Economic Analysis for Transport Network Evolution

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***Abstract*—This article presents an economic study of an alternative for evolving the transport network, illustrated by the network comparative analysis that involves CapEx and OpEx calculation. In this case, a friendly migration solution has been designed in order to take advantage of the existing backbone infrastructure minimizing the yearly CAPEX. Thus, the evaluation of a scalable solution to deploy a photonic mesh capable of absorbing great increases of traffic without impacting in the current network structure has been carried out and compared to the natural evolution of the IP backbone. Some assumptions were considered in this use case which is focused on the transport network for an incumbent operator. The results show important savings in the required investment for IP network when an increment in traffic demand takes place, which justifies the investment in the new transmission infrastructure from an economic point of view.**

***Index Terms*— Transport network, MPLS-TP, Optical, Economic analysis, Photonic Mesh.**

I. INTRODUCTION

THE increasing number of applications and growing bandwidth requirement represent a key issue for many telecommunication operators at the time of re-planning their current networks, fitting to dynamic behavior of traffic demands. The IP traffic volume and network convergence oriented to packet solutions force traditional infrastructure network to be more scalable and also to rethink the transport layer architecture and consider new approaches. In [1] an efficient technical solution for IP telephony transport has been proposed. Moreover, apart from defining a new desirable architecture, a feasible migration path should be defined for backbone networks towards next-generation network architectures taking advantage of existing infrastructure and assuming that investment capabilities of the companies are limited.

MPLS-TP arises as the current solution driven by the carriers who are in need to evolve SDH networks to support packet based services and networks, and the desire to take advantage of the flexibility and cost benefits of packet switching technology [2]. Moreover, MPLS-TP supports a comprehensive set of OAM and protection-switching capabilities for packet transport applications, with equivalent predictability and survivability to existing SDH OAM [3].

Operators are especially interested in seeking non-disruptive alternatives solutions that soften investment in the network core. Several discussions about IP centric transport has been extensively discussed in [4] and [5]. Between different architectures available for the core it is evaluated the possibility to switch the traffic in transport domain through a packet (MPLS-TP) and circuit (NG-SDH, OTN, WDM) technologies combination that allows switching the transit traffic in network core routers. In [6] it considers some key aspects as IP offloading is significantly cheaper than routing on the IP layer. This solution not only reduces the required size and number of IP routers, it also improves scalability and stability. New advanced functionalities such as restoration mechanisms or efficient bandwidth provisioning can be offered as well.

The recent trend is evolving towards lower CAPEX and OPEX next-generation network with synergies between different services that can be better exploited through economies of scope (see [7]). A techno-economic evaluation of the technology or solution combination that will be implemented has a vital importance in the decision taken.

The paper will provide an analysis more oriented to economic aspects from the point of view of an incumbent operator, searching alternatives to savings in the equipment investment CapEx (Capital Expenditures) and also some aspects of OpEx (Operational Expenditures), such as power consumption and footprint. On the one hand the operator must be able to continue investing in IP layer to absorb the traffic growth using large-scale IP backbone networks in a stable and cost-efficient way. On the other hand, it can assume an initial investment in a photonic network that allows the operator to absorb the traffic growth and reuse existing infrastructure while minimizing new investment in IP network and avoiding significant impact on its design and planning. It will be shown that this solution is significantly cheaper than packet forwarding on the IP layer and that includes a potential for reduction of network costs. Power consumption and footprint are the only OpEx concepts considered in this work. The detailed modelling of operational costs merits further study.

The analysis has been performed from an economic point of view, including financial assessment of the overall technology deployment based on measures such as net present value (NPV) and internal rate of return (IRR).

II. Assumptions on Transport Technologies

The study evaluates the investments for an incumbent operator in the case of improving its network to cope with yearly IP traffic growth and compares them to those which result from deploying a photonic mesh to route the major traffic flows between two points of that network.

The reference scenario is an IP over DWDM network for the demand of the first year under study which is assumed to be already deployed at that starting point. The initial network considered for the study consists of a hundred nodes where IP routers are present. It is a hypothetical core network which is supposed to cope with the traffic generated all over a large western European country. Incremental CAPEX is calculated taking into account that this starting point is sunk cost for the operator and trying to take the best advantage from the investment already done by the operator.

