Energy-Efficiency in the Future Internet

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Keynote Paper

***Abstract*—This paper summarizes the main content of a keynote talk, held at the 2015 ICETRAN conference, that explored the state of the art in energy efficiency in networking and datacenters, and the integration of green technologies in the framework of Software Defined Networking (SDN) and Network Function Virtualization (NFV), as a sustainable path toward the Future Internet stemming from the experience of the European projects ECONET (FP7) and INPUT (H2020).**

***Index Terms*—Green Networking, Power Management, Software Defined Networks; Network Function Virtualization.**

I. Introduction

ACCORDING to major Telecom operators worldwide, there is a significant need for Future Internet devices and network infrastructures to be more energy-efficient, scalable and flexible, in order to realize the extremely virtualized and optimized networks needed to effectively and efficiently support a very large number of heterogeneous user-led services.

In the computing world, an important recent trend has been the move to energy proportionality, i.e., the goal of having energy expenditure in proportion to the instantaneous (rather than the peak) computational load.

This has motivated the adoption of virtualization and cloud computing as methods to deliver software services. These developments save power in computation, but increase the load on datacenter networks and on the Internet that supplies them their data.

Thus, the goal of energy proportionality has been extended to datacenter networks and the Internet at large. However, the complex interactions between the energy consumed by virtualized servers, the server farms on which they execute, the datacenter networks that interconnect them, and the wider network from which users access services and data, require a holistic approach to energy efficiency, capable of embracing many different aspects and basic strategies of current ICT and network technologies, where the ultimate overall goal should be the rational usage of all physical resources.

In this perspective, energy efficiency (with respect to a non-optimized exploitation of ICT equipment) may be viewed as an indicator of the "health" of the overall computing and networking ecosystem [1]. It reflects the extent of exploitation of computing, storage, and communications hardware capabilities to the degree needed to support the current workload generated by applications at the required Quality of Service/Experience (QoS/QoE) level.

In this respect, flexibility and programmability in the usage of physical resources (obviously including the network) come naturally onto the scene as instruments that allow optimal dynamic resource allocation strategies to be really implemented in practice. The goal of such optimization can actually be energy efficiency, but it will be achieved under dynamic adaptation to the quality requirements imposed by running applications.

The paper is organized as follows Sect. II introduces the main motivations and drivers for making the current and future Internet technologies more sustainable. Sect III deals with state of the art green networking approaches, and reports some results and achievements obtained by the ECONET European project. Section IV discusses the impact of upcoming Internet technologies (i.e., SDN and NFV) and applications (i.e., cloud) on sustainability aspects. Then, the main approach pursued by the INPUT European project is presented. Conclusions are drawn in Sect. V.

II. The Energy Efficiency Quest in the Current Internet

The energy consumption of the Information and Communication Technologies (ICT) sector has followed an increasing trend in the last several years and it is estimated to have accounted for 2% of the total energy consumption in 2007 [2][3]. Because of the way energy is still being produced currently, most energy consumption is accompanied by non-negligible Green House Gas (GHG) emissions that have severe consequences on climate change. In a business as usual (BAU) scenario, the GHG emissions of the ICT sector are expected to reach 1.43 Gtons carbon dioxide equivalent (CO_2e) in 2020 (they amounted to 0.53 Gtons in 2002) [4]. On the other hand, taking global predictions into account, a decrease of between 15% and 30% in the emitted volume would be required before 2020 to keep the global temperature increase at less than 2° C [5].

The increasing trend in the energy consumption of the ICT sector has also been confirmed in recent reports published by large Telecom operators (Telcos) and Internet Service Providers (ISPs) worldwide. In 2006, the overall energy consumption of Telecom Italia had already reached more than 2 TWh (approximately 1% of the total Italian energy demand), which was an increase of 7.95% over 2005 [6-8]; in 2009, this consumption increased to 2.14 TWh. Another representative example is from British Telecom, whose overall power consumption for its network and estate during the 2010 financial year was 3.12 TWh [9, 10]. The Deutsche Telecom group reported an overall energy consumption of 7.91 TWh during 2009, compared with 3 TWh in 2007 [11], and this group attributes the steep increase to technology developments, increasing transmission volumes and network expansion. The power consumption of Verizon in 2010 was 10.24 TWh, up from 8.9 TWh (approximately 0.26% of USA's energy requirements) in 2006. AT&T accounted for 11.14 TWh in

