Worldwide Energy Needs for ICT: the Rise of Power-Aware Networking

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***Abstract*— As Information and Communication Technology (ICT) is becoming more and more wide-spread and pervasive in our daily life, it is important to get a realistic overview of the worldwide impact of ICT on the environment in general and on energy and electricity needs in particular. This paper reports on a detailed study to estimate this impact today and to predict how this will evolve in the future. From this survey important conclusions for the future of ICT industry and the internet will be drawn, and challenges and research directives will be deduced.**

***Index Terms*— power consumption, internet, statistics, forecast, electricity, network concept, servers.**

I. Introduction

ICT has a rather environmentally friendly image to the public community. This is largely correct: the worldwide communication via datacom and telecom networks has transformed society drastically and has opened opportunities to reduce the human impact on nature. Some typical examples are the rise of e-commerce, tele-working, tele- and video-conferencing, reducing the worldwide traveling of both people and goods and hence the consumption of petroleum and the emission of greenhouse gases. A quite different example is the use of environmental sensors. Through wireless sensor network technology, different parameters like temperature, sun light and humidity can be measured and exploited to optimize the energy management in buildings. This ICT revolution has only just begun, and will have an ever stronger impact in the years to come.

However, some dark clouds are looming at the horizon. The high penetration of ICT in our daily lives has as a drawback that the energy consumption of computers and network equipment is becoming a significant portion of the energy consumption worldwide and this portion is expected to grow steeply over the coming years. This energy consumption contains many obvious and less obvious facets. Of course electricity consumption of the ICT equipment during the operational lifetime is important. But also the complete manufacturing process to produce ICT equipment (with in many cases limited economical lifetimes) and the disposal process afterwards are having a large impact.

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II. Energy for ICT: Situation Today

Because it is crucial to get a good overview on the main energy footprint factors in ICT in order to detect possible improvements, we have carried out an extensive survey to assess the major energy consumption factors in ICT.

A. Electricity consumption of ICT equipment during use

The most obvious ICT effect is the electricity consumption of all kinds of ICT equipment during operational lifetime. A first important factor is of course the power consumption of devices during active mode. Some typical values are shown in Table 1.

Equipment type	**Power consumption during active mode (average load)**
Desktop PC with LCD display	100 W
Desktop PC with CRT display	150 W
Laptop PC	30 W
CRT TV	150 W (0.34 W / sq. inch)
LCD TV	190 W (0.29 W / sq. inch)
Plasma TV	330 W (0.34 W / sq. inch)
Gaming console	190 W
Volume server[2]	220 W
Mid-range server[2]	700 W
High-end server[2]	10000 W
Core routers and switches[3]	5 W per Gbit/s throughput
Access routers and switches	> 10 W per Gbit/s
Home gateway	7 W
GSM Base Station	700 W
WiMAX Base Station	400 W

Table 1: ICT equipment and corresponding power consumption.

A second important factor is the number of devices in use worldwide, ranging from 30 million volume servers and 1.5 billion TVs to 60 thousand high-end servers for instance. Also the percentage of time in active mode has a large influence, ranging from being active 24 hours a day and 7 days a week for many servers to devices where the standby electricity consumption is even larger than the active electricity consumption (for instance for infrequently used audio

[2] Infrastructure energy for cooling, UPS, etc. not included

[3] E.g. IP routers, SONET/SDH cross-connects and add-drop multiplexers, Ethernet switches

installations).

In our survey to estimate the total electricity consumption of ICT equipment during operational lifetime, we have included consumer electronics like TVs, audio equipment, DVD players, gaming consoles, etc. The boundary between these devices and classic ICT equipment like PCs is becoming more and more blurry, being more and more connected to the network and directly influenced by new network paradigms.

The following five main categories were distinguished:

1. Data centers: including servers, storage devices, network equipment at data centers, but also cooling, backup power infrastructure like UPS systems, and so on.
2. PCs, i.e. both desktop and laptop PCs, including computer screens, network interfaces in PCs, etc.
3. Network equipment, including datacom and telecom networks, but excluding network equipment inside data centers or built-in in PCs.
4. TV sets, including video and DVD players.
5. Other ICT equipment, containing all ICT equipment not contained in the first 4 categories, such as audio equipment, telephone handsets, gaming consoles, printers, copiers and fax machines.