The technology employed in the IP layer has been "Gigabit Ethernet" in every scenario simulated, using cards with ports of 1GbE or 10GbE capacity. Higher capacity links have not been considered since, for the reference prices available, they were found to be less effective in cost (40G port is more expensive than four 10G ports). Thus, WDM technologies by 10Gb ports rather than higher capacities (40Gb or 100Gb) are used to improve the maximum capacity per optical fibre (OF) link.

Scenarios which are compared in the study are the following:

A. IP over DWDM

The edge routers of the core network (those that manage a great part of the global traffic) are equipped with both 1GbE and 10GbE ports. Approximately half of these 10GbE ports are "coloured" and use DWDM links, while the other half and the 1GbE ports are supposed to be "grey".

The rest of the routers in the network use "grey" optics, whether they are 10GbE or 1GbE capacity.

B. IP over Photonic Mesh

The photonic network consists of reconfigurable optical add drop multiplexers (ROADM) that permit the active selection of wavelengths within a WDM signal, letting some of these wavelengths progress in the mesh while some others are extracted to upper-levels.

Outgoing traffic flows that exceed a threshold capacity are off-loaded to the photonic network from the border routers to interconnection.

All 10GbE ports are "coloured" (since they have to be connected to ROADMs and operate at a particular wavelength). It is important to bear in mind that a "mono-brand solution" (all the equipment deployed belongs to a unique vendor, both in the IP and the physical layer) has been considered, resulting in some saving for the equipment is optimally configured and there is no need of transponders for the ROADMs. These transponders are replaced by the optics equipped in the IP layer. All 1GbE ports in the layer IP are "grey" and do not use any WDM technology.

The study compares the incremental investment, annual costs and power consumption of both solutions (IP over DWDM, IP over Photonic Mesh) when the traffic demand increases as time goes by. From this point of view, there could be two different approaches:

- Greenfield approach, where the results from each scenario do not have any influence in the subsequent scenarios.
- Incumbent approach, incremental approach where the equipment deployed one year is not discarded for the next year. On the contrary, this approach takes into account the equipment deployed in the previous scenario and it could be used for the next year. This approach could lead into some inefficiency since there may be equipment not used but quantified in the economic evaluation.

The information about the number of ports needed in each node of the network has been reached after some dimensioning methods. In both cases, the IP traffic has been routed through the IP backbone using a shortest-path algorithm. In IP over Photonic Mesh scenario, the outgoing traffic flows that exceed 5Gbps threshold are off-loaded to the photonic mesh from the border routers to interconnection nodes. The "light-paths" that carry these flows are optimally routed over the mesh, following algorithms that prevent links from surpassing 40 lambdas or 80 lambdas. Those traffic flows that do not reach 5Gbps are still routed over the IP network with a shortest-path algorithm. This 5Gbps threshold was fixed in a previous study where it minimised the number of ports in the network.

However, it is important to note that the model does not evaluate the investment in fibre roll-out, which could be a disadvantage for the IP over DWDM solutions since they are supposed to be more expensive in terms of fibre deployment.

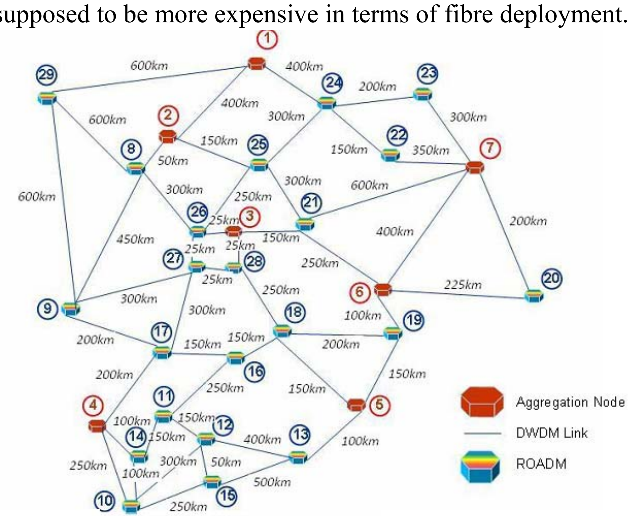

Fig. 1. Photonic Mesh Topology.

III. THE CASE STUDY

We have modelled the capital expenditure for the network topology depicted in Fig. 1 using traffic demand projections for the years 2008-2013, as well as list prices of router and transport equipment. We have considered a hypothetical reference network, representing a national transport network [8]. Taking into account geographic and population factors, aggregation and transit nodes have been placed. So the mesh consists of 29 nodes with a minimum physical connection degree of 2.

