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Cost Optimization Methods in the Design of Next Generation Networks

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ABSTRACT

A key development of telecommunication systems during the past two decades has been the evolution from the circuit-switched network toward the packet-switched network paradigm. Many operators are now migrating their PSTNs from circuit switched into multipurpose packet switched networks. This new approach is often called the next-generation network (NGN). NGN enables network operators to run all services (i.e., voice, data and video) on one network. In this article the migration of Iceland Telecom's circuit-switched PSTN toward NGN will be described. A cost model of the telecommunications system has been developed to enable cost and benefits analysis of transforming the network to NGN. Methods of optimization and their application to determine the optimal number and position of nodes in the future network will be described. The optimization produces a network structure with the lowest possible total cost of ownership, and the model can also indicate how deviations from the optimum affect cost. The feasibility of NGN can be assessed by comparing the cost of NGN migration to that of maintaining the current circuit-switched network.

INTRODUCTION

Since the 1970s, telecommunications networks have evolved toward digitally switched networks where each conversation is transmitted as a statically reserved 64 kb/s stream. Today the public switched telephone network (PSTN) faces a new evolution, transformation toward the packet-based next-generation network (NGN).

While most people agree that the future of communications networks is based on NGN concepts, less is known about the financial impact of this transformation. In today's competitive environment, financial feasibility is one of the main concerns of management. The success of a project is measured by its financial yardstick, and decisions are made based on monetary forecasts and impact. The potential cost reduction as inferred from the NGN presents a unique opportunity to build up a new network with increased efficiency.

The financial impact and complexity of the decision-making process in implementing NGN emphasizes the need to adapt advanced operations research techniques when structuring the future network. Although optimization-based methods have traditionally been used in technical design, such methods have not been used extensively by management from a financial viewpoint.

The transformation from circuit-switched to packet-based networks results in little change over the transport network. Speech and data are still transmitted over the same synchronous digital hierarchy (SDH) fiber network as before; the major difference is the nature of the traffic being transmitted, and changes in network switching and routing equipment. The immediate question is then why? Having already invested in different networks that work well and fulfill current needs, why change? The answer lies in total cost of ownership (TCO). Vendors as well as service providers are convinced that NGN solutions can reduce operational cost and produce new revenue generating opportunities [1–3]

The NGN concept is based on packet-based nodes called *media gateways* (MGWs) that take over the functionality of the switching hierarchy in the current PSTN system [4, 5]. The initial investment largely depends on the number of MGWs, which also shapes the future operational cost. The main decision problem is to determine the position and number of MGWs that minimize operational cost. Given this optimum configuration, the feasibility of the project can be determined and a future strategy devised.

Finding the cost-effective solution requires two things: a cost model to examine the effect of deviations and an algorithm to find the optimum. With the help of modeling and optimization, the task of implementing NGN in Iceland Telecom's network can be accomplished in the most economical manner possible.

Iceland Telecom plans to upgrade its circuit-

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switched PSTN to an NGN. The work described in this article focuses on minimizing the cost of the future PSTN, which is the first design step of the NGN. The conceptual model can later be extended to include other services.

BACKGROUND

Iceland is Europe's most sparsely populated country with around 290,000 inhabitants in a country of 103,000 km^2. Approximately 70 percent of the population lives in the southwest corner of the country, in and around the capital, Reykjavik. The country is connected by two submarine cables as well as satellite links to both Europe and the United States. Iceland Telecom, the country's incumbent operator, has laid a 1500 km optical fiber ring connecting most of the villages and towns with a 2.5 Gb/s SDH connection. A 40-color dense wavelength-division multiplexing (DWDM) system is now being deployed to connect to a new submarine cable that is taken ashore on the east coast.

THE CURRENT PSTN

Iceland Telecom's PSTN has evolved in the past decades in accordance with de facto European standards. The last drastic change occurred in the 1980s and early '90s when the network was upgraded with digital exchanges, based on Ericsson's AXE infrastructure. As depicted in Fig. 1, there are 10 local exchanges (LEs) in Iceland Telecom's PSTN that all connect to two transit exchanges (TEs).

