Techno-economic benchmarking of NOBEL solutions for end-to-end broadband communications*

(Invited)

Angel Ferreiro[1], Jan Derkacz [2], François Dorgeuille [3], Ralf Huelsermann[4], Marco Quagliotti[5], Sofie Verbrugge[6]

[1] Telefonica I+D, Madrid, Spain Tel: +34 913374820, E-mail: olivo@tid.es
[2] Dep. of Telecom., AGH University of Technology, Kraków, Poland (derkacz@ kt.agh.edu.pl
[3] Alcatel-Lucent France, Research & innovation, Nozay, France (francois.dorgeuille@alcatel-lucent.fr)
[4] T-Systems Enterprise Services GmbH, Berlin, Germany (ralf.huelsermann@t-systems.com)
[5] Telecom Italia Lab, Torino, Italy (marco.quagliotti@telecomitalia.it)
[6] Ghent University - IBBT, INTEC, Gent, Belgium (sofie.verbrugge@intec.ugent.be)

Abstract

Defining network architectures to provide end-to-end broadband communications in an integrated network scenario supporting both fixed and mobile services is a feature of NOBEL (Next generation Optical network for Broadband European Leadership) project (supported by EU funding). Such solutions must not only cope with requirements such as scalability, interoperability and resilience awareness but also must proof cost-effectiveness and socio-economic impact on improving the penetration of broadband services. This paper reviews techno-economic evaluation of different proposed solutions for the network segments covering the first aggregation level and the metropolitan networks as well as backbone/core long distance networks. New transport technologies have been studied for the sake of improving network services based on the next generation network paradigm established by the ITU: Ethernet, PON and optical (transparent) switching have been evaluated. Their benchmarking analysis is then performed so as to present a set of guidelines for network plausible evolution. Such analysis takes into account not only the performances of protocols, equipments, etc. but it is also based on realistic traffic models, applications requirements and main economic inputs and sensibility to their evolution for migration studies.

1. Introduction

In spite of the general agreement about telecommunication networks evolution towards the NGN concept and de facto traffic exponential growth dominated by IP packets transport supporting triple play applications within a convergent (fix-mobile) perspective, network operators (and also their customers and other market agents as well as governments) wish to plan the forecasted migration considering that IP may not be the only client, legacy services carried over ATM and SDH may still share the use of the optical NGN whereas Ethernet services and wholesale of

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12th

optical bandwidth are driving the evolution of the architecture provided the business model be sustainable.

If so far a VC4 granularity (150Mb/s) provided by SDH with 1+1 protection was appropriated for the transport layer and access networks were determined by specific applications and independently rolled out for fix and mobile communications, traffic growth and new business models impose progressive lowering of transporting bit/Km and interoperable network services while keeping QoS and transparency of infrastructure details to the customers. In this context, the network evolution schedule should take into account not only technical evolution, like WDM and optical switching, Ethernet expansion as transport technology or advancements in equipments for PON and fix-mobile convergent access networks and improvements in control and management but also a cost-effective balance of independent benefits derived from particular resource optimisations in different segments of the network with special attention to their interfaces as well as to the step by step evolution of the applications demands and business models that are appearing.

2.2

2. Access and backhauling segment

Although it is presumed that access network sets important conditions to the rest of the network and its exploitation, such segment is not the specific subject of NOBEL project. Thus this study starts at the *backhauling network*, whose role is collecting end-user traffic coming from the DSLAMs (thought whichever access network) to the carrier Point-of-Presence (PoP)[1].

2.1 Network technologies and scenarios for the metro-access area

The metro-access area usually refers to the first level of concentration/aggregation, as depicted in [1]. Current incumbent architectures rely on SDH/ATM rings for DSLAMs backhauling as an adaptation of former legacy-oriented architectures. But network operators seek to keep up with the traffic evolution by replacing their SDH/ATM ADMs by data aware next generation SDH platforms and/or Multi Service Transport Platforms (MSTPs) to cope with multimedia applications requirements.

New entrants implement Ethernet technology mainly based on a star topology that might be directly linked to EPON based solutions for the access segment. But packet-based ring solutions (among which RPR) still deserve the attention of network operators not only for the sake of migration process but for service and resilience considerations [1] as well. In any case, interoperability in such an heterogeneous environment is a requirement in the metro-access area.