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TABLE 1:
YEARLY ENERGY CONSUMPTION OF SOME OF THE MAJOR TELECOM OPERATORS WORLDWIDE. THESE DATA WERE OBTAINED BY THE SUSTAINABILITY REPORT OF EACH COMPANY. SOURCE

Energy Consumption (TWh per year)					
Telecom	2006	2007	2008	2009	2010
Deutsche Telekom (World)	7.10	7.22	7.84	7.91	-
France Telecom (World)	3.66	3.47	4.57	4.38	-
Telecom Italia	2.10	2.15	2.13	2.14	-
British Telecom (UK)	1.94	1.99	2.03	2.28	2.28
British Telecom (World)	-	-	2.6	2.71	3.12
AT&T (World)	-	-	-	11.07	11.14
Verizon	8.90	-	-	10.27	10.24
NTT	-	2.76	2.76	2.75	-
Telefonica	1.42	-	4.76	5.05	6.37
SwissCom	-	-	0.43	0.40	0.40
China Mobile	-	-	9.35	10.62	11.94
SK Telecom	-	-	0.94	1.09	1.09

2010 and declared a consumption of 654 kWh per terabyte of data carried on its network in 2008. The requirements of France Telecom were approximately 4.38 TWh in 2009 [12], while it is committed to a 15% reduction in its global energy consumption by 2020 relative to the 2006 level. In 2010, the Telefonica group consumed 6.37 TWh, compared with their 2006 figure of 1.42 TWh, which amounts to 0.6% of Spain's total energy consumption [13]. The NTT group reported that the amount of electrical power needed for telecommunications in Japan was 4.2 TWh in fiscal year 2004 [14] and that their direct energy consumption amounted to 2.75 TWh in 2009. Finally, China Mobile's energy requirements since 2009 have exceeded 10 TWh, an annual increase of more than 1 TWh. These and other data on the yearly energy consumption of some of the major telecom operators world-wide are presented in Table I.

In parallel with the increase in energy consumption, an even more aggressive trend is observed in Internet traffic, as well as in the number of devices connected to the Internet. Worldwide, the growth rate of Internet users is approximately 20% per year, while in developing countries, this growth rate is close to 40–50% [15]. According to the Cisco Visual Networking Index [16], global IP traffic has increased eightfold over the past 5 years and it will increase fourfold over the next 5 years. Overall, IP traffic is estimated to grow at a compound annual growth rate of 32% from 2010 to 2015, with busy-hour traffic growing more rapidly than the average rate. It is important to note that in 2010, global Internet video traffic surpassed global peer-to-peer (P2P) volume, and by 2012 Internet video is predicted to account for over 50% of consumer Internet traffic [16].

III. STATE OF THE ART APPROACHES IN GREEN NETWORKING

From the data reported in the previous section, it appears manifest that there is a need to introduce energy-efficient techniques both at the device level and at the network level.

Such techniques need to be developed and applied because the design of the Internet and even recent evolutions do not address energy consumption issues [17].

Today, overprovisioning is adopted in dimensioning both the number and the capacity of network devices and links. The degree of overprovisioning depends on the maximum load that the network has to carry during its peak hours, which is directly connected with the peak energy consumption of the network, as well as with the redundancy degree of the network.

This degree of overprovisioning is selected for increased resiliency and fault-tolerance of the current networks. In addition to the redundancy level of devices and links in the network that increase the total energy consumption, any drop in traffic is not followed by a corresponding drop in the amount of energy consumed by the network, which is largely due to the lack of energy proportionality in the current generation of network devices, which consume close to their peak energy independently of their actual traffic load. Improving hardware (HW) efficiency only would not be enough to reduce the impact of energy consumption.

