ICT Energy Challenges, Impact and Solutions

Thierry E. Klein
Nokia Innovation Steering
Murray-Hill, NJ, US
thierry.klein@nokia.com

Philippe Richard
Nokia Bell Labs
Villejust, France,
philippe.richard@nokia.com

***Abstract*— The explosion of the Internet traffic volume resulting from both the worldwide broadband subscriber base extension and the increasing number and diversity of available applications and services require a relentless deployment of new technologies and infrastructures to deliver the expected user-experience. At the same time, it also raises the issue of the energy consumption and energy cost of the Internet and more generally of the Information and Communication Technologies (ICT). The energy consumption is becoming one of the key challenges for the ICT industry and it is only expected to grow in importance. In order to deploy and support future data communication networks in an economic and sustainable way, service and content providers need to address the energy consumption of their networks as one of their top priorities.**

In this article we provide some key numbers on the ICT energy consumption and the energy hot spots in the Internet. We then describe an online tool designed by Bell Labs to help the ICT industry and its associated stakeholders fully understand the energy challenges and the opportunities from new technology evolutions: G.W.A.T.T. (Global 'What if' Analyzer of NeTwork Energy ConsumpTion) is publicly available at http://gwatt.net/. Finally we share some insights on promising research results that can strongly improve the effectiveness of the most energy voracious domains of ICT.

Keywords—ICT, energy efficiency, energy consumption, sustainability, network infrastructure evolution

I. Introduction

The rapid adoption of smart phones and tablets is driving up daily Internet traffic dramatically, and forecasts indicate that it will increase up to 85 times by 2017 compared to 2010. The Web population is expected to grow from 2.3 billion in 2012 to 3.8 billion people by 2016, or half of the world's population. By 2017 more than 5 trillion gigabytes of data will pass through the global communications network every year; this is the equivalent of everyone on the planet tweeting non-stop for more than 100 years. Cloud services and applications provide users around the globe with on-demand computing, storage, and software services that can be accessed from any location and any device. This dramatic traffic explosion, especially from mobile devices, requires ever-increasing resources at the network infrastructure level as well as in the data centers. According to several sources [6], the Internet, if it were a country, would be ranked as the sixth largest in terms of its energy demand and the ICT sector as a whole would be ranked as the fifth largest. To be economically viable and sustainable, the ICT stakeholders (telecommunication operators, service providers, content providers, equipment manufacturers, etc.) need to control their operational expenditure. In particular they need to control and limit the increasing percentage of their operational expenses attributed to the energy consumption.

II. THE ENERGY CHALLENGE

The global energy consumption of ICT (including operators' networks, devices, customer's equipment, data centers etc.) has grown significantly during the last years. In 2012, the energy consumed was about 900 TWh [1]. The network energy bill can represent about 10-15% of the operational expense of telecommunication service providers in mature markets and even up to 50% in some developing markets [8], [9] and [10]. In the mature markets, the Internet made up close to 10% of the region's overall electricity consumption in 2013. In some countries, the telecommunications operators are the largest consumers of electricity with overall energy bills of several hundred million dollars and Euros.

The average annual power consumed by ICT reached 122 GW in 2013 (or the equivalent of 117 standard nuclear reactors). Let us now see how these 122 GW are distributed. The devices (PCs, printers, smart and regular phones, tablets, etc.) consumed about 39 GW with the largest amount by far being consumed by personal computers (36.9 GW). Smart phones and mobile phones on the other hand consume 0.6 GW each, whereas printers represent 0.9 GW and tablets 0.2 GW. Since tablets and smart phones are more energy efficient than laptops and desktops and since they will be even more widely used in the future (as replacements of laptops and desktops), the global devices electricity consumption is unlikely to grow in the coming years. This trend is expected despite the fact that there is a growing number of broadband connected users and devices.

Looking at a total lifecycle analysis, up to 80% of the overall energy and carbon footprint of the end user devices is related to the manufacturing process and the so-called embedded energy footprint. The actual power consumption of the devices is quite small (0.2GW for tablets and 0.6 GW for smart phones). Therefore, given the rapid replacement cycles of the mobile devices, the main sustainability challenge for the devices is to find efficient manufacturing processes incorporating reuse and recycling of valuable natural resources. From a consumer perspective, battery lifetime is dominating the user experience rather than the actual total electricity consumption. Of course lower power devices along with more powerful batteries will be able to extend the energy autonomy of the devices. Different solutions for powering the devices are being studied, including the use of renewable energy sources and local energy harvesting, which look quite promising [2].

