Control Plane Framework Emergence and its Deployment Cost Estimation

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***Abstract*—Shortcomings of transport network technologies were the main driver behind strong efforts of standardization organizations to develop control plane frameworks since 2001. Despite the findings of previous studies that the control plane framework deployment will lead to a 50 percent decrease in OPEX and despite the fact that transport providers seek new ways to reduce network management complexity, lower operational cost, and to increase network utilization, transport providers mostly remain reluctant to deploy the control plane frameworks introduced by IETF and ITU-T. All studies about identifying the reasons have only investigated technical factors. These studies did not consider economic factors, although economic factors can have a huge impact on the diffusion of new technologies. In order to close this gap, we designed a cost model to calculate the deployment cost of new technologies in production transport networks. Apart from OPEX and CAPEX, which are considered to be the two main components of any cost model, we also included the depreciation cost of network components that are subject to be replaced during their useful lifespan. The cost model provides support for decision makers on when to switch to a new technology. To demonstrate the workings of the cost model, the cost for moving from a traditional network control system to a GMPLS control plane is calculated. Our findings suggest that the low GMPLS control plane deployment is not only rooted in technical factors but also in a lack of understanding of economic factors. Standard OPEX and CAPEX cost models underestimate the real cost that a network provider faces when migrating to a GMPLS-capable network.**

Keywords-multi-layer network management; control plane framework; telecommunication network cost factors; cost model; transport network; techno-economic analysis, OPEX, CAPEX

I. INTRODUCTION

Transport networks are composed of three planes: control plane, management plane, and data plane [1]. The main function of the data plane is the transmission of users' data. The functions of the management plane comprise operations, such as accounting, security evaluation, and monitoring reports. The control plane carries out centralized management functions, including the exchange of routing information, link state monitoring, and set-up and tear-down of connections.

A rapid technology change combined with an increasing demand for data communication encourages transport providers to move from a centralized and manually operated network to a more flexible and dynamic network, migrating some functionalities of the management plane to the control plane. The need for this dynamic and automatically operated network management system (NMS) becomes the major driver for a strong effort of standardization bodies, research organizations, and vendors to develop new management plane and control plane mechanisms for today's multi-layer, multi-domain network environments.

The major results of these efforts are two standards for the control plane: GMPLS and ASON. They have been introduced by IETF and ITU-T, respectively, and gained the attention of network providers, vendors, and scholars. The influence of the GMPLS control plane on the operational cost (OPEX) of network operator quantitatively has been studied by Pasqualini et al. [2]. Their finding suggests that the operational cost of networks with a GMPLS control plane are 50% less than the operational cost of traditional networks. Verbrugge et al. suggests that the main difference in the OPEX of traditional networks and a GMPLS capable network come from the savings in managing service offerings and service provisioning [3]. Managing service offerings and service provisioning are less expensive for networks with GMPLS because of their automated operations. The control plane impact, especially the ASON framework impact, is discussed in [4], where the authors found a significant impact of the control plane framework on the resilience and the service provisioning process. It is caused by the automated UNI signaling compared to the human intervention in traditional networks.

Although a significant impact of control plane frameworks on the network operation processes exists [3] [4], the findings of Pasqualini et al. and Chahine et al. suggest that the control plane framework deployment may lead to a 50 percent reduction in operational cost [2] [5]. Despite this estimated cost reduction and the fact that network operators are interested in control plane solutions [6], the migration towards a control plane is slower than expected [1].

When developing and analyzing the control plane frameworks, researchers mostly focused on the technical side of the problem [7]. They underestimated the economic factors, although economic factors have a significant impact on the attractiveness of technologies.

The objective of this paper is to investigate the problems faced by network operators, analyze the solutions proposed to address the problem, and to estimate the GMPLS control plane deployment cost. The deployment cost estimation is based on a new cost model for calculating the deployment cost of new technologies in production transport networks.

For investigating the problems faced by network operators, we start with highlighting the shortcomings of network management systems (NMS) and how the frameworks of standardization organizations (i.e., IETF and ITU-T) address these shortcomings. In a second step, we conduct a techno-economic analysis and introduce the cost factors that need to be considered when deploying new technologies in brown field scenarios. Based on these cost factors, a cost model is developed. It allows estimating the economic impact of technology deployment in a production transport network. Finally, we illustrate with our case study analysis of a GMPLS control plane framework that the cost model can be used as a decision support tool by network operators. Our results show that the economic factors have a significant impact on the deployment of the GMPLS control plane.

