low Energy COnsumption NETworks

The ECONET project aimed 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.

At a glance: ECONET

low Energy COnsumption NETworks

Project Coordinator:

Prof. Raffaele Bolla

Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT)

Tel: +39 010 3532075

Fax: +39 010 3532154

Email: raffaele.bolla@unige.it

Project website:

http://www.econet-project.eu

Partners:

CNIT (IT), Alcatel-Lucent Italia S.p.A. (IT), Ericsson (IT), Mellanox Technologies Ltd (IL), Teknologian Tutkimuskeskus VTT (FI), Telecom Italia S.p.A. (IT), Netvisor (HU), Politechnika Warszawska (PL), NASK (PL), Ethernity Networks Ltd (IL), Dublin City University (IE), LightComm S.r.l. (IT), Greek Research & Technology Network (EL), Lantiq GmbH (DE), Infocom (IT).

Duration: *Oct. 2010 – Dec. 2013*

Funding scheme: *Collaborative Project, large-scale Integrating Project (IP)*

Total Cost: *€ 9.96 M*

EC Contribution: *€ 6.1 M*

Contract Number: *INFSO-ICT-258454*

Main Objectives

The ECONET project has been devoted at re-thinking and re-designing wired network equipment and infrastructures towards more energy-sustainable and eco-friendly technologies and perspectives.

Enabling the reduction of energy requirements of wired network equipment by 50%

As the Future Internet is taking shape, it is recognised 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 and to carry across multiple networking domains for the achievement of a general target. There are two main motivations that drive the quest for “green” networking: the environmental one, related to the reduction of wastes and impact on CO_2 emissions, and the economic one, stemming from the need of operators to reduce the cost of keeping the network up and running at the desired service level, while counterbalancing the ever-increasing cost of energy.

The overall idea of the ECONET project has been to introduce novel green network-specific paradigms and concepts enabling **the dynamic 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.

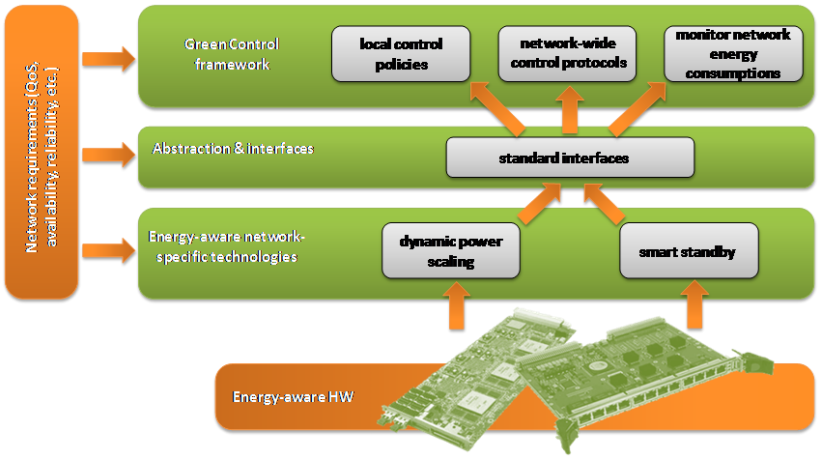
To this end, the main challenges have been to design, to develop and to test novel technologies, integrated control criteria and mechanisms for network equipment enabling energy saving by **dynamically adapting network capacities and resources to current traffic loads and user requirements, while ensuring end-to-end Quality of Service.** Therefore, ECONET project aimed at 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 proposed its innovative technologies to standardization bodies for extending the next generation network and Future Internet architectures and protocols toward the green direction. Such effort has led to the definition of novel device internal standards for managing and monitoring energy and performance profiles, the Green Abstraction Layer (GAL), which has been definitely approved as ETSI Standard 203-237 on 24 March 2014, shortly after the official end of the project.

Key Issues

The figure below summarizes the ECONET vision and identifies the three main research axes of the project, namely:

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



Within the first axis, ECONET has conducted a detailed investigation on novel network-specific capabilities to optimise the power management features (e.g. standby and power scaling primitives). Research activities have covered several hardware / firmware (HW / FW) -°and related°- technologies and network device categories (e.g. home-gateways, DSLAMs, switches, routers), in order to explore specific energy-saving solutions and techniques with respect to legacy and future HW and network requirements.