More disruptive solutions have been considered in NOBEL like the Dual Bus Optical Ring Network (DBORN) architecture (Fig. 2) [1]. It gathers the strengths of the all above-mentioned architectures/technologies, namely:

- Full protection based on double ring topology (as for SDH/ATM rings),
- Full Ethernet compliance (data aware solution),
- Cost-effectiveness (capitalises on low-cost technologies developed for access networks).

[1] PoPs may be located either in the metro-core or core network. They contain the main video servers (for VoD), the head-end station for Broadcast TV and other equipments for service providing.

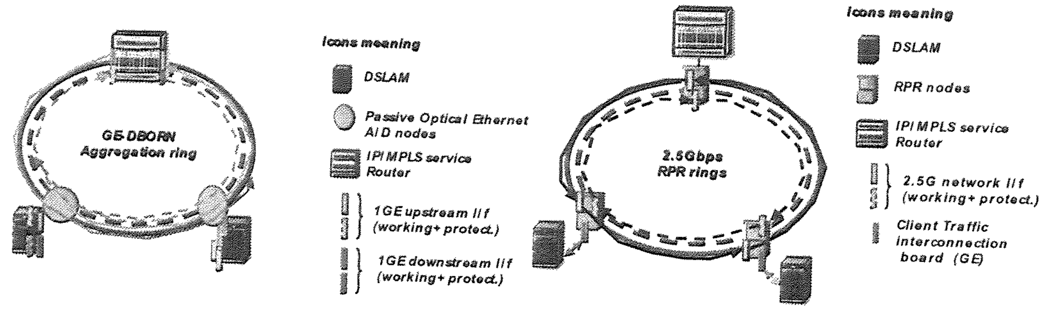

Figure 1: DBORN (left) and RPR (right) network architecture schemes.

2.2 CAPEX studies and comparison

A cost model has been developed within the NOBEL consortium as well as service and traffic model for broadband access subscriber [1]. Fig. 2 summarises the key results achieved in NOBEL considering the Milano metro-access network case which was split into different areas characterized by their size (in km²) and the number of subscribers. The Very Dense Urban Areas (VDUAs) 5km² with 30 000 subscribers and the Dense Urban Areas (DUA1) 7km² with 26 000 subscribers whose broadband subscribers are directly connected to DSLAMs co-located to the metro-core node (or PoP) via copper lines are not relevant in this studies.

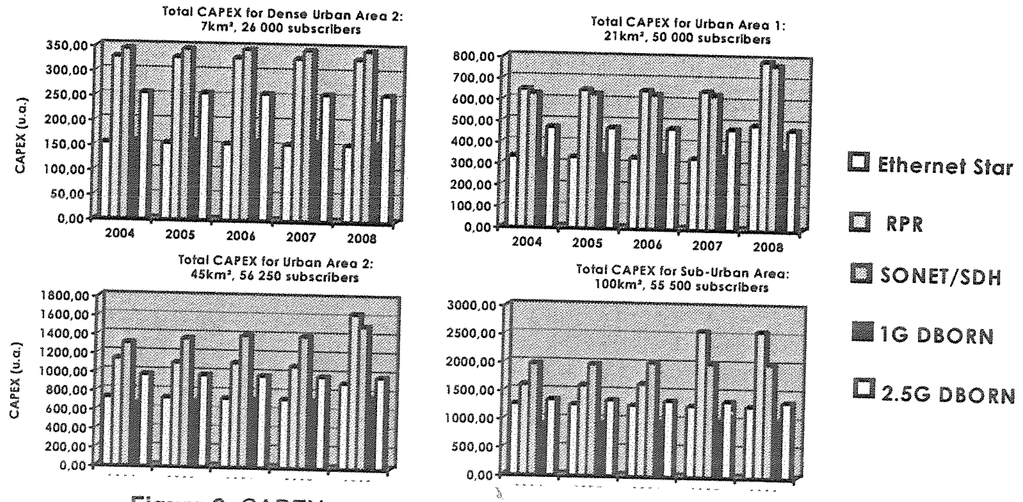

Figure 2: CAPEX comparison on the Milano metro-access network

The main trends can be summarized as follows:

- SDH solution is always more expensive than the others.

- The trend for RPR is more difficult to analyse as the Fig. 2 results strongly vary depending on the area considered. However, they are often close to the SDH ones.

- The Ethernet star solution is very cost-effective for dense urban area but becomes less attractive when the area covered increases.

- The 1GbE DBORN solution competes very well with the Ethernet star solution in all areas and even becomes clearly the most attractive for sub-urban area (i.e. the widest one), highlighting the benefits of efficient distributed statistical multiplexing combined with transparency.