The remainder of the paper is organized as follows. The next section describes the technical shortcomings of NMSs as well as their economic impact. Section 3 describes the efforts of standardization organizations put in place to overcome the shortcomings. Section 4 introduces the techno-economic evaluation of existing solutions and introduces a cost model. The cost model is used in Section 5 to calculate the GMPLS control plane framework deployment cost. Finally, the Section 6 concludes the paper with a short summary and discussion.

II. Shortcomings of Network Management Systems

A. *Technical Shortcomings of Network Management Systems*

The shortcomings of network management systems (NMS) have their origin in the history of transport networks. Originally, transport networks were designed for voice service, using centralized and manually operated circuit-switched technologies. Its geographically wide deployment was the main reason for its selection as the medium for data communication with packet switched technology.

As the demand for data capacity increased due to the popularity of IP-based applications and the transition from voice-centric to data-centric communication, the legacy SDH/SONET transport networks, which could not adapt quickly due to its static nature and its manual operation, were found not to be ready to deal with the demand. Furthermore, due to the use of multi-standard technology, the differences in communication languages, and the differences in switching technologies, a separation between networks emerged. This separation emerged not only between transport networks but also between the packet layer and the circuit layer. Consequently, a traditional, centralized network management system was found to be cumbersome [8]. Although new optical switching technologies and the introduction of multi-protocol label switching (MPLS) reduced management complications, operational expenses (OPEX), and opened new opportunities for quality-demanding applications (e.g., VoIP, Video conferencing, and IPTV) at the IP layer [9], network management is still restricted to a layer and a domain.

Because of these reasons, the current multi-layer Internet still suffers from manual and error-prone link service provisioning, long provisioning times, low resource utilization, complex network management, low reliability, and scalability problems [8] [10]. To address these problems, automatic interaction and coordination between circuit and packet switching technologies are needed.

B. *Economic Impact of the Technical NMS Shortcomings*

Although the shift from voice-centric to data-centric communication and the increasing demand for IP-based applications engender new business opportunities for equipment suppliers, software developers, and network operators [11], network operators are forced to transport an increasing amount of data at decreasing price.

Additionally, as the networks grew larger, centralized network management became more complex and expensive. The creation of isolated islands of IP/MPLS networks and transport networks made them manageable but increased the network management cost even further. The cost is incurred through the duplication of network management functions, the increase in the number of human resources needed, the manual intervention required, and the very low coordination between the IP network NMS and the transport NMS.

In order to counteract these developments, ensure an adequate return on investments, and to master this worldwide highly capital-intensive business, transport providers seek new ways to manage their networks [12]. Network complexity and large number of manual interventions have always been considered to be the main factors of network management operational costs [8]. According to Chahine et al., automatic service provisioning leads to an average cost saving of as much as 51% for service provisioning [5]. Similar findings have been reported in [2] [3] [4].

Another factor, contributing to the high operational cost of networks, is the static nature of transport networks and multi-vender technologies. It causes not only low interoperability and an increase in the complexity of the network but also becomes an obstacle for network management systems. It forces network operators to spend money for additional network management systems and their integration, increasing the overall operational cost for the network.

III. Efforts to Overcome the Shortcomings

To overcome the inflexibility of SDH/SONET network management systems, to allow automatic interaction and communication between the layers and between network domains, and to meet the capacity demand of future applications, a significant amount of research has been conducted by standardization organizations, research organizations, industry, and individual scholars. In particular, the multi-layer network management issues have mostly been studied within the framework of different projects or within study groups of standardization organizations. As a main result, two standard frameworks for network management and network control were introduced. We briefly review the solutions proposed and concentrate our focus on the two main standardized control plan frameworks of IETF and the ITU-T.

A. *Efforts of Research Organisations*

The Dynamic Resource Allocation via GMPLS Optical Network (DRAGON) project has been funded by the United States National Science Foundation [13]. This project aimed at developing infrastructures, concepts, and software to provide dedicated paths across heterogeneous network technologies of different domains. It established new algorithms for inter-domain advertising, service provisioning, authentication, routing, and accounting. GMPLS has been the basis for the DRAGON project.

The G-Lambda project aimed to create a standard interface between the computing Grid and network resources such that information processing services over GMPLS-based networks became possible [14]. In the course of the G-Lambda project, advanced reservation of paths, inquiries about reservation status, and the cancelation of reservations were implemented.

