

Energy Saving Perspectives of IP over Wavelength Division Multiplexing

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Abstract — The electrical consumption of the core global networks is becoming preoccupant. To reduce it, one may bet on technological advances improving the energetic profile of individual components. However, large energy savings can potentially already be achieved, by reviewing the organization of the core networks.

In this paper, we sketch directions which can be followed to improve the network organization toward reduced energetic consumption.

Index Terms—Energy efficient networking, multi-layer optimization, optical networks.

I. INTRODUCTION

INFORMATION and Communication Technology (ICT) sector has an increasing impact on carbon emissions. Its share might already have overtaken the one of the air transport sector. Moreover, it shows a higher growing rate the others, and might become an even greater carbon emitter if nothing is done to change the trends.

ICT energy consumption can be decomposed in several groups. Among it, the consumption of the “core networks” is estimated to 10 to 15% [1][2]. This share is however likely to increase in the future with an increasing part of the data stored remotely (video content on video-sharing websites, audio on music streaming services, data files on revision control systems, etc.), and more generally with the advent of cloud computing. In the context of ICT energy consumption reduction, rationalizing the consumption of the core networks is thus a wise objective.

The consumption of core networks has been broken down in several studies. In [3], the respective part of switching and routing, signal regeneration, signal processing, buffering and transport is roughly analyzed. In [4], it is suggested to analyze the consumption across several geographical regions: intra-device of site consumption, Autonomous System (AS) domain consumption and Internet wide consumption. In [5], the consumption of the core network is divided in a core network access part (edge nodes), interior part (core nodes) and transport part (WDM links). The consumption of the different functional blocks constituting a high-end electronic router is also provided in [6].

In this contribution, we sketch tracks aiming at reducing the core networks consumption. Beside the improvement of network components energy efficiency, we allege that main energy efficiency gains can be attained by revisiting the structural organization of core networks. We then present the challenges raised by the revisited network organizations.

II. BACK TO THE BASICS

As data transits through a core networks, it traverses several type of devices:

- Transmission devices: lasers, optical amplifiers
- Optical networking devices: OADM, OXC
- Low-level signal processors: modulators, demodulators, coders/decoders (transceivers)
- High-level signal processors: multiplexers-demultiplexers
- Switches and routers.

The core network energy consumption is obviously due to the consumption of these devices. Several tracks can be followed to bring them down:

- Technological advances: All these devices have an intrinsic consumption, which depend on technological factors (VLSI, voltage, etc.). For instance, RAM memory equipping routers has a consumption expressed in Watt per bit (buffering) and joules per bit (read/write operations). These profiles can all be improved (for instance lower operation voltage for RAM [7]). More energy efficient component designs can also be involved.
- Size or rate optimization: Independently of the technological implementation, any device architecture is likely to have an ideal (energy consumption speaking) rate or bandwidth. Hence, scale savings can generally be done, until a point where complexity issues arise. Core network consumption can be reduced by selecting the most efficient operating rates, or router sizes.
- Energy efficient networking schemes: The energy consumption is also sensitive to several controllable parameters of the networking scheme. In particular, the packet size and the address space. Hence, bigger packets and reduced address spaces induce respectively less numerous and less consuming switching operations. However, bigger packets include higher requirements in terms of memory. Moreover, packet drops have an

increased impact on network performances. There is therefore an energy efficient trade-off to find.

All these measures aim however at reducing the consumption of devices involved in actual architectures. There is nevertheless another way to reduce the consumption of core networks: rather than reducing the consumption of the devices, one might reduce the number of devices:

- installed in the network
- traversed by the traffic

Hence, as summarized in Fig. 1, although the network wide consumption of some devices scales with factors as the distance or the address space complexity, all obviously scale with either the number of installed systems and/or the installed bandwidth. It makes thus sense to reduce both of them. In that purpose, the architecture not of the devices but of the networks must be reviewed.