3. Metro segment

Following aggregation hierarchy, metro core networks are being studied. In addition to Ethernet based solutions, direct IP over optical transport solutions have been analyzed in the metropolitan segment. As first result, OCS technology was proved to be cost-effective as well, for the access or first grooming level ([1]), provided the traffic will increase as a result of massive introduction of multimedia applications.

For the second level of aggregation, optical switching should be considered as a realistic substitute for SDH rings since the forecasted traffic in cities like Madrid is expected to grow exponentially during next five years at least[2]. Thus as an extension of the referred results (in [1]), a sensibility analysis of the transceivers cost and a benchmarking of OCS vs OBS technologies was carried out using the scenario described in [1] for Madrid metro core network (Fig. 3) where PoPs are also included.

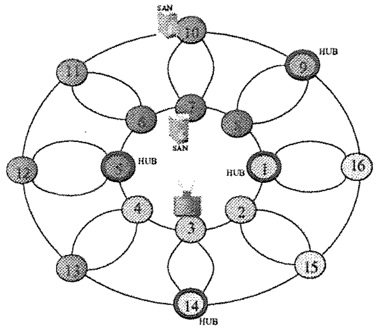

Figure 3: Double ring metro core network (access rings dual homed to it)

The evolution of this network is then addressed to using WDM with OADMs for p2p connections between nodes.

Based on a cost model focused in transceivers prices (using units of 2.5 Gbps Tx price), one can see the advantages of combining transceivers of different capacity instead of providing the same kind of transceivers in all nodes of the ring: For a realistic price ratio (around 2.5 or 3) between the Tx considered (2.5, 10 and 40 Gbps), using the same and unique Tx capacity requires four times CAPEX than combining different capacity Tx since the extra number of lambdas is not an issue for the network and scenario under study (dotted and continuous lines of Fig. 4).

In fact, this combination allows for more CAPEX savings (counterbalanced by OPEX increase) since estimations of traffic dynamicity (along a day or different situations) lead to considering a kind of statistical multiplexing: Exchanging capacities (set by the transceivers) of the links according to bandwidth demands using simple traffic engineering rules. But this link capacity rearranging gives no more than 20% cost of transceivers ([1]) when real cases are studied. Thus dynamic technologic solutions (tunable lasers) that can easily perform this link capacity adjustment should be considered only if the equipment price differences (more than 800% at present) reduce as much as to compensate the over provisioning and OPEX difference (almost negligible when comparing TE carried

[2] Cf, for example, Verizon experience in these scenarios

out with ROADMs versus OADMs) even if the fix-mobile convergence is taken into account.

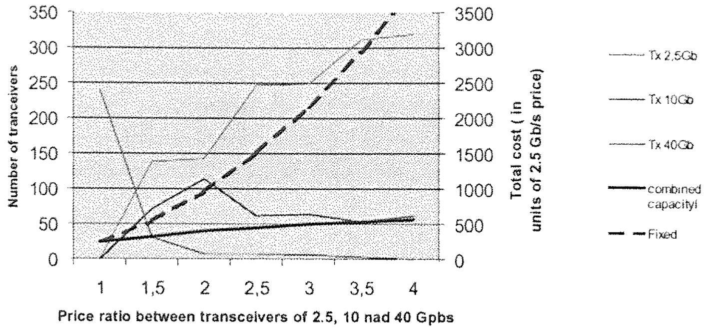

Figure 4: Number of transceivers and their (total) cost when using 40, 10 and 2.5 Gb/s devices

OBS technology could increase this flexibility (according to the statistical multiplex) of WDM rings[3]. However the requirement of sophisticated nodes (provided with tunable lasers) and a highly efficient control of the network limits its expectations form an economic point of view: Our estimations can be summarized as follows: Only for long term scenarios, when OBS technology will be mature enough and the prices of tunable lasers and other components of its nodes become cost-efficient, this solution will become useful for metro networks. However, the perspective of migrating these ring metro access segments with optical switching technologies should always be considered.

4. Backbone segment

The analysis of efficient architectures for multilayer backbone networks regarding architectural, technological and economic aspects is a key question in NOBEL project. These subjects are investigated by means of two exemplary case studies within the framework of a National and an European backbone network for multilayer IP transport network analysis and to evaluate the introduction of transparency in the transport layer respectively. A cost model developed within the Nobel project [1] has been used in the two case studies.

