D1.7 Integration and spreading of excellence results within TREND WP1

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Abstract:
Integration and spreading of excellence is presented for Work Package 1 on assessment of power consumption in ICT. Factual results in terms of collaboration within and outside TREND are detailed. Big pictures produced by the Work Package are also shown.

Keyword list:
Power consumption, ICT, big picture, energy-saving potential

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1. Executive Summary

This deliverable presents the outcome of the Work Package 1 of the TREND project in terms of integration, contacts with other projects and standardization. It gives an overview of the collaboration that was achieved during the three years of the project on assessment of power consumption in ICT, and briefly summarizes big picture studies that have allowed putting the technical achievements of the Work Package into a broader perspective.

During the three years of WP1, 51 papers were published in international journals or conferences (and 2 technical reports), and 21 mobility actions were organized between the WP1 partners. There were an increasing number of mobility actions over the years, indicating a stronger integration towards the end of the project. This also resulted in a growing number of joint partner papers.

Within WP1, we focused on assessing the power consumption of ICT in general and of telecommunication networks in particular. In all these studies, reliable power consumption data is a crucial means to make a fair and objective estimation. One integrated research activity (IRA) was set up in this technical domain, called IRA1.1 “Collection of data about energy consumption in network elements and subsystems”, resulting in ten joint papers. Further, forces were joined to set up an online database of ICT network equipment power consumption data, called Powerlib (http://powerlib.intec.ugent.be/). Not only power consumption data was collected in WP1, also general assessments were made about the energy saving potential of diverse network technologies and protocols. One IRA was defined, i.e. IRA1.2 “Comparison of circuit versus packet switching paradigm in terms of energy efficiency”, resulting in five joint publications. Additional joint work was made in the field of analyzing next-generation passive optical networks from an energy efficiency perspective (resulting in 3 joint papers) and investigating the impact of TCP traffic on energy-efficiency (resulting in 2 joint papers). Finally, two use cases were discussed and evaluated to stimulate energy efficiency in networks, resulting in two joint activities that will result in at least two additional joint publications.

Further, the WP1 work was supported by contacts with other projects (like GreenTouch, FP7 NoE EINS, FP7 IP STRONGEST, FP7 IP OASE) and with diverse industry contacts.

From a big picture perspective, the main WP1 achievements are:

- Consolidating power consumption values in an online database
- Mapping energy savings of the access and core network, in close collaboration with WP2 and WP3, respectively
- Estimating the worldwide electricity consumption of ICT in the time period 2007-2012

2. Introduction

New ICT and Internet solutions can lead to large energy-saving potential in many sectors of society, and in this way ICT can help to relieve some important problems affecting sustainability at planetary scale, including Greenhouse gas (GHG) emissions, energy production, sustainable lifestyles, and the related problem of climate change. However, ICT (including diverse telecommunication networks and network terminal devices) is also responsible for a considerable and quickly-increasing energy footprint on its own. A thorough and objective investigation in 2007 estimated that the complete life cycle of ICT equipment is responsible for about 4% of the worldwide primary energy consumption, and an updated study in the course of TREND confirmed these trends, however with a lowered expected growth rate. The relative share of the considered set of ICT products and services (we refer to Section 4.3 for more details) in the total worldwide electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012.

Within WP1, we focused on assessing the power consumption of ICT in general and of telecommunication networks in particular. In all these studies, reliable power consumption data is a crucial means to make a fair and objective estimation. Not only power consumption data was collected in WP1, also general assessments were made about the energy-saving potential of diverse network technologies and protocols. Finally, a few incentives were discussed and evaluated to stimulate energy-efficiency in networks.

To reach the above goals, a network of excellence, like the TREND project, is an ideal tool to set up a discussion forum among different people having the same objective in mind. Diverse collaborations and discussions among the TREND partners and collaborating institutions, supported by mobility actions, allowed us to perform various interesting studies, resulting in several joint papers and future research plans. Also the contacts with other European projects and TREND-external industry contacts delivered an important added value. This document describes the measurable results obtained by WP1 in terms of integration, dissemination and spreading of excellence. It completes a more technical report (D1.6) where a detailed description of the technical achievements of partners and collaborating institutions has been provided.

All WP1 partners, as listed below, contributed to this document.

Partner short name
PoliTo
ALBLF
HWDU
TID
Orange
FW
UC3M
iMinds
TUB
EPFL
CNIT
UTH

3. Added value of the NOE

This section shows the added value of WP1 of the TREND project in terms of integration, contacts with other projects and industries.

3.1 Integration

The project started with two clearly identified joint activities that resulted into a high number of joint papers and mobility actions. This also helped to attract collaborating institutions such as INRIA, TUD, FUB and IMDEA. The most important joint work of WP1 falls in the following domains:

3.1.1 Collection of data about energy consumption in network elements and subsystems

This work is performed in the framework of IRA1.1 (as part of Task TD1.1), and is an important part of WP1 as it gives input to various studies on energy-efficient network design. The general goal of this work was gathering detailed energy consumption data of a large variety of (energy-hungry) elements and subsystems in the network, based on the variety of expertises of the different involved partners. This data collection is based on literature, data sheets, experiments and measurements. Some important energy consumption data is collected in Powerlib (http://powerlib.intec.ugent.be/), an online database of ICT network equipment power consumption data. The main outcome of this work was presented in the TREND deliverable D1.3, and the results are summarized in several TREND papers, of which 5 are joint papers, especially between TID and HWDU; iMinds, TUB and Orange, and CNIT-PoliMi and HWDU:

- J. Montalvo (TID), J. Torrijos (TID), J. Xia (HWDU), Y. Ye (HWDU), “Energy efficiency in PON home network scenarios with network enhanced residential gateways”, in Proc. of IEEE Int. Conf. on Networking, Sensing and Control (ICNSC), pp. 141-145, April 2013. *[joint]*
- I. Haratcherev (ALBLF), A. Conte (ALBLF), “Practical energy efficiency in 3G femtocells”- Submitted to INFOCOM 2013.
- W. Van Heddeghem (iMinds), F. Idzikowski (TUB), W. Vereecken (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), P. Demeester (iMinds), Power consumption modeling in optical multilayer networks, Photonic Network Communications, Vol. 24, No. 2, pp. 86-102, October 2012. *[joint]*
- W. Van Heddeghem (iMinds), F. Idzikowski (TUB), E. Le Rouzic (Orange), J. Y. Mazeas (Orange), H. Poignant (Orange), S. Salaun (Orange), B. Lannoo (iMinds), D. Colle (iMinds), Evaluation of Power Rating of Core Network Equipment in Practical Deployments, IEEE online Greencom, online conference, September 2012. *[joint]*
- W. Van Heddeghem (iMinds), F. Idzikowski (TUB), Equipment power consumption in optical multilayer networks - source data, Technical Report IBCN-12-001-01, January 2012. *[joint]*
- A. Lombardo (CNIT), D. Reforgiato (CNIT), V. Riccobene (CNIT), G. Schembra (CNIT), “A Markov Model to Control Heat Dissipation in Open Multi-Frequency Green Routers”, Second IFIP Conference on Sustainable Internet and ICT for Sustainability 2012, October 2012.
- A. Lombardo (CNIT), C. Panarello (CNIT), D. Reforgiato (CNIT), G. Schembra (CNIT), “Measuring and modeling Energy Consumption to design a Green NetFPGA Giga-Router”, IEEE Globecom 2012, December 2012.
- D. Siracusa (POLIMI), V. Linzalata (POLIMI), G. Maier (POLIMI), A. Pattavina (POLIMI), Y. Ye (HWDU), M. Chen (HWDU), “Hybrid architecture for optical interconnection based on micro ring resonators”, Proc. of GLOBECOM 2011, Houston, TX, Dec. 2011, pp. 1-5. *[joint]*

- E. Bonetto (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO), “Energy Profiling of ISP Points of Presence”, IEEE ICC'12 Workshop on Green Communications and Networking, Ottawa, Canada, June 2012.
- A. Valenti (FUB), F. Matera (FUB), G. M. Tosi Beleffi (ISCOM), “Power Consumption Measurements of Access Networks in a Wide Geographical Area Test Bed and Economic Perspectives”, Future Networks and Mobile Summit 2012, July 2012.

