The low Energy COnsumption NETworks (ECONET) Project

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Abstract—**The ECONET project is a 3-year large-scale Integrating Project (IP) running from October 2010 to September 2013, co-funded by the European Commission under the 7th Framework Programme. The ECONET project aims at studying and exploiting dynamic adaptive technologies (based on standby and performance scaling capabilities) for wired network devices that allow saving energy when a device (or part of it) is not used. The project will be devoted to re-thinking and re-designing wired network equipment and infrastructures towards more energy-sustainable and eco-friendly technologies and perspectives. The overall idea is to introduce novel green network-specific paradigms and concepts enabling to reduce the energy requirements of wired network equipment by 50% in the short to mid-term (and by 80% in the long run). To this end, the main challenge will be to design, develop and test novel technologies, integrated control criteria and mechanisms for network equipment. The final aim is to enable energy saving by adapting network capacities and resources to current traffic loads and user requirements, while ensuring end-to-end Quality of Service.**

Keywords-green networking; energy efficiency; wire-line networks

I. INTRODUCTION

Triggered by the increase in energy price, the continuous growth of costumer population, the spreading of broadband access, and the expanding number of services being offered by telecoms and Internet Service Providers (ISPs), the energy efficiency issue has recently become a high-priority objective also for wired networks and service infrastructures.

In the past, economy and performance have been the main driving factors in the development of mass products and services, while energy and environmental aspects have not been considered as much. Notwithstanding this approach, Information and Communication Technologies (ICT) has been historically and fairly considered as a key objective to reduce and monitor "third-party" energy wastes, and achieve higher levels of efficiency [1]. However, until recently, ICT has not applied the same efficiency concepts to itself, not even in fast growing sectors like telecommunications and the Internet.

In the last years, many telecoms, ISPs and public organizations around the world reported statistics of network energy requirements and the related carbon footprint, showing an alarming growing trend [2]. For example, as shown in [3] and [4], energy consumption of the Telecom Italia network in 2006 has reached more than 2 TWh (ca. 1% of the total energy demand in Italy), increasing by 7.95% with respect to 2005, and by 12.08% to 2004. Similar energy requirements were reported by Telecom France with 2 TWh in 2006 and by British Telecom with 2.6 TWh in 2008 [5]. The latter absorbed about 0.7% of the total UK's energy consumption in the winter of 2007, making it the biggest single power consumer in the nation [6]. The European Commission DG INFSO report [7] estimated that European telecoms and operators had an overall network energy requirement equal to 14.2 TWh in 2005, bound to rise to 21.4 TWh in 2010 and to 35.8 TWh in 2020, in the absence of "green network technologies." These estimates have to be associated with the fact that, in order to continuously offer the maximum performance and reliability levels, today's networks, links and devices are designed with highly specialized hardware and software, which is provisioned for busy or rush hour loads and lacks power management capabilities. As a consequence, while peak load is rarely reached and only for short time periods, the overall power consumption remains more or less constant with respect to different traffic utilization levels.

As the Future Internet is taking shape, it is recognized that, among other basic concepts and key aspects, energy efficiency should pervade the network infrastructure as a whole to such extent as to become part of the network design criteria. Motivations that drive the quest for "green" networking [8] are environmental, related to the reduction of wastes and impact on CO_2 emissions, and economic, due the ever-increasing cost of energy. In this respect, the ECONET project is devoted to re-thinking and re-designing wired network equipment and infrastructures towards more energy-sustainable and eco-friendly technologies and perspectives. To this end, the main challenge will be to design, develop, and test novel technologies, integrated control criteria and mechanisms for network equipment enabling energy saving, by dynamically adapting network capacities and resources to current traffic loads and user requirements, while ensuring end-to-end Quality of Service (QoS).

Therefore, this project is exploring a coordinated set of approaches and concepts to deliver novel solutions and technologies for reducing the carbon footprint of next generation infrastructures for telecommunication networks. Thanks to the presence of major manufacturing companies, telecoms and ISPs, ECONET will propose its innovative technologies to standardization bodies for extending next generation networks and Future Internet architectures and protocols in the green direction.

The paper is organized as follows. Section II introduces the concepts driving the ECONET project, while Section III presents the main operational objectives it addresses. Finally, achievements and work in progress can be found in Section IV.