The total traffic volume (bi-directional demands) for the reference year is supposed to be 400GB. In this paper we are assuming the given traffic demands without considering different types of traffic. The different classes of services modelling merits further work.

Based on the topology and traffic assumptions, an optimized IP network dimensioning has been performed for those scenarios defined in Section II. 40λ and 80λ photonic meshes have been dimensioned for the topology given in Fig. 1 and capital expenditure in order to deploy this network has been calculated.

The study is focused on the incumbent approach, since it reproduces a situation where several operators across the world could be identified with, and can give an idea of which are the best steps to follow in the near future to achieve a more efficient and scalable network, taking advantage and reusing when possible the existing infrastructure.

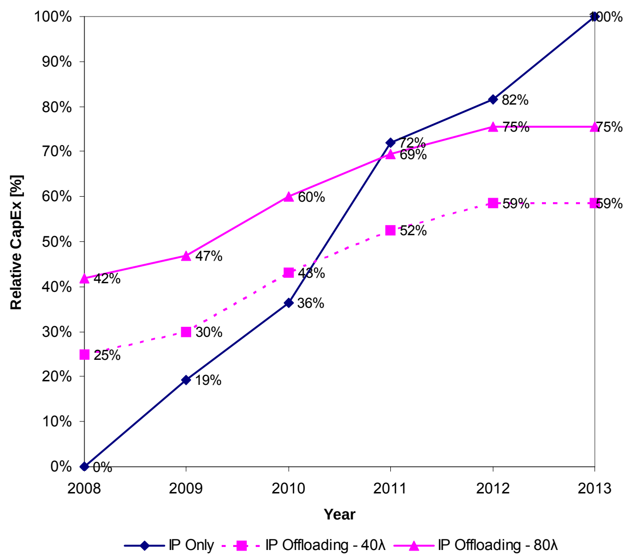

Fig. 2. Relative cumulative CapEx for the period under study.

The aim of this study is choose the best investment option between both possibilities in terms of transport technology and see which is the upgrade required to manage the traffic for next 5 years. The technical assessment is followed by an economic evaluation based on the use of CAPEX indexes.

IV. ECONOMIC ANALYSIS

Taking into account the former assumptions, yearly CAPEX that an operator must face in order to evolve its backbone network has been calculated for both case studies. Accumulated CAPEX is shown in Fig. 2 as a percentage of the total CAPEX for the IP only scenario in the period considered.

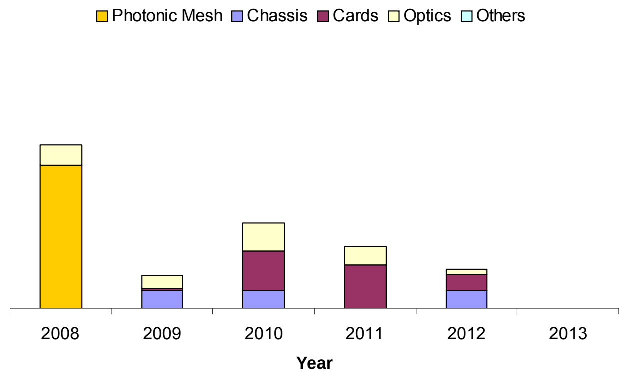

Fig. 3. IP Offloading Scenario – Relative Incremental CapEx.

As a result, it can be concluded that although an initial investment is necessary in order to deploy the photonic mesh; overall expenditure is 75% or 59% of the CAPEX needed in the IP only scenario, depending on whether 80 or 40 λ photonic mesh is deployed. Cost sensitivity to traffic of photonic backbone is lower and thus a significant number of ports and router upgrades are saved.

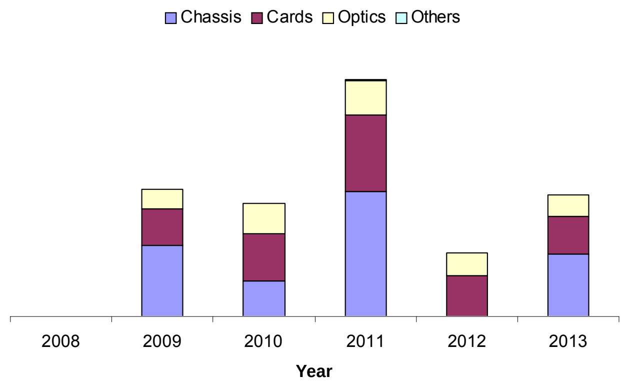

Fig. 4. IP Only Scenario – Relative Incremental CapEx.