Further, within the framework of IRA1.1, data was also collected about traffic patterns. This resulted in several publications on BitTorrent, Twitter and Google traffic, of which 5 are joint papers, especially between UC3M, TID and IMDEA Networks:

- R. Cuevas (UC3M), N. Laoutaris (TID), Y. Xiao (TID), G. Siganos (TID), R. Pablo (TID), Deep Diving into BitTorrent Locality, The 30th IEEE International Conference on Computer Communications (IEEE INFOCOM 2011), Shanghai, China, April 2011. *[joint]*
- M. Kryczka (Institute IMDEA Networks), R. Cuevas (UC3M), C. Guerrero (UC3M), A. Azcorra (UC3M), Unraveling the structure of live BitTorrent Swarms: methodology and analysis, IEEE International Conference in Peer-to-Peer Computing - IEEE P2P 2011, Kyoto (Japan), August 2011. *[joint]*
- M. Kryczka (IMDEA), R. Cuevas (UC3M), A. Cuevas (UC3M), C. Guerrero (UC3M), A. Azcorra (UC3M), Measuring the Bittorrent Ecosystem: Techniques, Tips, and Tricks, IEEE Communications Magazine, Vol. 49, No. 9, pp. 144-152, USA, September 2011. *[joint]*
- R. Cuevas (UC3M), R. Gonzalez (UC3M), A. Cuevas (UC3M), C. Guerrero (UC3M), “Understanding the Locality Effect in Twitter: Measurement and Analysis”, Personal and Ubiquitois Computing, USA, February 2013.
- R. Cuevas (UC3M), M. Kryczka (IMDEA Networks), A. Cuevas (UC3M), S. Kaune (Technical University of Darmstadt), C. Guerrero (UC3M), R. Rejae (University of Oregon), “Unveiling the Incentives for Content Publishing in Popular BitTorrent Portals”, IEEE/ACM Transactions on Networking, USA, February 2013. *[joint]*
- R. Cuevas (UC3M), N. Laoutari (Telefonica Research), X. Yang (Telefonica Research), G. Siganos (Telefonica Research), P. Rodriguez (Telefonica Research), “BitTorrent Locality and Transit Traffic Reduction: when, why and at what cost?”, IEEE Transactions on Parallel and Distributed Systems, April 2013. *[joint]*
- R. Gonzalez (UC3M), R. Cuevas (UC3M), R. Motamedi (University of Oregon), R. Rejaie (University of Oregon), A. Cuevas (Telecom Sud Paris), “Google+ or Google-? Dissecting the Evolution of the New OSN in its First Year”, 22nd International Worldwide Web Conference WWW 2013, Rio de Janeiro, May 2013.

3.1.2 Comparison of circuit versus packet switching paradigm in terms of energy efficiency

This work is performed in the framework of IRA1.2 (as part of Task TD1.2), and its key goal was to compare the circuit switching and packet switching paradigms from an energy perspective. Next to the classical comparison in terms of capacity needs and performance differences, this work specifically concentrates on the energy needs of both paradigms and investigated if this emphasis leads to different conclusions. The main outcome of this work was presented in the TREND deliverable D1.5, and the results are summarized in several TREND papers, of which 5 are joint papers, mainly between CNIT, PoliTo and FW, but also with the involvement of TUB and iMinds:

- F. Bota (PoliTO), F. Khuhawar (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO), “Comparison of Energy Efficiency in PSTN and VoIP Systems”, Proceedings of the 3rd International Conference on Future Energy Systems (e-Energy 2012), Madrid, Spain, May 2012.

- F. Musumeci (CNIT), L. Hernandez (CNIT), L. Zapata (CNIT), M. Tornatore (CNIT), M. Riunno (FW), A. Pattavina (CNIT), "Dynamic routing and resource allocation in time-driven-switched optical networks", Proceedings of HPSR 2012, Belgrade, June 2012. *[joint]*
- F. Musumeci (CNIT), M. Tornatore (CNIT), G. Fontana (University of Trento, Italy), M. Riunno (FW), S. Bregni (CNIT), A. Pattavina (CNIT), "Energy-efficiency of all-optical transport through time driven switching", IET Optoelectronics, Vol. 6, No. 4, pp. 173-182, August 2012. *[joint]*
- E. Bonetto (PoliTO), A. Finamore (PoliTO), M. Munafò (PoliTO), R. Fiandra (FW), "Sleep mode at the edge: how much room is there?", Networks 2012, Roma, Italy, October 2012. *[joint]*
- A. Bianco (PoliTO), E. Bonetto (PoliTO), F. Musumeci (CNIT), A. Pattavina (CNIT), M. Tornatore (CNIT), "CapEx/OpEx Evaluation of Circuit vs Packet Switched Optical Networks", Optical Network Design and Modelling 2013, April 2013. *[joint]*
- W. Van Heddeghem (iMinds), F. Musumeci (CNIT), F. Idzikowski (TUB), A. Pattavina (CNIT), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), "Power Consumption Evaluation of Circuit-Switched Versus Packet-Switched Optical Backbone Networks", OnlineGreenComm, online, October 2013. *[joint]*

3.1.3 Other joint work related to the assessment of the energy-saving potential of network technologies and protocols

A. Energy efficiency analysis of the TDM statistical gain in PONs

Within the framework of TD1.2 the energy saving of time division multiplexing (TDM) in passive optical networks (PONs) was analyzed, taking advantage of the statistics of user traffic in access networks. This work resulted in 3 joint papers between iMinds and TID:

- S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds, "Energy Efficiency Analysis of Next-Generation Passive Optical Network (NG-PON) Technologies in a Major City Network", in Proc. of 15th International Conference on Transparent Optical Networks (ICTON), June 23-27, 2013, Cartagena (Spain). *[joint]*
- S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), "Energy Demand of High-Speed Connectivity Services in NG-PON Massive Deployments", 39th European Conference and Exhibition on Optical Communication (ECOC), 22-26 September 2013, London (United Kingdom). *[joint]*
- S. Lambert (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), J. Montalvo (TID), J. Torrijos (TID), P. Vetter (Alcatel-Lucent, Murray Hill, NJ, US), "Power Consumption Evaluation for Next-Generation Passive Optical Networks", 24th Tyrrhenian International Workshop on Digital Communications (TIWDC), 23-25 September 2013, Genoa (Italy). *[joint]*