The Bandwidth Reservation for User Work (BRUW) Internet 2 project aimed at managing rights of authorized users for bandwidth reservation across packet switched backbone networks [15]. The objective of the project was to minimize human intervention in the service provisioning process and in the bandwidth reservation process, to improve reliability across the network, and to simplify the reservation process.

IPsphere is an inter-domain automation framework for linking service ordering, service purchase, service provisioning, and fulfillment [16]. IPsphere aims at creating service controls network operators, content providers, and system integrators. This framework can be considered a new business layer for IP networks.

MUPBED (Multi–Partner European Test Beds for Research Networks) is a project funded by the European Community under FP 6 IST [17]. The main goal of the project has been to integrate and validate the ASON/GMPLS control plane within European research infrastructures.

The Next Generation Optical Networks for Broadband European Leadership (NOBEL) has been funded by the European Commission as part of FP 6 [18]. The goal of the project has been to define an intelligent and flexible optical transport network. The project defined a network architecture based on the ASON/GMPLS technology, specified technical requirements, and studied survivability mechanisms.

NOBEL2 has been the continuation of the NOBEL project [19]. The main goals of the NOBEL project’s second phase was to carry out analysis, feasibility studies, and experimentally validate new network solutions for a flexible, scalable and reliable optical network. While the project gave insight into the evolution of networks, the ASON/GMPLS control plane tests remained limited to a single domain. The project document mentioned that many issues may rise, when considering the tests for a multi-domain scenario.

To provide a solution for the shortcomings of today’s transport networks (i.e., the high operational cost, limited scalability, and no guarantees for end-to-end quality of service, the European Commission recently funded the project STRONGEST [20]. The aim of the project is to design and demonstrate an evolutionary ultra-high capacity multi-layer transport network capable of handling Gbit/s access rate in a multi-domain, multi-technology control plane environment.

An control plane architecture, called ODIN, has been developed as part of the Optical Metro Network Initiative [21]. It allows applications, which need to quickly adjust to changing conditions, to directly address and control core network resources (e.g., lightpaths). For this, ODIN provides highly adaptive, dynamic, and deterministic resource provisioning.

On-demand Secure Circuits and Advance Reservation System (OSCARS) is a project that focused on the automation of bandwidth provisioning [22]. It was a single domain software solution developed on the basis of Internet2 project.

Dynamic Resource Allocation Controller (DRAC) is a tool developed by Nortel in collaboration with SURFnet [23]. The DARC tool aims at providing the functionality required to flexibly schedule light paths over the layer one and layer 2 topologies.

B. *Efforts of Standardization Organisations*

The demand of users and small vendors for technology that conforms to a standard is well known and understandable, as standards lower the risk of customers to be locked-in, reduce the risk of making false investments, and increase the interoperability. In particular, this is also true for network management systems. Consequently, some large effort has been made by standardization organizations. The results of those efforts are two main standards, namely the IETF Generalized Multi-Protocol Label Switching (GMPLS) framework and the ITU-T Automatically Switched Optical Network (ASON) framework.

1) IETF’s GMPLS: The Generalized Multi-Protocol Label Switching (GMPLS) framework is an Internet Engineering Task Force (IETF) standard [24]. GMPLS has its root in the well-known MPLS framework [25]. MPLS brought four main advantages. The first advantage is the opportunity of provisioning VPNs, which allow connecting many locations with bandwidths much higher than frame relay could provide. Second, it allows network operators to reduce the operational cost and to improve network security. Third, MPLS ensures quality of service (i.e., bandwidth, latency, jitter, and packet loss). Finally, MPLS provides class of services.

Unlike MPLS, GMPLS is also capable of interoperating with different switching technologies such as packet switching, label switching, time division multiplexing, lambda switching, and fiber switching. GMPLS was designed to address the shortcomings of multi-layer, multi-domain environments. Its goal has been to configure any kind of network element automatically through a centralized network management.

The extensions to well-known protocols (e.g., RSVP-TE, OSPF-TE) and the introduction of link management protocols (LMP) make GMPLS capable of end-to-end protection, end-to-end control, automatic provisioning, and multi-layer traffic engineering [26] [27] [28]. Therefore, theoretically, the GMPLS framework is capable of addressing the shortcomings of manual provisioning, low network utilization, and fault management problems.

2) ITU-T’s ASON: The Automatically Switched Optical Network (ASON) is an ITU-T standard, which attempts to overcome the challenges of interoperability and network management complexity. It introduces standardized interfaces between layers and between domains, allowing automatic and standardized interaction between layers and between domains.