		Consumption scaling with	
Links	Amplification		# of WDM systems Distance
	Optical processing (mux/demux, OXC)		# of systems
	Transmission (lasers)		# of lightpaths
Nodes	Processing		# of nodes, node bandwidth
			# of nodes, node bandwidth
	Switching	Lookup, classifying	Address space complexity
		Buffering	Latency

Fig. 1: Classification of core network functionalities

III. ACTUAL CORE NETWORKS ARCHITECTURE

We consider the following architecture as the dominant one in nowadays core networks. The customer is connected via the access network to the Provider Edge (PE) router which is an IP router. The PE is the entry point in the core networks in our description. From that point, the traffic can have three destinations (Fig. 2):

- 1) another customer of the same provider, connected to the same PE
- 2) a customer of the same provider connected to another PE
- 3) a destination located outside of the provider domain.

In the first case, the traffic leaves directly the core networks as it is sent back to the access network. This traffic is not considered in our study. In the second and third case, the traffic is dispatched *within the provider domain* either to another PE, either to an Autonomous System Boundary Router (ASBR), which are both assumed to be IP routers, too. Finally, in the third case, the traffic is passed to another ASBR of a neighboring domain. The traffic is then again dispatched within this second domain, either to another ASBR, either to a PE, and so on.

IV. INTRA DOMAIN ARCHITECTURES

Within each domain, the IP-routers are connected in between with point-to-point (P2P) IP links which form the IP topology. These links rely on MPLS (or equivalent technology, e.g. ATM) connections.

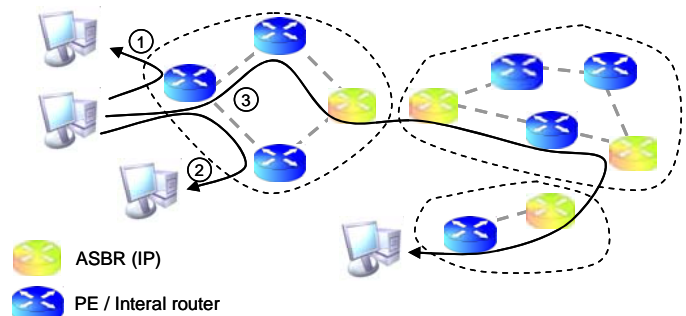


Fig. 2: The traffic entering in the core network can be directly returned to the access network (1), or can transit within the domain (2 and 3). It may also transit over several domains (3).

MPLS connections are supported by MPLS routers interconnected with MPLS links, forming the MPLS topology. MPLS connections can be either P2P or routed. If routed, several MPLS links, interconnected with intermediate MPLS routers, are involved. If P2P, traffic flows directly from one ingress MPLS router to the egress one.

MPLS links are in turn typically supported by optical connections referred to as lightpaths. These optical connections can be P2P, i.e. they traverse a single fiber link. They can be on the contrary optically routed, i.e. they transit over one or more nodes equipped with optical cross-connects (OXC) or optical add-drop multiplexers (OADM).

Finally, lightpaths are routed over a WDM topology, made of fibers and optical amplifiers.

Hence, one is in presence of a *traffic-over-IP-over-MPLS-over-lightpaths-over-fiber* intra-domain architecture. This architecture can in turn be applied in several variants.

A. Overlaid IP topology

In this simplest case, IP routers are placed at the extremities of the optical fibers. The IP topology thus reproduces the physical topology. Lightpaths and MPLS connections (which can be in this case simply Ethernet links) are however still required to fill the “protocol gap” between IP and the physical link, and ensure redundancy checks, for instance. Lightpaths and MPLS topologies thus also mimic the IP topology.

Assuming a not fully-meshed fiber topology, traffic might flow between not directly connected pairs of IP routers (PE to PE or PE to ASBR). Several *IP-hops* are thus required as depicted in Fig. 3.

B. Full-meshed topologies

Another variant consists in connecting each pair of IP routers with a dedicated P2P IP link. These links can be supported by routed MPLS connections (Fig. 4a). In this case, the traffic achieves one hop on the IP topology but several hops on the MPLS topology.

