Optical Networks: How Much Power Do They Consume and How Can We Optimize This?

Willem Vereecken, Ward Van Heddeghem, Bart Puype, Didier Colle, Mario Pickavet and Piet Demeester

Ghent University - IBBT, Department of Information Technology (INTEC); Gaston Crommenlaan 8, Bus 201, 9050 Ghent, Belgium; http://www.intec.ugent.be; ✉ Willem.Vereecken@intec.ugent.be

Abstract *Both bandwidth demand and energy consumption of ICT and communication networks is increasing and optical networks are regarded to provide high bandwidth solutions while enabling more energy efficiency. In this article we give an overview of energy consumption in access and core networks with a focus on optical technologies. Also, possible strategies to enable power reductions are discussed.*

Introduction

In the current Internet the demand for bandwidth is increasing exponentially. New services such as video on demand or community gaming drive these growing data volumes. For example, the thin client paradigm is considered to enable community gaming but requires high definition images to be transported over the network with very little delay[1]. In order to deliver these high bandwidths, optical technologies are regarded as a key enabler.

Also, the attention for climate change is influencing the ICT sector. ICT accounts for 2 to 4% of the worldwide carbon emissions. About 40 to 60% of these emissions can be attributed to energy consumption in the user phase, whereas the remainder originates in other life cycle phases (material extraction, production, transport, end-of-life). By 2020 the share of ICT in the worldwide carbon emissions are estimated to double in a business as usual scenario[2]. Since optical signals consume less power than electrical signals, optical technologies could enable a higher energy efficiency.

In this paper we give an overview of the power consumption of the optical network technologies. We make a distinction between access and core networks. Additionally we review the possibilities being considered to optimize this power consumption.

Core Networks

Core networks consist of multiple nodes connected to each other in mesh or ring topologies. These topologies are designed based on the traffic patterns between the two nodes and the trade-off between redundancy and cost optimization. The connections between the nodes typically consist of wavelength-division multiplexed optical fiber links. In the largest core networks, between 40 and 80 fibers wavelengths are used. Each wavelength has a capacity of 1, 2.5, 10, 40 or 100 Gbps depending on the modulation scheme used. Modulation schemes allowing lower bit rates can be carried over longer distances, typically between 1000 and 4000 km. Higher distances require complete regeneration of the optical signal.

When calculating the power consumption of the optical fiber link one needs to account for the optical amplifiers and the regenerators. An optical amplifier typically consumes 25 W/fiber (bidirectional) and is placed every 80 km. As discussed above, based on the modulation scheme a bit rate per wavelength B_w is achieved with a regeneration distance of D_r. After D_r a regenerator is required consuming 50 W/wavelength (bidirectional). When we denote the number of wavelengths on a link as N_w we get:

$$P_{link}(l) = \lfloor l/80 \rfloor \times 25 + \lfloor l/D_r \rfloor \times N_w \times 50 \quad (1)$$

Due to many legacy deployments the core networks use a variety of technologies. Thus there is no uniform way of characterizing the nodes of the core networks. Generally one can say that the nodes use a mix of several network layers such as e.g. IP-over-ATM-over-SDH. The trend is to gradually move to an IP-over-WDM architecture where the layers in between are omitted.

The power consumption of IP routers is dependent on the throughput capacity of the router. Based on the datasheets of the Juniper T series routers we see a dependency of:

$$P_{node}(C) = 0.032 \times C^{0.82} \quad (2)$$

Note that the exponent 0.82 is estimated to be about 2/3 in other sources[3].

In Fig. 1 we see a summary of the core networks power consumption. Approximately 10% of the power is consumed in the links whereas 90% is consumed in the routers. Based on the datasheets of juniper T series routers[4] we derived that in the routers 25% is consumed by the backplane divided over power supply and fans (40%), routing engine (20%) and switch fabric

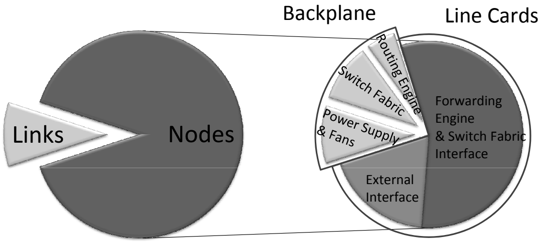

Fig. 1: Core Power Distribution

(40%). The remaining 75% is consumed in the line cards, divided over the forwarding engine and switch fabric interface (75%) and the external interface (25%).

In current considerations we have only accounted the energy consumption of the network equipment. However, in reality some overhead power consumption needs to be accounted for as well. This overhead power consumption originates mainly in the cooling of the equipment, the uninteruptable power supplies (UPS) and some other facility equipment. To account for this overhead a term called *power usage effectiveness* (PUE) is used[5]. It denotes the total consumed facility power divided by the ICT equipment power consumption. In current facilities a PUE of 1,5 to 2 is common. Thus in order to know the total facility power consumed to run a node, equation (2) needs to be multiplied by the PUE.