B. Impact of TCP traffic on energy-efficiency

Another joint study performed in the framework of TD1.2 is the impact of the Transport Control Protocol (TCP) congestion control on the energy efficiency of capacity scaling approaches. This work resulted in 2 joint papers between CNIT and PoliTo:

- C. Panarello (CNIT), M. Ajmone Marsan (PoliTO), A. Lombardo (CNIT), M. Mellia (PoliTO), M. Meo (PoliTO), G. Schembra (CNIT), "On the Intertwining Between Capacity Scaling and TCP Congestion Control", in Proc. of e-Energy 2012, Madrid, Spain, 9-11 May 2012. *[joint]*
- F. Khuhawar (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO), Modeling the interaction between TCP and Rate Adaptation, ITC 2013, September 2013.
- C. Panarello (CNIT), A. Lombardo (CNIT), G. Schembra (CNIT), M. Meo (PoliTO), M. Mellia (PoliTO), M. Ajmone Marsan (PoliTO), "Power Management and TCP Congestion Control: Friends or Foes?", SSEEGN 2013, November 2013. *[joint]*

3.1.4 Guidelines for policies and incentives to stimulate energy-efficiency in networks

This work is performed in the framework of Task TD1.3, and resulted in two joint activities which will be finalized in two joint paper submissions at the beginning of 2014. The main outcome of this work is presented in the TREND deliverable D1.6 (section 5). A first study analyses the concept of home router virtualization (between iMinds and TID), and a second study deals with base station sharing / mobile network cooperation (between iMinds, UTH, PoliTo and TUB):

- TID / iMinds, accepted for invited talk at ONDM2014. *[joint]*
- G. Koutitas (UTH), G. Iossifidis (UTH), B. Lanoo (iMINDS), M. Tahon (iMINDS), S. Verbrugge (iMINDS), P. Ziridis (IHU), L. Budzisz (TUB), M. Meo (PoliTO), M. Marsan (PoliTO), L. Tassiulas (UTH), A Game Theoretic Approach for Mobile Network Operators Cooperation, to be submitted Journal, 2014. *[joint]*

3.1.5 Joint activities across multiple workpackages, especially to generate the big picture

During the three years of TREND, WP1 has integrated its own research with other WPs, mainly WP2 and WP3. More precisely, for WP2 there has been joint research on modelling power consumption in different parts of the access network and also investigation of mobile network cooperation. For WP3 there has been a joint work on modelling, measuring and analysing power consumption in different parts of the core network, like core routers. With both WP2 and WP3, there is a general overview made of the power consumption in optical networks. This last study resulted in a joint paper with 7 TREND partners and 3 collaborating institutions:

- E. Le Rouzic (Orange), E. Bonetto (PoliTO), L. Chiaraviglio (INRIA), F. Giroire (INRIA), F. Idzikowski (TUB), F. Jiménez (TID), C. Lange (DT), J. Montalvo (TID), F. Musumeci (CNIT), I. Tahiri (INRIA), A. Valenti (FUB), W. Van Heddeghem (iMinds), Y. Ye (HWDU), A. Bianco (PoliTO), A. Pattavina (CNIT), "TREND towards more energy-efficient optical networks", in Proc. of Optical Networks Design and Modelling (ONDM), pp. 210-215, April 2013. (WP1-WP2-WP3) *[joint]*

3.2 Contacts with other projects

TREND partners have established contacts with other collaborative projects (initiatives, European FP7) as a means of fostering the dissemination of TREND results within the research community, and starting collaboration between projects on related topics. The most important collaborations were with:

- **GreenTouch** foundation: The partners presented WP1 activities and collaborated in the organization of common workshops and exchange of information and ideas. More specifically, the following TREND work was presented and discussed in a GreenTouch meeting:
  - Worldwide electricity consumption of ICT (presented at the Stuttgart meeting in Nov. 2012).
  - Power consumption evaluation of NG-PON2 technologies (presented at the Shanghai meeting in May 2013, and the Paris meeting in Nov. 2013).
- **FP7 NoE EINS**: Within the FP7 EINS project (Network of Excellence in Internet Science), there is one work package dealing with energy efficiency, i.e. "WP8: Internet for Sustainability", investigating, from a multi-disciplinary angle, how the Future Internet could help to relieve the main problems affecting sustainability at planetary scale, including Greenhouse gas emissions, energy production, sustainable lifestyles, and the related problem of climate change. Within this work package, attention is also paid to research activities on ICT and Internet energy reduction. More

specifically, the TREND study on the estimation of the worldwide electricity consumption of ICT was partially performed in the framework of EINS.

- **FP7 IP STRONGEST**: Some of the studies related to core networks were in collaboration with the FP7 STRONGEST IP project (Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport, grant agreement 247674, 01/2010 – 12/2012) or some of its partners:
  - The work on representative power values, which ultimately resulted in the powerlib online database, contained in its initial stages substantial input and feedback from STRONGEST partners. These findings were updated and fine-tuned within TREND using more operator-specific input.
  - The survey on the power saving potential in the core was a joint work with the University of Essex, a partner of STRONGEST [W. Van Heddeghem, M. C. Parker, S. Lambert, W. Vereecken, B. Lannoo, D. Colle, M. Pickavet and P. Demeester, "Using an Analytical Power Model to Survey Power Saving Approaches in Backbone Networks", NOC, Vilanova (Spain), June 2012].
  - Similarly, a study on energy-efficient upgrade paths for edge routers was also in collaboration with this same partner. [M. C. Parker, R. Martin, S. D. Walker, W. Van Heddeghem, B. Lannoo, "Energy-Efficient Master-Slave Edge-Router Upgrade Paths in Active Remote Nodes of Next-Generation Optical Access", ACP 2012, Guangzhou (China), November 2012]

  An overview of the relevant work on energy efficiency in the STRONGEST project was presented at the TREND workshops in Ghent (February 2012) and Volos (October 2012).
- **FP7 IP OASE**: Some of the input related to optical access networks was originating from the FP7 OASE project (Optical Access Seamless Evolution), grant agreement 249025, 01/2010-02/2013):
  - Several power consumption values used in the study on power consumption evaluation of NG-PON2 technologies are originating from public data from the OASE project.
  - iMinds, as OASE partner, had several discussions on the used values with the two vendors participating in OASE, i.e. Ericsson and ADVA.

  An overview of the relevant work on energy efficiency in the OASE project was presented at the TREND workshop in Volos (October 2012).

3.3 Contacts with industries

TREND and WP1 of TREND created synergies with industry, especially for the estimation of the worldwide electricity consumption of ICT, organizing several discussions with TREND-external industrial partners, and especially operators, to create a clear picture of the worldwide electricity consumption. We had direct contacts with Deutsche Telekom and British Telecom.

A set of dynamic traffic matrices was added to the SNDlib online database that is managed by Zuse Institut Berlin (ZIB) with support of atesio GmbH. The set contains numerous traffic matrices originating from traffic measurements in core networks. More details about this data can be found in the TREND deliverable D1.3. These traces can be accessed through: http://sndlib.zib.de/dynamicmatrices.overview.action.

A set of measurements of weekly activity in base stations of an Italian MNO (Mobile Network Operator) was collected, as a result of the cooperation of Politecnico di Torino with the MNO, and made available to the TREND partners for the realistic estimation of energy saving in mobile access networks.