Within the second research axis, ECONET has investigated the design and development of local and distributed frameworks for energy-efficient flexible and cognitive network Operations, Administration and Management (OAM), with the aim to enable 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.

Within the third axis, the work on the Green Abstraction Layer (GAL) has been focused on the identification and definition 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 has been 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.

ECONET has ultimately delivered a number of novel energy-aware device prototypes, on which large-scale experimental tests have been conducted.

With a significant dissemination effort allocation, the project has aimed at maximising the impact of project results on industrial and network operator communities as well as on standardization bodies, thus bridging the gap between long-term research and industrial deployment. **The whole ECONET consortium is extremely proud of the noteworthy results obtained in the dissemination and standardization fields, among which the final approval of the GAL as ETSI Standard represents an outstanding flagship**.

Technical Approach

ECONET has been organized in 7 work-packages (WP), 5 of which were strictly technical WPs (WP2-6) The project developments has covered 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. In WP6, these developments have been demonstrated and qualified in representative industrial test cases, realized in the test plant of Telecom Italia. Moreover, WP7 has been dedicated to the dissemination of results and the transfer of knowledge for exploitation purposes. As one of the main project objectives, WP7 has also included activities related to the establishment of new standards. Finally, WP1 has assured the efficient and effective project coordination and management.

First Year Achievements

In the first year, five of the seven ECONET WPs were active; more specifically: WP1, WP2, WP3, WP4 and WP7. The consurtium realized the first design of thirteen prototypes of energy-aware network devices able to modulate power requirements with respect to their network performance. Among the main achievements in the first year, the following results deserve a special mention.

- The characterization of energy consumption sources and traffic profiles in today's ISP and Telecom network infrastructures.
- The breakdown of energy requirements of internal components of today's network devices, which are usually deployed in home, access, transport and core networks.
- The detailed definition of Telcom and ISP requirements for future green network technologies.
- A selection of technological approaches that will be explored in the project for realizing the green technologies in compliant way with respect to Telcom and ISP requirements.
- The definition of the final demonstration test beds

that will include a complete network chain of green network device prototypes.

- The methodologies to be used for evaluating the effectiveness and the impact of the green technologies developed in the project.
- A first design of network prototypes including adaptive rate, low power idle and standby modes. Many of such prototypes are already running and first tests have been carried out.
- Theoretical studies on the impact of energy adaptive technologies, whose results have been published in the most relevant scientific conferences and journals.
- A first definition of the structure of the Green Abstraction Layer and of power states.
- The estabilishment of many and valuable relationships with a large number of projects and research initiatives related with the green networking field.
- The strong dissemination activity that has been initialized by presenting the project in many important contexts with large audiences.
- The concrete initialization of effective interactions with different standardization bodies (e.g., ITU, ETSI, IEEE, HGI).

Second Year Achievements

In the second year, six of the seven ECONET WPs were active; more specifically: WP1, WP3-7. WP2 closed its works at the end of the first year, reaching all of its planned objectives. The consortium extended, refined, finalized and experimentally evaluated most of the energy-aware network device prototypes, whose number also increased up to fifteen. Moreover, the definition of the Green Abstraction Layer was finalized and its standardization process in ETSI officially initialized. Among the main achievements in the second year of the project, the following results deserve a special mention.

