Growth and Sustainability Aspects of WDM

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Abstract: Internet growth leads to exponentially increasing WDM-systems energy consumption. WDM systems should be replaced by more-efficient successors after certain time to optimize related use-phase carbon emissions. These emissions are overcompensated by the Greening-by-ICT effect.

1. Introduction

Globally, we face severe environmental problems, most notable regarding carbon emissions or climate change, but also related to abiotic resource depletion, waste generation and general pollution. The former is addressed by attempts toward decarbonization, the latter are addressed by circular economy. The ICT sector globally consumes substantial energy and produces ~3% of global emissions [1]. From this, approximately 25% can be associated with the networks, the reminding majority with data centers and end-user equipment [2]. The network part splits approximately equally into wired and wireless networks. The WDM contribution to ICT energy consumption or emissions is in the range of 5%. Despite the relatively small detrimental contribution, WDM must become more environmentally friendly, following customer pressure and potentially upcoming regulations. This is particularly true since energy consumption of WDM is exponentially increasing, following similar growth of total Internet throughput. At the same time, WDM, as the backbone of the ICT sector, supports decarbonization in other sectors, the so-called Greening-by-ICT effect.

In this work, an overview is given on Internet growth and related ICT equipment throughput, power consumption, and emissions, with particular focus on WDM. This is compared to the potential decarbonization effects in sectors other than the ICT sector, e.g., mobility or the energy sector. Finally, the question of replacing ICT equipment after a certain use period for reasons of energy efficiency and resulting carbon emissions is discussed.

2. Growth, growth, growth, …

Since the global ramp-up of the Internet, its throughput and the associated bitrates have been growing exponentially. This can be derived, e.g., from the Cisco Visual Networking Index, VNI, [3]. It is shown in the left part of Fig. 1. The traffic growth is driven predominantly by video traffic, as can also be derived from [3].

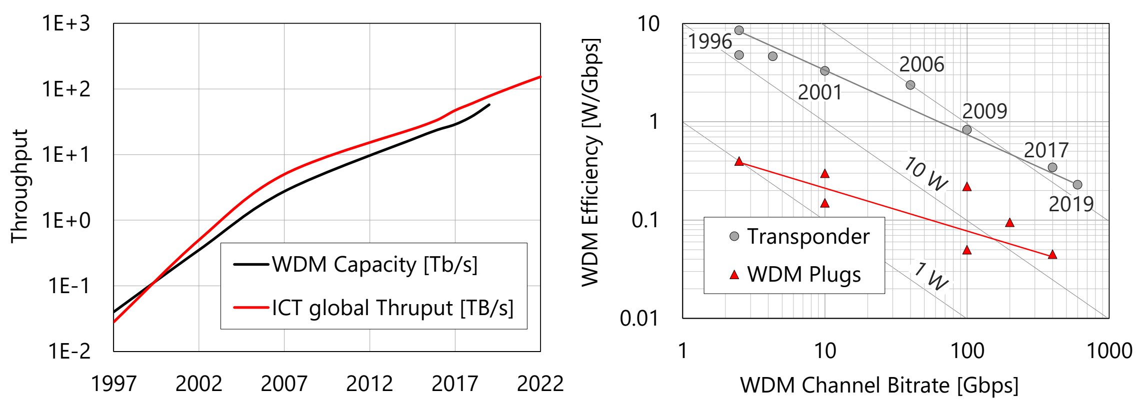

Fig. 1. Development of Internet throughput and WDM-system capacity, respectively, over time. Note the different units Tb/s and TB/s (left). Development of WDM power consumption and efficiency over bit rate or time (right).

The exponentially growing bitrates of Internet applications lead to respectively growing throughput per ICT equipment. In the last one to two decades, this increase has been overcompensated for end-user equipment regarding energy consumption and related emissions due to strong gains in energy efficiency. ICT data-center and network equipment also got more efficient. However, it also had to cope with the accumulated bandwidths of an increasing number of applications. For core-network equipment (switches, routers, and WDM equipment) it has not been possible to cope with this bandwidth growth by gains in energy efficiency: *as a result, core-network equipment, over time, consumes more energy* [4, 5]. As an example, the power efficiency for WDM transponders improved by a factor of ~50 from approximately 10 W/Gbps in the mid-90s to almost 0.2 W/Gbps for the latest generation in 2021. The power-efficiency development for WDM is shown in the right part of Fig. 1. When comparing the trend curves for WDM transponders and pluggables to the iso-lines of constant power consumption, it becomes apparent that WDM power consumption increased over time.