At ECOC 2012 (Sep. 19, 2012, Amsterdam, The Netherlands) iMinds organized a symposium on “Energy Consumption of the Internet” in collaboration with the European Photonics Industry Consortium (EPIC). This symposium, supported by TREND, analysed the

relationship between the Internet and its energy requirements now and in the coming decade. Renowned speakers from both energy and ICT background presented their view on this matter. There was a lot of industry involvement in this symposium, with speakers from the International Energy Agency (IEA), Orange Labs, Alcatel-Lucent and Ericsson.

The powerlib (http://powerlib.intec.ugent.be/) online database was presented at the International Energy Agency (IEA) 'Network Standby' workshop in Paris (September 2013). The presentation raised substantial interest and feedback, and was particularly useful as almost all collaborators of the workshop did not have any links with the TREND project. The study on the worldwide electricity consumption of ICT was also a valuable input to the IEA workshop and the upcoming IEA publication on 'Network Standby'.

4. Big picture

One important result of the WP1 activities has been the elaboration of big pictures on ICT power consumption involving the work from several partners.

4.1 Consolidating power consumption values (joint activity with WP3 and WP2)

When starting our TREND studies, we rapidly faced incoherence in the values found in the literature about network equipment power consumption. Several partners from WP1/WP3 joined their effort to generate a consolidated power consumption model [1] that could be used for core networks. This work gave birth to a more general library on telecommunication equipment, named powerlib. At http://powerlib.intec.ugent.be/ we host an online database of ICT network equipment power consumption data. Its main and initial purpose is to collect and provide this data for use in research towards more power-efficient ICT networks. By providing a single source, we hope to facilitate power consumption data collection and referencing.

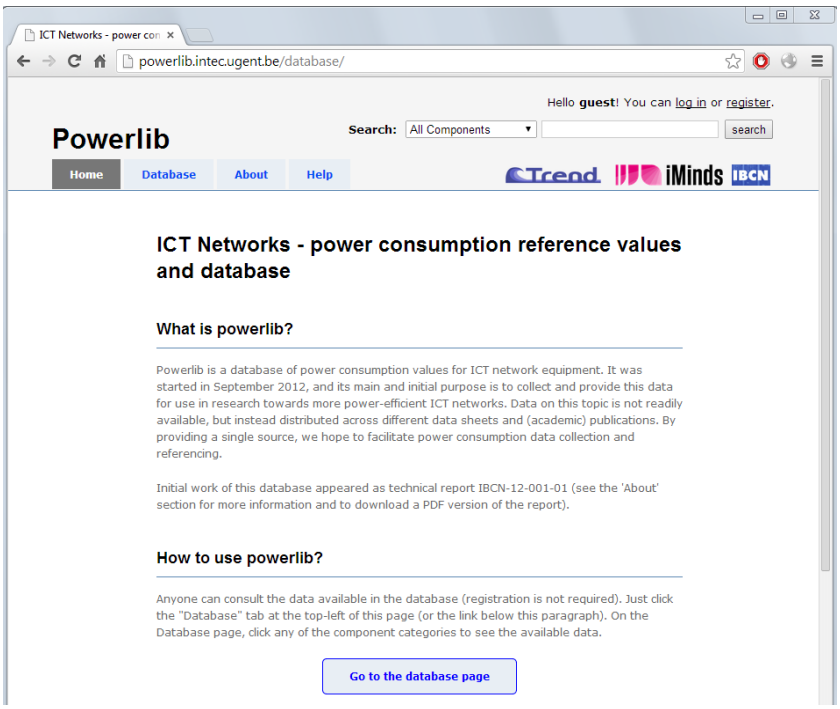

Figure 1: Powerlib website – start page

As Powerlib is originating from joint work between WP1 and WP3, originally, it only contained data for core networks. However, in the final year of TREND, some partners also included data for access networks, and especially for optical line terminals (OLT) and customer premises equipment (CPE) in optical access networks. The future plans of Powerlib are elaborated in the TREND deliverable D1.6.

4.2 Mapping energy savings of the access and core network (joint activity with WP2 and WP3)

WP2 and WP3 provided a mapping of possible (expected) energy savings if one implements the proposed technologies and schemes. The aggregated presentation of the findings is based on the collaborative work between WP1, WP2 and WP3 partners. For the detailed savings in the access and core networks, we refer to the respective WP2 and WP3 documents. Figure 2 and Figure 3 summarize the general trends in both domains.

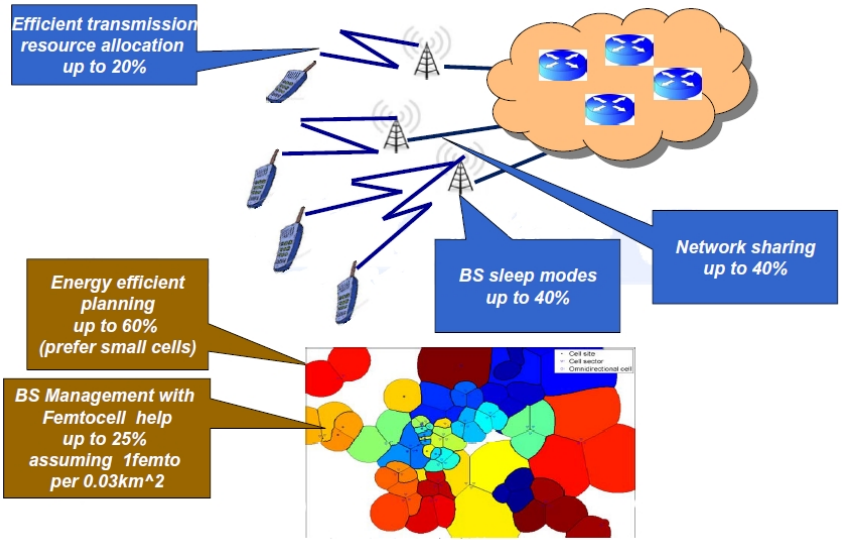

Figure 2: Expected energy savings for different access network parts studied within TREND

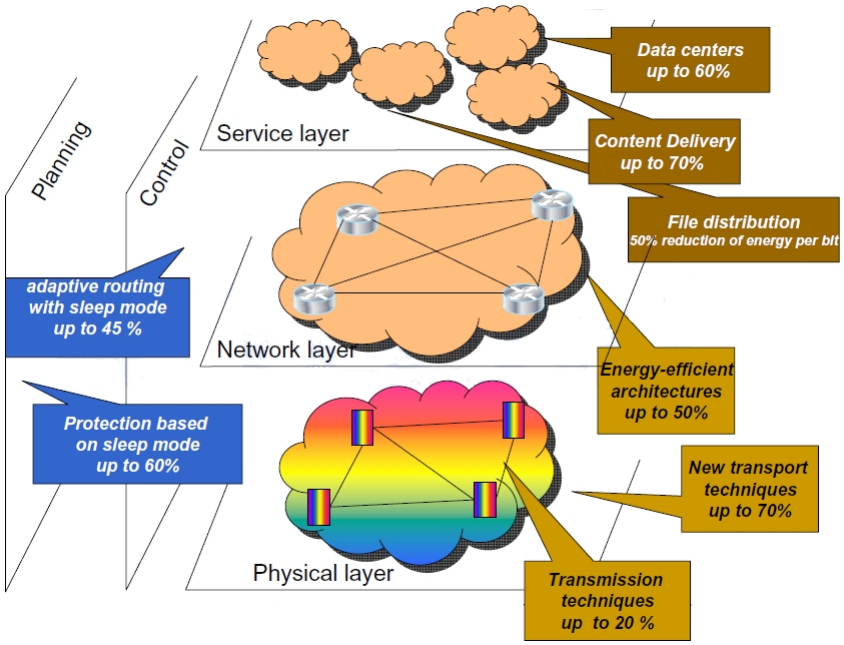

Figure 3: Expected energy savings for different core network parts studied within TREND

4.3 Worldwide electricity consumption of ICT

ICT devices and services are becoming more and more widespread in all aspects of human life. Following an increased worldwide focus on the environmental impacts of energy consumption in general, there is also a growing attention to the electricity consumption associated with ICT equipment.