Indeed, even though data from network device manufacturers show capacities continually increasing by a factor of 2.5 every 18 months, the energy efficiency of silicon technologies improves at a slower pace, in accordance with Dennard's law (i.e., by a factor of 1.65 every 18 months) [18].

Starting from the above considerations, it should be clear that reducing the energy consumption of the Internet might be one of the main challenges that the ICT sector will have to face in the future. Thus, the main objective of the Energy COnsumption NETworks (ECONET) project [7] was to design and develop innovative solutions and device prototypes for wired network infrastructures (from customer premises equipment to backbone switches and routers) by 2013. The resulting network platforms adopted green networking technologies for aggressively modulating power consumption according to the actual workloads and service requirements.

Within the framework of the ECONET project, a large-scale demonstrator has been setup. The demonstrator (see Figure 1) reproduces a complete wire-line network chain from the core devices to the subscriber terminals, integrating several heterogeneous "green networking" solutions. For this reason, a significant effort has been devoted to designing and developing a suitable abstract interface, namely, the Green Abstraction Layer (GAL), to expose and control the novel energy-aware capabilities. This interface has been accepted as ETSI Standard 203 237. Thanks to the GAL, all the prototypal parts have been easily interfaced to compose a complete green-enabled network chain, where heterogeneous green data-plane mechanisms, control-plane, central monitoring and management frameworks can effectively interoperate and achieve significant reductions in energy consumption. A further objective of this demonstration was to obtain realistic experimental results capable of assessing not only that the technical solutions are working in an efficient way, but also to evaluate the potential impact of the proposed technologies if applied to real networks [18].

The results experimentally obtained highlight how the goal of reducing the energy consumption of wire-line network infrastructures by 50%-80% can be achieved. In more detail, the impact of the ECONET technologies has been evaluated for the usual operating conditions of a medium-scale Telecom Operator (which corresponds to the 2020 evolution of the network infrastructure of Telecom Italia) under three different scenarios: the scenario corresponding to the final demonstration, the short-term impact scenario, and the long-term one. The obtained results suggest that energy savings with respect to the Business-as-Usual of approximately 39.7%, 51.6%, and 78%, respectively, can be achieved in the cases above. These savings can be quantified in a cut of 148, 197, and 290 M€ of the OPEX per year of operation.

IV. Moving to the Future Internet: SDN, NFV and the Cloud

The continuous growth of Internet content, applications and services has resulted in ever more demanding requirements of energy consumption, data storage capacity and data transfer speed. In order to cope with the limited resources of "small" user devices, there have been significant developments the migration of applications and services to "cloud" paradigms [21,22], which move most of the computational and storage weight to large-scale powerful datacenters. The potential of these new paradigms are not being exploited to the full due to limitations of the foundations of the "cloud" are sapped by the underlying networking technologies and infrastructures [23,24], which are too ossified and obsolete to provide a suitable support for the Future Internet. As underlined in the "Future Internet" call of the H2020 ICT workprogramme, "*the technology perspective needs primarily to address the limitations of communication networks and cloud computing infrastructures and services when moving towards a hyper connected world with hundreds of billions of devices fuelled by ambient and pervasive services*." New approaches to the joint design of cloud applications and the networks that underpin them will be needed to maximise their potential.

ITU-T [25] suggests that a radical change in networking key technologies is necessary to achieve the performance scalability levels needed to cope with this hyper connected world, while significantly reducing the energy consumption and footprint of next-generation Internet service infrastructures. Major Telecom operators worldwide [26] and different European Technology Platforms [27,28] have also confirmed that Future Internet devices and network infrastructures need to be significantly more energy-efficient, scalable and flexible in order to realize the extremely virtualized and optimized ICT/network infrastructures to adequately support a very large number of heterogeneous user-led personal cloud services [25].

