The Future Internet – an Energy Consumption Perspective

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Abstract
We compare the abilities of photonic and electronic technologies for improving energy efficiency of the Internet. It is not clear whether photonic signal processing technologies will provide a pathway to improving Internet energy efficiency.

Introduction

The continued growth of the Internet is accepted as a fact of modern life. Despite the 2001 dot-com crash and the recent economic downturn, the Internet continues to grow with vigour [1]. Expectations are that interactive video services will drive significant ongoing growth of Internet traffic [2]. However, it may not all be plain sailing. Concerns regarding cost constraints and power consumption are now appearing [3,4]. In this paper we will discuss the opportunities afforded by electronic and optical technologies to improve the energy efficiency of the Internet as access rates increase.

Power Consumption in the Internet

Recent modelling of power consumption of the Internet show that, today (with access rates around 1 Mb/s), the Internet (excluding home networks and PC's, and data centres) consumes about 0.5% of the current electricity supply of a typical OECD nation [4,5]. With current (2009) technology, this will grow towards 0.75% as access rates increase to 100 Mb/s [5].

Although 0.75% of national electricity generation may appear to be a relatively small fraction, this consumption is concentrated in a small number of network facilities. These facilities require significant power input and heat extraction, which are already significant challenges for the IT industry [6,7].

The model in [4,5] shows that today power consumption is dominated by the access network, particularly home gateway, which typically consumes around 5 to 7 Watts. As access rates increase, core router power consumption will grow and become dominant.

In core routers power consumption is dominated by forwarding and cooling [8]. Forwarding consumes approximately 40% of router power. This includes tasks such as: address resolution, packet forwarding, forwarding table updating, packet monitoring and security [9]. These functions require significant signal processing of the packets. Cooling also consumes 40% of router power. The cumulative power consumption of the remaining router functions and the transmission links between routers constitute only a few percent of total power consumption of the Internet [8].

With current technology, power consumption in the Internet is overwhelmingly dominated by signal processing in the home modem and in the router forwarding engine. Therefore to attain significant improvements in the energy efficiency of the Internet, attention needs to be focused on these two areas, rather than sub-systems such as buffering and O/E/O conversion.

Using this approach, Internet energy efficiency can be improved by combination of the following: a) making the signal processing technologies in the router and home gateway more energy efficient; b) placing these subsystems into a low energy (sleep) state when not in use; c) reducing the usage of these subsystems.

Signal processing technologies.

Currently routers and the home gateway use CMOS electronics. However, as router throughput increases, photonic signal processing has been proposed as a candidate for improving their energy efficiency [10].

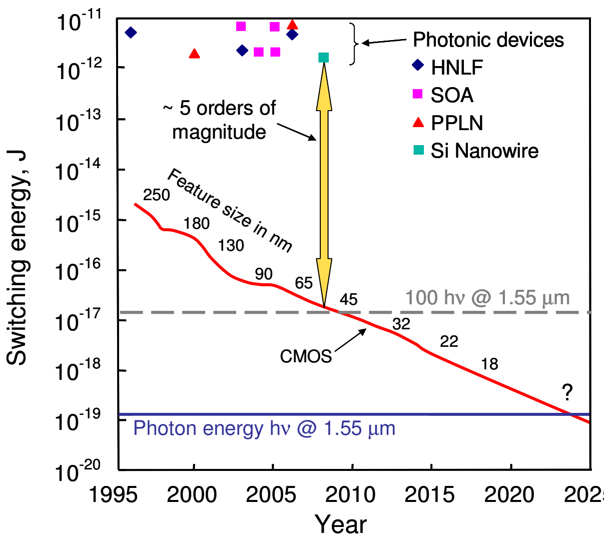

Fig. 1 Switching energy trends of electronic CMOS and photonic signal processing technologies of Highly Nonlinear Fibre (HNLF), Semiconductor Optical Amplifier (SOA), Periodically Polled Lithium Niobate (PPLN) and Silica Nanowire (Si Nanowire) [11].

