Integrated Electrical/Optical Switching for Future Energy Efficient Packet Networks

Gert J. Eilenberger
Bell Labs, Alcatel-Lucent Deutschland AG, Lorenzstr. 10, 70435 Stuttgart, Germany
Gert.Eilenberger@alcatel-lucent.com

Abstract: Future packet transport networks need to cope with rapidly growing Internet traffic. Hybrid architecture approaches combining limited electronic with massive optical switching can help to overcome the severe cost, energy and scalability issues.
OCIS codes: (060.4510) Optical communications; (060.4256) Network optimization; (060.4259) Packet-switched networks

1. Introduction

The rapidly growing Internet traffic will be further driven by the development of optical high-speed access for a large percentage of households (cf. for example the EU Guideline for Next Generation Access: all European Citizens should have 30 Mb/s access until the year 2020) together with the evolution of interactive and mobile broadband services as well as the increasing video content distribution over the Internet. The average traffic growth over the next 10 years will reach a factor of 100 according to recent forecasts and based on measurements in real networks over the last years; at selected hot spots like large Internet exchanges, traffic is even doubling each year [1,2]. Future packet transport networks need to cope with challenging requirements in terms of scalability and in particular energy efficiency. Some key strategies and solution approaches will be described in this paper.

2. Challenges for future transport networks

The expected traffic growth is not only challenging in terms of scaling up the network infrastructure in order to simply carry the amount of data. This may sound like we have to progress the technology as we did in the past, but 100 times more traffic means that we will need core nodes with a total capacity of 100-150 Tb/s and the key question won't be if we could achieve this technically, but if we could do it in a cost and energy efficient way.

The cost per transported bit needs to be reduced dramatically in view of the stagnating revenues of operators. Their networks are currently being transformed from separated SDH/SONET and IP backbones towards converged packet transport networks while IP and packet based services become more and more dominating. Processing the entire packet traffic electronically with large IP routers according to today's way of operation will certainly raise strong issues in terms of complexity and energy consumption.

The evolution of electronic processing speed is still following Moore's Law, but recently more by deploying multi-core and massive parallelization rather than raising clock frequencies accordingly. Furthermore, scaling down the feature size of CMOS technologies won't result in related power savings like in the past because of increasing problems with leakage currents. Finally, the throughput of memories as essential prerequisite for all high-speed electronic packet processing and buffering is being extrapolated to grow by a factor of only 15 over 10 years. Thus, scaling up today's electronic nodes to the needs of 2020 is absolutely not straightforward. Massive parallel deployment of equipment could possibly cope with the traffic increase, but energy will then become the most critical factor, since the energy consumption of routers is overall increasing with throughput, despite of all improvements in semiconductor technologies. A study from Japan, for example, on the evolution of all-electronic IP router backbone networks shows that by 2020 routers will consume ~50% of the nation's total energy generation in 2005, thus becoming unsustainable [3].

3. Packet network architectures and solutions

Since scaling up electronic router based architectures will most probably not meet the cost and energy targets in 2020, we must consider new approaches first to reduce electronic packet processing to the bare minimum: just one single processing instance (classification, header inspection, table look-up, scheduling, etc.) for each end-to-end flow and then exploit transport techniques based on photonics offering a remarkable energy saving potential. However, it is well accepted that optical techniques are not suitable for complex signal processing tasks as well as large storage and buffering needs, but show their benefits in the field of circuit switching and wavelength routing [4]. This seems to be a contradiction to the requirements of transporting IP based multi-Gigabit packet streams. But one can easily discover that 80-90% of the traffic in a core node is transit traffic which isn't generated or terminated in this particular node and thus, there is no need for electronic packet switching/routing operations required to forward the packets to the next node and the traffic can be bypassed in the optical domain applying much less complex and less energy hungry circuits.

Still, a large variety of packets carrying from a few bytes up to a few kilobytes of data are entering the metro and core network where at least a fraction needs to be processed and packet switched as long as it's not efficient to put this traffic onto an optical circuit or an entire wavelength channel. Processing lots of tiny and variable length packets is an extremely complex and energy hungry task. Thus, we can use traffic aggregation into large, fixed length macro-frames according to destination and service class at the edges of the network and can reduce header processing complexity by at least 2 orders of magnitude inside the core and the energy consumption of related line cards by 30% [5]. This will also minimize the deployment of complex Deep Packet Inspection mechanisms in the core.