We believe that among the steps required to realize this new scenario, a key requirement will be the larger use of Network Functions Virtualization (NFV) in the access and metro networks, accompanied by the increased control capabilities enabled by the Software Defined Networking (SDN) paradigm. We will show that flexibility and programmability, along with datacenter offloading and energy efficiency can be simultaneously achieved using the approach proposed here. By exploiting newly available software techniques and hardware technologies, we want to bring cloud-computing services closer to the users, by adopting in-network cloud functionalities for all those applications that do not necessarily need access to the computational power of the datacenter. In particular, we will use energy efficiency, taking into account both the user premises and the network infrastructure, as an indicator of the "health" of the overall networking/computing ecosystem. The goal is to optimise the users' Quality of Experience (QoE) subject to the requirement to achieve energy efficiency. This will be done by identifying and

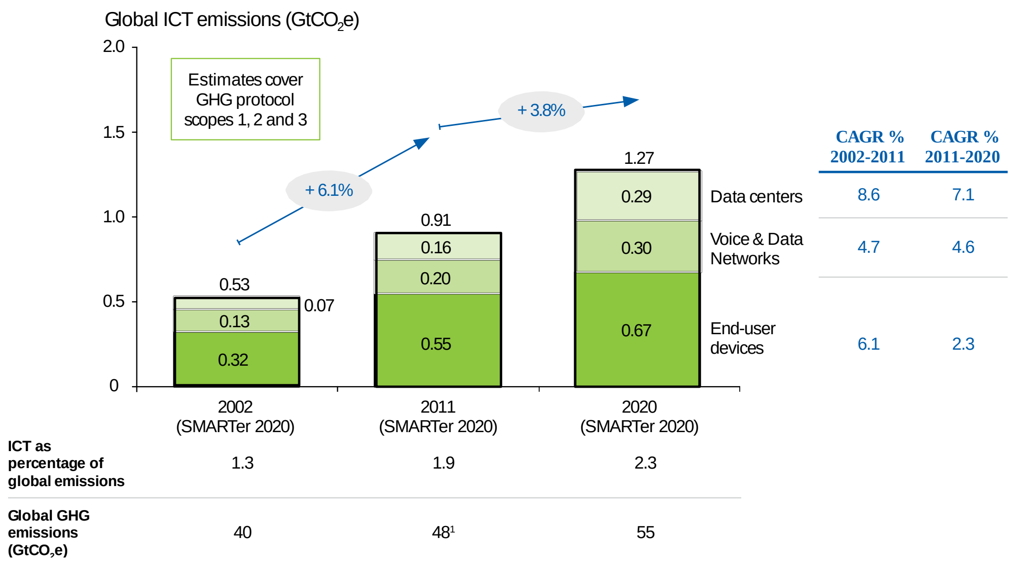

Fig. 1. . ICT emissions' growth expected in 2020. Source: SMARTer2020 [31].

evaluating architectural solutions capable of balancing energy consumption and QoE, as mapped into Quality of Service (QoS) requirements for the network.

Energy efficiency is indeed a concern. In 2012 alone, it was estimated that datacenters consumed 30 billion watts of electricity worldwide [29], thus bringing to attention the inadequacy and unsustainability of current networking and computing infrastructures to satisfy an ever-growing demand for mass ICT services [30] with the scalability, flexibility and effectiveness needed to cope with future technology and traffic trends, as well as environmental and economic challenges. The Global e-Sustainability Initiative (GeSI) [31], considering current technology trends and main efforts for reducing the ICT footprint, foresees the overall contribution of ICT sector Greenhouse Gas (GHG) emissions rising to 2.3% of the global footprint (equivalent to 1.27 GtCO2e) by 2020 with an increase of 3.8% as compared to 2011 (see). In particular, end-user devices are expected to cause more than half of the ICT carbon footprint (i.e., 0.67 GtCO2e), and datacenters are expected to almost double their GHG emissions reaching a footprint equivalent to network infrastructures. A confirmation of these trends also comes from major telecom operators world-wide [26], which reported that more than 9 million servers were shipped in 2011 against 1.5 million routers shipped in 2012.