However, the internal operation of each domain and domain is protocol independent and can be implemented as needed by the provider [29].

The functional architecture of ASON includes three planes, namely the control plane, the transport plane, and the management plane. One of the most important features of the ASON framework is the establishment of three distinct types of connections, which are called permanent connection, switched connection, and soft permanent connection.

Apart from routing, signaling, protection, and restoration, which are regular enabling mechanisms, ASON introduces discovery mechanisms and call/connection control mechanisms, adding more intelligence to the network. For example, neighbor discovery, resource discovery and service discovery of ASON allow network-aware traffic engineering and resource allocation. Call and connection control separation provides increased network stability against faults of network components.

Worth mentioning here is that, although the ASON framework introduces a complete architecture for an automatically switched optical network, its implementation is delayed because of the ambiguity of the specification of its communication protocols.

3) ASON/GMPLS: Although there are several common goals between GMPLS and ASON (e.g., both frameworks address interoperability, system automation, and dynamicity), the approaches of both standardization bodies are different. While ASON focused on the interfaces and the requirements, GMPLS provided concrete specifications of protocols.

In order to be able to combine the advantages of both frameworks, interoperability between the two frameworks became necessary. For this purpose, the Optical Internetworking Forum (OIF) specified different network management interfaces. Specifically, OIF made the ASON and the GMPLS frameworks interoperable by specifying the ASON interfaces, namely UNI, as an interface between the IP and the transport layer, E-NNI, as an interface between domains, and I-NNI, as an interface for internal communication between the sub-domains of the same administration [30]. For this, they used GMPLS protocols. This and the agreement between IETF and ITU helped to overcome the uncertainty over ASON communication protocols, bridge the disadvantages of both approaches, and create a unified framework.

By combining the ASON architecture with the GMPLS protocols, the standardization bodies IETF and ITU (and with the help of OIF, Global GRID Forum (GGF), and Tele Management Forum) addressed some of the technical shortcomings as well. For instance, the ASON framework proposes call and connection separation, which ensures the continuation of active connections, when a fault occurs on the call control part of a network. The GMPLS framework does not have such call and connection separation.

IV. TECHNO-ECONOMIC EVALUATION OF CONTROL PLANE FRAMEWORKS

The network operators' requirements for using the ASON/GMPLS framework have been assessed by the SCORPION project [31]. The assessment focused on the technical requirements such as visibility, network management, reliability, addressing, traffic management, and quality of service. However, apart from these technical requirements, economic factors such as current and future application demand, application requirements, deployment challenges, cost efficiency, and return on investments are also important to consider when making the decision about implementing such a framework.

The GMPLS and the ASON efficiencies compared to the traditional systems have also extensively been studied [2] [3] [4] [5]. The authors discuss the efficiencies of control plane frameworks in terms of service provisioning time and cost, resilience, restoration, and capacity savings. The challenges faced by operators when deploying the control plane frameworks have also been highlighted by many scholars [32] [33] [34]. The main challenges discussed are the complexity of the approaches, the requirements for highly flexible policies, the GMPLS inefficiency to cope with unexpected incidences, and the difficulty of managing the new GMPLS-based services.

In the context of this paper, we focus on providing a clear picture of the deployment costs of new network technology. In particular, we model the migration from a traditional network control system to a new one. This cost model can support network operators in their decision making processes.

Costs factors in the telecommunication industry have been studied by many scholars using different methodologies [2] [3] [4] [37]. As part of this investigation of the deployment cost, the capital expenditure (CAPEX) and operational expenditure (OPEX) have been defined. In our cost model, besides defining CAPEX and OPEX slightly different, we also consider the depreciation expenditure (DEPEX).

A. *CAPEX Factors*

CAPEX for telecom operators includes the cost of infrastructures that is directly related to building the network (e.g., network management systems) and the cost for facilities that are indirectly related to the infrastructure (e.g., residence places for staff). Therefore, CAPEX is subject to depreciation.

