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Research challenges on energy-efficient networking design

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ABSTRACT

The networking research community has started looking into key questions on energy efficiency of communication networks. The European Commission activated under the FP7 the TREND Network of Excellence with the goal of establishing the integration of the EU research community in green networking with a long perspective to consolidate the European leadership in the field. TREND integrates the activities of major European players in networking, including manufacturers, operators, research centers, to quantitatively assess the energy demand of current and future telecom infrastructures, and to design energy-efficient, scalable and sustainable future networks. This paper describes the main results of the TREND research community and concludes with a roadmap describing the next steps for standardization, regulation agencies and research in both academia and industry.

1. Introduction

Telecommunication/computer networks have become a critical infrastructure for our societies: from an academic playground they have grown to become an essential enabler for information access and knowledge sharing, for electronic commerce and entertainment. Broadband Internet access has drastically changed the way we live and work. Just few examples: every student today finds on the Internet much more information than what could be found only on the most respected source of general information, such as the Encyclopædia Britannica, before the Internet; travel planning has become so much easier on the Internet that a large number of travel agencies are going bankrupt; movies and TV series can now be watched on the Internet with a much wider choice than with movie theatres or traditional TV programs. As a result, the access to the Internet is becoming a primary need for a large portion of the world population, up to the point that some groups advocate its introduction in the list of human rights, and that some forms of addiction are emerging.

From a technical perspective, this implies that the number of Internet users, and the amount of traffic they generate, keeps growing at an exponential pace. The famous Cisco Visual Networking Index report [1] forecasts that global average Internet traffic will grow at a compound annual rate of 23% from 2012 to 2017, and peak Internet traffic will increase even more rapidly. The annual global Internet traffic will reach 1.4 zettabytes by the end of 2017 (a figure which is far beyond our normal accounting habits), and the peak hourly Internet traffic will reach 865 Tbps by the same date, equivalent to 720 million people streaming a high-definition video continuously. Regarding equipment, end users are installing more and more networking devices in their homes and offices, and network operators need to react with a parallel increase in their network equipment and in its capabilities.

One of the consequences of this "race to networking" is that the amount of energy necessary to operate the installed equipment is growing to worrisome levels. The networking research community started realizing this issue in the first half of the last decade, and energy-efficient networking (or green networking) became a hot topic around 2007. Researchers started looking into key questions on energy consumption of communication networks, like: "*Is the current growth of energy consumption in telecom infrastructures sustainable?*"; "*Can we generate and transport enough electricity to provide high bandwidth access to everyone in metropolitan areas?*"; "*Are optical technologies more energy-friendly than electronics?*"; "*Is the Internet protocol suite needlessly wasting energy?*".

The European Commission was quick in realizing the relevance of this topic, which started appearing in the Work Programmes of its 7th Framework Programme (FP7). A pioneer FP7 project, EARTH (Energy Aware Radio and neTwork tecHnologies) [2], was launched in 2010, with the goal of "addressing the global environmental challenge by investigating and proposing effective mechanisms to drastically reduce energy wastage and improve energy efficiency of mobile broadband communication systems, without

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compromising users perceived quality of service and system capacity".

In 2011, FP7 activated the TREND (Towards Really Energy-efficient Network Design) Network of Excellence (NoE) [3], whose aim was "to establish the integration of the EU research community in green networking with a long term perspective to consolidate the European leadership in the field".

TREND has contributed during the last three years to the international research on green networking, establishing itself as one of the primary hubs for researchers in this field. Some of the most relevant achievements of TREND include:

- Collection of comparable data to assess the power consumption of terminals, devices and infrastructures, and identification of the power consumption trends in the field of networking.
- Identification of energy-friendly devices, technologies, algorithms, protocols and architectures and investigation of how they can be introduced in operational networks.
- Definition of new energy-aware network design criteria.
- Experimentations that prove the effectiveness of the proposed approaches.
- Identification of a roadmap for energy-efficient networking.

A holistic approach was taken, considering all network segments, from user terminals, to access networks, to metro and backbone networks, to applications, to data centers, both in evolutionary scenarios and in clean-slate designs.