Users are connected with a pair of copper wires (local loop) to the closest remote subscriber stage (RSS). For subscribers located in the proximity of an LE, the RSS is collocated with the LE. If, however, a group of subscribers is located far away from the LE, they connect to a detached RSS that connects to the nearest LE with trunk lines. There are 210 RSSs in 170 different locations in Iceland. The detached RSSs are mostly used in small towns where they connect to one of the five regional LEs.

For transmission, numerous 2 Mb/s leased lines are used, each capable of carrying 30 digital voice channels. The leased lines can be classified into two categories: local trunk lines (LTLs) that connect RSSs to LEs, and transit trunk lines (TTLs) that connect LEs to TEs (Fig. 2).

THE NEXT-GENERATION NETWORKS

The term NGN is commonly used for changes in network infrastructure that have already started in the telecom and information technology (IT) industry. As such, it is not a term that can be precisely defined but is rather an umbrella term that varies among individuals, vendors, and literature. While efforts in standardization are not finished, vendors have gone their own way in product development to meet industry needs. One characteristic most solutions have in common is that they are based on multiservice backbone networks that can transmit and fulfill requirements for different types of information.

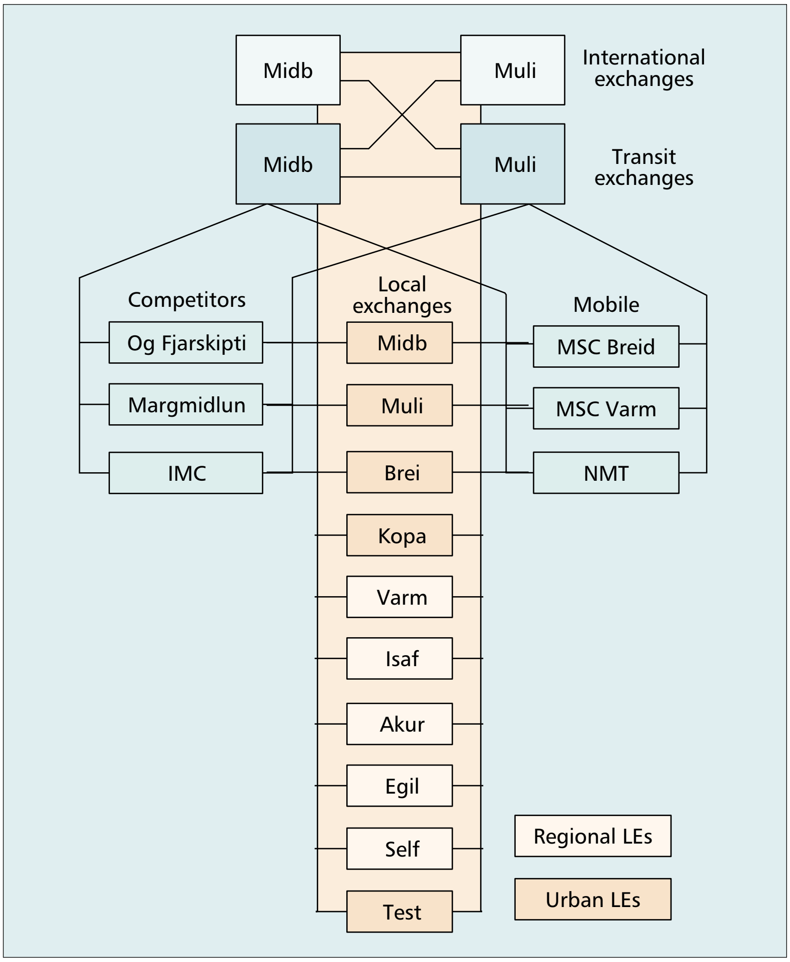

Figure 1. *Exchanges in Iceland Telecom's current circuit-switched PSTN network.*

Ericsson's vision of the future telecommunications networks is called Engine and relies on packet-based multiservice networks. The Engine concept is based on migration of the current circuit-switched network over to NGN, using an asynchronous transfer mode (ATM) or IP backbone network. One of the benefits of Engine is that it offers a migration strategy; the current equipment is upgraded to become components in the NGN [4].