One could, however, note that the predicted wide deployment of the Internet Of Things (IOT) might impact the percentage of the devices in the ICT energy footprint. Nevertheless the current understanding is that the IOT will rather impact the data traffic and related services in the Internet and consequently the electricity consumption of the Internet and networking infrastructure itself. According to an International Energy Agency report [14], by 2017 49% of IP traffic and 39% of consumer Internet traffic would originate from non‐PC networked‐enabled devices.

Of the 122 GW of total ICT power, the remaining 83 GW represent the share of the infrastructure equipment. This power is distributed as follows:

- 13.7 GW for the home and enterprise network
- 21.6 GW for the access network including the wireless and fixed access network
- 43 GW for the service core and data center
- 4.7 GW for the metro, edge and core network domains.

It is important to notice that the fastest growing domains in terms of electricity consumption of the Internet infrastructure are the mobile access and the data center domains. In contrast to the end user devices, smart phones and tablets, the electricity consumption during the use phase of the infrastructure equipment is the dominant factor (over 80%) of the overall energy consumption. It is therefore evident that the major challenge with the largest immediate impact is the reduction of the in-use energy consumption of the equipment. Other aspects such as manufacturing, deployment, removal and recycling remain important nevertheless, but we have chosen to focus on the dominant component at this time.

The energy challenge for ICT can only become more stringent in the coming years if no specific action is taken. As put in evidence by the Global e-Sustainability Initiative (GeSI) in its SMARTer 2020 and 2030 reports [3], the ICT can be a dramatic enabling technology for other industries to reduce their Green House Gas (GHG) emission and increase their energy efficiency. GeSI notably points out industrial sectors such as transportation, energy production and distribution, smart buildings and cities together with agriculture and food distribution. GeSI estimates that the potential of CO_2e abatement is up to 9.1 gigatons in 2020, which represents 16.5% of the world emissions. Of course this implies that the usage of ICT and IOT must be strongly developed and generalized at a fast pace. This makes the optimization of the energy efficiency of ICT even more important. The issue of network energy consumption is global and affects all service providers, operators and content providers, albeit in possibly different ways and different levels of severity:

- In mature markets, service providers are mostly concerned with the rising cost of their electricity bills and their overall operational expenses. They also have to cope with some technical challenges that have a direct impact on network deployments and capital investments. These include for example the heat dissipation and floor space required for hosting a growing and energy consuming/dissipating infrastructure. Thermal densities are starting to become limiting factors in the design, development and deployment of network equipment. In addition, the ongoing migration of traffic from fixed access networks to mobile access networks further compounds this challenge.
- In developing markets that rely on increased broadband access to sustain their economic development, the issue is not only the electricity cost but also the access to reliable and stable energy sources. Very often, such access cannot be guaranteed because of a poor or even a completely absent power grid. A commonly used solution to provide energy autonomous network elements (such as radio base stations) relies on the extensive use of diesel generators. This solution, however, has several major drawbacks, including the cost of the diesel fuel, the degraded quality of service because of the poor reliability of diesel generators, the cost of logistics to refuel the sites, etc. Hybrid or solar / wind powered solutions are starting to be deployed. More wide-spread deployment requires further improvements in the solar cell cost, higher density batteries and a reduced total cost of ownership of the system as well as more energy efficient network elements to make such solutions practical and economically viable at large scale.

The energy challenge has of course been recognized by the ICT sector for several years now and increasing attention has been paid to improve the energy efficiency of network equipment. Generally, the energy efficiency of new releases of network equipments has improved by 10% to 20% year over year and continues to do so. New technologies are coming to market that are more energy efficient than previous generations: for example LTE versus 2G or 3G, VDSL2 versus ADSL, latest GPON technologies.

Although this puts ICT among the fastest evolving technology sectors, an even greater energy efficiency improvement rate is needed to keep pace with the data traffic explosion. This challenge has triggered the creation of numerous research programs such as GreenTouch™ [4], Opera-Net1 & 2 [12, 13] or EARTH [5]. These programs aim at finding disruptive solutions that go far beyond the business as usual improvements such as the benefits from Moore's law (see section 5). Results from the international research programs quoted above are translated, among others, into the work of 3GPP to improve LTE networks and fully exploit energy efficient solutions in the design of 5G networks. The overarching goal is for next generation networks to provide up to 1000 times the current capacity, reduce latency to milliseconds and still keep the total energy consumption flat.