For the estimation of total power consumption in data centers worldwide (incl. cooling), various sources can be found that are more or less in agreement. A recent and quite extensive study can be found in [1]. Based on these studies, a yearly average of about 29 GW can be expected for data centers worldwide in 2008.

The estimation of PC power consumption is mainly based on the number of PCs used worldwide, the average power consumption of different desktops, laptops and computer screens when in active / standby / off mode and the average weekly ratios of these 3 modes for professional and residential users. After critical comparison of these results with previous estimations in literature, the 2008 estimation is about 30 GW.

Due to its distributed character and wide diversity in network equipment types (routers, switches, modems, line cards, etc.), a direct estimation of network equipment power consumption worldwide is notoriously difficult. However, based on many inventory surveys (e.g. [2]) in the past, together with annual power growth estimates and comparison with the power consumption of data centers and PCs in the same surveys, a reasonable estimation can be made, leading to a worldwide network equipment consumption of about 25 GW.

In the case of TVs, the estimation is mainly built upon the number of used TVs worldwide, the average power consumption during active/standby/off mode for different TV types (mainly CRT, LCD and plasma) and the average number of hours per week in each mode. After matching with previous surveys in some countries, we concluded that the total power consumption of TV sets worldwide is about 44 GW.

A lot of other ICT equipment types are not falling within the 4 categories mentioned above: audio installations, gaming consoles, office equipment like printers, copiers and fax machines represent considerable power consumption. As in many previous country-specific survey studies, we have combined all remaining ICT equipment types in a fifth category. Typical estimations here are in the same range as the contribution of TVs: about 40 GW.

The main results of this survey have been summarized in Fig. 1. This leads to a total of about 168 GW, which is more than 8% of the global electricity consumption and about 2.6% of the worldwide primary energy consumption.

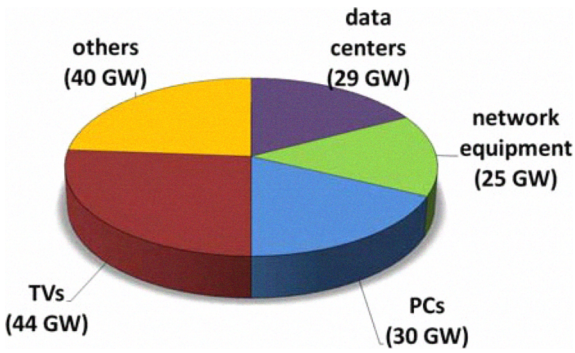

Fig. 1: Electricity consumption of ICT equipment during operation worldwide (yearly average 2008).

B. Energy consumption for manufacturing of ICT equipment

Electricity consumption during the use phase may be the most obvious energy demand of ICT equipment, it is definitely not the only one. A regular PC for instance requires considerable energy sources before it is plugged in for the first time: the production of PCs is a manufacturing process with high energy needs. The life cycle assessment of ICT devices is a highly complex task, because it involves the modeling of the complete manufacturing process, from the extraction of the raw constituting materials, via the different steps to produce the building blocks and the transportation of all kinds of components between different geographical locations, to the final product. Moreover, it also involves the end-of-life process, from e-waste collection to recycling or landfills [3].

Taking all influencing factors into account, the complete life cycle (production, use and end-of-life) of ICT is probably responsible for about 4% of the worldwide primary energy consumption.

III. Energy for ICT: Future Trends

To judge where we are heading to, the absolute numbers of ICT energy use today are important, but even more crucial is to predict how these numbers will evolve in the next years. For the main categories of ICT equipment, it will be estimated how much the electricity consumption during use will change in the years after 2008. This evolution will be characterized by estimating the annual growth rate, as explained below.

For data centers, detailed recent studies [1] indicate that the overall power consumption of data centers worldwide is expected to grow by 12% p.a. This considerable growth is mainly caused by the ever growing data volumes to be

processed, stored and accessed, and the associated power for cooling.

