolved into technology i at time t. The incoming arc from (s,i,t-1) denotes the demand accommodated by the same technology i at both time (t-1) and t.

The outgoing arcs represent the evolution from technology i to advanced technologies to accommodate growing demand. The outgoing arcs at (s,i,t) correspond to the evolution to the advanced technologies or the same technology. The arc from (s,i,t) to (s,i,t+1) indicates the demands at time t are provided by the same technology i at time (t+1). The outgoing arc to (s,j,t+1) means the demands taken by the technology i at time t are transferred to the new technology j at time (t+1). At node (s,i,t), a conventional flow conservation constraint should be applied to yield a feasible solution.

To calculate exactly the total cost for improving an access network, the additional constraints should be added to the flow conservation constraints. In order to use a technology i at time t, the technology had to already be selected before time t. For the technology i, the investment cost (fixed cost) should be taken into account at the time of the installation. The expansion of the capacity for technology i at time t is available only if the technology has been run to accommodate the broadband services. Figure 1-b) shows an example of evolution paths for an access network among alternative technologies as represented by a conventional network flow problem. In Figure 1, Path 1 is the unsatisfied demand of $D_{t-1}(s)$ for service s at the time t-1 is transferred to the time t; then technology i accommodates it at time t. Path 2 describes the demand $D_{t-1}(s)$ for service s at the time t-1 is accommodated by technology i at time (t-1), and it continues operating at time t. Path 3 depicts the demand $D_{t-1}(s)$ for service s at the time t-1 is accommodated by technology i at time (t-1); it is also transferred to technology j at time t. Path 4 represents the existing demand accommodated by technology i at the time t is supported by the same technology i at time t. Path 5 denotes the existing demand accommodated by technology i at the time (t-1) is transferred to technology j at time t. From Figure 1, we see our problem can be represented as a network flow problem with some side constraints.

To formulate an optimization model for our problem, we define the following variables.

$X_{ij}^{t}(s)$: the demand for s service, which is accommodated by technology i at time t and then transferred to technology j at time (t+1),

S_i^t : the installation capacity of technology i at time t,

Z_i^t : the cumulated capacity of technology i at time t,

Y_i^t : (0,1) variable indicating the use of technology i at time t,

The costs related with the variables $X_{ij}^{t}(s)$ and S_i^t are defined as $c_{ij}^{t}(s)$ and w_i^t respectively. $c_{ij}^{t}(s)$ includes the operation, the maintenance, the conversion and the compensation costs. If there are some unsatisfied demands for services at time t, they should be deferred to the next time and the their compensation cost must be added. Otherwise, $c_{ij}^{t}(s)$ is represented as the sum of the unit maintenance cost and the cost for technology conversion.

$$c_{ij}^{t}(s) = \begin{cases} \theta(s), & i = j = 0, \\ g_i^t + h_{ij}^t(s), & otherwise. \end{cases}$$

The unit maintenance cost may be increased by the time. When the initial maintenance cost and its increasing rate are given by g_i^0 and γ respectively, the unit maintenance cost at time t is defined as follows: $g_i^t = g_i^0 (1+\gamma)^{t-1}$.

To define the cost associated with Y_i^t, we consider the incremental cost of the total fixed cost for technology i at time t: $f_i^t = F_i^t - F_i^{t+1}$. F_i^t can be represented as the sum of these incremental costs.

$$\begin{aligned} F_i^t &= (F_i^t - F_i^{t+1}) + (F_i^{t+1} - F_i^{t+2}) + \dots + (F_i^T - F_i^{T+1}) \\ &= f_i^t + f_i^{t+1} + \dots + f_i^T \qquad (F_i^{T+1} = 0) \end{aligned}$$

Once the first installation of technology i occurs at time t, technology i will be used continuously to the end of the planning period. This means the following relationship is true: $Y_i^s = 1,\ s = t, t+1, \ldots\ldots, T.$ Thus, F_i^t can be represented as $\sum_{s=t}^{T} f_i^s Y_i^s$, and f_i^t can be used as the fixed cost corresponding to Y_i^t.

With these variables and notations, we formulate our problem as a mixed Integer Programming model, which is represented as a variation of a multi-commodity network flow problem.

$$[P] \quad Min. \sum_{i \in N \cup \{0\}} \sum_{j \in J(i)} \sum_{t \in T} \sum_{s \in M} c_{ij}^t(s) X_{ij}^t(s) + \sum_{i \in N} \sum_{t \in T} w_i^t S_i^t + \sum_{i \in N} \sum_{t \in T} f_i^t Y_i^t \quad (0)$$

$$s.t \quad \sum_{j \in J(0)} X_{0j}^0(s) = D_0(s) \qquad s \in M, \quad (1)$$

$$\sum_{j \in J(i)} X_{ij}^t(s) - \sum_{j \in I(i)} X_{ji}^{t-1}(s) = 0 \quad i \neq 0 \in N,\ t \neq 0 \in T,\ s \in M \quad (2)$$

$$X_{ii}^{t-1}(s) + D_t(s) = \sum_{j \in J(i)} X_{ij}^t(s) \qquad i = 0,\ t \neq 0 \in T,\ s \in M \quad (3)$$

$$X_{ij}^t(s) \le Q_i Y_i^t, \qquad i \in N,\ j \in J(i),\ t \neq 0 \in T, s \in M \quad (4)$$

$$X_{ij}^t(s) \le Q_j Y_j^{t+1}, \qquad i \in N \cup \{0\}, j \in J(i), t \in T, s \in M \quad (5)$$