The Engine multiservice network architecture comprises the following four principle parts, as shown in Fig. 3.

TELEPHONY SERVER

The telephony servers (TSs) handle call and service control in the new system. They assume the responsibility of the control layer in the current PSTN and control switching resources in the MGWs. In the migration plan, the two current TEs will be upgraded to TSs.

MEDIA GATEWAY

The MGWs are core switches in the new IP or ATM backbone network. The function of the MGWs is to switch narrowband and broadband signals within the transmission network and to access ramps (ARs). In the migration plan, an optimal number of LEs will be upgraded to MGWs.

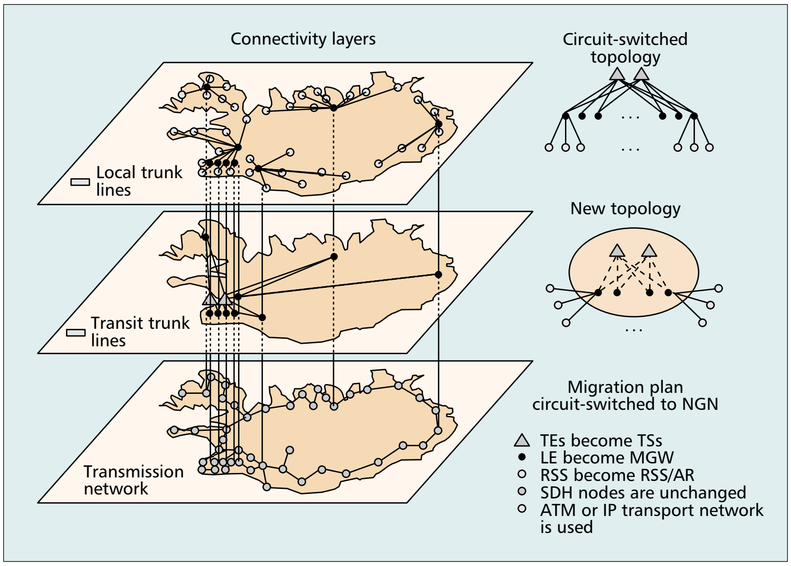

Figure 2. *The connectivity and topology map for the circuit-switched network and NGN. In NGN MGWs replace LEs, and TSs replace TEs. Both systems use the same SDH transmission network to connect components according to different topologies.*

ACCESS RAMP

The ARs are termination points of the local loop. They provide customers with both narrowband and broadband connectivity. Each AR is connected to the nearest MGW. In the first step of the migration plan, the current 210 RSSs will be kept unchanged as they are compatible with Engine (i.e., can connect to MGWs).

CONNECTIVITY NETWORK

The connectivity network is a backbone IP or ATM network between MGWs. The connectivity network will be built on leased slots between nodes in the existing SDH fiber network. In the migration plan, MGWs can be located wherever there is an SDH node and will be connected to the TSs with SDH slots of the required bandwidth (i.e., TTL). The difference between TTL in the current circuit-switched network and the future NGN is the size of SDH slots used. In the current network, all LTLs and TTLs were limited to a multiple of 2 Mb/s SDH slots. In NGN, LTLs and TTLs can be of any SDH slot size.

MIGRATION PLAN

In essence, the migration from the circuit-switched paradigm to NGN is based on upgrading the existing TEs to TSs and LEes to MGWs, and connect them all using an ATM or IP connectivity network. The topology of the circuit-switched network, the new NGN, and required connectivity layers is depicted in Fig. 2. A system diagram of an NGN network is shown in Fig. 3.

The problem at hand is to find the position and number of MGWs that minimize the TCO of the NGN network. A methodology to achieve this goal will be described in the following section.