Other projects have recently been proposed and developed, targeting challenging issues and aspects of green communications and networking. In the FP7 framework of the European Commission, some projects look at wireless networks. Among those more closely related to TREND, CONSERN (https://www.ict-consern.eu/) focuses on small scale wireless networks and, in particular, on two aspects: how to make the elements of the wireless network interact in an energy efficient way and how to make the network evolve in an energy efficient way. Thus, the project introduces the concept of energy-aware self-growing network. The project CROWD (http://www.ict-crowd.eu/) investigates dense heterogeneous wireless networks, in which the density of network nodes is needed to sustain the fast traffic growth; one of the objectives is to make traffic-proportional the network energy consumption. Wireless access technologies are also investigated in C2Power (http://www.ict-c2power.eu/), a project that proposes energy saving technologies based on a combination of cognitive radio and cooperative strategies.

Other projects focus on aspects related to the interconnection of the devices in the core and metro network. In the ECONET (http://www.econet-project.eu/) project, energy efficiency of wired devices is achieved by using low consuming standby modes and performance scaling capabilities that adapt active resources to current traffic loads. The objective of the STRAUSS (http://www.ict-strauss.eu/) project is to define an energy-efficient optical infrastructure for Ethernet transport, whose architecture is based on software defined networking principles. The main goal of FIT4Green (http://www.fit4green.eu/) is to optimize resources in data centers by turning off devices when unused due to load fluctuations.

The COST action project titled IC0804-energy efficiency in large scale distributed systems (http://www.cost804.org/) aims at proposing solutions for improving energy efficiency of large systems that share distributed resources; the approach consists in working in a complementary way at network, middleware and applications levels.

One of the prominent worldwide initiative is GreenTouch (http://www.greentouch.org/), a large forum that involves manufacturers, operators, research institutions, with the ambitious goal to increase network energy efficiency by a factor of 1000 with respect to 2010 levels in just five year. The organization investigates efficiency in a comprehensive way, including different technologies and network segments, and proposing architectures, specifications and roadmaps for energy efficiency improvement.

This paper describes some of the main achievements and contributions of the TREND NoE as well as some indications for future steps towards energy-efficient networking. The rest of this paper is organized as follows. Section 2 describes and explains the main insights of one the initial goal of the TREND researchers on collecting data on real electricity consumption of communication networks. Section 3 focuses on the segment of backbone networks, including aspects of network design and operation. Section 4 is devoted to energy-efficient data centers. The access part of the networks is discussed in Section 5 (wireless access networks) and Section 6 (optical access networks). Finally, Section 7 introduces a roadmap in energy-efficient networks covering aspects to be tackled by equipment designers, operators, standardization fora and networking researchers.

2. Worldwide electricity consumption of communication networks

Collecting data on real electricity consumption of communication networks has been one of the initial goals of the TREND researchers [4]. It is an essential first step in order to play with trusted data, share them with the research community, design energy aware networking solutions and finally assess the impact of introducing new energy efficient technologies.

Often-cited values of the footprint of communication networks and ICT in general date back from five to ten years ago or are extrapolations based on these values. A previous report [5] on the worldwide energy needs for ICT was based on data from 2007; in the Smart2020 report [6], which studied both the footprint of ICT and its enabling effect to reduce emissions, the network section of the analysis was based on reported energy consumption values of telecom providers in 2002. These values were then extrapolated based on the expected increase in subscriptions in 2002–2020. Another extensive study on greenhouse gas emissions and operational electricity use in ICT by Malmodin et al. [7] also provided estimates for 2007. In the past five years, the electricity consumption of networks was likely transformed by fiber rollout, smart devices requiring mobile Internet access and rapid customer base growth in emerging markets.

TREND contributed to energy consumption data collection and forecast with a top-down analysis of the total global electricity consumption in communication networks, based on results on recent data (2007–2011), aiming to obtain an updated estimate of the network share of the worldwide electricity consumption in 2012. The considered components of the communication networks are: telecom operator networks, office networks, and customer premises equipment. Only the in-use electricity consumption is taken into account: the energy consumption due to the manufacture and dismissal phases is not considered.

The results are summarized in Fig. 1. Telecom operator networks make up almost three quarters of the network electricity consumption, the remaining quarter is used by customer premises equipment and office networks. Among networks, the contribution of mobile networks is estimated to be between 40% and 60%.

The total worldwide electricity consumption of communication networks has increased from 219 TWh per year in 2007 to 354 TWh per year in 2012. This corresponds to an annual growth rate of 10%. When this is compared to the total worldwide electricity consumption [8], we see that the share of networks is becoming increasingly important (dotted line in Fig. 1). Where communication networks only consumed about 1.3% of worldwide electricity in 2007, their relative contribution has increased to 1.8% in 2012.