Within WP1 of TREND, we assessed how ICT electricity consumption in the use phase has evolved from 2007 to 2012, based on three main ICT categories: communication networks, personal computers, and data centers. We provided a detailed description of how we calculate the electricity use and evolution in these three categories. The relevance of estimating the worldwide ICT electricity use is twofold. A first purpose is to assess whether ICT is a significant contributor to the worldwide electricity consumption, or by extension, to the worldwide carbon emissions. A second purpose is to assess where efforts should be concentrated in order to reduce the worldwide ICT electricity consumption.

Our estimates showed that the yearly growth of all three individual ICT categories (10%, 5%, and 4%, respectively) is higher than the growth of worldwide electricity consumption in the same time frame (3%). The relative share of this subset of ICT products and services in the total worldwide electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012. We found that the absolute electricity consumption of each of the three categories is still roughly equal. This highlights the need for energy-efficiency research across all these domains, rather than focusing on a single one.

5. Summary of the papers and mobility actions

5.1 Published/submitted papers

Involved partners/Collaborating Institutions	Authors	Title	Conf/journal	Date of presentation/ publication
CNIT / Princeton University	S. Buzzi (CNIT), H. V. Poor (Princeton University), A. Zappone (CNIT)	*Transmitter waveform and widely linear receiver design: noncooperative games for wireless multiple-access networks*	Journal IEEE Transactions on Information Theory	Oct. 2010
CNIT / UniRoma1	R. Bolla (CNIT), R. Bruschi (CNIT), A. Cianfrani (UniRoma1), M. Listanti (UniRoma1)	*Introducing standby capabilities into next-generation network devices*	Conference Workshop on Programmable Routers for Extensible Services of Tomorrow (PRESTO)	Nov. 2010
CNIT / University of Cassino	S. Buzzi (CNIT), D. Saturnino (University of Cassino)	*A Game-Theoretic Approach to Energy-Efficient Power Control and Receiver Design in Cognitive CDMA Wireless Networks*	Journal IEEE Journal of Selected Topics in Signal Processing	Feb. 2011
UC3M / TID *[joint]*	R. Cuevas (UC3M), N. Laoutaris (TID), Y. Xiao (TID), G. Siganos (TID), R. Pablo (TID)	*Deep Diving into BitTorrent Locality*	Conference The 30th IEEE International Conference on Computer Communications (IEEE INFOCOM 2011)	Apr. 2011
CNIT / Scuola Superiore Sant'Anna di Pisa	S. Buzzi (CNIT), G. Colavolpe (University of Parma), D. Saturnino (Scuola Superiore Sant'Anna di Pisa), A. Zappone (CNIT)	*Potential Games for Power Control and Subcarrier Allocation in Uplink Multicell OFDMA Systems*	Conference 2nd International ICST Conference on Game Theory for Networks	Apr. 2011

iMinds	W. Van Heddeghem (iMinds), W. Vereecken (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), P. Demeester (iMinds)	*Distributed Computing for Carbon Footprint Reduction by Exploiting Low-Footprint Energy Availability*	Journal Future Generation Computer Systems (FGCS)	May 2011
EPFL / Czech Technical University in Prague / University of Belgrade	K. Dufkova (Czech Technical University in Prague), M. Popovic (EPFL), R. Khalili (EPFL), J. Y. Le Boudec (EPFL), M. Bjelica (University of Belgrade), L. Kencl (Czech Technical University in Prague)	*Energy Consumption Comparison Between Macro-Micro and Public Femto Deployment in a Plausible LTE Network*	Conference e-Energy 2011: 2nd International Conference on Energy-Efficient Computing and Networking 2011	Jun. 2011
PoliTO / IMDEA / University Antonio de Nebrija *[joint]*	M. Ajmone Marsan (PoliTO), A. Fernández Anta (IMDEA), V. Mancuso (IMDEA), B. Rengarajan (IMDEA), P. Reviriego Vasallo (University Antonio de Nebrija), G. Rizzo (IMDEA)	*A Simple Analytical Model for Energy Efficient Ethernet*	Journal IEEE Communication letters	Jun. 2011
CNIT / PoliTO *[joint]*	A. Zappone (CNIT), G. Alfano (PoliTO), S. Buzzi (CNIT), M. Meo (PoliTO)	*Energy-efficient non-cooperative resource allocation in multicell OFDMA systems with multiple base station antennas and MRC combining*	Conference Annual Meeting of the Italian Telecommunication Group	Jun. 2011
iMinds	W. Vereecken (iMinds), W. Van Heddeghem (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), B. Dhoedt (iMinds), P. Demeester (iMinds)	*The Environmental Footprint of Data Centers: The Influence of Server Renewal Rates on the Overall Footprint*	Conference Green Communications and Networks 2011 (GCN 2011)	Jul. 2011
UC3M / IMDEA *[joint]*	M. Kryczka (IMDEA), R. Cuevas (UC3M), C. Guerrero (UC3M), A. Azcorra (UC3M)	*Unraveling the structure of live BitTorrent Swarms: methodology and analysis*	Conference IEEE International Conference in Peer-to-Peer Computing - IEEE P2P 2011	Aug. 2011

TUB	S. Chiaravalloti (TUB), F. Idzikowski (TUB), L. Budzisz (TUB)	*Power consumption of WLAN network elements*	Technical report TKN Technical Reports Series	Aug. 2011
UC3M / IMDEA *[joint]*	M. Kryczka (IMDEA), R. Cuevas (UC3M), A. Cuevas (UC3M), C. Guerrero (UC3M), A. Azcorra (UC3M)	*Measuring the Bittorrent Ecosystem: Techniques, Tips, and Tricks*	Journal IEEE Communications Magazine	Sep. 2011
CNIT / University of Parma	S. Buzzi (CNIT), G. Colavolpe (University of Parma)	*Maximizing Bits-per-Joule Capacity over Parallel Channels*	Conference 2011 IEEE Online Green Communications Conference	Sep. 2011
CNIT / TUD *[joint]*	A. Zappone (CNIT), S. Buzzi (CNIT), E. Jorswieck (TUD)	*Green power control and receiver design in relay-assisted interference channel wireless networks: A game-theoretic approach*	Conference 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2011)	Oct. 2011
Orange / Universite Bretagne Sud	S. Le Masson (Orange), D. Nortershauser (Orange), B. Deddy (Orange), P. Glouannec (Universite Bretagne Sud)	*Thermal Model for Data Centre Cooling*	Conference INTELEC Amsterdam 2011	Oct. 2011
EPFL / TUD *[joint]*	T. T. Tesfay (EPFL), R. Khalili (EPFL), J. Y. Le Boudec (EPFL), F. Richter (TUD), A. J. Fehske (TUD)	*Energy Saving and Capacity Gain of Micro Sites in Regular LTE Networks: Downlink Traffic Layer Analysis*	Conference 6th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks	Oct. 2011
UTH	L. Gkatzikis (UTH), G. Paschos (UTH), I. Koutsopoulos (UTH)	*Medium Access Games: The Impact of Energy Constraints*	Conference International Conference on NETwork Games, COntrol and Optimization (NETGCOOP 2011)	Oct. 2011