SIMULATING THE TOTAL COST OF OWNERSHIP

To investigate the potentials of cost minimization in implementing NGN, knowledge is needed about the characteristics of the cost and from where it stems. This was done by applying a Pareto analysis [6] to the registered total cost of Iceland Telecom's PSTN for 2002. The results showed that leased line cost is the single largest cost factor, amounting to roughly half the total cost. Along with depreciation, interests, housing, and internal services, these five cost factors amount to roughly 98 percent of the annual total cost. By simulating these five cost factors in a mathematical model for both the current and future networks, the financial effects of implementing NGN in Iceland can be estimated.

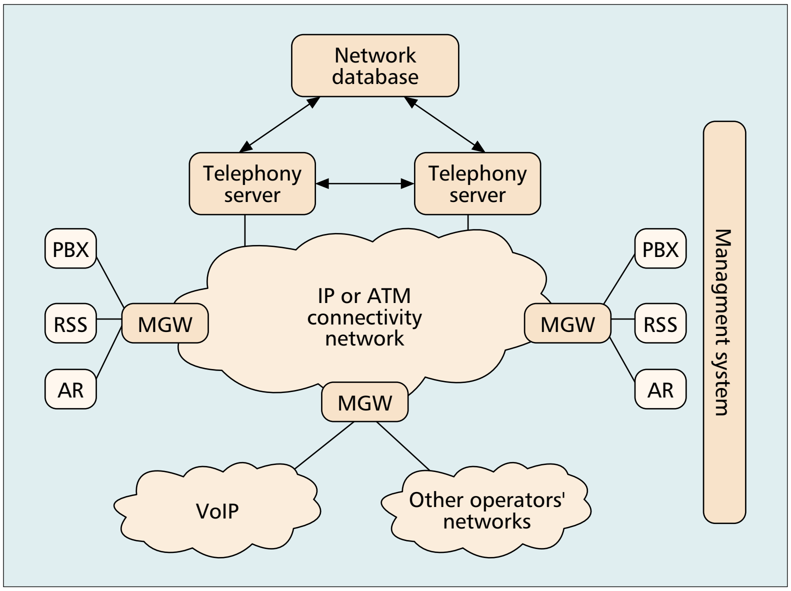

Figure 3. *The system diagram of an NGN network.*

MINIMIZING THE TOTAL COST OF OWNERSHIP

The single largest design factor controlling the cost factors of the new NGN network is the number and position of MGWs. This factor controls the initial investment, and the distance and path of all information flow in the network, and shapes the operational cost. By combining structural changes with the migration to NGN, Iceland Telecom can gain the functional benefits of NGN at the lowest possible price.

To find the network structure that minimizes the total cost we assume that the only way to affect the total cost is to change the number or position of MGWs. An additional variable would be the position of the TSs. For redundancy reasons there are two TSs in the Icelandic network. It is logical to confine their location to two major operation centers in Reykjavik. The hypothesis is then that there exists an optimal number and position of MGWs that minimizes the total cost. The hypothesis can be explained in two steps with the following reasoning.

Step 1 — The local leased line cost is the biggest single cost factor in Engine. This cost is related to the distance (in kilometers of fiber) needed to connect each RSS in the network to the nearest MGW. As the number of MGWs increases, the distance to MGWs decreases, and thus the total local leased line cost. If the position of MGWs for each number of MGWs is optimized, a function of minimum total leased line cost relative to the number of MGWs can be found, according to Fig. 4. These expenses decrease rapidly when there are few MGWs, but as their number increases less is saved.

Step 2 — The rest of the cost factors are either fixed or vary approximately linearly with respect to the number of MGWs. As the number of MGWs increases, these cost factors start increasing more rapidly than is saved in local leased line cost. At that point, the total cost is at a minimum, as seen in Fig. 5.

Mathematical Modeling

The biggest challenge in constructing a mathematical model for the total cost of ownership of a telephone network is to simulate the required bandwidth. Given the number of subscriber lines connected to each AR in the network, its accumulated bandwidth requirements can be estimated based on empirical data and a statistical multiplexing factor. The model must match these bandwidth requirements with appropriately sized LTLs from the AR to the nearest MGW. In the same way, the model must calculate the accumulated bandwidth requirements of each MGW into the connectivity network and match them with TTLs. Finally, to support optimization, the model must be able to reallocate the bandwidth for all possible combinations of number and location of MGWs.