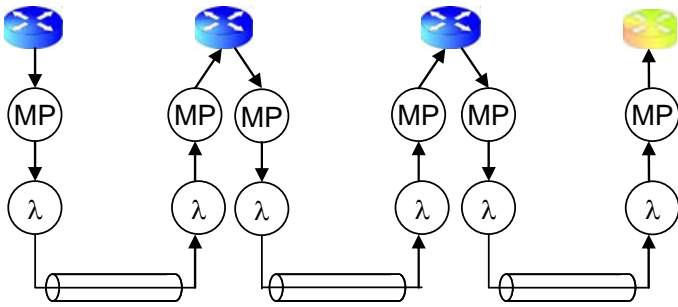


Fig. 3: Overlaid topologies cases: all layer have the same topologies. Traffic is transferred to and from and layer at each intermediate hop.

Alternatively, the fully meshed IP topology can be directly mapped into a fully-meshed MPLS topology, supported by optically routed lightpaths (Fig. 4b).

Finally, in the extreme case, one or more parallel WDM systems can be installed between each IP router pair. In this case, no optically switching is required (Fig. 4c).

Note that as in both (b) and (c) case no routing is achieved by the MPLS layer, this last can be replaced by simple point-to-point scheme.

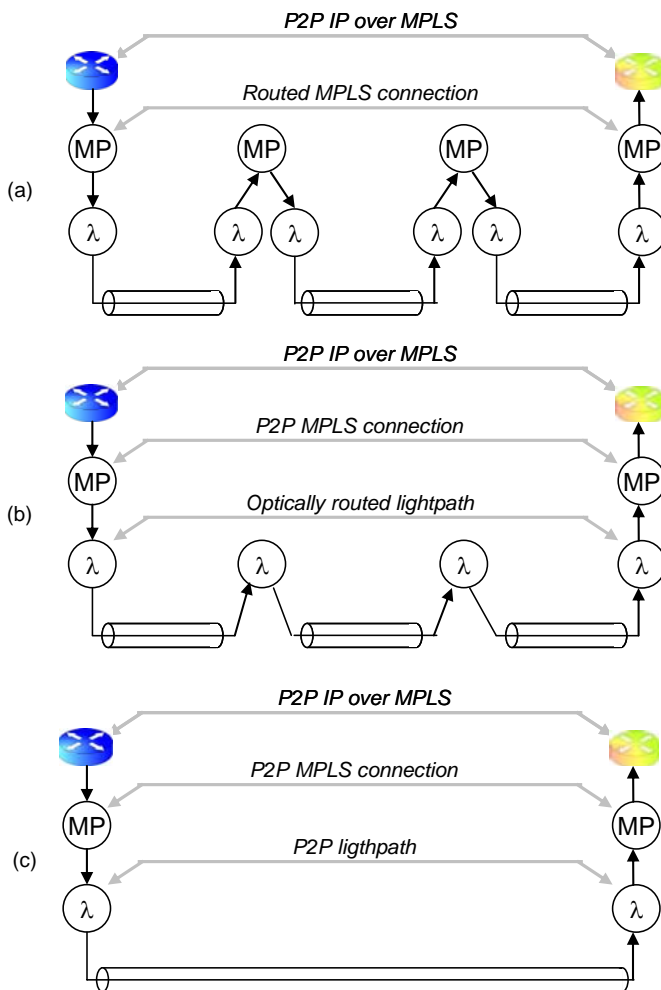


Fig. 4: IP topology being assumed fully meshed, IP links must be supported by either router MPLS connections (a) or P2P MPLS connections. These last can be either supported by optically routed lightpaths (b) or by direct WDM systems.

C. Star topologies

One more variant consists in using star topologies. In this way, all the traffic may be first concentrated at one node where one IP router dispatches it to the egress router (achieving in this way 2 IP hops). Star branches are MPLS connections, made either of juxtaposed MPLS links, either of P2P MPLS links, themselves possibly optically routed (Fig. 5).