Access Networks

Access networks are designed to connect as many subscribers as possible to the Internet. They are typically organized in a tree structure. The access bit rate the subscriber perceives is determined by the equipment in the access network. Due to the burstiness of the subscriber traffic, network operators use aggregation factors so the nodes deeper in the access network have a lower throughput capacity than the aggregated capacity of the nodes near the edge. Thus, for the subscriber, there is a difference between the peak bit rate and the average bit rate.

When investigating the power consumption of the access network we look at the power consumption per subscriber. In[3] we find a formula for the per subscriber power consumption:

$$P = P_0 + \frac{PUE_1 P_1}{M_1} + \frac{PUE_2 P_2}{M_2} + \dots \qquad (3)$$

Here P_i denotes the power consumption at node i, M_i the number of subscribers connected to the node and PUE_i the power usage effectiveness of the node i equipment. PUE is again a factor denoting the overhead power consumption. We denoted the highest i the deepest in the network and i=0 as the customer premises.

Due to the tree structure we see that the power consumption of the access network will be determined by the equipment nearest to the customer. We distinct the *customer premise equipment* (CPE, i=0) and the operator owned access network (i>0).

First we discuss the operator owned access network. Due to the increasing demand for higher available bandwidth optical technologies are implemented to replace the current copper based technologies. There are three main types.

In a point-to-point (PtP) architecture a dedicated fiber is used to connect each subscriber. Currently, this implementation is often not feasible since the cost for each connection is high and the bandwidth provided to the subscriber exceeds the demand. Thus, the architecture is often used in government sponsored projects. Deeper in the access network tree the architecture is used to aggregate user traffic since it allows higher bit rates.

A cheaper option is to split the fiber capacity over multiple users. This can be done with either an active splitter, known as an active star architecture or a passive splitter, a passive optical network (PON). The advantage of this approach is that, although the bandwidth is split over 32 or 64 users, high peak bit rates become available to the users. In the mean time the power consumption of the active equipment is shared among the subscribers.

In some situations it is not possible to immediately deploy a full optical access network. Therefore copper based technologies, such as ADSL or VDSL are combined with optical technologies to allow higher bit rates. These solutions are denoted as fiber to the cabinet (FTTC), fiber to the building (FTTB), etc. The available bit rates are lower than the full optical solution, denoted as fiber to the home (FTTH), but still higher than the older, fully copper based solutions.

For numbers of the power consumption of the optical access network equipment we use the Code of Conduct on Power consumption of Broadband Equipment[6], datasheets of different equipment vendors and own measurements in the laboratory. As can be seen from equation (3) the relevant measure for the power consumption of the access network is the power consumed per subscriber. Thus, the power consumption is expressed in Watts per subscriber. Note that in the numbers we give here we have not accounted the PUE. Again, the PUE is about 1.5 - 2. The numbers are based on the power consumption in the first active aggregation node which is responsible for most of the power consumption at the access

Technology	Bit Rate (Mbps)	Power/subs (W/subs)
ADSL	8 – 24	1 – 2
VDSL	26 – 100	3 – 5
GPON	2488 / 32–64	0.2 – 0.8
PtP	1000	3 – 5
	> 10000	10 – 20

Tab. 1: Access Bit Rates And Power Consumption

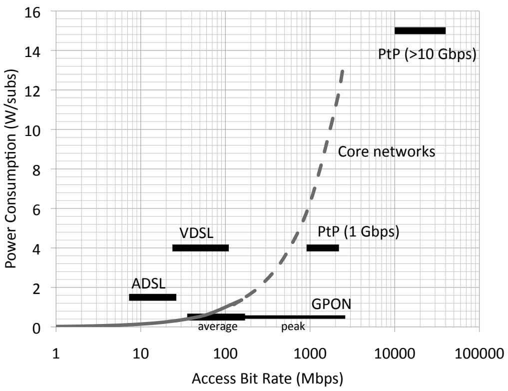

Fig. 2: Bit Rate and power consumption of access network technologies and influence on core power consumption

network provider side.

For PtP technologies the power consumption is between 3 and 5 W/subscriber for bit rates of 1 Gbps and 10 to 40 W per connection for higher bit rates. For GPON (Gigabit PON) technologies the power consumption per subscriber is between 0.2 and 0.8 W/subscriber. This is lower than the power consumption of ADSL (1 - 2 W/subscriber) or VDSL (3 - 5 W/subscriber). These numbers are, together with the access bit rates summarized in Table 1.