In Iceland, bandwidth tariffs are based on a fixed monthly fee plus a distance fee that is calculated from distance in kilometers of fiber. Constructing a cost function for all LTLs and TTLs can be accomplished using a distance matrix. This matrix represents the shortest distance between any two nodes in the network and can be populated using available operations research solutions of the shortest path problem [6].

The monthly TCO can now be simulated by adding depreciation, interests, housing, and internal services to the already calculated leased line cost. Each of these expense components can be simulated as accurately as needed, but for simplification all cost factors apart from leased line cost were estimated with one fixed and one variable cost component. The variable cost was assumed to vary linearly with respect to the number of MGWs. This is a good approximation as the number of MGWs controls the initial investment, housing, and amount of internal services. The TCO becomes the objective function in the optimization and can be expressed as total leased line cost plus the sum over other cost components.

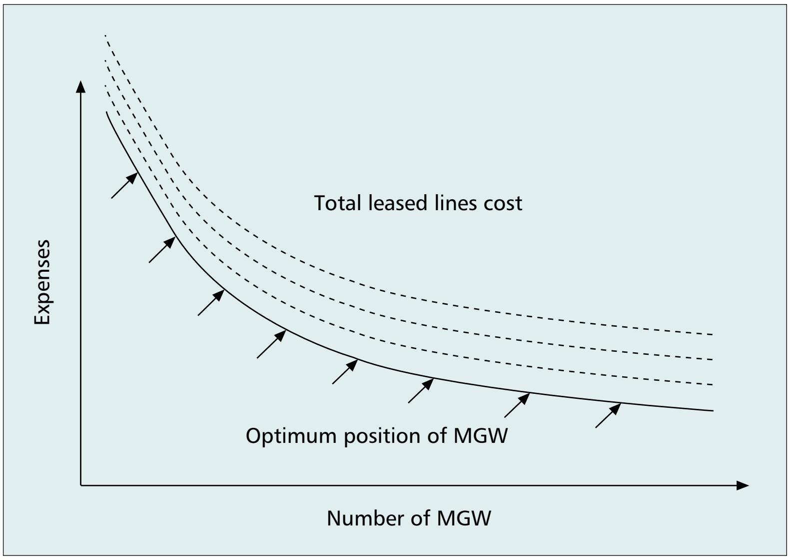

Figure 4. *A hypothetialc graph of the optimized local connection cost.*

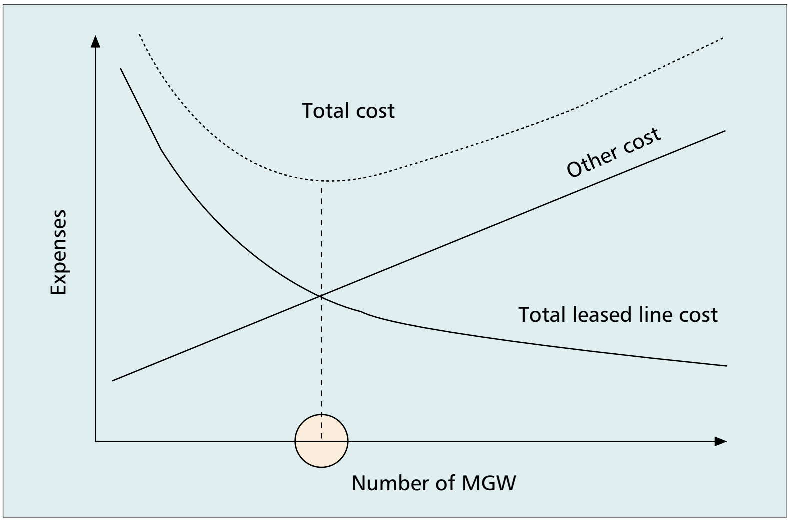

Figure 5. *A hypothetical graph of the optimal number and position of MGWs.*

Implementing the Model

After formulating a mathematical model for the TCO, the next step is to develop a procedure for deriving solutions to the optimization problem. Typically, this is done by programming the mathematical equations and data sets into an optimization program, and then using solvers to solve the problem.