II. Project Concept

Nowadays, it is widely recognized that the sole introduction of low consumption silicon elements may not be sufficient to effectively curb tomorrow's network energy requirements. Based on this assumption, the ECONET project will investigate, develop and test new capabilities for the Future Internet devices that can enable the efficient management of power consumption to strongly reduce the current network energy wastes. The overall idea is to introduce novel green network-specific paradigms and concepts enabling the reduction of energy requirements of wired network equipment by 50% in the short to mid-term (and by 80% in the long run) with respect to the business-as-usual scenario. The ECONET project addresses such challenges by focusing its research and development efforts along three main research axes, namely (see **Error! Reference source not found.**):

1) Green Technologies for Network Device Data Plane
2) Green Strategies at the Control Plane, and
3) Green Abstraction Layer.

In the first axis, novel network-specific capabilities are investigated and developed to optimize the power management features (e.g. standby and power scaling primitives). Research activities cover several hardware/firmware (HW/FW), as well as network device typologies (e.g. home-gateway, DSLAM, switches, routers), in order to explore specific energy-saving solutions with respect to legacy and future HW and network requirements. The second research axis investigates the design and development of local and distributed frameworks for energy-efficient flexible and cognitive network Operations, Administration and Management (OAM), with the aim of enabling dynamic, scalable, ad-hoc optimized resource allocation in terms of trade-off between energy consumption and network performance, as well as differentiated performance, fault-tolerance and robustness levels.

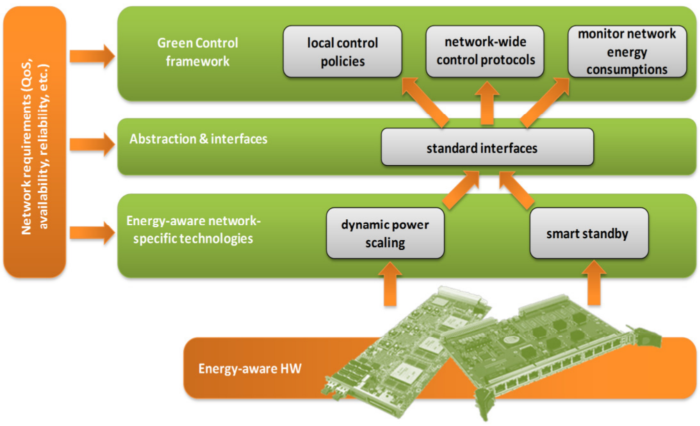

Figura 1. The ECONET vision and its main research threads.

The third axis, the Green Abstraction Layer, focuses on the development of a standard and general-purpose interface for exposing and controlling the novel green capabilities and functionalities, realized with different typologies of network equipment and of HW technologies, towards "general purpose" OAM frameworks. This research axis represents the key for the integration and the development of energy-aware device prototype platforms, including both data-plane green capabilities and control strategies, for project dissemination, demonstration, and proof-of-concept activities. Moreover, it leads to the definition of novel device internal standards for managing and monitoring energy and performance profiles.

The project will ultimately deliver a significant number of novel energy-aware device prototypes (representing all the different aggregation and logical levels of a real operator network), on which large-scale experimental emulations and tests will be conducted. The ECONET consortium joins 15 partners, including network device and chip manufacturers, telecom operators, Internet service providers, research and academic institutions (see Table I). ECONET is organized in 7 Work-Packages (WPs), 5 of which are strictly technical WPs (WP2-6). The project development covers the definition of requirements, metrics and performance indexes in WP2, the design and development of network-specific energy-aware capabilities in WP3, the introduction and the design of the novel green abstraction layer in WP4, and the introduction and the development of control strategies aimed at optimizing and monitoring energy consumption of single devices and of the overall network in WP5. These developments will be demonstrated and qualified in representative industrial test cases in WP6, realized in the test plant of Telecom Italia Labs. Moreover, WP7 is dedicated to the dissemination of results and the transfer of knowledge for exploitation purposes. As one of the main project objectives, WP7 also includes activities related to standardization. Finally, WP1 assures efficient and effective project coordination and management.

III. Objectives

This section introduces the main technical challenges and operational objectives addressed by the ECONET project.