The star topology is also possible at the MPLS layer, as support for a fully meshed IP topology: traffic flows in one single IP hop from the PE to the egress router, but in two MPLS hops, one toward the MPLS hub node, and one from it to the egress IP router. In this case, star branches are made of optically routed lightpaths.

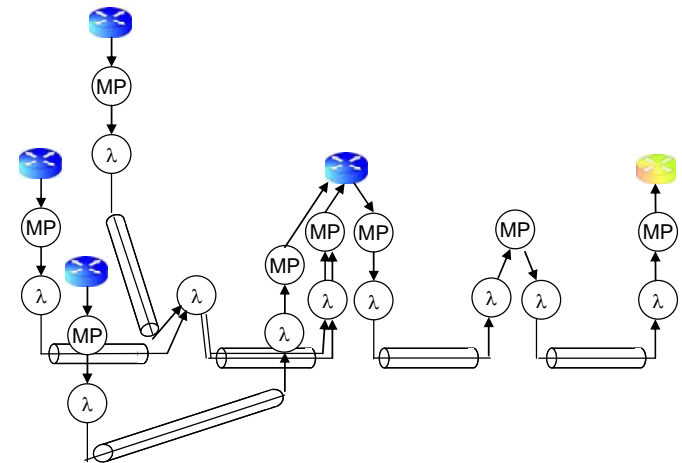


Fig. 5: IP star topology: one IP router centralizes the traffic. Traffic from other routers can be dispatched either with P2P MPLS connections supported by lightpaths, either by routed MPLS connections.

D. Arbitrary topologies

The organization of the network is not restricted to the three architectures mentioned here (overlaid, fully-meshed, star). Arbitrary topologies can also be adopted on each layer, typically providing direct paths between node pairs exchanging large traffic amounts, and indirect paths for less intensive traffic routes.

V. OPTIMIZATION ISSUES IN INTRA DOMAIN ARCHITECTURES

The presented *traffic-over-IP-over-MPLS-over-lightpaths-over-fiber* architecture can be optimized in several aspects to improve energy efficiency.

A. Detours avoidance

Traffic consumes energy as it flows along the links, and as is it electronically switched by a node. In order to be energy efficient, the distance traveled and the number of switched crossed must be minimized. This is equivalent to minimize physical and logical detours, respectively.

Physical detours are taken when the traffic is diverted from the shortest physical path between the ingress and egress routers. Physical detours obviously arise because fibers and WDM system cannot be laid as straight lines, and because fiber topologies are rarely fully-meshed as assumed in Fig. 4c. But physical detours can also be related to network design

choices. Hence, in any star related topology, the transit by the hub node might induce long physical detours.

Logical detours are taken when the traffic traverse one of more layers of the architecture more than strictly necessary. Except in the case assumed in Fig. 4c, where the traffic goes exactly once through each layers to reach the fiber, all other situations involve more or less logical detours. These detours can be more or less problematic. Hence, a detour via the lightpath layer does not involve electronic processing, but only causes the optical signal quality to diminish (this point is addressed later). On the contrary, a logical detour to the MPLS or even worse to the IP layer imply coding/decoding operations, addressing, buffering, etc. and should thus be minimized to a larger extent. Fig. 6 depicts this concept of detours.