4.1 Comparison of Multilayer Architectures for the Network Backbone

In this case study we have quantified the necessary CapEx for the backbone part of a network supporting a various mix of L1, L2 and L3 services. Two different network architectures have been investigated: 1) a 'All IP/MPLS' network architecture and 2) a GMPLS controlled integrated multilayer network [7]. In the 'All IP/MPLS' reference architecture MPLS enabled IP routers are connected via a statically configured optical layer and switching is performed in the IP/MPLS layer only. In the GMPLS scenario the IP switches at the network edge are interconnected via a flexible L1 platform [Fig. 3]. In our scenario we assume a VC-4 agile SDH platform in the network core but also an ODU-1 agile OTN/OTH platform is feasible. Switching of

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[3] Client data packets are aggregated at the network edge nodes into larger variable length data units (bursts) before being sent thought a reserved (signalled) circuit allowing the intermediate nodes to reconfigure their switching matrix and then adapt the link capacities to the traffic in a very dynamic way.

coarse granular traffic streams offers the opportunity to reduce the switching costs compared to fine granular packet processing in the IP layer. So then IP functionality in the core nodes is only needed for the network control although it might also be efficient to groom some traffic in the IP layer if the traffic is transported in SDH/OTH channels with low filling. From the service production point of view we have distinguished between the integration of all network services (L1/L2/L3 services) in the IP/MPLS layer and the separation of packet oriented and circuit oriented (L1) services, which is an additional option in the GMPLS scenario.

The architectures evaluation is based on a comparative dimensioning study followed by a CapEx estimation. The network dimensioning was carried out using a hypothetical reference network scenario of Germany. The calculation of end-to-end traffic demands exchanged between the PoPs is based on a population model [8]. We assume a uniform mix of L1/L2/L3 services with respect to the traffic volume. The used cost model covers prices for IP routers and router interfaces (10G), SDH EXC and EXC interfaces (10G/STM-64) as well as 10G WDM transponders. All prices are normalized to the price of a 10G WDM transponder.

The deployment of SDH switching in the network core reduces the total network equipment costs significantly compared to the IP/MPLS reference scenario (Figure 4). This cost reduction is mainly caused by the fact, that the price for SDH EXC interfaces is about 66% lower than the price for IP router interfaces in our cost model. In the 'All IP / MPLS' scenario IP routers are installed at the network edge (PoPs – LER) and in the core part (IC/OC – LSR) of the network. In the GMPLS scenario we assume pure SDH EXC in the network core and integrated multilayer switches with IP and SDH switching capability and SDH EXC interfaces at the network edge.

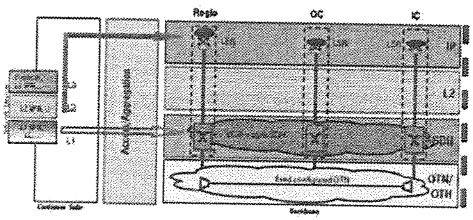

Figure 5: GMPLS controlled multilayer network

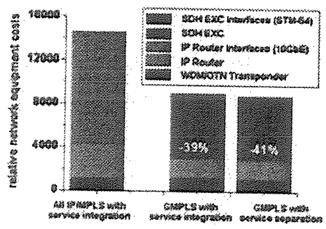

Figure 6: Comparison of CapEx

Nevertheless, the costs for the node interfaces (interface + transponder) are still dominant, even in the GMPLS scenarios. Thus, a high utilization of installed interfaces (=filling of optical channels) is recommended to minimize the network costs.

4.2 Introduction of transparency in the transport layer: Technical and economic issues

The evaluation of the economic advantages of *semi transparent* networks in comparison with opaque networks has been carried out with a SW that allows designing and analyzing opaque or transparent (semi-transparent if regenerations are necessary) networks. A physical model is used to evaluate the impairment suffered by a lightpath when it is routed across the network. For a given lightpath, when the signal cannot be detected at the destination node (i. e. the Q Personick's factor [9] [10] closely connected with the BER, doesn't satisfy the required threshold), a regenerator has to be installed in one or more intermediate nodes, the number of regenerators depending on the distance.