In fact, CAPEX structure differs between both scenarios. Fig. 3 and Fig. 4 show yearly investment breakdown in the backbone for the IP only and IP offloading with 40 λ photonic mesh.

If the operator does not use off-loading, it has to invest an important quantity of money in chassis, cards and optics almost every year to deal with the traffic increment. By contrast, IP off-loading allows the operator to continue using the existing IP network and also to smooth the investment in the IP backbone by deriving the increment of traffic through the photonic mesh. A photonic mesh of 40 λ produces similar figures to Fig. 3 but, since it is smaller, the investment required for the initial year is consequently lower.

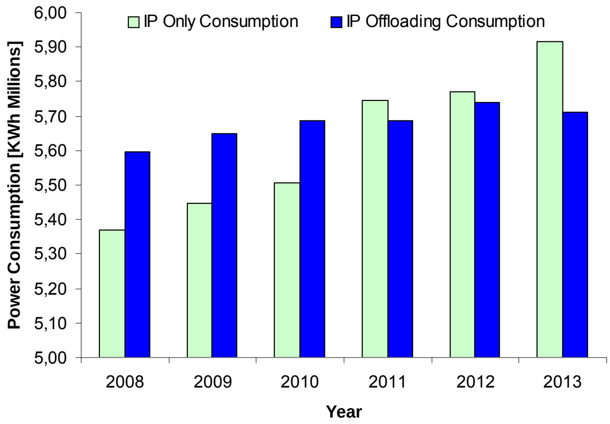

Fig. 5. Power Consumption Comparison between Scenarios.

Power consumption savings are expected to take place at the end of the period under study (see Fig. 5), due to the lower number of optics and cards needed in the IP offloading scenario. Initially the deployment of the photonic mesh introduces additional power requirements. As the traffic increases, this increment is compensated by the power savings in the IP backbone. This effect is accelerated due to the fact that ROADM power consumption is a fourth of an IP router.

TABLE I
INVESTMENT METRICS FOR IP OFFLOADING

	Photonic Mesh of 40 lambdas	Photonic Mesh of 80 lambdas
Payback Period (years)	2	3
IRR	40%	14%
NPV (10%)	6,3 euro millions	1,1 euro millions

However, this saving is not as high as it could be desired since the off-loading has not translated into a removal of IP routers, which is the equipment that implies the higher power consumption. In fact, important savings may be achieved in power requirements if the operator manages to replace IP switching (routers) by optical switching.

IP offloading may be considered as an investment project for an operator. By investing in a photonic mesh to perform the offloading of IP traffic, the operator will obtain in the following years savings in IP backbone CAPEX. In that sense it is possible to calculate some metrics in order to decide whether this investment is convenient for the operator or not (see Table I).

IRR figure is substantially lower for the 80λ case, due to the higher initial investment. Nonetheless, initial 40λ photonic mesh may be deployed and later on upgraded when necessary. Lightpath planning optimization may delay additional investments in the photonic mesh, approaching IRR to the 40λ case. Table I shows a higher NPV for 40λ with a discount rate of 10%. The Net Present Value (as a function of the discount rate) is shown in Fig. 6. Initial investment in the photonic mesh reports an IRR of 14%-40% depending on its photonic capacity (number of wavelength), with payback period of 2-3 years. The 40λ photonic mesh is better than 80λ because it be able to absorb the same offloaded traffic with fewer investments.

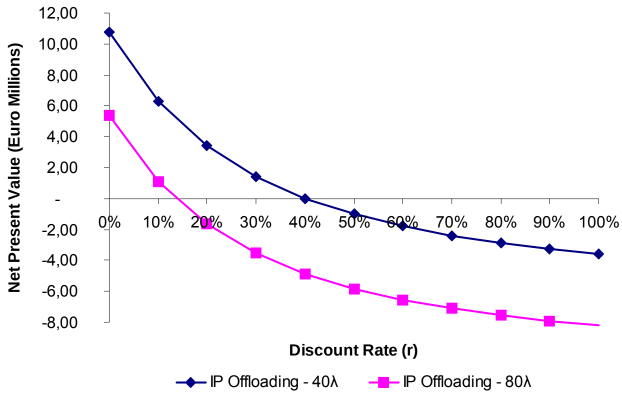

Fig. 6. Investment Profitability.