To avoid detours, topologies of reduced diameter (more meshed) must be employed. This means increasing

- the number of IP links and thus MPLS connections
- the number of MPLS links and thus of lightpaths
- the number of P2P lightpaths and thus of fibers

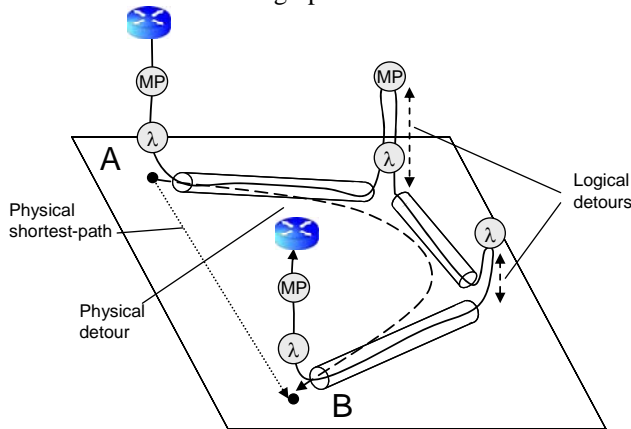


Fig. 6: Physical and logical detours prevent an energy optimal dispatching of the traffic: physical ones because they lengthen the transmission distances; logical ones because they multiply the number of switching operations.

B. Node bandwidth and WDM system minimization

Referring to Fig. 1, the total consumption generally scales with the nodes bandwidth. This last is directly proportional to two elements: the number of links active on the considered layer, and the average throughput of these links. Hence, the total bandwidth of the IP routers is equal to the number of links in the IP topology multiplied by the average throughput of these links.

Note that if MPLS is used as intermediate aggregation layer, IP router bandwidth can be reduced to the effective traffic bandwidth. Indeed, transceivers are not directly connected to the IP router but to the MPLS router. Only the traffic effectively received or emitted by these transceivers might eventually be forwarded to the IP router. In this way, the IP router capacity can be reduced. In opposition, if P2P links are used to interconnect IP routers, their bandwidth must be equivalent to the transceivers bandwidth.

Several strategies can be applied to minimize the bandwidth related consumption. First, the IP routers bandwidth can be reduced by letting local traffic only flow through them, i.e. by delegating all switching operations to the MPLS layer (and thus

by adopting a fully meshed IP topology). Second, the number of transceivers can be minimized. This can be achieved by employing star instead of fully meshed MPLS topologies. Third, the transceiver throughput (i.e. the lightpath rate) can be optimized.

On the optical domain, the consumption scales with the number of WDM systems, independently of the lightpaths throughput. Figure 7 summarizes these “number of elements” related consumptions.

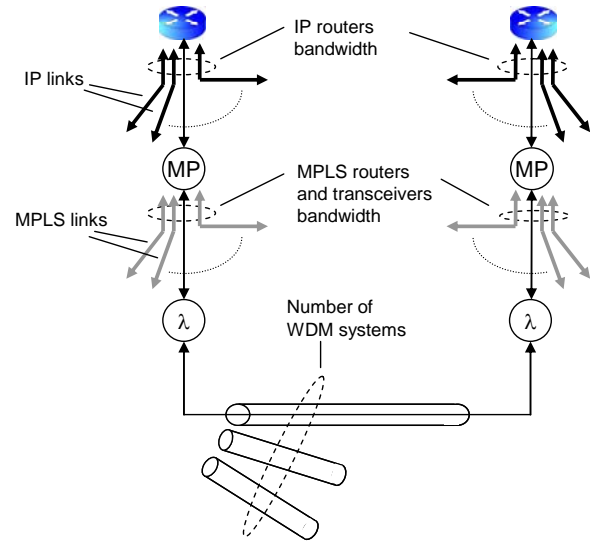


Fig. 7: Energy consumption scales with the bandwidth of switching node, and with the number of WDM systems.

C. Lightpath regeneration minimization

Nothing has been said so far concerning optical transmission. Whereas “on the paper” lightpaths can be switched optically as many time as required, and propagate on infinite distances, in practice the optical signal quality suffers from switching operations and long propagation distances. The signal quality additionally degrades more as the lightpath throughput increases.

To nevertheless use long spanning and multi-hop lightpaths, regenerators can be introduced at given network nodes. Regenerators are devices implementing only the strictly required material to decode the lightpaths signal, correct eventual errors and reemit the signal again. As they perform no routing operation at all, they are assumed more energy efficient than the MPLS routers, for a given bandwidth.