III. G.W.A.T.T. PRESENTATION AND USE

In order to help the ICT community understand this challenge and visualize the various ways of coping with it, the G.W.A.T.T. tool shows a five year forecast of the network infrastructure energy consumption using a wide variety of traffic growth scenarios and technology evolution choices. G.W.A.T.T. has been developed by Nokia Bell Labs as a public mindsharing tool. G.W.A.T.T is available on the Internet (http://gwatt.net) and is based on a model that uses global statistical data on the Internet traffic and performance. It provides an end-to-end view of how much power is used each year and at each point and sub-domain in the network. Thanks to G.W.A.T.T. the user quickly identifies 'hot spots' in the network where most of the energy is consumed and how this could be mitigated through technology evolutions to make the overall network more energy efficient.

Figure 1 shows the Network Model screen where the user is able to pick and choose network domains and technologies and test their corresponding energy consumption. In the shown screenshot, G.W.A.T.T. displays the baseline data for the reference year of 2013. For each network domain (Home & Enterprise, Access & Aggregation, Metro, Edge, Core and Service Core and Data Centers), the technology sub-domains are shown in the colored circles. By clicking on these colored circles, the user is able to select different technologies and test their impact. At the bottom of the screen, the results are displayed through bell curves with the colors matching those of the network domains above. In particular these bell curves display respectively:

- The traffic data according to the user selection (worldwide or regional) expressed in exabytes per month
- The network efficiency expressed in megabits/Joules
- The total power consumed by the network expressed in megawatts and
- The power savings when a new technology is selected.

The user can toggle between the different traffic, efficiency, power and power savings views.

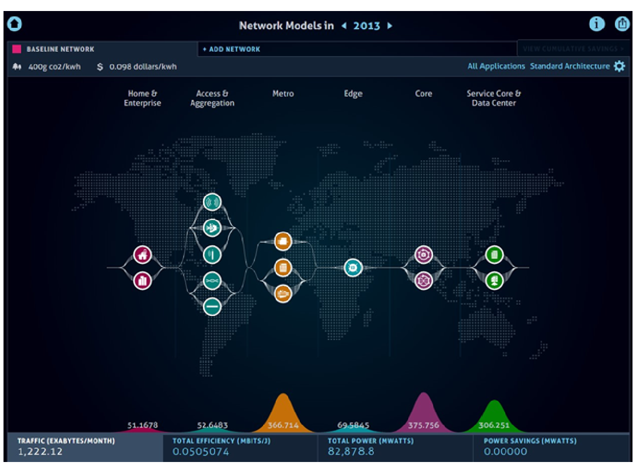

Fig. 1. Screenshot of G.W.A.T.T. Network Model in 2013, Traffic view

When a specific network sub-domain is selected, the display changes to focus on the specific sub-domain traffic, energy efficiency and power data. It also provides the user with a selection of technologies to test for their associated energy consumption.

Using the tool, the user can play various scenarios and visualize their impact on the network power and energy consumption over the timeframe of interest (from 2013 to 2019). For instance, the user can select the wireless radio access network domain and check the impact of a migration of the network to the Heterogeneous Network (HetNet) technology. The tool displays the overall power of the network (around 93GW) along with the savings generated in 2016 by the HetNet technology with respect to the 2G/3G baseline. In this particular use case, the power savings are about 35 GW (on a worldwide basis).

One can also select a specific data or application traffic in order to visualize its specific impact on the energy consumed. To that effect, G.W.A.T.T. provides the user with an application mode as shown in Figure 2.

Fig. 2. Screenshot with the selection of the video traffic

In this case, the user is selecting the video application. When applied, G.W.A.T.T then displays the corresponding data (traffic per network domains, efficiency, power consumed by the video application worldwide). Through this selection the user is able to compare the respective weights of various traffic types. For instance, in 2014 the global Internet traffic is 939 exabytes per month (2000 in 2018) and the video traffic represents 558 exabytes per month (1380 in 2018). This also indicates why some network transformations such as virtual video content delivery networks may have a huge impact in terms of energy savings on the global network. In addition to the video application, the user can also select online gaming, consumer/business web browsing, file sharing or video transmission.

