Solutions to Increase Energy Efficiency of Optical Networks

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Abstract: Power consumption of devices and network functionalities in optical infrastructures is reviewed. Then, possible short-, medium-, and long-term solutions to reduce and make energy consumption scalable are discussed.

1. Introduction

Today the ICT sector accounts for 5-9% of electricity use [1], around 3% of global greenhouse emissions, an amount similar that produced by the airline industry globally [2] – although a much wider number of people benefits from Internet rather than the airline traffic. European Commission – in shaping Europe's digital future – estimates that the ICT carbon footprint could increase to 14% of global emissions by 2040. Solutions to make sustainable the power consumption and the carbon footprint of world network infrastructures, as well as to limit energy expenditure, are mandatory for our society and planet.

Optics applied to communications and networking has been identified since the last century as a technology providing high capacity and offering chances for energy saving: e.g., the power required by operations such as switching or grooming, when performed in the optical domain instead of in the electronic domain, increases much less rapidly with respect to the amount of exchanged data [3]. However, as mentioned before, networks still require high energy, whose value increases with traffic (that constantly grows year by year): i) optical transceivers exploit digital signal processing (DSP) performed by power-hungry electronic ASICs; ii) different network domains are connected through electronic interfaces (IP routers); iii) traffic aggregation is performed at the electronic layer. The identification of solutions to reduce energy consumption, from a short- to a long-term perspective has become mandatory to start planning and setting up a transition to (at least more) green telecommunication networks.

In this paper, we review the power consumption of current commercial devices and network operations. Then, the identification of solutions to increase energy efficiency at the short-, medium-, and long-term is carried out.

2. Power consumption in optical networks

The following power values are retrieved experimentally or through datasheets and are summarized in Tab. 1.

Device/Operation	[W]
Transponder equipped with 2 $\times$ 600G tx/rx	300
ZR+ Pluggable	25
EDFA	15
WSS	12
Aggregation	Hundreds

Table 1: Power consumption [W]

Transponders: commercial transponders include energy-hungry ASICs performing DSP, e.g. for impairment compensation (such as linear dispersions) and signal recovery. As an example, a commercial transponder equipped with two active transceivers at 600G may require around 300 W [4]. The same transponder consumes 120 W when transceivers interfaces are inactive. The power consumption may fluctuate depending on the configured modulation format (or the *operational mode* defining the line rate, the code, and the modulation format), but even on the optical reach to be achieved (a possible explanation may rely on the amount of accumulated impairments which increase with the optical reach, requiring more effort to the DSP). It has been shown that fixing the bit rate is possible to optimize the power consumption through a proper selection of the operational mode [4]. This can bring benefits in the order of 7% in power saving.

Pluggables: while transponders including transceivers are connected to routers through a grey interface, pluggable transceivers are directly installed in router interfaces, thus removing an energy-hungry media/interface between the router and the transponder, and the transponder board itself. Thus, pluggables are already a more green solution for this reason. A single ZR+ pluggable has a target power consumption of 25 W. The main drawback of pluggable transceivers with respect to transceivers installed into transponders is that the optical reach is shorter, since the DSP is designed to meet that power requirements. Currently, the optical reach is in the order of 500 km, but likely in the next few years will increase.

Amplifiers: an Erbium-doped-fiber amplifier (EDFA) may present a power consumption of around 15 W (e.g., WDMLIGHT EDFA), which may slightly fluctuates depending on the output optical power. The recent interest on multi-band optical networks poses the attention on Thulium-doped-fiber amplifiers (TDFA) operating in the S band. TDFAs are based on a higher number of pumps (i.e., three) with respect to EDFA and it is possible to achieve the same target optical output power with different pump configurations. Our preliminary experimental tests on a commercial TDFA show that different pump configurations bring more or less to the same power consumption (around 20 W when amplifying four channels), with only slightly differences. Maybe, amplifiers do not offer many possibilities for energy saving.