CAPEX in the telecommunication industry consists of three types of cost components. The first type comprises the total cost for information and communication equipment (e.g., switches, routers, cables, and installation cost). The second cost component type includes the total cost for real estate that is directly or indirectly involved in the production (e.g., office buildings). The last cost component type represents the total cost for the telecommunication industry business licenses. Equation (1) shows the three types of CAPEX components.

$$CAPEX = \sum_{i=1}^{k_E} \left(C_{E_i} * N_{E_i}\right) + \sum_{i=1}^{k_P} \left(C_{P_j} * N_{P_i}\right) + \sum_{i=1}^{k_L} \left(C_{L_m} * N_{L_i}\right) \quad (1)$$

In (1), C_{Ei}, C_{Pj}, and C_{Ll} represent the cost of equipment type i, real estate type j, and license type m, respectively. N_{Ei}, N_{Pj}, and N_{Lm} denote the number of equipment types i, the number of real estate types j, and the number of license types m, respectively. In total, there are k_E, k_P, and k_L types of equipment, real estate, and licenses, respectively.

B. OPEX Factors

OPEX includes continuously occurring costs that are related to cost of maintenance and cost of keeping a production network going. Unlike the classification of [4], where the authors distinguish between telco-specific OPEX (e.g., operational network planning, pricing, billing, service provisioning, and marketing), non-telco-specific OPEX (i.e., general operational cost), and the up-front planning and first time installation costs to be specific class of OPEX, we follow a different approach.

In our model, we consider the first time installation cost to be part of CAPEX, as the equipment cost includes the first time installation cost in today's practices [37]. Note, upgrading network devices as part of a regular maintenance, however, is considered to be part of operational expenditure. We also assume that the up-front planning activity cost is part of the normal operational planning activity cost. Furthermore, the network administration cost is a cost factor in our OPEX model. The cost for leased infrastructure is part of operational infrastructure cost. Finally, we distinguish between general human capital cost and the cost of human capital to perform repairing and maintenance activities.

Based on the previous model assumptions, we define nine major factors of operational expenses, which are currently experienced by information and communication businesses. Those are the continuous cost of infrastructure, maintenance, repairing, service provisioning, planning, marketing, pricing & billing, human resources, and administration. Those nine factors define OPEX, as shown in the following equation.

$$OPEX = \sum_{i=1}^{k_I} C_{I_i} + \sum_{i=1}^{k_{Ma}} C_{Ma_i} + \sum_{i=1}^{k_R} (C_{R_i} * N_{R_i}) + \sum_{i=1}^{k_{SPM}} (C_{SPM_i} * N_{SPM_i}) + + \sum_{i=1}^{k_{Pl}} C_{Pl_i} + \sum_{i=1}^{k_{Mr}} C_{Mr_i} + \sum_{i=1}^{k_{BP}} C_{BP_i} + \sum_{i=1}^{k_H} C_{H_i} + \sum_{i=1}^{k_A} C_{A_i} \quad (2)$$

In (2), C_{Ii} represents the continuous expenses related to the infrastructure (e.g., electricity cost and cooling cost). C_{Mai} denotes the maintenance cost (e.g., upgrading software), C_{Ri} the reparation cost, and C_{SPMi} the service provisioning management cost. C_{Pli} specifies the planning activity cost, C_{Mri} the marketing cost for different services, C_{BPi} the billing and pricing cost, and C_{Ai} the administration cost. Finally, C_{Hi} represents the cost of human resources (e.g., wages and training). N_{Ri} and N_{SPMi} denote the frequency of the actions performed. k_I, k_{Ma}, k_R, k_{SPM}, k_{Pl}, k_{Mr}, k_{BP}, k_H, and k_A indicate the number of different items for each type of OPEX factor.

C. DEPEX Factor

For modeling the migration from old technology network to new technology network, we need to consider that not all network equipment is capable to be upgraded (i.e., can support new technology protocols). Therefore, some portion of network hardware and software must be replaced [36], although they did not reach their useful lifespan (i.e., the depreciation time period has not been reached its end). This cost is called depreciation expenditure (DEPEX) and is defined through the following equation:

$$DEPEX = \sum_{i=1}^{k_d} C_{d_i} \quad (3)$$

Where C_{di} denotes the remaining depreciation costs of hardware and software i, which needs to be replaced. This cost occurs as this equipment cannot be used until the end of its expected lifespan. The variable k_d represents the number of equipment that need to be replaced.

D. Deployment Cost of New Network Technology

Based on the previous definitions, the overall deployment expenditure DEX can now be defined as the sum of CAPEX, OPEX, and DEPEX, as shown in (4).

$$DEX = CAPEX + OPEX + DEPEX \quad (4)$$

The deployment expenditure DEX can also be used to model the cost DEX_{TToG} for migrating from a traditional network to a GMPLS-capable network.