A. *Green Technologies for Network Device Data Plane*

The starting basis for ECONET embraces a heterogeneous set of energy-aware hardware technologies available on the market and generally employed to build current network equipment. The project target is to effectively exploit and adapt their power management features and capabilities in device architectures in order to meet network operational constraints. To this end, focus is mainly on the data-plane of network equipment, since this usually includes the most energy starving HW elements. Starting from this basis, the ECONET project considers two main kind of network-specific energy-saving capabilities, i.e. dynamic power scaling and smart standby, respectively.

The first type of mechanism allows network devices tuning dynamically the trade-off between energy profile and processing capacity of internal processing blocks/engines, while meeting the actual traffic load and QoS constraints. When the system is under partial load, then parts of the system switching logic can be powered off or throttled in order to reduce overall system power consumption without an impact on the overall performance. With these mechanisms, the overall system power can be adjusted. As far as the link protocols are concerned, among other efforts in this field, the ECONET consortium takes into account green extensions for lossless Ethernet (i.e., 802.1Qau, 802.1Qaz and 802.1Qbb). The properties of such protocols can contribute to power reduction/saving across the network by maintaining smaller buffers and avoiding energy investment on retransmissions. The second type of mechanisms allows putting currently unused parts of a network device (such as redundant network interfaces, unused network terminations, etc.) into very low energy consumption modes, where only some basic functionalities are performed (e.g. heart-beating message reply). The key advantage of such solution with respect to a simple switching-off consists in reduced recovery times as well as in the possibility of avoiding useless signaling storms of routing protocols at each active/sleep transition of links or nodes.

B. *Green Strategies in the Control Plane*

ECONET investigates innovative criteria and policies that will allow next generation networks and related equipment to locally and jointly control, manage and monitor energy consumption according to traffic volumes and performance requirements. This will be achieved exploiting the novel green capabilities and technologies resulted from the previous research axis. Here, the desired output consists of a new integrated framework for flexible and cognitive network management and operations. Such framework enables dynamic, ad-hoc and optimized resource allocation, control, deployment, and administration, at both levels of the individual devices and of the network. To this end, as illustrated in **Error! Reference source not found.**, the ECONET project is focusing its efforts on:

- The development of local control policies to optimally configure and synchronize the energy-aware capabilities of all the modules and elements in the same network device or in the same cabinet/Point of Presence;
- The introduction and development of novel algorithms and optimization criteria for network-wide control, which take green metrics and device capabilities into account;
- The design of novel green extensions for network-wide control protocols (i.e., for traffic engineering and OAM purposes) to suitably coordinate the energy savings and performance profiles of each network node;
- The derivation of new paradigms to continuously monitor network energy consumption.

Local control policies are devoted to coordinate the energy profiles and resource allocations of all energy-aware elements in a device, thus optimizing the trade-off between its overall power consumption and traffic loads/requirements. This result is obtained by jointly synchronizing and effectively tuning the capacities and the behavior of processing engines, network interfaces, etc., which generally constitute the data-plane chain of network devices.

Regarding the algorithms and protocols for distributed network control, it is worth noting that telcos and ISPs already adopt frameworks that allow the short- and long-term monitoring and control, but only on the basis of network performance. Current network-wide control plane frameworks generally use different criteria to allocate network resources ranging from QoS requirements to bandwidth optimization. In more detail, such frameworks commonly allow modifying the way by which traffic flows cross the network (e.g., by changing their internal paths or by assigning a different QoS level), and can be usually divided in two main categories: traffic engineering and routing protocols, and centralized OAM.

Traffic engineering and routing protocols (like OSPF-TE) allow autonomic and distributed network reconfigurations to optimally meet short-term traffic volumes and service requirements. They are generally needed to better follow network dynamics. In this respect, the main ECONET objective consists of extending current state-of-the-art technologies, methodologies and protocols for network-wide control by introducing novel energy-aware optimization criteria. The base concept pursued by ECONET consists of acting at the network-wide control-plane, by changing the paths of traffic flows in order to find the optimal network configuration, where end-to-end service requirements are satisfied and the overall network energy consumption minimized. To this end, such novel mechanisms have to know