Video content as being expected to play a dominant role in future will also benefit from transport in large containers or even optical circuits since it can be mostly characterized as large, contiguous chunks of data.

The resulting network architecture ideally pushes all electronic packet processing towards the borders of the network, preceded by aggregation stages, and restricts the core as far as possible to optical circuit switching techniques with a limited amount of energy efficient macro-frame switching, thus following the strategy to switch traffic at the lowest possible layer.

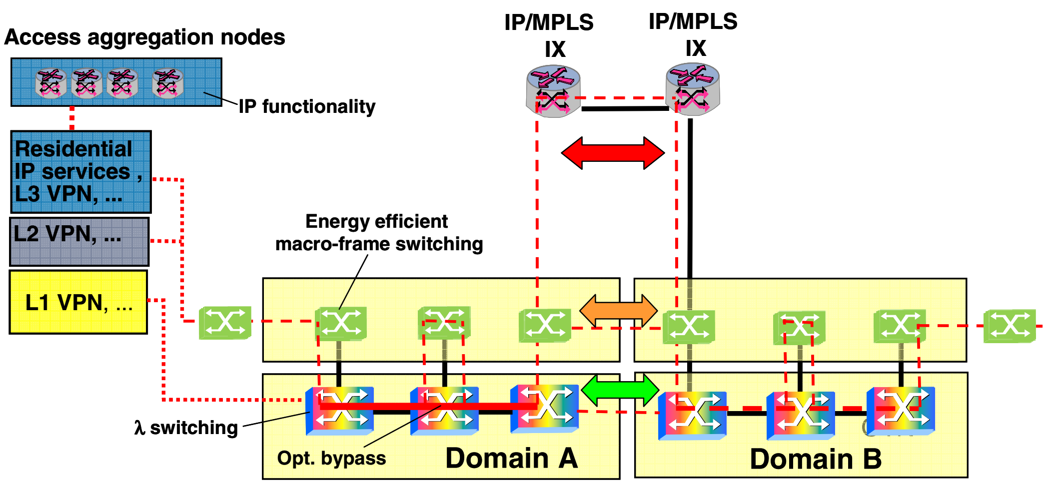

Figure 1: Long term network architecture vision

The architecture vision (fig. 1) unveils a potential blocking point for end-to-end energy efficient transport, namely the interfaces between administrative or vendor domains which perform hand-over today on IP/MPLS level. When aiming at a single packet processing entity for each end-to-end flow and allowing L1 and L2 services (e.g. video) directly entering the network without IP layer mapping, then we need to consider introducing novel inter-domain interfacing approaches on L2 (aggregated packet streams, circuits) or even on L1 (switched wavelengths).

The architecture vision is relying on integrated L1/L2 switching capabilities in order to shift the traffic between electronic packet/circuit switching and optical circuit switching blocks back and forth along the path through the network in a flexible way according to the traffic demands and the most cost and energy efficient transport means.

Fig. 2 depicts the structure of an integrated el./opt. node scalable for an overall throughput beyond 100 Tb/s and consisting of an electronic agnostic switch supporting macro-frame and circuit switching as well as a photonic switch for handling wavelength channels. The share of each technology is determined by the network topology and the traffic demands. Although nearly all these large nodes will have to handle add/drop traffic on L1, L2, and L3, there is no IP routing function foreseen in the electronic switching fabric. For cost and energy efficiency reasons, we assume that all IP based packet traffic has been aggregated into macro-frames in the access nodes or –if appropriate- on specific line cards of the integrated node before entering the core network where it is mapped and transmitted at the lowest possible layer depending on the required bandwidth and the available bandwidth on the core links. Thus we can decide for each node, if a certain ingress traffic could just traverse the node on a wavelength channel, or a switched time slot of a wavelength (depending on the capabilities implemented in the photonic switch), or if it needs to enter the electronic sub-wavelength switching part of the node to be rearranged either on the basis of circuit switched containers (e.g. OTN) or on macro-frame level. Note that an integrated control plane encompassing all involved layers is indispensable. With this approach, we attempt to get as close as possible to the most efficient distribution of traffic over the layers weighting the granularity of traffic against the granularity of the different transport layers on the core links.