G.W.A.T.T. visualizes the impact of SDN/NFV transformations. Figure 3 illustrates the case to assess the impact of a virtual Content Delivery Network (CDN) architecture on the energy cost of the video application for the North America Region. The video traffic data for the NAR region has been selected and then the virtual CDN network transformation has been applied. The tool shows that this would result in energy savings of around 8 GW in 2018. The domains that appear in grey are impacted by the network transformation (metro, edge, core and data center). G.W.A.T.T also computes the impact on the traffic flow through the network resulting from the transformation.

Fig. 3. Power savings on Video application generated by virtual CDN

IV. G.W.A.T.T. MODELING

The energy consumption models and scenarios used in G.W.A.T.T. are based on traffic forecasts and network modeling results coming from various sources: public data, results from Bell Labs modeling and other independent consortia including GreenTouchTM [4] and the Global e-Sustainability Initiative (GeSI) [3].

G.W.A.T.T is not indented to be a detailed network planning and dimensioning tool. We have instead adopted a statistical approach in order to provide an end-to-end view of the network infrastructure and its energy consumption according to traffic forecast and averaged efficiency of the network domains. In particular the energy efficiency and power consumption values used are industry averages and generally representative of current technologies without being specific to any one particular vendor or service provider network.

G.W.A.T.T is based on three models:

- A traffic data model. For each sub-domain of the network, we use a traffic volume expressed in exabytes/month.
- A network element efficiency model. An efficiency expressed in megabits/joules is associated with each sub-domain.
- From the traffic and efficiency data and the underlying network model, G.W.A.T.T. computes the total end-to-end network power (expressed in megawatts), consumption (in gigajoules), energy cost (in €, $ and ¥) and greenhouse gas emissions (expressed in gigatons of CO2 equivalent).

V. HOW TO COPE WITH THE ENERGY CHALLENGES

A. *GreenTouch™: an open research initiative*

In this section we outline how it is possible to make ICT more and more sustainable over the years despite an ever-increasing traffic and usage demand. We first use the GreenTouch™ consortium (www.greentouch.org) as an example.

GreenTouch™ was an open pre-competitive research consortium launched by Bell Labs in 2010 with the focus to dramatically improve network energy efficiency. Its objective was to develop a portfolio of technologies, architectures and solutions, and to demonstrate key contributing technologies, to improve the energy efficiency of networks supporting 2020 traffic volumes by a factor of 1000x with respect to the 2010 state of the art reference network. GreenTouch™ brought together more than 50 members globally including service providers, equipment manufacturers, research institutes and universities.

The final results were announced by the consortium in June 2015 The results of the research study, called the "Green Meter" are published in a white paper [11] based on GreenTouch assumptions on traffic growth and modeling of state of the art networks and future technologies. The research study concluded that in a theoretical network without practical implementation constraints it would be possible to improve the energy efficiency in mobile networks by a factor 10,000x, in fixed access networks by a factor 254x and in core networks by a factor 316x. The energy improvements are not only the result of efficiency improvements of specific network components but through a combination of improved network architectures, hardware improvements, wireless transmission technologies, efficient algorithms and control mechanisms and optimized content distribution strategies, as well as business-as-usual technology improvements, such as those derived from Moore's Law.

It is of course understood that improving the energy efficiency (in bits/Joule) doesn't mean a corresponding reduction of the energy consumption for existing telecom services. Indeed the traffic growth rates need to be taken into account to determine the actual energy consumption.

B. *Other initiatives*

It is well recognized, for example from the G.W.A.T.T application, that the largest energy hot spots are the radio access networks and the data centers. Figure 4 shows the split of power consumption (in GW) for the network infrastructures worldwide in 2015. We see that out of a total of 108 GW, the data centers account for 43GW and the radio access networks for 27 GW. In addition to being the largest consumers today, the data centers are predicted to be the fastest-growing ones as well.