The growth rate for PCs power consumption worldwide is expected to be somewhat lower: about 7.5% per year. This is mainly caused by the growing number of PCs that are used worldwide (growing by about 10% p.a.) and the ever rising data volumes to be processed by a PC. On the other hand, the gradual trends to replace CRT by LCD screens and to replace desktop by laptop PCs have a positive impact on the power consumption.

For network equipment, the power consumption growth rates are typically in the same range as for data centers: about 12% per year overall. Especially the growing wireless access infrastructure (for mobile phones, wireless computer access, etc.) and the quick rise of home networks are responsible for steeply growing power consumption rates.

For the other ICT equipment types, large differences in growth rates can be noticed. Worldwide power consumption of TVs is growing considerably (estimated growth rate of 9% p.a.), mainly due to the gradual replacement of CRT technology by (larger and hence more power consuming) flat screens. On the other hand, worldwide power consumption of audio equipment is stagnating. On average, an annual growth rate of 5% p.a. is a reasonable estimate.

Based on these growth rates and the absolute power consumption values from section III, the electricity consumption in the coming years can be estimated. The results are shown in Fig. 2.

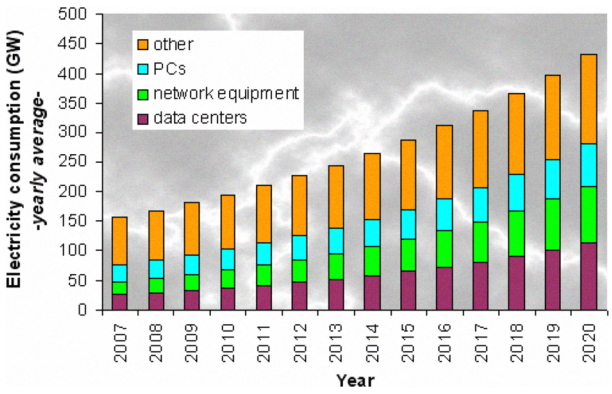

Fig. 2: Electricity consumption forecasts of ICT equipment during use.

From this figure, a key conclusion can be drawn. The overall power consumption of ICT equipment is growing steadily, from 168 GW in 2008 to about 430 GW in 2020. Even if we assume a 3% electricity consumption growth of all other (non-ICT) equipment, this comes down to a relative contribution of ICT in electricity consumption from 8% in 2008 to more than 14% (i.e. 1/7) in 2020! Note that the manufacturing energy for ICT equipment is not even included in these figures.

IV. Research Challenges

From these forecasts, it is clear that the pressure on power-efficiency for ICT will become more and more prominent in the coming years. The relative importance of power consumption in the total cost of ownership (TCO) of ICT infrastructure will grow significantly, and become a key cost factor. For the ICT industry, it is crucial to anticipate to this trend by initiating research actions as soon as possible.

One of the key measures is the power optimization of the hardware of individual devices. The 'room for improvement' is large, as the example of laptop versus desktop PCs shows. The power consumption of a laptop PC is typically only a small fraction of a desktop PC, for basically the same functionality. Another example is the world of flat screen TVs: more energy-efficient technologies (e.g. based on LEDs) have the potential of huge energy savings.

Although software is only indirectly linked with power-efficiency, its impact can be considerable. A typical example is the new release of an operating system and the resulting PC replacements (leading to extra manufacturing energy). On the other hand, intelligent power management software, adapting to the user behavior, can lead to important power savings for PCs, screens and in data centers.

Whereas the previous measures concentrate typically on one type of equipment, it is crucial to consider also the big picture of various terminals all around the world interconnected via a common network infrastructure. New, clean-slate network paradigms could change the energy footprint of ICT drastically, leading to lower power consumption for both network infrastructure and terminal devices. For instance, the so-called 'Thin Client' concept could severely reduce power needs [4].

An important initiative on the network level was taken by the IEEE Study Group on Energy-efficient Ethernet [5]. The Study Group explores the realization of an Adaptive Link Rate, allowing to temporally reduce the bandwidth and hence also the power consumption of Ethernet links during quiet hours and to return quickly to full bandwidth when needed. A similar concept can be applied to ADSL access networks, or to keep PCs connected to the LAN while sleeping [6].

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