The carbon footprint estimates of ICT in part reflect the sector's social and economic importance globally. An alternative view is that they demonstrate the inefficient exploitation of computing, storage, and communications hardware capabilities to support the current workload generated by applications at the required QoS/QoE level. Its large carbon footprint is as an indicator of the poor "health" of the overall computing and networking ecosystem [32], which does not provide a suitable level of scalability to cope with projected, and perhaps unduly conservative, estimates of traffic increase [24,30]. As claimed by L.G. Roberts [33], one of the original designers of today's Internet, most ICT inefficiencies are due to the obsolescence of the IP/network protocol stack, and related basic functionalities, network architectures and paradigms. IP technology cannot provide the suitable levels of flexibility, scalability and energy efficiency to foster better integration of cloud service innovation, while supporting enormous traffic volumes.

A. *The INPUT Project Approach*

The INPUT Project [36] aims to contribute to the evolution of the Internet "brain" beyond current limitations due to obsolete IP network paradigms, by moving cloud services much closer to end-users and smart-devices. This evolution will be accomplished by introducing intelligence and flexibility ("in-network" programmability) into network edge devices, and by enabling them to host cloud applications (Service_Apps) capable of cooperating with and of offloading corresponding applications residing in the users' smart objects (User_Apps) and in datacenters (DC_Apps), to realize innovative personal cloud services. The conceptual approach of the INPUT Project, including the Service_Apps operating at the edge network level, is shown in Fig. 2.

The presence of such Service_Apps will allow user requests to be manipulated before crossing the network and arriving at datacenters in ways that enhance performance. Such manipulations can include pre-processing, decomposition and proxying. Moreover, the Service_Apps will take advantage of a vertical integration in the network environment, where applications can benefit from network-cognitive capabilities to intercept traffic or to directly deal with network setup configurations and parameters. The integration of Service_Apps at the network edge level is a fundamental aspect, since this level is the one where the Telecom Operator terminates the user network access, and a direct trusting/control on user accounts and services is performed. Therefore, this level is the best candidate to host personal Service_Apps, and to provide novel network-integrated capabilities to the cloud environment in a secure and trusted fashion. To achieve this purpose, the INPUT Project will also focus on the evolution of network devices acting at this level beyond the latest state-of-the-art Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies, and on how to interface them with the "in-network" programmability. This approach will reduce the reaction times of cloud applications, by exploiting the ability to directly access network primitives, and by providing improved scalability in the interactions of the network with users and datacenters.

The INPUT Project will design a multi-layered framework that will allow, on the one hand, multiple Personal Cloud Providers to request IT (e.g., in terms of computing, storage, caching, etc.) and network resources of the Telecom Infrastructure Provider via an extended Service Layer Agreement. On the other hand, in order to minimize the OPEX and increase the sustainability of its programmable network infrastructure, the Telecom Infrastructure Provider will make use of advanced Consolidation criteria that will allow Service_Apps to be dynamically allocated and seamlessly migrated/split/joined on a subset of the available hardware resources. The unused hardware components will enter low-power standby states. The presence of these power management criteria and schemes is a key aspect for maximizing the return of investment of the INPUT technology to Telecom Infrastructure Providers.

The INPUT architecture will also provide additional degrees of freedom and ground-breaking capabilities to design innovative personal cloud services, which can be substituted for (and/or can integrate the hardware capabilities of) smart objects usually placed in users' homes (e.g., set-top-boxes, network-attached storage servers, etc.). This will be achieved using "virtual images" of these objects, making them always and everywhere available to users through a virtual personal network. These virtual images will obviously contribute in providing services to end-users in a cheaper way, avoiding the costs of buying physical smart objects and enabling continuous evolution of object performance and capabilities. On the other hand, the presence of the virtual personal network will give users the perception of a familiar personal environment with well-known legacy network and application protocol interfaces (e.g., Samba folder sharing and DLNA– Digital Living Network Alliance – streaming from a NAS server) usually applied in the home Local Area Networks (LANs). In this respect, Personal Networks have to provide the same