In Fig. 2 we see that both the power consumption and the access bit rate of access technologies increases. However, this increase is not proportional. The exception is GPON, where, due to medium sharing the power consumption is significantly lower. The increase in access bit rate has it's effects on the core power consumption as well. If we consider the power consumption consumed in the different core nodes and account this power consumption per subscriber, at access bit rates of 8 Mbps, the overall core network consumes about 0.12 W/subscriber. If we use the relation (2) to estimate the impact on the core power consumption we see that the core power consumption will become more significant. Note that this estimation is assuming the current technology level. If the energy efficiency of the core power consumption increases this impact will be lower.

As stated before, the customer premise equipment (CPE) also has to be accounted for. Commercial optical network units (ONU) consume between 3 and 10 W. This is significantly higher than the power consumption per subscriber at the operator side in a GPON access network. Secondly, on average the CPE for optical technologies tends to be higher compared to their DSL counterparts. Thus, there is a risk that the power optimizations in the access network get annihilated by the increased power consumption at the customer premises.

Power Saving

When it comes to strategies to save power in these networks different strategies are possible. On the highest level one can investigate if optimizations are possible in the network topology. Currently, networks are designed to handle peak loads. This means that when the loads are lower an overcapacity is present in the network. The load on the network is variable. At night time the traffic load can be 25% to 50% of the load during day time. This lower load could allow a more simplified network topology at night which in turn allows certain links to be switched off. Additionally, the switching off of these links allows for line cards to be switched off and thus leads to reduced node power consumption. An example which implements this principle is multilayer traffic engineering[7]. The MLTE approach can lead to power savings of 50% during low load periods.

Since access networks are organized in tree structures, shutting down links is not a feasible option. Thus, dynamic topology optimization cannot be applied in an access network.

On a given topology further optimizations can be achieved by using adaptive link rates and burst mode operation. *Adaptive link rate* is based on the principle that lower link rates lead to lower power consumption in the network equipment. By estimating the average link rate required on a line and adapting the link rate to this level power saving becomes possible. Another possibility is *burst mode operation* where packets are buffered in a network node and then sent over the link at the maximal rate. In between the bursts the line can be powered down. These strategies can be mainly useful in access networks due to the burstiness of the traffic. However, the difference in power consumption between different link rates is mainly manifested at the higher bit rates. Secondly, burst mode operation works on very small time scales so the number of components which can be switched off is limited. Finally, both approaches require larger packet buffers which also need powering. Hence it is yet unclear whether the strategies in reality can lead to significant

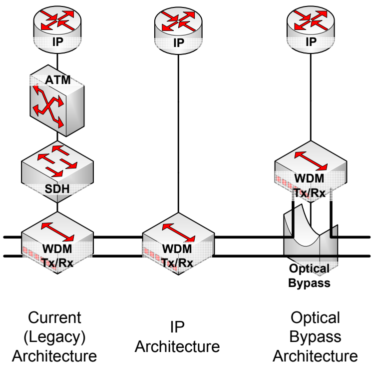

Fig. 3: Core Architecture Evolution

power optimization.

Optical bypass is a strategy where the traffic which is not intended for an intermediary node in a network is bypassed. The technique is displayed in Fig. 3. Instead of processing every packet arriving in the node, certain traffic is bypassed in the node and forwarded to a node further in the network. This leads to lower traffic requirements for the nodes, but longer optical path lengths. In low traffic scenario's the gain can be low due to the limited use of channel capacity on the links, e.g. 2 Gbps traffic on a 10 Gbps channel. However, with increasing traffic demands optical bypass can lead to power savings up to 50% compared to fully opaque networks. In these cases the share of router power consumption is closer to 80%[8].

In PON networks, the technique could also be used to separate the traffic meant for other destinations in the PON from traffic intended for the external network.

The individual components in a network can be optimized as well. Currently, all routing is electrical, so in routers optical-electrical-optical conversions need to take place. Optical packet switching could eliminate these conversions and thus can lead to lower power consumptions. However, the technique is quite novel and whether or not it will lead to significant power savings is still under debate.

Finally, the CPE allows for significant power consumption reduction. It only needs to be active when a user is active and when the user is inactive, it can be put in standby. With emerging legislation concerning 1 W or 0.5 W norms for standby operation this can lead to significant optimizations.

New network paradigms

Finally, the higher bandwidths optical technologies offer can also lead indirectly to power savings. In the introduction we already mentioned the thin client paradigm as a solution to enable community gaming. The paradigm, however, can allow the replacement of desktop computers by less power consuming thin clients. It is estimated that implementing thin clients could lead to 66% power consumption reductions[9].

Acknowledgements

The work described in this paper was carried out with the support of the BONE project (”Building the Future Optical Network in Europe”), a Network of Excellence funded by the EU's Seventh Framework; the IBBT-project GreenICT and the STRONGEST project funded by the EU's Seventh Framework Programme FP7/2007-2013 under grant agreement n 247674.

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