For modeling the migration of a traditional network control system to a GMPLS-capable network control system, we make the following assumptions: First, network operators, who are willing to deploy new network technology, need to upgrade some items of network equipment such that these items are capable of executing the new GMPLS functions. Second, two kinds of OPEX factors need to be considered, when upgrading network devices. Those are personal training cost (i.e., training people to work with the new technology) and planning activity cost. Third, not all network equipment is capable to be upgraded. Therefore, some portion of network hardware and software must be replaced, although they did not complete their useful lifespan.

Considering these assumptions, DEX_{TToG} can be calculated by just using four terms, as shown in equation (5). In this equation, all other cost factors, which have a value of zero, have been removed.

$$DEX_{TToG} = \sum_{i=1}^{k_E} (C_{E_i} * N_{E_i}) + \sum_{i=1}^{k_{Ma}} C_{Ma_i} + \sum_{i=1}^{k_H} C_{H_i} + \sum_{i=1}^{k_d} C_{d_i} \quad (5)$$

Equation (5) considers equipment cost C_{Ei}, covering the cost of hardware and software that needs to be replaced. The cost of upgrading the network hardware and software can be considered an irregular maintenance cycle and, therefore, is considered maintenance cost C_{Ma}. The human resource cost C_{Hi} covers the cost of training network engineers so that they can operate the new technology. The cost of technology selection and bidding process is part of the human resource cost as well. C_{di} covers the depreciation costs of hardware and software that needs to be replaced although is not yet fully depreciated.

V. CASE STUDY: MIGRATION TO A GMPLS CONTROL PLANE

To demonstrate the workings of the cost model that has been introduced in the previous section, we use the cost model as the basis for decision making support of network provider.

A. *Case Study Description and Data Selection*

To illustrate the cost model for deploying a GMPLS control plane, we analyze a case study, in which a network provider with wavelength division multiplexing technology (WDM) investigates the cost of upgrading the network to a GMPLS-capable one. Each link of the WDM network can carry 2.5 Gbit/sec, which are leased from a DWDM transport layer provider. The WDM nodes are co-located at the transport layer provider's premises.

In our case study, the network service provider can upgrade the majority of their network equipment. The remaining network equipment, however, needs to be replaced. Considering the sophistication of network planning, it is reasonable to expect that a regular replacement of equipment in the network leads to acquiring new equipment with improved level of capabilities. Based on this, we assume that 80% of the network equipment has sufficient capabilities to be upgraded.

The remaining portion 20% of the network hardware needs to be replaced due to its lack of being upgradable to a GMPLS-capable one or because of less useful life time left. For our calculation we assume that half of the replaceable network equipment is not capable to be upgraded and the second half needs to be replaced because of less useful time left. To better describe the impact of replaceable hardware in the migration cost, we consider the percentage replaceable hardware 20%, 30%, 40%, and 50% for the network with 10, 20, 30, and 40 nodes.

The actual number of servers of a GMPLS framework deployment, which need to be replaced in WDM networks with 10, 20, 30 and 40 nodes, is specified in Table 1 (case a).

TABLE 1. PERCENTAGE OF REPLACABLE HARDWARE AND THE TOTAL NUMBER OF EQUIPMENT REPLACED

Number of nodes in the network	Number of hardware that is not upgradeable and needs to be replaced								Total number of hardware replaced if 20%, 30%, 40%, and 50% need to be replaced, respectively
	Not capable to be upgraded				Not eligible to be upgraded				
	(a) 10 %	(b) 15 %	(c) 20 %	(d) 25 %	(a) 10 %	(b) 15 %	(c) 20 %	(d) 25 %	
10 nodes	1	1	2	3	1	2	2	2	2,3,4,5
20 nodes	2	3	4	5	2	3	4	5	4,6,8,10
30 nodes	3	4	6	7	3	5	6	8	6,9,12,15
40 nodes	4	6	8	10	4	6	8	10	8,12,16,20

Following the description for the case of 20% of replaced hardware (i.e., case (a) of Table 1), we set the actual numbers of hardware to be replaced for three more cases. These cases assume that 30%, 40%, and 50% of the hardware has to be replaced. For those cases, Table 1 also shows the actual number of hardware to be replaced for networks with 10, 20, 30, and 40 nodes.

Since the network equipment cost is negotiable and no vendor data is available openly, we use data found in literature for our calculations [3]. Additionally, we assume that the cost of GMPLS control plan software will be equivalent to an un-equipped OXC [3]. The values used are depicted in Table 2.