Wavelength selective switches (WSSs): compose reconfigurable optical add/drop multiplexers (ROADMs) and present a maximum power consumption of 20 W at startup and less than 12 W at steady state [5].

Opto/Electronic conversion and traffic aggregation: different network segments are typically connected by IP routers or electronic switches, such as the edge nodes connecting metro and access networks. In these network points, such as in the metro edges, optical channels are terminated through transponders/transceivers, then traffic aggregation is performed at the electronic layer, thus relying on power-hungry electronic interfaces and processing. Such architecture is often referred to point-to-point (P2P, see Fig. 1a). As an example, the work in [6] assumes several traffic aggregation scenarios at the edge: e.g. A) 2×100G, where half of the traffic is related to the access (as several flows at 10G) and the other half to the data center inter-connections, all aggregated at Layer 3; B) a similar scenario of (A) with the aggregation carried out by 2× Layer2/Layer3 switches; the related power consumption values can reach 2000 W for the former scenario and 400 W for the latter. Thus, traffic aggregation is a very important functionality impacting the overall network power consumption.

3. Possible solutions to increase energy efficiency

Adaptability and sleep mode: traffic presents fluctuations during the 24 hours, even with drops of 50% in the night time [7]. Transmission rates should adapt to these fluctuations to reduce energy consumption, while currently connections are over provisioned. Regarding sleep mode, similarly to the start & stop system of cars, it has been proposed in the literature to set devices at a sort of stand-by mode at negligible power consumption when such devices are not used [8]; ideally, they can be promply re-waken up when needed. By leveraging traffic fluctuations, it can be possible to re-route the reduced traffic in the network in order to maximize the number of unused devices putting them in sleep mode. However, some problems are present with this solution. First of all, re-routing operations are "costly" and they create instability within the network: as an example, the setup or tear down of optical channels creates variations on the gain profile of amplifiers, impacting the quality of transmission of channels, which is an event that can be even unacceptable. Then, the time required to re-start a optical transponder card and finally having a stable transmission may be in the order of a minute. Thus, to avoid loss of traffic after a sleep mode setup, transponders should be equipped with an intelligence able to predict the traffic patterns. Currently, the sleep mode may have sense in the access segment (on Optical Network Units), rather than in higher-capacity networks (metro/backbone). In order to have a actual support of adaptability and/or sleep mode, a new generation of transceivers is required providing fast adaptation capabilities (e.g., switching on / sleep mode, or partial use of transceiver capabilities) of the full transceiver and also of transceiver functionalities. Then, the energy savings are strictly related to the time window when the traffic daily decreases.

A wider use of pluggables: as mentioned earlier, pluggables are directly installed in routers thus removing the "grey" interface between the router and the transponder, and the transponder itself. This solution can save around 120 W each saved transponder [4].

Digital sub-carrier multiplexing (DSCM) and point-to-multi-point (P2MP): DSCM is a transmission technique proving an additional level of multiplexing: i.e., digital sub-carriers over a wavelength channel. First of all, DSCM offers a finer granularity in setting the line rate of a wavelength channel, thus without the need of always use a wavelength channel at his maximum rate (which usually coincides with its maximum power consumption). Most of all, DSCM offers an interesting property: sub-carriers can be all-optically aggregated over the same wavelength [9]. In recent studies, the P2MP aggregation node architecture has been proposed being based on passive couplers to all-optically aggregate digital sub-carriers. If P2MP is applied to metro/access edge nodes is possible to aggregate traffic by relying on sub-carriers and passive couplers. As shown in Fig. 1b, some transponder interfaces at the edge and the electronic aggregation can be removed. Without considering the contribution of the electronic aggregation, P2MP can achieve even 40% of power saving [9]. Thus, accounting for electronic aggregation, savings are even higher. Regarding the timeline for DSCM and P2MP, transceivers supporting DSCM are already commercially available, moreover they are also available in the form of pluggables. However, further improvements may be needed, e.g., in case of laser drifts, equalization, and additional control functionalities may be required. Furthermore, currently, DSCM is mainly envisioned for the access segments (e.g., with horseshoe topology) in a filterless scenario. New advances are required to extend the P2MP concept for its use in the whole metro segment. Indeed, current switch-&-select ROADM architectures do not support channel switching over more than one port. Moreover, also the control plane is currently designed for P2P connections.