The reference network adopted for the study is the Pan European network of 68 nodes and 100 links and a static traffic matrix of 1090 connections of 10 Gbit/s. In this network the longest routes for the working path and back-up path are approximately 6100 and 8100 Km respectively; these are very critical distances when implementing a fully transparent network, even in the case of very high quality optics. In the case of opaque network two cases are considered: with 1+1 protected connections and with shared protected connections (restored). In the case of semi-transparent network four cases are considered, all characterized by dedicated protected connections The four semi-transparent cases correspond to two values of tolerated Q (matching with a signal coding without and with FEC respectively) and two extreme conditions of Non Linearity (NL) effect (low and high). Costs are reported in [Figure 3] where the values are expressed in Nobel Cost Unit and the whole cost is shown with its partitioning details (costs of lines, amplifiers and DCFs, tributary cards, regenerators, switch ports).

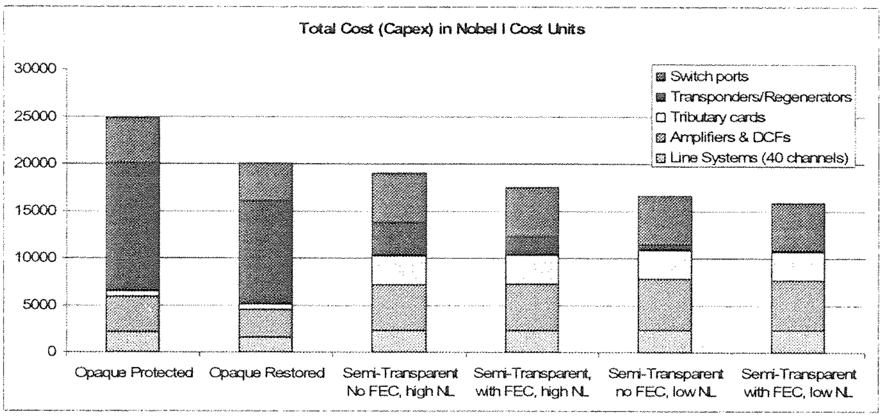

Figure 7 - Cost of network for different implementation alternatives as regards transparency and resilience

The cost evaluation confirms the significant advantage of shared protection in the opaque case (-20% saving). When comparing the opaque and the semi transparent solution the cost evaluation shows an advantage in CapEx for the semi-transparent cases (up to -30% with FEC and low NL effects), but this advantage depends on the non linearity impact and requirement on Q factor; transparency may not be so convenient in the worst cases. The restoration applied to semi-transparent cases (not yet available but under development in the Nobel project) are expected to give additional cost saving in favour of semi-transparent solutions.

5. Conclusions and general migration guidelines

This paper summarizes a great deal of case studies analysis in order to present some guidelines derived from a techno-economic benchmarking performed within the NOBEL project proposed solutions to the future end-to-end broadband communications.

The analysis of different multilayer architectures for the backbone segment of a network supporting services in different layers shows that IP router interfaces are the main drivers for the total network installation costs. Therefore one of the main network design goals is to reduce the number of such interfaces: Possible architectural options to carry out this task are: a) Replacement of IP switching in the network core and deployment of coarse granular traffic switching with the use of a flexible L1 platform (SDH/OTH) to avoid packet processing in the IP layer in transit nodes. b) The introduction of cost efficient multilayer switches (L1/L2/L3) at the network edge to avoid the need of interfaces between nodes of different layers. Such integrated multilayer nodes can also be used to provide service interfaces towards the customers on lower layers. This allows for a separate production of L1/L2/L3 services on the bases of a common network platform which might also help to reduce the operational costs.

The introduction of transparency in the transport layer of the backbone segment seems to be interesting from an economic point of view in case of low non linear effects (and a low impairment degree in general). The most important item contributing to the cost reduction in case of the semi-transparent solution is the reduced need for regenerators. This cost savings can be achieved even though the requirements on the quality of the optics needed for the amplifiers and line systems in the semi-transparent case are higher. A future decrease of the cost of OEO conversion could change this current conclusion.

For metro networks, the techno-economic analysis tends to make the Ethernet star solution a good candidate in a short-term view. DBORN also provides a cost-effective solution combining the benefits of the statistical multiplexing with ring topologies resilience features. The GPON technology (similar) is now deployed in carrier access networks. However, long-reach burst-mode transceivers are not yet widely available on the market, meaning that deployment can be only envisaged at a longer time-scale, farther than year 2008.

Furthermore optical switching technologies can be seen as cost-effective solutions for metro core networks in a medium term allowing for a direct upgrading of the SDH rings so far the basic architecture feature in this segment. New approaches like TMPLS and other carrier-grade Ethernet based solutions are still under consideration in NOBEL project.

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