In addition to bandwidth growth which is likely to be sustained over the next couple of years, we are approaching another problematic area. The increase of energy efficiency in electronic switching and fiber-optic transport is approaching some fundamental limits in the next 20 years or so. Ultimately, for both, electronic switching and photonic signal transmission, this will be the Shannon-von Neumann-Landauer (SNL) thermal limit [6-9]. Here, the per-bit energy is lower-bound by:

$$E_{\mathrm{bit}} \geq E_{\mathrm{SNL}} = k_{\mathrm{B}} T \ln 2$$

Here, k_{B} is Boltzmann's constant, and T is absolute temperature in Kelvin. Minimum size and switching time of a machine at the SNL limit can be derived from Heisenberg's Uncertainty relation:

$$t_{\mathrm{min}} = \hbar/\Delta E = 0.04\ \mathrm{ps}\,,\ x_{\mathrm{min}} = \hbar/\Delta p = 1.5\ \mathrm{nm}$$

Here, ΔE and Δp are the energy and momentum uncertainties, and $\hbar$ is the reduced Planck constant, respectively. The power dissipation per unit area of such a machine is given by, with size-limited density of switches n_{max}:

$$P = n_{\mathrm{max}} E_{\mathrm{bit}} / t_{\mathrm{min}} = 3.7 \cdot 10^6\ \mathrm{W/cm^2}$$

This switch has only a factor of 6 less size than 22-nm node CMOS technology (complementary metal-oxide semiconductors with physical gate length of 9 nm). Its power density is $4 \cdot 10^4$ larger than end-of-ITRS (International Technology Roadmap for Semiconductors) projections. It would thus require forced cooling. The practical consequence is the end of combined density / switching-speed scaling. Without disruptive developments, minimum switch size will stop somewhere near 1.5 nm.

Disruptive new developments are not clear right now. Theoretically, thermodynamically reversible computing can break the SNL limit [6, 9]. Other technologies like carbon nanotubes [8] or biological-cell processors [9] may allow to get closer to the SNL limit than CMOS technology. However, they do not yet present mature technology.

3. ICT impact and Greening-by-ICT

As a consequence of the persistent traffic growth, the related negative ICT environmental impact grows as well. This holds for all environmental impact like global-warming potential, resource depletion, ozone depletion and others.

There is one important aspect that can relax the emissions situation, which results from the energy consumption. This aspect is sometimes referred to as *Greening-by-ICT*. It results from emissions savings in sectors other than ICT that are enabled by ICT. According to [1], the carbon-saving on a global scale can be almost a factor of 10 higher than the ICT emissions themselves. This is indicated in Fig. 2. It shows the development of the total global carbon emissions [10], forecasted ICT emissions and the potential Greening-by-ICT carbon savings.

Global ICT-enabled CO_2 Reduction 2030	
Sector	**$GtCO_2e$**
Manufacturing	2.7
Energy	1.8
Buildings	2.0
Mobility	3.6
Agriculture	2.0
Total global	**12.1**
Global ICT Emissions 2030	**1.25**
Saving Factor	**9.7**

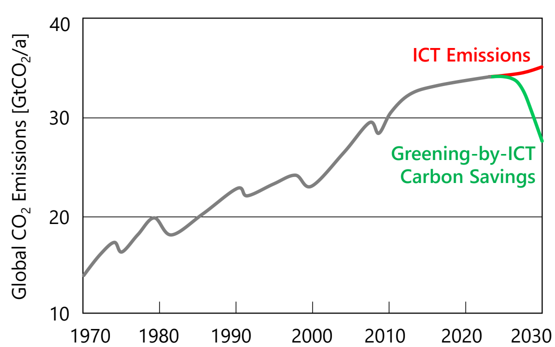

Fig. 2. Forecasted ICT carbon emissions and emission savings in other sectors (listed in the table on the left, [1]).

Greening-by-ICT will not solve the energy-efficiency problem of ICT that are to become apparent in one to two decades. This has to be tackled by a holistic approach considering all layers from semiconductors via systems to finally networks. Neither can it solve any of the resource-depletion and electronics-waste problems that may result from using an increasing amount of ICT equipment. The latter have to be addressed by circular-economy principles [11, 12].

In turn, ICT most likely will become the most relevant enabler for massive decarbonization in other sectors.

4. Lessons to be learnt from lifecycle assessment

Any action intending to improve WDM environmental footprint must be guided by lifecycle assessment (LCA). This is the structured, data-based approach to consider all impact across the entire lifecycle, from production via distribution and usage up to the end-of-life treatment (electrical and electronic equipment must not be land-filled) [13]. For WDM and other classes of ICT equipment, it must be known if energy consumption and related emissions cause the highest environmental impact, or if material (resource) consumption and the related circular-economy characteristics need stronger attention. Circular economy attempts to keep all equipment, components and finally material in closed loops as long as possible [11, 12]. Consequently, longevity or extended usage are key elements.