CNIT / PoliTO *[joint]*	A. Zappone (CNIT), G. Alfano (PoliTO), S. Buzzi (CNIT), M. Meo (PoliTO)	*Non-cooperative resource allocation in multi-cell OFDMA systems with multiple base station antennas*	Conference 8th International Symposium on Wireless Communication Systems (ISWCS 2011)	Nov. 2011
CNIT-PoliMI / HWDU *[joint]*	D. Siracusa (POLIMI), V. Linzalata (POLIMI), G. Maier (POLIMI), A. Pattavina (POLIMI), Y. Ye (HWDU), M. Chen (HWDU)	*Hybrid Architecture for Optical Interconnection based on Micro Ring Resonators*	Conference GLOBECOM 2011	Dec. 2011
iMinds / TUB *[joint]*	W. Van Heddeghem (iMinds), F. Idzikowski (TUB)	*Equipment power consumption in optical multilayer networks - source data*	Technical report Technical Report IBCN-12-001-01	Jan. 2012
PoliTO	F. Bota (PoliTO), F. Khuhawar (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO)	*Comparison of Energy Efficiency in PSTN and VoIP Systems*	Conference 3rd International Conference on Future Energy Systems (e-Energy 2012)	May 2012
CNIT / PoliTO *[joint]*	C. Panarello (CNIT), M. Ajmone Marsan (PoliTO), A. Lombardo (CNIT), M. Mellia (PoliTO), M. Meo (PoliTO), G. Schembra (CNIT)	*On the Intertwining between Capacity Scaling and TCP Congestion Control*	Conference e-Energy2012	May 2012
iMinds / University Of Essex	W. Van Heddeghem (iMinds), M. C. Parker (University Of Essex), S. Lambert (iMinds), W. Vereecken (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), P. Demeester (iMinds)	*Using an Analytical Power Model to Survey Power Saving Approaches in Backbone Networks*	Conference NOC 2012	Jun. 2012

CNIT / FW *[joint]*	F. Musumeci (CNIT), L. Hernandez (CNIT), L. Zapata (CNIT), M. Tornatore (CNIT), M. Riunno (FW), A. Pattavina (CNIT)	*Dynamic routing and resource allocation in time-driven-switched optical networks*	Conference HPSR 2012	Jun. 2012
PoliTO	E. Bonetto (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO)	*Energy Profiling of ISP Points of Presence*	Conference IEEE ICC'12 Workshop on Green Communications and Networking	Jun. 2012
FUB / ISCOM	A. Valenti (FUB), F. Matera (FUB), G. M. Tosi Beleffi (ISCOM)	*Power Consumption Measurements of Access Networks in a Wide Geographical Area Test Bed and Economic Perspectives*	Conference Future Networks and Mobile Summit 2012	Jul. 2012
CNIT / FW / University of Trento *[joint]*	F. Musumeci (CNIT), M. Tornatore (CNIT), G. Fontana (University of Trento), M. Riunno (FW), S. Bregni (CNIT), A. Pattavina (CNIT)	*Energy-efficiency of all-optical transport through time driven switching*	Journal IET Optoelectronics	Aug. 2012
iMinds	S. Lambert (iMinds), W. Van Heddeghem (iMinds), W. Vereecken (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds)	*Estimating the global power consumption in communication networks*	Conference ECOC 2012	Sep. 2012
iMinds / TUB / Orange *[joint]*	W. Van Heddeghem (iMinds), F. Idzikowski (TUB), E. Le Rouzic (Orange), J. Y. Mazeas (Orange), H. Poignant (Orange), S. Salaun (Orange), B. Lannoo (iMinds), D. Colle (iMinds)	*Evaluation of Power Rating of Core Network Equipment in Practical Deployments*	Conference Greencom 2012, online conference	Sep. 2012

CNIT	A. Lombardo (CNIT), D. Reforgiato (CNIT), V. Riccobene (CNIT), G. Schembra (CNIT)	*A Markov Model to Control Heat Dissipation in Open Multi-Frequency Green Routers*	Conference Second IFIP Conference on Sustainable Internet and ICT for Sustainability 2012	Oct. 2012
PoliTO / FW *[joint]*	E. Bonetto (PoliTO), A. Finamore (PoliTO), M. Munafò (PoliTO), R. Fiandra (FW)	*Sleep Mode at the Edge: How Much Room is There?*	Conference 15th International Telecommunications Network Strategy and Planning Symposium (NETWORKS 2012)	Oct. 2012
iMinds / TUB *[joint]*	W. Van Heddeghem (iMinds), F. Idzikowski (TUB), W. Vereecken (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), P. Demeester (iMinds)	*Power consumption modeling in optical multilayer networks*	Journal Photonic Network Communications	Oct. 2012
iMinds	S. Lambert (iMinds), W. Van Heddeghem (iMinds), W. Vereecken (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds)	*Worldwide electricity consumption of communication networks*	Journal Optics Express	Dec. 2012
A-LBLF	C. S. Chen (A-LBLF)	*On the peak-to-average power ratio of pre-equalized OFDM based on Base-Field Hartley transform*	Conference IEEE Global Communications Conference, workshop on Emerging Technologies for LTE-Advanced and Beyond-4G (LTE-B4G)	Dec. 2012
CNIT	A. Lombardo (CNIT), C. Panarello (CNIT), D. Reforgiato (CNIT), G. Schembra (CNIT)	*Measuring and modeling Energy Consumption to design a Green NetFPGA Giga-Router*	Conference IEEE Globecom 2012	Dec. 2012
TID	J. Montalvo (TID), J. Torrijos (TID), R. Canto (TID), I. Berberana (TID)	*Energy Efficiency and Cost Optimization of OTDR Supervision Systems for Monitoring Optical Fiber Infrastructures*	Conference International Conference on Networks (ICN 2013)	Jan. 2013

