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ICT ENERGY CONSUMPTION – TRENDS AND CHALLENGES

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ABSTRACT

Information and communications technology (ICT) systems are the core of today's knowledge based society. Innovations in this area are adapted at tremendous speed and worldwide use of ICT has soared in recent years. However, this unprecedented growth comes at a price: ICT systems are meanwhile responsible for the same amount of CO_2 emissions as global air travel. If the growth of ICT systems energy consumption continues at the present pace, it will endanger ambitious plans to reduce CO_2 emissions and tackle climate change. Increasing the energy efficiency of ICT systems is thus clearly the major R&D challenge in the decades to come.

I. ICT MARKET TRENDS

Rarely have technical innovations changed everyday life as fast and profoundly as the massive use of the Internet and introduction of personal mobile communications. In the past two decades both grew from niche market applications to globally available components of daily life: The first GSM phone call took place 1991 in Finland – only 15 years later there were over 2 billion GSM users [1]. In November 2007, every second inhabitant of this planet possessed a mobile telephone [2]. In the same time span, the number of internet servers rose by roughly a factor of 1000: from 376'000 to 395 million [3]. The driving force behind these two developments was, and continues to be, "Moore's Law" (or rather the ITRS roadmap), according to which both the processing power of CPUs and the capacity of mass storage devices doubles approximately every 18 months. This in turn renders the use of ever more powerful ICT systems attractive for the mass market. In order to be able to transport this exponentially rising amount of available data to the user in an acceptable time, the data transmission rates both in the (wired) internet and wireless networks (including cellular, WLAN and WPAN) have been rising at the same speed – by about a factor 10 every 5 years, as illustrated in Figure 1.

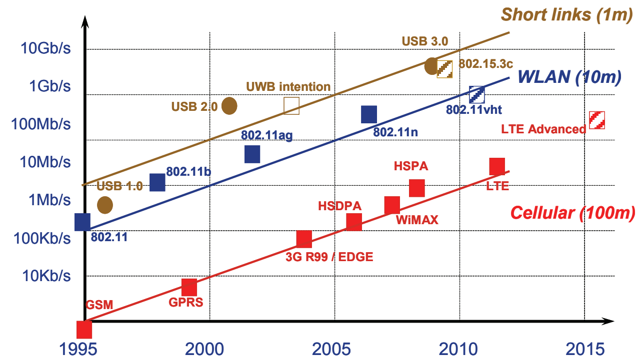

Figure 2: Development of data rates in wireless networks over time. A ten-fold increase can be observed every five years, coinciding with the speed of "Moore's Law"

Many achievements of information society are based on the global success of information technology which has been made possible by innovations in microelectronics. In the last years, ICT systems have been responsible for the enormous economic boom not only of former developing countries like Taiwan, South Korea and Singapore, they have also been the source of at least a fourth of the BIP growth of developed nations like the United States [4] and the European Union [5]. Instead of opening up a "digital divide" between the first and the third world, the use of ICT has so far lead to the opposite.

II. ICT ENERGY CONSUMPTION TRENDS

The price paid for this enormous growth in data rates and market penetration is a rising power requirement of ICT systems – although at a substantially lower speed than "Moore's Law".

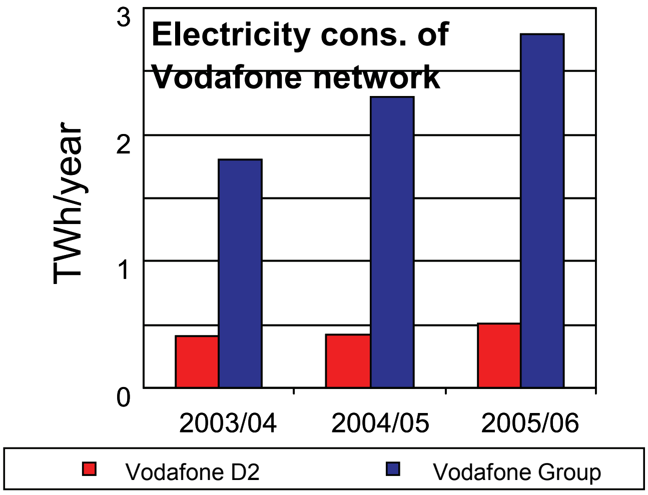

Figure 1: Increase in power consumption of Vodafone's radio access network over the past years [7].

Both in server farms as core units of the internet [6], as well as in mobile communications systems [7], a rise of the power consumption of 16-20% per year can be observed in the last years, corresponding to a doubling every 4-5 years, as illustrated by Figures 2 and 3. As result of this development, server farms meanwhile consume approximately 180 billion kWh of electricity per year – over 1% of the world-wide electricity consumption[1]. This corresponds to the typical yearly electricity consumption of 60 million households – over a third of the number of households in the EU.