For practically all ICT equipment, usage and production are the two most relevant LCA phases, other phases can be neglected to first order. If extended usage is to be assessed, the changing electricity emission factors, i.e., the amount of carbon emissions generated per kWh of electrical energy consumed, must be considered. These factors improve due to the amount of renewable energy increasing over time. Similarly, the (saturating) energy-efficiency gain of later equipment generations must be taken into account. Then, emissions of WDM and other equipment can be displayed over time, see Fig. 3. The steps in the diagrams mark the respective production emissions.

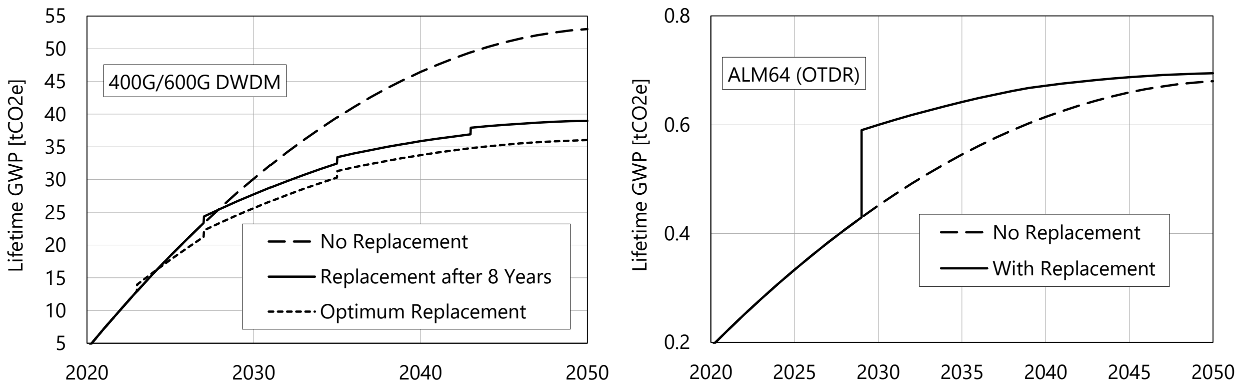

Fig. 3. Lifetime optimization of the global-warming potential (GWP) for high-capacity WDM equipment (left) and for a fiber-plant monitoring device (OTDR, right). The steps mark the next-generation production GWP.

For latest high-capacity coherent WDM (Fig. 3, left), replacement by more efficient successor generations is advisable in order to minimize total lifetime carbon emissions. Over time, replacement periods get longer due to changing emission factors and efficiency gain. Similar behavior can be derived, e.g., for core routers and switches. Different behavior can be seen, e.g., for OTDRs intended to permanently supervise passive fiber plant (Fig. 3, right). Here, replacement by a more efficient unit after certain time would increase total resulting emissions. The reason obviously is the different ratio of use-phase to production emissions. This ratio is derived from LCA.

5. Conclusions

Like other ICT equipment, WDM is running into a scaling problem. Ever since the ramp-up of the Internet in the mid-90s, it has seen exponential bandwidth growth, and the gains in energy efficiency could not compensate this growth. Meanwhile, further slow-down of efficiency improvements is seen, and it is at least unclear if disruptive future developments like biological-cell processors can be exploited quickly enough.

Carbon emissions are not growing exponentially due to improving emission factors. Moreover, WDM and more general, ICT emissions are over-compensated by emission savings in other sectors. Therefore, WDM is more an enabler of decarbonization, rather than one of the relevant environmental problems.

6. References

[1] #Smarter2030 ICT Solutions for 21st Century Challenges, Executive Summary, GeSI and Accenture, 2015
[2] Hintemann et al., Electronic Goes Green 2016+, Berlin, September 2016
[3] Cisco White Papers, "The Zettabyte Era," 2016, 2017, Cisco Visual Networking Index (VNI), 2018
[4] H. Mellah, B. Sansò, June 2011, DOI: 10.1109/WoWMoM.2011.5986484
[5] Vereecken et al., IEEE COMMAG, Vol. 49, No. 6, 2011
[6] MIT OpenCourseWare 6.701 / 6.719, Spring 2010
[7] Mamaluya and Gao, Appl. Phys. Lett. 106, 193503 (2015), dx.doi.org/10.1063/1.4919871
[8] Zhirnov et al., Proc. IEEE, Vol. 91, No. 11, 2003
[9] Zhirnov et al., in: ICT – Energy – Concepts Towards Zero – Power Information and Communication Technology, dx.doi.org/10.5772/57346
[10] Retrieved from: ourworldindata.org/co2-and-other-greenhouse-gas-emissions
[11] Cesaro et al., Global NEST Journal, 20(4), 743-750, 2018
[12] Ellen MacArthur Foundation,www.ellenmacarthurfoundation.org/circular-economy/concept/infographic
[13] M. Finkbeiner et al., Int. J. LCA, Vol. 11, No. 2, 2006