UC3M / IMDEA / Technical University of Darmstadt / University of Oregon *[joint]*	R. Cuevas (UC3M), M. Kryczka (IMDEA), A. Cuevas (UC3M), S. Kaune (Technical University of Darmstadt), C. Guerrero (UC3M), R. Rejae (University of Oregon)	*Unveiling the Incentives for Content Publishing in Popular BitTorrent Portals*	Journal IEEE/ACM Transactions on Networking	Feb. 2013
UC3M	R. Cuevas (UC3M), R. Gonzalez (UC3M), A. Cuevas (UC3M), C. Guerrero (UC3M)	*Understanding the Locality Effect in Twitter: Measurement and Analysis*	Journal Personal and Ubiquitois Computing	Feb. 2013
UC3M / Telefonica Research *[joint]*	R. Cuevas (UC3M), N. Laoutari (Telefonica Research), X. Yang (Telefonica Research), G. Siganos (Telefonica Research), P. Rodriguez (Telefonica Research)	*BitTorrent Locality and Transit Traffic Reduction: when, why and at what cost?*	Journal IEEE Transactions on Parallel and Distributed Systems	Apr. 2013
Orange / PoliTO / TUB / TUD / CNIT / iMinds / HWDU / INRIA / DT / FUB *[joint]*	E. Le Rouzic (Orange), E. Bonetto (PoliTO), L. Chiaraviglio (INRIA), F. Giroire (INRIA), F. Idzikowski (TUB), F. Jiménez (TID), C. Lange (DT), J. Montalvo (TID), F. Musumeci (CNIT), I. Tahiri (INRIA), A. Valenti (FUB), W. Van Heddeghem (iMinds), Y. Ye (HWDU), A. Bianco (PoliTO), A. Pattavina (CNIT)	*TREND towards more energy-efficient optical networks*	Conference Optical Network Design and Modelling (ONDM 2013)	Apr. 2013

PoliTO / CNIT *[joint]*	A. Bianco (PoliTO), E. Bonetto (PoliTO), F. Musumeci (CNIT), A. Pattavina (CNIT), M. Tornatore (CNIT)	*CapEx/OpEx Evaluation of Circuit vs Packet Switched Optical Networks*	Conference Optical Network Design and Modelling (ONDM 2013)	Apr. 2013
TID / HWDU *[joint]*	J. Montalvo (TID), J. Torrijos (TID), J. Xia (HWDU), Y. Ye (HWDU)	*Energy Efficiency in PON Home Network Scenarios With Network Enhanced Residential Gateways*	Conference IEEE Conference of Networking, Sensing and Control (ICNSC)	Apr. 2013
UC3M / University of Oregon / Telecom Sud Paris	R. Gonzalez (UC3M), R. Cuevas (UC3M), R. Motamedi (University of Oregon), R. Rejaie (University of Oregon), A. Cuevas (Telecom Sud Paris)	*Google+ or Google-? Dissecting the Evolution of the New OSN in its First Year*	Conference 22nd International Worldwide Web Conference WWW 2013	May 2013
CNIT / TUD *[joint]*	S. Buzzi (CNIT), A. Zappone (TUD)	*Potential games for energy-efficient resource allocation in multipoint-to-multipoint CDMA wireless data networks*	Journal Physical Communication	Jun. 2013
UTH / iMinds *[joint]*	D. Hatzopoulos (UTH), I. Koutsopoulos (UTH), G. Koutitas (UTH), W. Van Heddeghem (iMinds)	*Dynamic Virtual Machine Allocation in Cloud Server Facility Systems with Renewable Energy Sources*	Conference ICC 2013	Jun. 2013
iMinds / TID *[joint]*	S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds)	*Energy efficiency analysis of next-generation passive optical network (NG-PON) technologies in a major city network*	Conference International Conference on Transparent Optical Networks (ICTON 2013)	Jun. 2013
PoliTO	F. Khuhawar (PoliTO), M. Mellia (PoliTO), M. Meo (PoliTO)	*Modeling the interaction between TCP and Rate Adaptation*	Conference International Teletraffic Congress (ITC 2013)	Sep. 2013

iMinds / TID / Alcatel-Lucent *[joint]*	S. Lambert (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), J. Montalvo (TID), J. Torrijos (TID), P. Vetter (Alcatel-Lucent, Murray Hill)	*Power Consumption Evaluation for Next-Generation Passive Optical Networks*	Conference 24th Tyrrhenian International Workshop on Digital Communications (TIWDC '13)	Sep. 2013
iMinds / TID *[joint]*	S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds)	*Energy Demand of High-Speed Connectivity Services in NG-PON Massive Deployments*	Conference 39th European Conference and Exhibition on Optical Communication (ECOC 2013)	Sep. 2013
iMinds / CNIT / TUB *[joint]*	W. Van Heddeghem (iMinds), F. Musumeci (CNIT), F. Idzikowski (TUB), A. Pattavina (CNIT), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds)	*Power Consumption Evaluation of Circuit-Switched Versus Packet-Switched Optical Backbone Networks*	Conference OnlineGreenComm, online	Oct. 2013
CNIT / PoliTO *[joint]*	C. Panarello (CNIT), A. Lombardo (CNIT), G. Schembra (CNIT), M. Meo (PoliTO), M. Mellia (PoliTO), M. Ajmone Marsan (PoliTO)	*Power Management and TCP Congestion Control: Friends or Foes?*	Conference ITC SSEEGN 2013 - 22nd ITC Specialist Seminar on Energy Efficient and Green Networking	Nov. 2013
CNIT / Orange / PoliTO / Polimi UC3M *[joint]*	R. Modrzejewski (INRIA), L. Chiaraviglio (CNIT), I. Tahiri (INRIA), F. Giroire (INRIA), E. Le Rouzic (Orange), E. Bonetto (PoliTO), F. Musumeci (POLIMI), R. Gonzalez (UC3M), C. Guerrero (UC3M)	*Energy Efficient Content Distribution in an ISP Network*	Conference Globecom 2013	Dec. 2013

5.2 Mobility actions

Involved partners	Person	Topic	Period
PoliTO – FW	Edoardo Bonetto	*Energy Profiling of Fastweb Points of Presence*	from 25/02/2011 to 25/02/2011
PoliTO – FW	Edoardo Bonetto	*Energy Profiling of Fastweb Points of Presence*	from 24/03/2011 to 24/03/2011
CNIT-POLIMI – FW	Mirko Gattulli	*Traffic measures*	from 06/09/2011 to 08/09/2011
TUB – iMinds	Filip Idzikowski	*Power consumption modeling - core networks*	from 16/11/2011 to 16/11/2011
UC3M – PoliTO	Roberto Gonzalez	*Greening the Networking Infrastructure of OSNs*	from 20/11/2011 to 03/12/2011
TUB – iMinds	Filip Idzikowski	*Power consumption of IP-over-WDM network devices - theory vs. practice*	from 16/02/2012 to 16/02/2012
Orange – iMinds	Esther Le Rouzic	*Contribution to the joint activity on power consumption of IP-over-WDM network devices*	from 16/02/2012 to 16/02/2012
CNIT – TUD	Alessio Zappone	*Energy efficient resource allocation for the relay-assisted interference channel*	from 11/04/2012 to 06/05/2012
UC3M – CNIT	Roberto Gonzalez	*Experimental activity for measurement and management the energy cost of networking intensive applications: P2P and OSN*	from 08/07/2012 to 15/07/2012
CNIT - UC3M	Olga Jaramillo	*Experimental activity for measurement and management the energy cost of networking intensive applications: P2P and OSN*	from 22/07/2012 to 29/07/2012
CNIT – FUB	Stefano Buzzi	*Energy efficiency in communications networks*	from 18/09/2012 to 18/09/2012
CNIT – FUB	Chiara Risi	*Energy efficiency in communications networks*	from 18/09/2012 to 18/09/2012
CNIT – FUB	Alessio Zappone	*Energy efficiency in communications networks*	from 18/09/2012 to 18/09/2012