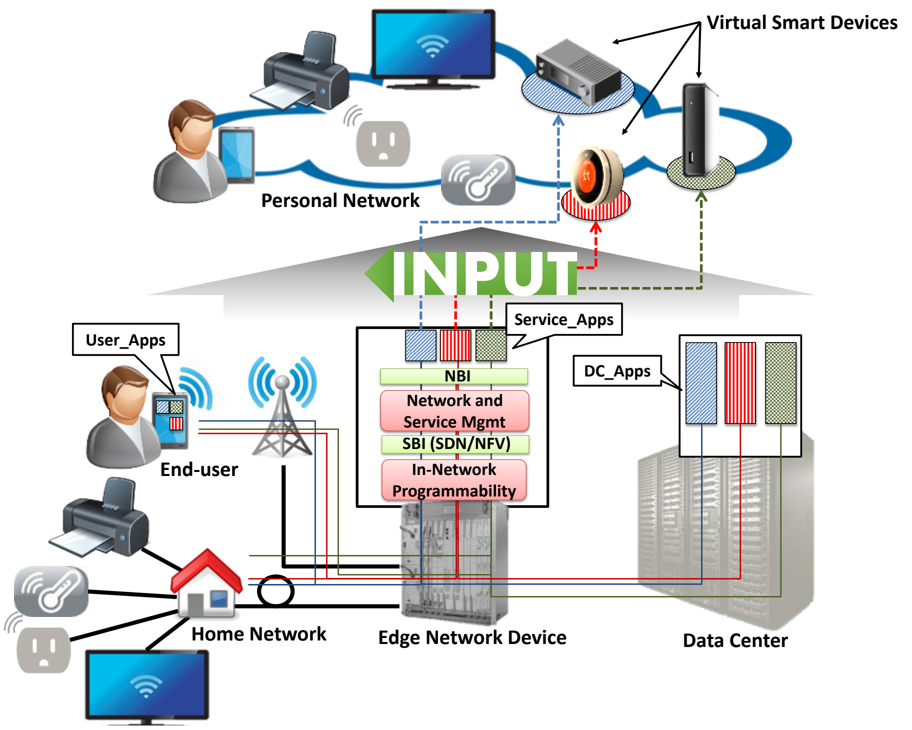

Fig. 2. Logical and physical view of the INPUT network and functional architectures.

perceived levels of security, privacy and trust as in today's home networks, and have to expose these primitives to overlying cloud services.

In order to achieve the aforementioned architecture and overlaying proof-of-concept services, the INPUT Research & Innovation approach will be organized along three complementary research axis, namely "Smart Network Programmability Support", "Network and Service Abstraction and Virtualization Interfaces", and "Smart Personal Cloud Services" (see [36]).

The first axis ("Smart Network Programmability Support") aims to design and to develop a prototype of network node with extended SDN/NFV functionalities, advanced "in-network" programmability and power management capabilities. These extended capabilities and functionalities will be specifically designed to provide an effective and scalable "in-network" support to Personal Cloud Services, and the possibility of vertically integrating such services with the network layer.

The second axis ("Network and Service Abstraction and Virtualization Interfaces") will implement the core of the INPUT framework by:

- defining the interfaces towards both the "in-network" programmable devices and the Personal Cloud Services (named SouthBound and NorthBound Interfaces (SBI and NBI), respectively),
- developing the management logic to drive the long- and the short-time optimal configurations of the network infrastructures and of "in-network" cloud services in order to meet the workload and user's QoE, while minimizing the energy consumption (and consequently the OPEX).

Finally, the third research axis ("Smart Personal Cloud Services") will design and explore innovative Personal Cloud Services that explicitly exploit the ground-breaking nature and features of the "in-network" programmability paradigm at the network edge, of Personal Networks as smart virtual container users' services, as well as of the extended set of innovative network-integrated primitives.

V. Conclusion

This paper summarized the main content of a keynote talk, held at the 2015 ICETRAN conference. The paper discussed the main motivations and drivers for making the current and future Internet technologies more sustainable. State of the art green networking approaches have been discussed by reporting some results and achievements obtained by the ECONET European project. The paper also extended the discussion in order to embrace aspects related to the impact of upcoming Internet technologies (i.e., SDN and NFV) and applications (i.e., cloud) on sustainability aspects. In this respect, the main approach pursued by the INPUT European project has been presented as an example on how to design more sustainable Internet and cloud technologies.

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