$$Y_i^t \le Y_i^{t+1}, \qquad i \in N,\ t \in T \quad (6)$$

$$\sum_{j \in I(i)} \sum_{s \in M} X_{ji}^{t-1}(s) \le Z_i^{t-1} + S_i^t, \qquad i \in N,\ t \in T, \quad (7)$$

$$Z_i^t \le Q_i Y_i^t, \qquad i \in N,\ t \in T, \quad (8)$$

$$S_i^t \le Q_i Y_i^t, \qquad i \in N,\ t \in T, \quad (9)$$

$$Z_i^t = Z_i^{t-1} + S_i^t, \qquad i \in N,\ t \in T, \quad (10)$$

$$\sum_{i \in N} \sum_{j \in J(i)} X_{ij}^t(s) \ge \delta_t(s), \qquad s \in M,\ t \in T, \quad (11)$$

$$Z_i^t \ge \xi_i^t, \qquad i \in N,\ t \in T, \quad (12)$$

$$X_{ij}^t(s), Z_i^t, S_i^t \ge 0,\ Y_i^t \in \{0, 1\}, \qquad i \in N \cup \{0\}, j \in J(i), s \in M, t \in T. \quad (13)$$

The objective function (0) minimizes the total cost for installing, converting and maintaining the networks. Constraints (1)-(3) denote the restriction of the demand for each service. (1) shows the demand requirement for each service at the beginning of the planning period. The demand should be accommodated by alternative technologies, or the service is deferred to the next time. Constraint (2) is a flow conservation constraint on technology i for service s at time t. That is, the total demand accommodated by technology i at time t is equal to the sum of the demands transferred to technology j at time (t+1) and the demands maintained by the same technology i at time (t+1). Constraint (3) denotes that the unsatisfied demands (i=0) at time (t-1) for service s and the new demands for service s required at time t should be accommodated at time t by the alternative technologies, or deferred to the next time (t+1).

Constraints (4) and (5) show the service s can be accommodated by technology i, only if it is available to operate at time t. This means that once technology i is operating at time t, the demands for various services can be accommodated up to its capacity Q_i. If technology i is determined to be efficient at time t, it should be used continuously to the end of the planning period. This is represented by constraint (6). Recall that we use the incremental cost f_i^t rather than the total fixed cost F_i^t. Once technology i is installed at time t, constraint (6) guarantees the total fixed cost for technology i is included in the objective function (0).

Constraint (7) means the total demand for technology i at time t has to be accommodated by the existing capacity and the expansion of technology i. It is possible to expand the capacity of technology i at time t (S_i^t), only if technology i has been operated to accommodate services from the past. In other words, if technology i is used at time t, its capacity can be expanded to the maximum installation capacity (Q_i). (8) and (9) represent these constraints. Constraint (10) means when the capacity of technology i is expanded at time t, the total cumulate capacity is increased by the amount expanded. Constraints (11) and (12) denote the minimum requirement to be accommodated at time t for service s and the minimum installation requirement for technology i at time t, respectively.

Since the optimization model [P] for selecting an evolution path for a broadband access network is represented as a mixed Integer Programming problem, we can develop an efficient heuristic by applying several approaches such as Lagrangean relaxation method, LP relaxation method and Tab-search. However, as a result of improvements in computer hardware and software, it is now possible to solve a large-scale mixed Integer Programming problem within a short computation time without the help of special algorithms. We can try to find optimal solutions of [P] by applying CPLEX program [10], a commercial computer package for solving mathematical programming problems.

4. Conclusions

To establish a broadband multimedia network, the best alternative technology would be FTTH connecting each user to a central office by optical cable. Although FTTH is the most efficient means to deliver broadband service, it requires a massive investment cost and lengthy time to complete the network. Therefore, several technologies such as ADSL, CATV, VDSL and SHDSL are suggested as alternatives to FTTH, because they can provide relatively high-speed data services efficiently and evolve to FTTH economically. For selecting the technology for a broadband multimedia network, the most important factors are the demand for broadband services and the facility costs for the selected technology. The development of an optimization tool to analyze the evolution path for a broadband network is required to aid in the selection of the best technologies under uncertain demand and facility costs varying with time.

Worldwide there have been extensive attempts to evolve current networks into broadband multimedia networks. Since broadband networks will have pronounced economical effects, there have been many studies and a great deal of investment internationally in this realm. Due to the differences among the technical aspects and the investment costs for the suggested technologies, there is no dominant technology for the broadband network. However, with appropriate assumptions, we suggest some alternative technologies for selection during the planning period. According to the growth of demand and facility costs, we can select the best technology or decide to transfer the current technology into others to accommodate the growing demand economically.

In this research, we have focused on the development of an optimization model to select the best evolution path for a broadband multimedia network. To this end, we have considered some alternative technologies and reviewed the types of broadband services. The optimization model is formulated as a variation of a multi-commodity network flow problem. With appropriate input parameters, our model suggests the evolution plan for a broadband network with the minimum cost. From the evolution plan, we can see the time of the introduction and the amount of facilities to be installed for each technology, and determine the optimal time of transferring the current technology to other technologies. Once the cost and the demand are defined in detail to reflect the real-world case, our model will be useful to generate effective evolution plans for real-world applications. Although this paper focused on the selection of a technology evolution path for broadband networks, our approach can be applied to other industries in terms of building technology evolution strategies and providing a good guideline to make a cost-effective technology selection.

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