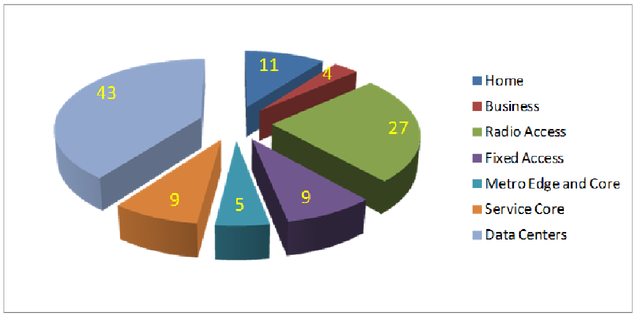

Fig. 4. Split of power consumption for the networks' infrastructure domains in 2016

OPERA-net [12], started in June 2008, was the first larger international project dealing specifically with mobile network energy efficiency. It finished in May 2011 and was followed up by OPERA-net2 [13] and some of the main results were presented in a series of workshops [15]. The project addressed both 3G and 4G wireless networks through a holistic approach considering a complete end-to-end system, identifying all relevant network elements and their interdependencies, and developing improvements especially for energy and material efficiency in the radio base station (BS).

The EARTH project [5] is another early example of a dedicated research effort to improve the energy efficiency of wireless communication networks.

Finally the Nokia Technology Vision 2020 predicts flat energy consumption for mobile radio networks for the next 5-10 years together with improved battery life. To achieve this, Nokia adopts a holistic end-to-end view of the mobile networks that includes:

- Base station energy efficiency: more efficient baseband processing and high-performance radio front end amplifiers;
- Site optimization: lower energy costs by eliminating cooling and feeder losses, and implementing more renewable energy sources;
- Network architecture evolution: improved resource utilization and capacity increase through multi-radio, densification, beam forming and distributed base stations. Capacity-driven network evolution increases resource utilization avoiding idle network elements;
- Network management and control: teaching networks to be energy aware with advanced dormancy concepts.
- Network modernization: modernization at the right time to achieve optimum CAPEX and OPEX. The phase out of legacy technologies can be justified by energy savings alone.

As illustrated in Figure 5, the Nokia target is to support a 1000 times traffic growth by 2020 (with respect to 2010) with flat network energy consumption. With electricity as the energy source for telecom networks we can reach zero greenhouse gas emissions with the usage of renewable energy sources.

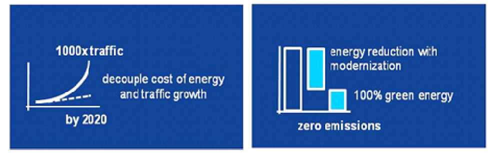

Fig. 5. 1000 times traffic by 2020 and zero emissions

VI. CONCLUSION AND NEXT STEPS

Over time, Nokia Bell Labs will continue to expand the capabilities of G.W.A.T.T., refining its modeling capabilities, adding new network scenarios and including future technologies and architectures currently being investigated by Bell Labs Research. We have also partnered with the GreenTouch™ consortium [4] to design a dedicated G.W.A.T.T. site that incorporates the consortium's advanced results. Finally we are actively engaging with service content providers and operators to design dedicated versions of G.W.A.T.T. that correspond to their specific data models and network efficiency data.

Nokia Bell Labs has designed G.W.A.T.T. as a mind sharing tool to help the ICT stakeholders understand the key energy challenges of ICT triggered by the data traffic explosion. G.W.A.T.T. also measures how the deployment of current and future technologies positively impacts this energy footprint. We regularly update the tool to reflect the latest state of the art in terms of traffic evolution forecast and networking and communication technological advances. Bell Labs also encourages partnerships with other actors of the ICT industry to further enrich the data models being used.

The results outlined in this paper clearly show that the ICT industry can sustainably manage the increase of traffic and usage that is forecasted for the coming years. At the same time, with the appropriate investments in R&D, network upgrades and planning, the communication networks can flatten their absolute energy footprint in the next years. ICT is one of the few human activity domains that allow other industries reducing their own energy impact while having both a strong growth and a flat energy footprint.

VII. LIST OF ACRONYMS

- ADSL: Asymmetric Digital Subscriber Line
- CDN: Content Delivery Network
- 3GPP: 3rd Generation Partnership Project
- GHG: Green House Gas
- GPON: Gigabit Passive Optical Network
- HetNet: Heterogeneous Network
- IOT: Internet Of Things
- LTE: Long Term Evolution or 4G
- NFV: Network functions virtualization
- ICT: Information and Communication Technologies
- SDN: Software-defined networking
- VDSL: Very-high-bit-rate Digital Subscriber Line

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