[1] Based on the data from [6] and a 20% increase for 2006 and 2007. World wide electricity consumption and production data taken from [8].

According to a study by ABI research, the base stations and backhaul networks of the cellular communications networks operators consume approximately 60 billion kWh per year [9], corresponding to roughly 0.33% of global electricity consumption [8]. Similar figures have been reported in a White Paper of Ericsson [18], which estimates that mobile networks are responsible for 0.12% of primary energy use (electricity typically makes up for roughly one third of primary energy use). The base stations themselves often have a share of over 80% of the electricity consumed by an operator's mobile network [7]. Server farms and cellular networks taken together consume as much electricity as produced by 27 power stations with an output of 1 Gigawatt each, or nearly 10% of the electricity produced by nuclear power stations world wide in 2005 [8]. This is equivalent to CO_2 emissions of approximately 130 millions tons per year, comparable with the CO_2 emissions caused by the whole of Belgium [10]. However, in 2005 "only" 27 millions server nodes were located in server farms – compared to over 300 million host in the entire internet (today there are nearly 500 Mio [3]). The total amount of electricity consumed by the internet (including all routers, switches, etc.) will thus actually lie far above that of the server farms alone.

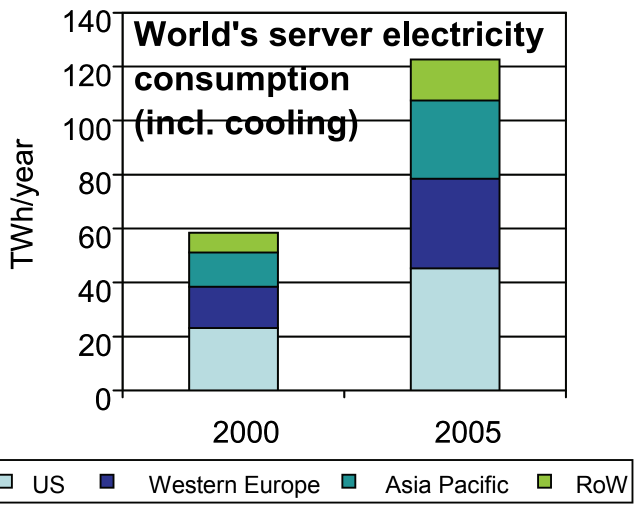

Figure 3: Increase in power consumption of data centers [6].

If one sums up the energy consumed by the infrastructure of cellular wireless networks, wired communications (PSTN) networks, and the internet (outside of and within the server farms), a portion of 3% of the world-wide electric power consumptions appears to be a conservative estimate.

But this percentage is still relatively low compared with the quantity of electricity consumed by ICT systems in private households and offices of enterprises, in particular by laptops, desktop PCs and displays/monitors. In Germany, the power consumption of ICT systems added up to 38 billion kWh already in 2001 – 8% of the total electricity consumption [11]. Due to the strong growth of market penetration and power consumption of ICT systems, this value might meanwhile lie beyond 10%, as is confirmed by recent studies from the UK [12].

III. Environmental and Society Impact

The immense influence ICT systems on the power supply situation can by read from the following 3 facts:

- Currently, server farms and telecommunications infrastructure are responsible for roughly 3% of the world wide electricity consumption. If the present growth trend of 16% per year continues, as the increase of internet traffic[2] and the number of mobile phone subscribers suggests[3], this consumption rises by a factor of 30 in only 23 years: the current level of world electricity consumption. The doubling of consumption predicted by the WEC for 2050 [15] would thus be reached already 20 years earlier, in 2030, due to server farms and telecommunications infrastructure alone.
- 10% of the electricity consumption of North America, Western Europe and Japan corresponds to roughly 900 billion kWh per year, equivalent to the amount of electric power produced in the whole of Central and South America[4]. To spread the "information technology standard of living" of the mentioned countries over the whole world would already today require 40% of the globally installed electrical power generation capability. In less than 10 years, the entire existing power generation capacity would not be sufficient for this task[5]. The power supply problem alone would thus lead to the opening of a "digital divide" between developing countries and the developed world. Already today, more than two thirds of the operational expenses in cellular networks in India are due to the buying of diesel for running the generators of the cellular base stations. Cellular network operators spend beyond 200 Mio. Euros each year for their electricity bills in Germany alone. Electricity has grown to a cost factor comparable to the total wages of the engineers who keep the network running.
- According to a study by Gartner research [16], ICT systems cause 2% of global CO_2 emissions already today, corresponding to
  - 2/3 of the CO_2 emissions of Germany [10]
  - the total CO_2 emissions caused by the international air traffic [16]
  - 1/4 of the CO_2 emissions produced by passenger cars world-wide [17]