TABLE 2. EQUIPMENT AND SOFTWARE PRICES FOR WDM NETWORKS BASED ON FINDINGS OF VERBRUGGE ET AL. [3]

Equipment type	Footprint (ETSI)	Price K €
WDM line system (40 Lambda)	3 Racks	12.00
Optical Amplifier	0.25 Rack	7.90
SR Transponder (2.5 Gbps)	Inserted in OXC	2.00
LR transponder (2.5 Gbps)	Inserted in OXC	2.50
Unequipped OXC (512 prot)	3 tacks	100.00
GMPLS software	One license	100.00

Furthermore, based on the fact that hardware and software vendors provide discounted rates when selling large quantities of hardware and software licenses, we assume that the discount varies between 0%, 5%, 7%, and 10% of the total equipment price, depending on the number of ordered network components (i.e., 1-4 nodes, 5-6 nodes, 7-10 nodes, >10 nodes, respectively). Similarly, the per-person training cost also depends on the number of trainees. To capture this effect, we assume that the discount for training varies between 0%, 10%, and 20% depending on the number of trainees (i.e., < 15 people (20 node network), 16-29 people (30 node network), > 30 people (40 node network), respectively). As also assumed by [3], we consider the maximum per-person training cost to be as high as 0.5% of the hardware cost. The depreciation cost of equipment is calculated based on the useful lifespan of telecommunication equipment, which is 7 years according to the Internal Revenue Manual (IRM) [38].

B. *Case Study Result*

Using the case study settings, the cost model can be applied for networks with 10, 20, 30, and 40 nodes. Figure 1 shows the cost estimates. The horizontal axis in Figure 1 shows the percentage of hardware that needs to be replaced within the networks, while the vertical axis shows the GMPLS deployment costs for these networks.

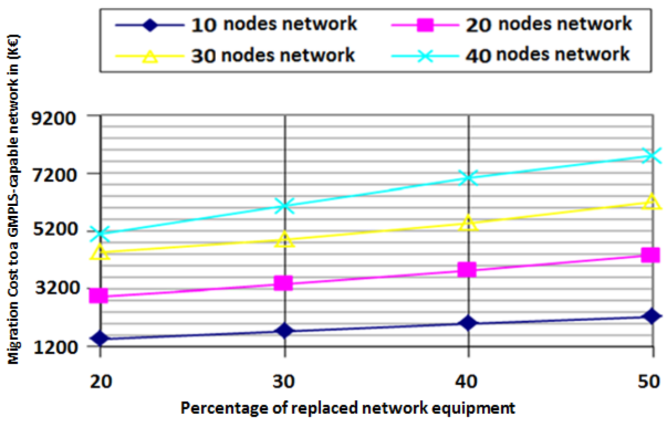

Figure 1. Cost estimation for migrating to a GMPLS-capable network with 10, 20, 30, or 40 nodes and 20%, 30%, 40%, or 50% network equipment to be replaced

The results of our cost model calculation (Figure 1) suggest that the deployment cost of the GMPLS control plane depends on the number of network equipment that needs to be replaced. Specifically, the GMPLS control plane deployment cost increases as the number of nodes to be replaced increases.

Figure 2 suggest that the GMPLS deployment cost per node decreases, if more nodes needs to be replaced in a network. For example, the cost per node for a network with 40 nodes and 20% replaced hardware is 19K € less than the cost per node for a network with 10 nodes and 20% replaced hardware. It is caused by the discount for hardware, software, and training.

Furthermore, the per-node costs for the network with 10 nodes and for the network with 20 nodes are the same (Figure 2). This is due to the 0% discount for hardware, software, and the training for the network with 20 nodes or less and the little increase in the number of replaced hardware.

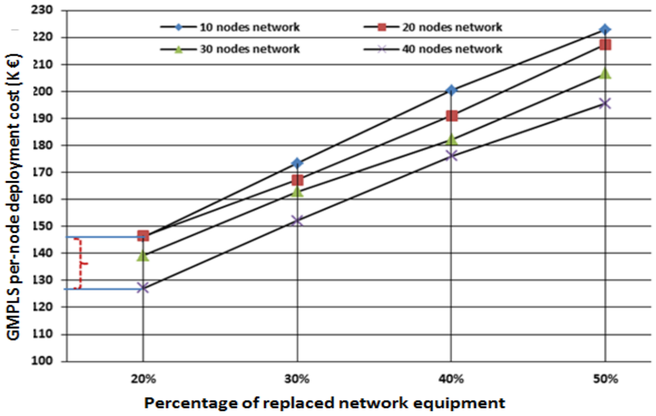

Figure 2. GMPLS per-node deployment cost for different networks and different number of replaced network equipment