Fig. 1 shows the switching energy trends of electronic (CMOS) and several key photonic technologies [12,13]. We see that photonic technologies are significantly more power hungry than CMOS.

Current trends in the telecommunications industry indicate that CMOS based core router energy efficiency is improving by about 20% per annum [6]. But to transfer this full 20% annual improvement to the network, all core routers would have to be replaced each year. Such an aggressive capital expenditure program is very unlikely. A more realistic strategy is to deploy the latest generation of equipment to accommodate increases in capacity demand. With an expected IP traffic annual growth rate of 42% [2], the effective annual energy efficiency improvement rate will be around 10%. In contrast to this, we see from Fig. 1 that photonic signal processing technologies have not shown anything close to this magnitude of annual energy efficiency improvement over recent years

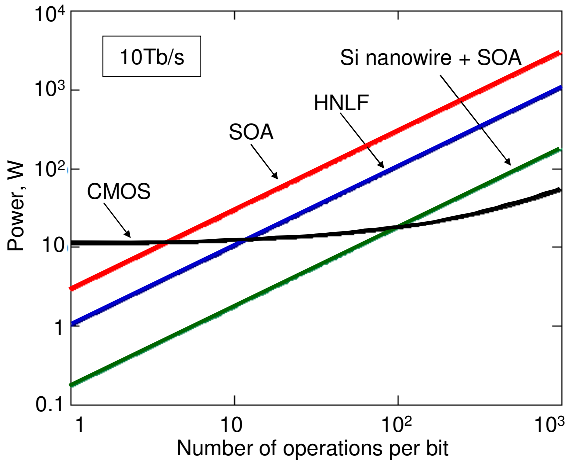

Fig. 2 Power consumption vs number of operations per bit for CMOS and photonic signal processing technologies at 10 Tb/s.

As bit rates increase to cope with increasing traffic volumes, CMOS signal processing will continue to be the most power efficient technology when significant processing is required [14]. Switching and routing require several operations to be performed on the data stream. Fig. 2 shows the power requirements of CMOS (including O/E/O) and photonic technologies as a function of the number of processing operations per bit at throughput of 10 Tb/s [14]. Except for very simple signal processing sub-systems, CMOS requires the least power of the technologies considered.

Sleep state and rate adaptation

CMOS power consumption is dependent upon processing speed [15]. Therefore, power savings can be attained by either reducing processing speed (rate adaptation) or placing the processor into a sleep state when traffic demands are sufficiently low [15]. In contrast, photonic signal processing technologies rely on an optical non-linearity which requires an ongoing supply of power independent of the processing speed [13]. Therefore, rate adaptation strategies cannot be easily applied to reduce energy consumption of these devices. Using a sleep state may be applicable provided the 'wake-time' is sufficiently brief [15].

Circuit switched WDM optical bypass

Although signal processing cannot be avoided in the home gateway, some (but not all) of the routers can be by-passed. Router bypass is implemented by grooming the data flows so that traffic not destined for a given router is placed onto a WDM wavelength that is not processed by that router [5,16]. This is accomplished by placing a WDM (circuit switched) optical cross connect between the router and the incoming optical port so as to direct WDM channels, not destined for that router, directly to the node output rather than into the router [5]. Optical bypass saves power because the switching energy of an all-optical circuit-switched cross connect is lower by two orders of magnitude than the equivalent router switching energy [4].

Conclusions

Signal processing in the home gateway and router forwarding engine dominate power consumption in the Internet today and may continue do so into the future. Because photonic signal processing technologies require significantly more power than CMOS, all-optical signal processing technologies are not a pathway to improving energy efficiency of the Internet even as IP traffic volumes and bit rates increase.

The energy saving strategy of rate adaptation is available in CMOS technologies but not current photonic signal processing technologies. Sleep state strategies can be applied to both CMOS and photonic technologies.

All optical circuit switching technologies will provide for significant energy savings by use of optical bypass.

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