IP offloading profitability benefits from the continuity in the IP backbone, which maintains its structure, taking advantage of the IP infrastructure already deployed by the operator. As a result, initial investment is less important than CAPEX needed to accomplish other more disruptive approaches to IP backbone evolution, which result in deep IP backbone re-design.

Results may be further improved by taking into account savings in OF. Pure IP backbone without DWDM consumes one OF link per two ports between IP routers. Photonic mesh takes advantage of DWDM by sharing OF among a number of lightpaths, doing a better use of the available resources.

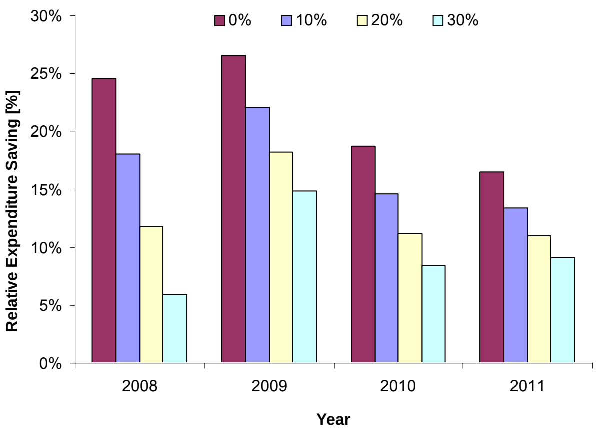

Fig. 7. Expenditure & investment savings in case of deploying a photonic mesh in different years versus evolving current IP network for different discount rates used to calculate 2008 value for the different scenarios.

Static DWDM may also be used in OF links in order to make the most of the existing OF infrastructure. In this case, dynamic lightpath management performed by the ROADM is expected to decrease operational expenditures in the optical transmission infrastructure.

All the former results lead to the idea that offloading IP traffic to a photonic mesh in the IP backbone result in CAPEX savings. However, it is interesting to study which is the best moment in time to begin performing IP offloading in the backbone network. Supposing each year the operator has the choice of either continue evolving its IP backbone network or deploy a photonic mesh and perform IP offloading, present value (at 2008) of investment and expenditure savings (including power, space requirements and cost of capital) due to photonic mesh deployment is calculated throughout the period under study. This is done supposing photonic mesh deployment in each of the first years of the period 2008 – 2011. The relative expenditure saving obtained if compared to the reference IP over DWDM scenario are calculated.

Fig. 7 shows the comparative analysis where the operator is able to make decision based on future expenditure savings. The future expenditure saving is evaluated considering the investment year in the 40λ photonic mesh. For example, in the first case the photonic mesh investment takes place in 2008, different discount rates are considered in order to calculate the value in 2008 of investment and expenditures throughout period. If the photonic mesh investment is postponed to 2009 and the operator continues growing its IP network in 2008 postponing the investment in the photonic mesh to 2009 or 2010 turns out to be even a more convenient choice for the operator because the savings is higher. However, if the investment is postponed to 2011 the expenditure saving will start to deteriorate, obtaining worse results due to that the operator would continue strongly investing on IP network during more time.

Considering the discount rate is useful, for instance, in order to take a decision on when to invest in the backbone network when there are different investment choices. In this case, relative savings with discount rates of 20% and 30% are worst because NPVs are lowers and the difference (%) between IP only and IP Offloading for both cases is lower.

V. CONCLUSION

In this paper we have analyzed an alternative for evolving next generation transport network, taking advantage of the existing infrastructure and trying to minimize yearly investment for the operator. Our results show that it is interesting for the operator to perform IP offloading of traffic from the IP network to a photonic mesh. Power consumption savings start from the fourth year. The energy consumption could be substantially reduced by replacing electrical switching with optical switching technology.

It is interesting to evaluate also when it is the best moment to introduce the photonic mesh and stop growing the IP backbone. In the reference scenario chosen we conclude that, although investing in photonic mesh is profitable from 2008, the best moment to invest on 40λ photonic network is 2009 from a financial point of view. Moreover, an adequate network planning improves the profitability ratios of this investment project.

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