The presence of regenerators adds however some complexity in the networks. Regenerator must be monitored and maintained. In particular, spare regenerators must be additionally kept at each node where regeneration is achieved. The number of nodes performing ad-hoc regeneration should thus be minimized [7]. Are more radical solution consists in forbidding regeneration, and thus avoiding high rate long spanning lightpaths.

D. Trade-offs

Summarizing the objectives mentioned so far:

- Detours must be avoided. In this purpose, more links are required.

- Bandwidth must be minimized. Transceivers should thus be minimized, too. This objective hence conflicts with the previous one. Star topologies can be a good compromise. Alternatively (to avoid logical detours), reduced throughput links can be used.
- Reduced throughput links do not require regeneration. However, they might be energy inefficient. Hence, although less consuming per unit, they might consume more per bitrate.

There are thus two tradeoffs which must be jointly balanced: more or less meshed topologies (at all layers), and more or less link bitrate.

Assuming a fixed transceiver rate, highly meshed MPLS topologies are generally characterized by poor link utilizations with high link rates [8], resulting in over-dimensioned switches. On the contrary, with low link rates, link utilization is adequate but less energy efficient lower rate lightpaths proliferate. For scarce topologies, the link utilization is improved but detours are achieved. With different transceiver rates (mixed line rate problem), the regenerations can be minimized, as well as the number of transceivers [9].

But to the best of our knowledge, no study considers yet the energy profile of each transceiver rate as an optimization parameter. In this resides a good research opportunity.

VI. INTER-DOMAIN OPTIMIZATIONS

A similar approach can be adopted for inter domain routing. In particular, the number of IP hops can be minimized. This can be achieved by delegating inter-domain routing to sub-IP protocols. In particular, inter domain MPLS extension have been proposed [11].

Besides, inter-domain routing protocols can be adapted to achieve energy efficient routing across the ASs [12], something that BGP fails to achieve so far [10]. Eventually, the ASs topology diameter should be reduced. This has more to see with the economics of the internet. However, simplified schemes permitting at least technically to easily connect two ASs are hardly wished.

VII. CONCLUSIONS

The actual organization of the core networks involves many layers. In this paper, a four layers model has been presented: IP-over-MPLS-over-lightpaths-over-fibers. Based on this model, architectures leading to reduce energetic consumptions have been sketched.

By using a good equilibrium between fully-meshed topologies, energy efficient due to the absence of logical detours, and less connected topologies as the star, energy efficient due to the reduced number of links, the consumption can be optimized. Moreover, by using data links of various rates, the granularity issues inherent to the virtual topology design problem are solved as no links might suffer from bad utilization. Mixed line rates also permit to mitigate the requirements in terms of regenerations.

Energy efficient architectures are thus likely to rely on a fine

mix of low and high throughput data links, organized in a cleverly weaved meshed. Moreover, additional layers may be introduced (hierarchical MPLS).

Optimization models and associated heuristics able to deal with all these aspects and permitting to setup such energy efficiency architectures are now required. This can be one objective of the COST action IC804 focus group on green wired networks.

Besides, efforts must be continued to ease the utilization of MPLS. Tearing up or down an IP link spanning over several MPLS links, each one relying on optically switch lightpaths, should be made as easy as adding a line in a routing table. GMPLS, which involves optical transmission related extension, can be used in that purpose.

These efforts should be accompanied with others aiming at extending the benefits of MPLS to inter-domain communications. In this way, more IP routers will be bypassed, resulting in reduced consumption. Moreover, MPLS can be used to shrink the diameter of the ASs topology, further reducing the energy requirements.

Finally, all these aspects may be considered under both static or dynamic points of view. If dynamic traffic is considered, devices should be able to be put in sleep mode as traffic remains low. Depending on the sleep-mode vs. active-mode consumption ratios, it might be more efficient to multiply low throughput links rather than concentrating all the traffic in few high throughput ones. Hence, the former solution permits a finer modulation of the active links.

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