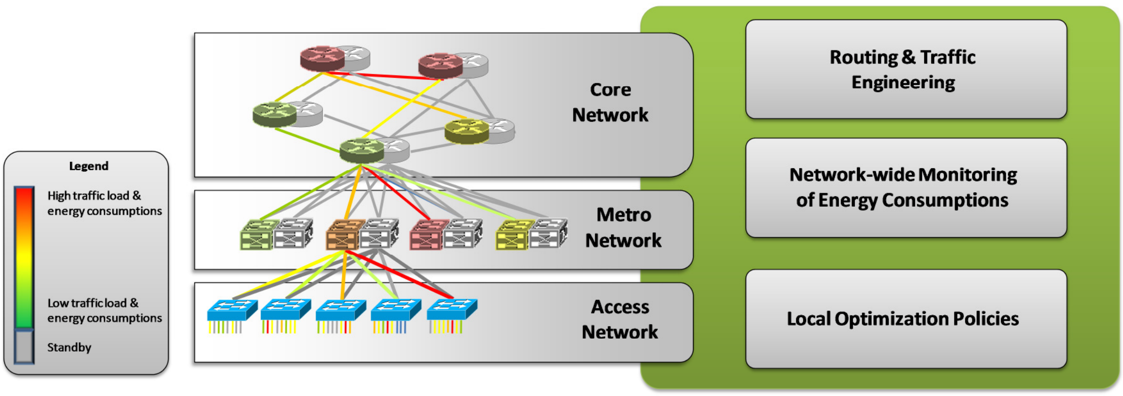

Figure 2. Energy-aware control and monitoring strategies proposed by the ECONET project.

the available green capabilities (i.e., power scaling, smart standby, etc.) and relative features (e.g., power consumption, etc.) at each node, in order to calculate the optimal network configuration. In more detail, the novel green criteria and mechanism studied by ECONET aim at providing:

- Traffic engineering/routing policies to dynamically rerouting traffic for optimizing at short-term the ratio between performance and energy consumption;
- OAM tools for energy-aware long-term configurations of networks and devices;
- Green OAM criteria for the long-term network design, planning and provisioning, which will take economic aspects (OPEX and CAPEX) into account.

To support these novel network-wide control criteria, the project is thus developing new energy-efficient protocols for the dynamic network optimization, devoted to obtain key information on traffic profiling, power measurements, traffic engineering issues and impact of networking devices on energy costs. In the same framework, equipment manufacturers are delivering guidelines on how to integrate new device functionalities in support of the new energy-efficient protocols and hardware elements able to quickly enter / exit the idle state. Regarding network-wide monitoring frameworks, they are a crucial part of centralized OAM frameworks, and are needed for providing input data to the novel green criteria for network design and long-term configurations. In this respect, the ECONET project is developing novel network distributed tools able to effectively collect data on energy consumption at the device and device component level.

C. Green Abstraction Layer

The third research axis is devoted to the study and the development of an Abstraction Layer to expose and control the novel energy-aware capabilities introduced. The Green Abstraction Layer (GAL) is specifically conceived to hide the implementation details of energy-saving approaches, as well as to provide standard interfaces and methodologies for interactions between heterogeneous green capabilities and HW technologies, on one hand, and energy-aware control and monitoring frameworks, on the other hand. To this purpose, the ECONET project involves all partners working at the device data-plane and control-plane level to accurately define a synthetic set of energy- and performance-aware profiles (i.e., states) and parameters, able to logically represent the different approaches and requirements of such green capabilities. Here, the specific goal is to extend and re-engineer the ACPI standard [9] for computing systems, and adapt it to network equipment architectures, functionalities and paradigms. Then, special effort will be devoted to design and develop the GAL as a modular and easily extendable SW framework.

D. Performance Metrics and Benchmarking Methodologies

The introduction of energy saving mechanisms involves the need for commonly accepted criteria to evaluate their effectiveness and, hence, the standardization of a set of benchmarking methodologies and performance indexes. The most innovative features introduced in this respect are the use of latency to characterize the performance degradation due to the power management methods, the use of bursty traffic in order to perform more realistic tests and thus stay closer to a real Internet scenario, and the examination of the trade-off among the energy consumption in all the network devices and the Quality of Experience (QoE) perceived by the end-users. Evaluation criteria are defined for both data and control plane, focusing mainly on the device and its components or the entire network accordingly.