[2] A 40% annual growth in IP traffic is predicted in [13] and by Cisco's Global IP traffic forecast [19]
[3] 8 million subscribers are added/month in India alone [14]
[4] North America, Western Europe and Japan produced 8'600 billion kWh of electrical energy in 2005, Central and South America produced 909 billion kWh [8]
[5] Assuming a 16% growth of the 3% of electrical power consumption due to server farms and telecommunications infrastructure; the above mentioned countries correspond to roughly 13% of the world' population; a percentage figure which is obviously bound to shrink

IV. RESEARCH CHALLENGES AND SOLUTION APPROACHES

ICT systems are the key to the innovation capability and thus the economic success of developed and developing nations. New challenges arise due to the drastic increase in data rates and processing power of ICT systems, which require a massive research effort into the energy efficiency of ICT systems. To cite Viviane Reding: "To meet Europe's energy efficiency goals by 2020, we need a high growth, low carbon economy. Research and rapid take-up of innovative energy efficient ICT solutions will be crucial […] There is a win-win situation in which ICT will promote the competitiveness of EU industry while leading the fight against climate change". A study by the McKinsey Global Institute found that „The economics of investing in energy productivity […] are very attractive. With an average internal rate of return of 17%, such investments would generate energy savings ramping up to $900 billion annually by 2020“. Research into energy efficient wireless networks is thus not only ecologically, but also economically very relevant.
Relevant research areas for the next years include:

- The use of high temperature electronics and alternative energy backup solutions, instead of batteries. Thus, the energy overhead due to air conditioning can be avoided, which takes up a significant part of the overall energy consumption in server farms and cellular base stations [6].
- Energy aware strategies for distributed computing and data storage (distributed data centers), to enable next generation peer-to-peer and content distribution services at minimum energy cost.
- Adaptive power management based on current traffic / system load in all areas of ICT systems, e.g.:
    - In the radio access network, to reduce the power invested in “pilot pollution” in empty cells, under the condition of not compromising on coverage.
    - In data centers using massively parallel computing, which currently often run at full performance, even at low system load.
    - In electronic devices for telecommunications, such as complex systems-on-chip.
- New network architectures based on high density low transmit power microcells and relaying as opposed to low density, high transmit power, macro cells. The key here is to find a suitable trade-off between the power consumption analog and digital hardware blocks.
- Highly efficient power amplifiers for transmit signals with large peak-to-average-power ratio.
- Programmable, application specific, highly parallel, power efficient digital baseband processors, which on the one hand allow for higher flexibility than ASIC hardware accelerators, and on the other hand consume much less power per function than “general purpose” DSPs and FPGAs.
- Physical and MAC layer optimized for maximum energy efficiency, also making use of cross-layer optimization. Spatially, temporally and spectrally localized transmission strategies which minimize the energy spent to transmit a single information bit will be crucial to achieve high energy efficiency. This speaks very much in favour of OFDM-based PHY/MAC schemes (LTE and beyond) as opposed to spread spectrum techniques (3G).
- The development of suitable utility functions, which enable to solve the multi-criteria optimization problems arising from the inclusion of energy efficiency beyond spectral efficiency and coverage as optimization criteria in an efficient and transparent way.

Only by finding solutions to these challenging questions can a continuing growth of ICT be made ecologically – and economically – sustainable. Tackling these challenges will also allow for a shift in paradigms in how cellular networks operate. Reducing the power consumption of base stations down to few tens of Watts will enable to build base stations which can be powered solely based on renewable energy sources like solar and wind power. Together with wireless backhaul (e.g. based on microwave links), these sites will be extremely easy to deploy. This will again help to narrow the digital divide between developed and developing nations, where access to energy and telecommunications infrastructure is often a limiting factor.

Improving the energy efficiency of ICT components up to the level where energy autarchy can be reached is also crucial for a relatively young, but rapidly growing, sector of the ICT industry: sensor networks. Ridding sensor nodes of the need of a wired interconnect and the lifetime and form factor limitations which a battery powered device has to accept is a key enabler for a massive deployment of sensor networks. Such “smart dust” may then be used in applications in which the stated limitations so far prevented the massive use of sensor nodes: for example in structure surveillance of buildings, bridges, industrial facilities and carbon/fiber reinforced composite materials used in modern planes and cars or in machine and facility surveillance in industry. Thus, the WWRF vision of a thousand wireless devices serving each human being by 2017 can be realized.

V. IMPACT ON OTHER SECTORS OF ECONOMY

The solutions developed for increasing the energy efficiency of ICT will provide new tools, technologies and insights which can – and should – also be used for further applications. Low power microelectronics can for example help building cars that produce less CO_2 per km: already today, 20% of the value creation in modern automotive industry is based on car electronics. It is expected, that this percentage grows to 40% by 2015. If energy efficiency is not improved, gasoline consumption due to car electronics will rise accordingly – from 0.5 l / km today to more than 1 l / km. Car manufacturing and industry automation thus constitute the logical next steps to apply energy efficiency paradigms learned in ICT to other sectors of economy.

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