To make the simulation model adaptable for Iceland Telecom's management, the decision was made to implement the model in a spreadsheet program. Spreadsheet programs are not ideal for optimizing models requiring calculations of large matrices like the distance matrix in this model. However, their ubiquitous availability, flexibility, and ease of use gives them strong appeal.

Using an easy-to-use graphical user interface on top of the spreadsheet model, management can now get the estimated total cost of ownership for the future NGN and examine the financial effect of combining structural changes with the migration.

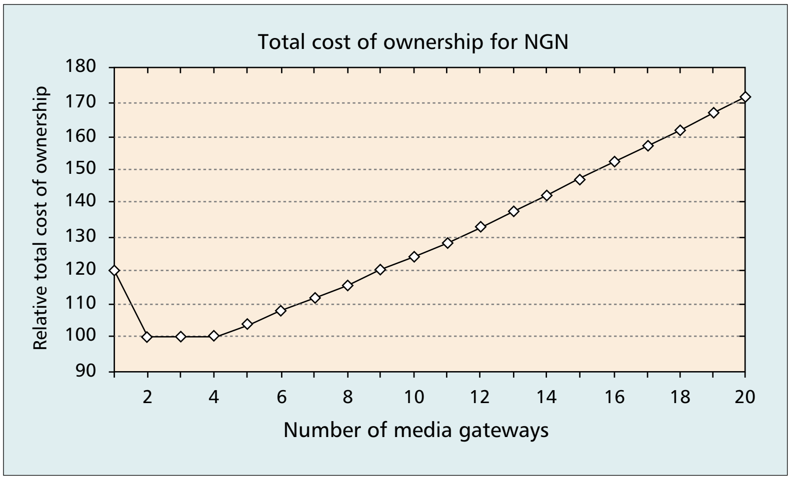

Figure 6. *Results from simulation of total cost of ownership of Iceland Telecom's future PSTN. These results are based on actual data. [7].*

OPTIMIZING THE MODEL

The mathematical model described in this article falls into a general problem description within operations research called the facility location problem. The problem becomes that of solving a facility location problem, where the so-called facilities to establish are MGWs, and the so-called customers to attach are ARs.

Solving large optimization models in spreadsheet programs requires a third party solver add-in. Although some of these solvers can handle advanced optimization methods, calculation time often limits their use to finding local optimums. By combining intuition and heuristics, accurate approximations to the global optimum can be reached.

To verify the spreadsheet solution and ensure a global optimum, the model presented in this study was also implemented in the General Algebraic Modeling System (GAMS). GAMS is a powerful modeling language that can cope with very large programming problems of various types.

CONCLUSION

This article has focused on the economical aspects of migrating Iceland Telecom's circuit-switched PSTN to a packet-based next-generation network. The findings were incorporated in an intuitive model that simulates the total cost of ownership of Iceland Telecom's future PSTN. Feasibility of NGN can now be estimated by comparing the TCO of the current and future networks. The main influential factors on TCO are the number and location of telephone exchanges, or media gateways as they are called in the new network. The problem of finding the optimal structure was modeled mathematically and solved using methods of optimization. The result gives the optimal number and location of MGWs in Iceland and thus the lowest possible TCO.

Running a simulation with actual data indicates that a 19 percent reduction in TCO can be achieved by changing the structure to three MGWs instead of upgrading all 10 LEs in the current circuit-switched configuration (Fig. 6). Comparing the TCO of the optimum NGN configuration to the TCO of the current circuit-switched network indicates that a cost reduction of 25 percent may be achieved by implementing the optimal NGN configuration [7].

Using an easy-to-use graphical user interface built on top of a spreadsheet model, the management of Iceland Telecom can now simulate TCO and estimate the monetary effect of adding, removing, or changing the location of MGWs.

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BIOGRAPHIES

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