The principle of shifting traffic to lower layers –also known as optical bypass- is on one hand a static process at the network design phase when we can optimize the deployment of node equipment according to gross average traffic dependencies in a static traffic demand matrix. Much better energy efficiency could be achieved by establishing bypass links dynamically according to actual traffic demands. Fig. 3 explains this principle using a two layer example, an electronic packet layer and a WDM circuit layer. Each node keeps track of the bandwidth used by the packet type flows crossing the node. As soon as a certain threshold of transit traffic is detected the node issues a bypass request to a decision instance which receives all bypass requests inside its responsibility region, coordinates the mutually interfering requests, and initiates the set-up and tear down of those optical bypass circuits matching the most energy efficient traffic distribution. This dynamic bypass provisioning scheme –as part of a distributed control plane or as centralized block- may become an autonomous network function for efficient network control [5].

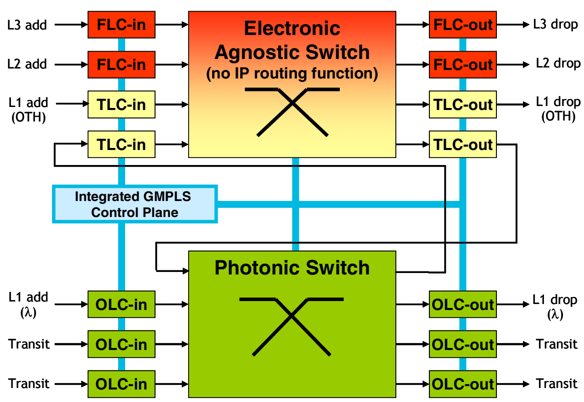

Figure 2: Integrated electronic/optical node

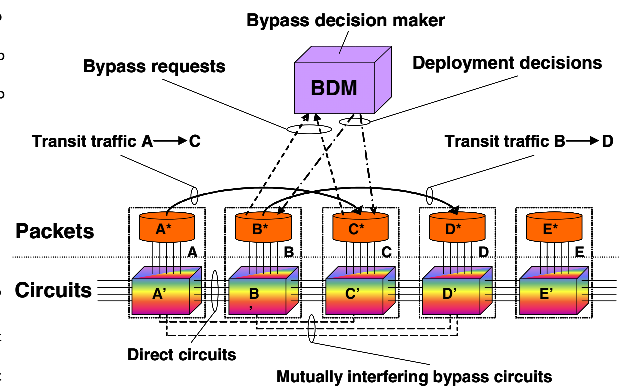

Figure 3: Dynamic optical bypass principle

The design and dimensioning of this network architecture with integrated electronic/optical nodes in national scale arrangements of more than 1000 nodes is a challenging multi-layer optimization task. We prepared a number of sophisticated heuristics and optimization strategies to prove the potential of the described approach in realistic network scenarios applying a related dimensioning and optimization tool.

4. Conclusions

The Internet traffic in the year 2020 is expected to reach a volume of 100 times the traffic of today. The network infrastructure will need to carry this volume in the most cost and energy efficient way, since cost per bit need to decrease dramatically in view of collapsing operators' revenues and energy consumption is becoming a critical factor in the operational cost. Scaling up the electronic all-IP based approaches will most probably not meet the 2020 requirements in terms of cost and in particular energy, so novel architectural and technological solutions are indispensable. We propose to minimize the processing effort on packet level by reducing it to a single instance, by aggregation into large macro-frames, and by pushing the traffic to the optical layer as far as possible. This leads to transport network architectures with IP routers at the edges only and integrated electronic/optical switching nodes in the core exploiting static and dynamic, autonomously controlled bypassing techniques for lowest energy and cost; novel approaches for inter-domain interfaces on L1 and L2 need to be considered, as well as efficient ways to transport large video content chunks.

Acknowledgement: The research leading to these results has partly received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 247674.

5. References

[1] Germany, Federal Network Agency, Annual Report 2008.
[2] DE-CIX, German Internet Exchange, "Traffic Statistics", <http://www.de-cix.net/content/network/Traffic-Statistics.html>.
[3] H. Imaizumi and H. Morikawa, "Directions Towards Future Green Internet," Proc. 12th Internat. Symposium. on Wireless Personal Multimedia Commun. (WPMC '09) (Sendai, Japan, 2009)
[4] R. Tucker et al., "Evolution of WDM Optical IP Networks: A Cost and Energy Perspective", JLT, vol. 27, no. 3 (2009)
[5] G. Eilenberger, S. Bunse, L. Dembeck, U. Gebhard, F. Ilchmann, W. Lautenschlaeger, J. Milbrand, „Energy-efficient transport for the future internet", Bell Labs Technical Journal, vol. 15, no. 2 (2010)