Analog processing: a relevant contribution to the power consumption of transponders is due to ASICs implementing DSP. Enabling processing in the optical domain would strongly reduce the energy requirements. Recently, analog computing is being rediscovered as a low-latency and power-efficient tool for artificial intelligence. In particular, *neuromorphic photonics* allows to implement neural networks (NN) with photonic integrated circuits

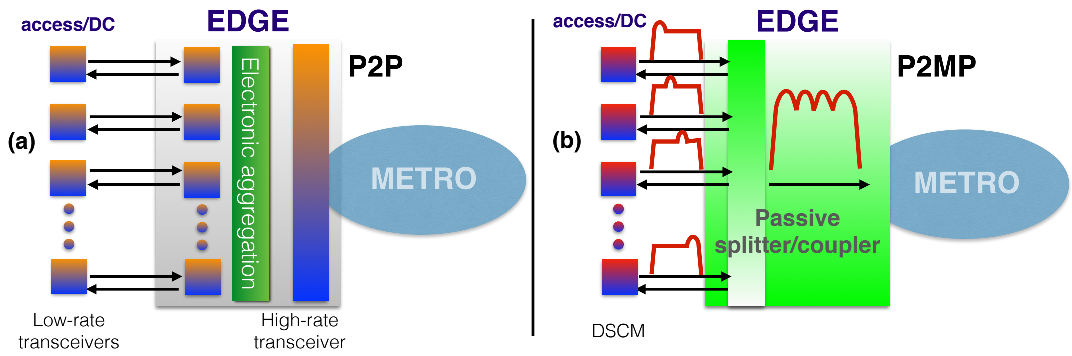

Fig. 1: (a) Traditional traffic aggregation; (b) P2MP traffic aggregation

(PICs), re-creating the linear and non-linear operations of NNs through the behaviour of optical elements such as lasers, switching matrices, and optical modulators. Neuromorphic photonics finds an almost natural fit within the optical communication scenario. The high-bandwidth and low-latency requirements posed by high-speed optical links are well met by PICs, while electronic processors fail to deliver NN processing at such rates. Moreover, the signals are conveniently available in the optical domain, relieving the need for input signals electro-optical conversion. As an example, a PIC compensating fiber non-linearities has been demonstrated in [10]. This technology – or other analog processing techniques – are at a very early stage and can be only thought for long term perspectives, but may strongly increase energy efficiency, by replacing at least the electronic adaptive equalization (which contributes to 50% of the power consumption for electronic DSP [11]).

This discussion is summarized in Tab. 2.

Method	Saving	Issues	Time line
Adaptability / Sleep mode	Tied to traffic fluctuations	Time needed to re-activate the device; possible loss of traffic	short/ medium
Pluggable	$\sim$ 120 W each saved transponder	Reduced optical reach	short
P2MP	$>$ 40% at the edge node	Transmission issues and control aspects to be investigated; P2MP connectivity in metro	medium
Analog processing	Replacing some/all DSP $\geq$ 50%	Immature technology, lack of software standards for implementations	long

Table 2: Methods to increase energy efficiency

4. Conclusions

Possible solutions to increase energy efficiency in optical networks are discussed. At the short term, a wider use of pluggable transceivers is feasible and can reduce power consumption. At the short/medium term, the adoption of P2MP nodes can bring to savings higher than 40% at the edge node. At a long term, analog processing solutions such as meuromorphic photonics should be investigated to reduce power contribution due to DSP. In parallel, advances on electronics should be achieved to reduce energy consumption of electronic components.

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