To show the impact of the depreciation cost on the deployment cost, we compare the results shown in Figure 1 with the cost of migrating to a GMPLS-capable network without considering the depreciation cost. Figure 3 shows both costs for the four different networks (i.e., 10, 20, 30, and 40 node network) and with different number of replaced network equipment. The four curves on the right hand side of Figure 3 show the cost for migrating to the GMPLS-capable network without considering the depreciation cost, while the left hand side curves show the costs, which include the depreciation cost.

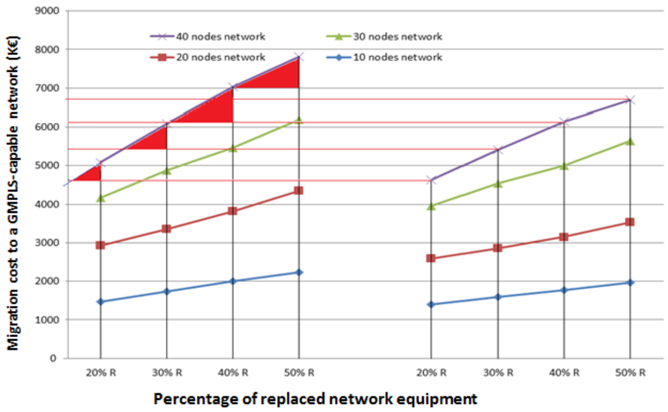

Figure 3. Migration cost to a GMPLS-capable network with and without considering the depreciaiton cost of replaced network equipment.

As Figure 3 also shows, the deployment cost difference between the network with 40 nodes, 20% of replaced hardware, and no depreciation cost considered (the right hand side) and the same network with depreciation cost considered is about 448000 Euros. In detail, the original cost estimation underestimates the GMPLS deployment cost by 7.4% on average in the case of networks with 20% replaced network equipment, 8.6% for networks with 30% replaced network equipment, 11.95 % for networks with 40% replaced network equipment, and 12.8% for networks, which needed to replace half of its network equipment.

C. Discussion

The novelty of our approaches comes from considering the depreciation cost of hardware that needs to be replaced though it did not reach the end of its depreciation period. Most of recent studies consider only OPEX and CAPEX when comparing a GMPLS-capable network with a traditional network. Considering the depreciation cost, however, allows the cost estimation of a GMPLS control plane migration to be more realistic. This can be seen when comparing the sum of OPEX and CAPEX with the deployment cost (DEX), which considers the depreciation cost (DEPEX), OPEX, and CAPEX (Figure 3).

In general, the analysis of the reasons for a low GMPLS deployment led us to the development of more realistic cost model. Our findings suggest that the low GMPLS control plane deployment is not only rooted in technical factors but also in a economic factors. The cost model lists in detail the deployment costs that occur when the network is migrated from a traditional network to a GMPLS-capable network. Therefore, it can help network operators to define strategies for a cost efficient migration. Thus, it lowers the uncertainty of a GMPLS deployment for network operators.

VI. Conclusion

The shortcomings of legacy transport networks in addressing the demand for dynamic provisioning of high-capacity data communication services was the reason behind a decade-long, strong effort of standardization organization (IETF and ITU-T) in developing control plane frameworks. The results are two main standard control planes, namely GMPLS and ASON. However, both frameworks suffer from a low deployment.

To counteract this situation, we developed a detailed cost model, which can help network operators understanding the migration cost from an old technology to a new technology in detail. In particular, we applied the cost model for calculating the cost of migrating from a traditional network to a GMPLS-capable network. The cost model shows significantly different results as it considers depreciation cost that were not considered in other studies.

In detail, our results suggest that a standard OPEX and CAPEX cost model underestimates the real cost that a network provider faces when migrating from a traditional network to a GMPLS-capable network. By considering the depreciation cost in addition to the CAPEX and OPEX cost, hidden cost to the network provider become visible. Therefore, our results might help network operators to find new migration strategies to GMPLS-capable networks.

ACKNOWLEDGMENT

This research was performed within the ONE project. It was supported by the European Commission (contract no. 258300) and the International Research & Development Program of the National Research Foundation of Korea of the Ministry of Education, Science and Technology of Korea (Grant number: K21001001625-10B1300-03310).

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