E. Green Network Device Prototypes

In order to maximize the impact and the short-term adoption of proposed green technologies in the telecommunication industry, ECONET is developing several green energy-aware device prototypes based on heterogeneous HW technologies. Such rich set of energy-aware technologies provides two main advantages to the project:

- Enabling the realization and test of a comprehensive set of energy-saving solutions feasible at data- and control-plane in real operating environments, which will have a strong impact on both end-users communities and standardization bodies.
- Thanks to the heterogeneity of prototypes (in terms of HW technologies and networking functionalities), providing the opportunity for: (i) evaluating all the possible facets and viable approaches to network energy saving, and (ii) effectively integrating such different technologies and solutions by means of the GAL, aiming at emphasizing the modular design, simplifying the interworking among different energy-aware techniques (at data- and control-planes), and providing an additional support to the short-term deployment of ECONET SW and HW outcomes on commercial platforms by the project partners.

To this end, the ECONET demonstration activities will follow a three-step approach:

- Development and evaluation of specific technologies and energy-aware capabilities separately;
- Assembly of the most promising capabilities and green technologies into integrated prototypes of energy-aware network devices (also including local mechanisms for energy efficiency optimization);
- Integration of network-wide control with monitoring frameworks on energy-aware devices and prototypes for their evaluation in large-scale networks and experimentation facilities.

Regarding this last demonstration activity, the ECONET project will massively exploit test-plant facilities made available free of charge by telecom and ISP partners. The testing methodologies and instrumentation will be the same "real-life" ones that telcos and ISPs usually adopt for evaluating commercial network devices before putting them in production networks.

IV. MAIN ACHIEVEMENTS AND WORK IN PROGRESS

The characterization of the energy aware design space for networks and its breaking down into data-plane-related and control-plane-related actions has been described in [10]. In detail, a thorough account of energy aware techniques has been provided, with further breakdown based on network layer, home, access, transport and core.

At the data plane, a combination of re-engineering, dynamic adaptation, sleeping, and energy-efficient design approaches has been proposed, in order to meet the requirements for network devices at different network levels. At the control plane, energy aware traffic engineering [11] [12], resource allocation, and virtualization approaches have been proposed to manage the energy conservation capabilities of individual devices and making the ensemble network be more energy proportional than its constituent elements. The above techniques have been integrated and positioned within three representative reference scenarios involving telecom operators and Internet service provider networks. The reference scenarios combine technologies in both planes and all layers and are thus suitable for a complete assessment of the energy-aware propositions of ECONET [13]. While [10] has dealt with the description of the reference scenario, the aim of [14] has been to describe the demonstration scenario, including the test cases and evaluation methods [15], which will be adopted for the final project test beds.

Within the WP3, as part of its common target of reducing energy consumption in wired networks, the ECONET project is trying to introduce, explore, and develop two main kinds of network-specific energy-saving capabilities, i.e. dynamic power scaling and smart standby, respectively. The document in [16] includes a description of the ECONET prototype platforms that have been used and/or developed in the WP3 activities for enabling the green primitives. The main objectives achieved in WP3 regard studying how power management capabilities can be effectively exploited inside network devices to adaptively meet network load and operational constraints [17]. This activity has led to explore and to extend current link protocols (with a special focus on Ethernet, InfiniBand and DSL) towards novel and advanced energy-aware capabilities, and novel network-specific mechanisms and paradigms, working at the device data-plane for effectively optimizing the use of power-scaling primitives at the HW level. Finally, novel network-specific mechanisms and criteria for effectively putting device elements into standby HW states have been proposed, while maintaining vital functionalities and network presence.

Within the first year of activities, WP4 had the objective to lay the first brick in the way of building and consolidating the GAL. A synthetic set of energy-aware and performance-aware profiles (i.e., states) and parameters, able to logically represent the different approaches and requirements of such green capabilities, has been defined. Similarly to other standards in the same field, like the ACPI and the IETF EMAN among others, these types of information are formalized through the concepts of “energy-aware” states. Special effort has been devoted to design and to develop the GAL as a modular and easily extendable structure. In particular, a Green Standard Interface (GSI) has been designed to for exchanging power management data among data-plane elements and processes. This will allow realizing control plane strategies in a standard and simplified way.

Regarding WP5, new local and network-wide strategies have been proposed to optimally balance the device energy consumption with the end-to-end QoE perceived by users [11] [12] [17].

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