- The definition of models and procedures to represent and to drive Dynamic Adaptation Mechanisms (Low Power Idle and Adaptive Rate) and their impact on network performance in a heterogeneous set of green devices, spanning from customer premises equipment up to the Core Network nodes.
- The design, definition, development and experimentation of:
  - Energy-saving solutions working inside network devices, in order to adopt new hardware technologies and to optimize the use, or the design of local hardware implementing Adaptive Rate, Low Power Idle, and Standby.
  - Energy-saving solutions working between communicating devices, which include approaches that can be adopted to save energy in interconnected network equipment (Green extensions for link protocols, mechanisms/frameworks to trigger wake-up signals and to shape the transmitted traffic for optimizing the behaviour or the “induced” energy consumption of directly attached nodes).
  - Energy-saving solutions oriented at bypassing devices or functionalities, to be used at different network layers in order to avoid potential drawbacks caused by the use of standby primitives (e.g., Network Connection Proxy to guarantee network presence in the application of smart standby techniques).
- The final definition of the detailed Green Abstraction Layer structures and methods.
- The successful proposal of the GAL for standardization in the ETSI-EE technical Committee, and the start of the standardization process within a dedicated Work Item.
- The preliminary development and evaluation of a number of Local Control Policies (LCPs) for the joint optimization of energy consumption and network performance.
- The proposal of a first set of Network Control Policies to extend traffic engineering protocols with the new green capabilities available at network nodes.
- The enlargement of the number of relationships with other projects and research initiatives related with the green networking field, and the resulting increased collaboration.
- The further increase in the dissemination activity - already strong during the first year - in both quantitative and qualitative terms, by presenting the project and its current results in many important contexts with large audiences; 35 papers have been published during the two years (12 in the first year and 23 in the second year), with a total number of 79 presentations (31 in the first year and 48 in the second one).
- The concrete development of effective actions inside different standardization bodies (ETSI, ITU-T, HGI and EC JRC), with specific focus on GAL and Network Connection Proxy technologies.

Third Year Achievements

In the third year, six of the seven ECONET WPs were active; more specifically: WP1, WP3-7.

During the last period of the project, all the three objectives have been completely achieved. The first axis (Green Technologies for Network Device Data Plane) has been almost successfully completed during the first two years, and only some minor activities related to the monitoring techniques have been finalized during the third year.

The activities related to the second line of the project have been definitely concluded by refining, enriching and testing proposed mechanisms, algorithms

and protocols for both local and network-wide control. A subset of these proposals has been further elaborated upon to prototype implementations, in order to be integrated into the final demonstrator. Moreover, a set of protocol extensions has been defined both for supporting the usage of the GAL interface across the network (e.g., by means of OAM systems), and for carrying additional energy-aware information needed by the proposed new energy-aware Traffic Engineering (TE) and routing mechanisms.

The GAL interface has been refined by using the experience acquired with the final demonstrator setup (where the GAL has been included in all the prototypes), and by interacting with the standardization participants in ETSI (WI GAL 0030) and in IETF (reference persons of the EMAN working group).

Finally, a large quantity of effort has been devoted to integrate all the main achievements produced by the project in a single large-scale demonstrator, which has been implemented and operated at the Test Plant of Telecom Italia. This final demonstrator is the real quintessence of the ECONET project, since it takes the most significant building blocks developed in the project, and reassembles them in a complete and concrete network vision.

Among the main achievements in the final year of the project, the following results deserve a special mention.

- The finalization of the GAL as an ETSI Standard: ETSI ES 203 237, with the substantial cooperation with the IETF EMAN working group, and with its explicit mention in the BroadBand Code of Conduct (BB-CoC) v5.0 as “important technology” for energy consumption reduction. This mention only included other two standards: the IETF EMAN and Energy Efficient Ethernet (IEEE 802.3az).
- The design, the development and the experimentation of the final large-scale demonstrator, which represents the entire fixed network infrastructure of a telecom provider, from the customer home up to the core equipment. This demonstrator provides an actual and effective indication on the relevant global impact of the ECONET work on the energy consumption of telecom networks.
- The final demonstrator allowed witnessing that the ECONET project achieved its goal of reducing the energy-consumption of wire-line networks by a factor of 50% in the short term and of approximately 80% in the long term. The experimental results have been re-elaborated in order to forecast the potential project impact under various scenarios; among others, the case in which the network is still composed by a relevant amount of legacy (non-green) hardware elements.
- The definition of relevant new protocols and of extensions of existing protocols, e.g. the GAL-REST for transporting GAL-related information between equipment and management systems, and the extensions of the OpenFlow protocol towards GAL-like metrics.
- The final development and evaluation of a number of Local Control Policies (LCPs) for the joint optimization of energy consumption and network performance.
- The proposal of a set of Network Control Policies to extend traffic engineering protocols with the new green capabilities available at network nodes.
- The enlargement of the number of relationships with other projects and research initiatives related with the green networking field, and the resulting increased collaboration.
- A further increase in the dissemination activity – already strong during the past years – in both quantitative and qualitative terms, by presenting the project and its current results in many important contexts with large audiences; 70 papers were published during 39 months (12 in the first year, 23 in the second year and 35 in the last period), with a total of more than 100 scientific publications. Besides the quantity, a clear indication of the quality of the work produced by ECONET is demonstrated by the very high quality of quite a few among the journal publications. Among others, we can cite: Science, IEEE/ACM Transactions on Networking, IEEE Communications Magazine, IEEE Network, IEEE Internet Computing, Elsevier Computer Networks, IEEE Journal on Selected Areas in Communications, etc. Moreover, two exhibitions and a large number of videos, accessible on the web, have been produced.
- The concrete development of effective actions inside different standardization bodies (ETSI, ITU-T, HGI and EC JRC), with specific focus on GAL, Network Connection Proxy technologies, and the promotion of the network consumption reduction within regulatory actions (i.e., BB-CoC).

Expected Impact

The major expected impact of ECONET is ambitious and consists in having strengthened, in a mid- long-term perspective, the positioning of the European industry in the field of Future Internet technologies, thanks to the original solutions studied, designed and developed during the project lifespan.

Among other valuable outcomes, it is worth to mention the following list of goals, which the ECONET consortium is very proud to have achieved:

- The development of ***innovative integrated technologies*** for the enablement of energy efficiency in next-generation wired network devices.
- The ***standardization of novel interfaces*** (i.e., the ***Green Abstraction Layer – GAL***), internal to the devices, for easy intercommunication between heterogeneous energy-aware HW and SW.
- The ***formalization of innovative criteria for***

smart control, management and monitoring of energy consumption, both in local and distributed ways, as outcomes of the Green Control Plane.

- The ***definition of protocol extensions*** for the support and the network-wide interoperability of energy efficiency enhancements.
- The ***contributions to various Standardization Bodies*** (in particular: ETSI, HGI, EC JRC and ITU-T) in the area of consumption reductions.
- The enablement of the ***concrete reduction of Telecoms' and ISPs' operating costs (OPEX)*** with advantages in their competiveness towards end-customers.
- The paving of the way for ***wider market opportunities and competitiveness for manufacturers*** in selling their energy-aware products, thanks to the increase of CAPEX of Telecoms and ISPs.

All the developed technologies may be cited as concrete exploitable results of the ECONET project, since they can become enablers of future products and solutions for energy-aware telecommunication networks. More specifically, on the basis of the exploitation plans outlined by the ECONET partners and the analysis of the know-how acquired in the course of the project, the most promising technologies can be itemized as follows:

- Board Power Measurement and Control technologies.
- Power scaling technologies.
- Smart standby technologies.
- Green Network Control Plane.
- Energy-aware traffic engineering for IP and MPLS networks.
- Network virtualization techniques.
- Distributed energy-aware monitoring frameworks.
- Technologies for the power management in IP Routers.
- ABSOLUT (ABstract inStruction wOrkLoad & execUtion plaTform) based evaluation method for data-link layer energy estimation.

In addition to the aforementioned technologies, also the experimental results obtained in the network-wide test bed are worth to be taken into account in terms of exploitation. These results, especially when the potential reduction of OPEX for power consumption has been confirmed, have allowed validating the estimation of the costs for the development of the business cases, required for the planning of future energy-aware products.

Finally, the importance of creating a reference framework must be emphasized, as represented by the GAL, which permits a systematic, standardized and effective approach to reduce the networking energy consumption.

In terms of potential impact, ECONET has set a systematic approach to energy efficiency in wired networks, by clearly decoupling the set of HW technologies that constitute the power-consuming elements in the network and their logical abstractions at various levels. At the same time, it has highlighted the relevance of taking into consideration all layers in the Data Plane protocol stacks and their interaction with the Control Plane, in order to understand their relation in the constant trade-off between energy consumption and QoS/QoE.