iMinds – TID	Sofie Lambert	*Energy efficiency in NGPON deployments*	from 08/01/2013 to 18/01/2013
UC3M – CNIT	Roberto Gonzalez	*Experimental activity for measurement and management the energy cost of networking intensive applications: P2P and OSN*	from 20/01/2013 to 25/01/2013
ZIB – TUB	Axel Werner	*Traffic and energy consumption in IP-over-WDM networks -- design, heuristics and physical constraints*	from 04/03/2013 to 01/11/2013
ZIB – TUB	Frank Pfeuffer	*Traffic and energy consumption in IP-over-WDM networks -- design, heuristics and physical constraints*	from 04/03/2013 to 01/11/2013
ZIB – TUB	Inken Olthoff	*Traffic and energy consumption in IP-over-WDM networks -- design, heuristics and physical constraints*	from 04/03/2013 to 01/11/2013
TUB – DT	Filip Idzikowski	*Traffic and energy saving in IP-over-WDM networks*	from 10/04/2013 to 10/04/2013
iMinds – TID	Koen Casier	*Guidelines for policies and incentives to stimulate energy-efficiency in networks: home router virtualization in FTTH networks*	from 04/06/2013 to 05/06/2013
TUB – DT	Filip Idzikowski	*Traffic and energy saving in IP-over-WDM networks*	from 26/11/2013 to 26/11/2013

6. Conclusions

6.1 Global view

During the 3 years of WP1, 51 papers were published in international journals or conferences (and 2 technical reports), and 21 mobility actions were organized between the WP1 partners. The general statistics for the published papers are presented in Figure 4.

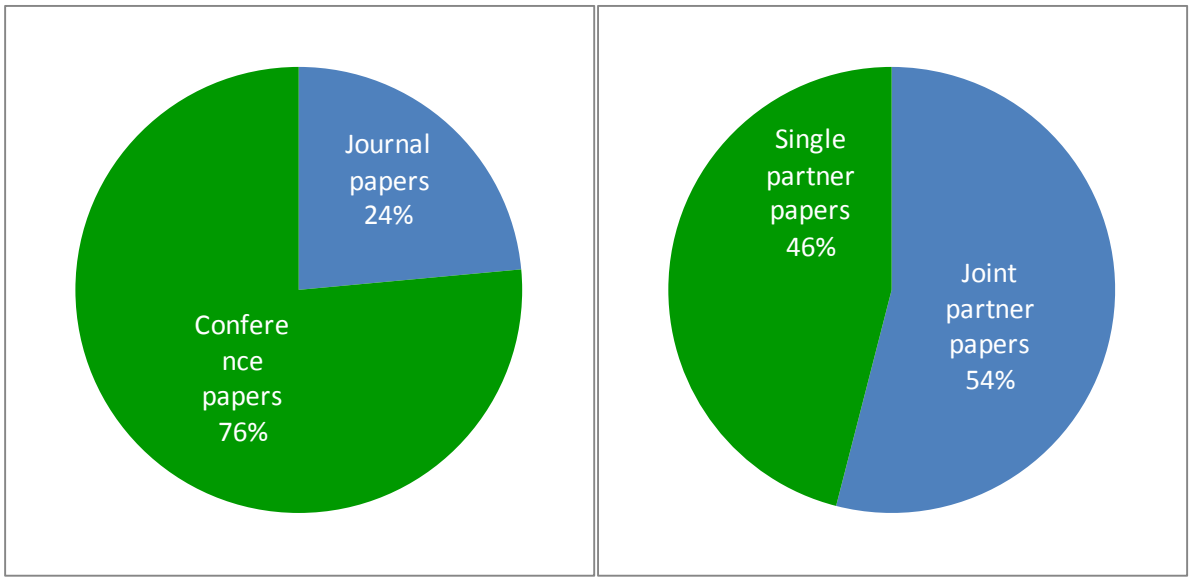

Figure 4: Statistics of WP1 TREND papers

6.2 Project integration (factual results in terms of collaboration)

This section describes the integration of the WP1 TREND partners, and its evolution during the three TREND years. It presents the joint activities, like mobility actions, that were performed during TREND in order to achieve the joint publications and results of WP1. The total number of mobility actions was 21, and in Figure 5 we can clearly see an increasing number of mobility actions over the years, indicating a stronger integration towards the end of the project. This also resulted in a growing number of joint partner papers.

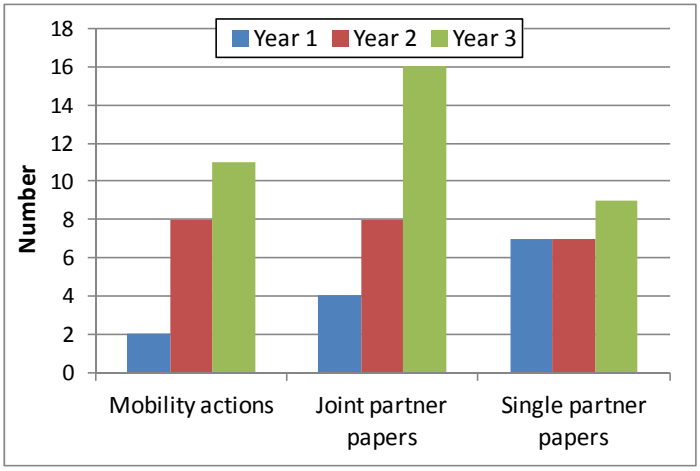

Figure 5: Amount of papers and mobility actions produced each year

7. References

List of all papers from WP1

[1] R. Modrzejewski (INRIA), L. Chiaraviglio (CNIT), I. Tahiri (INRIA), F. Giroire (INRIA), E. Le Rouzic (Orange), E. Bonetto (PoliTO), F. Musumeci (POLIMI), R. Gonzalez (UC3M), C. Guerrero (UC3M), Energy Efficient Content Distribution in an ISP Network, Globecom 2013, December 2013.

[2] C. Panarello (CNIT), A. Lombardo (CNIT), G. Schembra (CNIT), M. Meo (PoliTO), M. Mellia (PoliTO), M. Ajmone Marsan (PoliTO), Power Management and TCP Congestion Control: Friends or Foes?, SSEEGN 2013, November 2013.

[3] W. Van Heddeghem (iMinds), F. Musumeci (CNIT), F. Idzikowski (TUB), A. Pattavina (CNIT), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), Power Consumption Evaluation of Circuit-Switched Versus Packet-Switched Optical Backbone Networks, OnlineGreenComm, online, October 2013.

[4] S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lanoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), Energy Demand of High-Speed Connectivity Services in NG-PON Massive Deployments, 39th European Conference and Exhibition on Optical Communication (ECOC 2013), London, United Kingdom, September 2013.

[5] S. Lambert (iMinds), B. Lannoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), J. Montalvo (TID), J. Torrijos (TID), P. Vetter (Alcatel-Lucent, Murray Hill, NJ, US), Power Consumption Evaluation for Next-Generation Passive Optical Networks, 24th Tyrrhenian International Workshop on Digital Communications (TIWDC '13), Genoa, Italy, September 2013.

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[7] S. Lambert (iMinds), J. Montalvo (TID), J. Torrijos (TID), B. Lanoo (iMinds), D. Colle (iMinds), M. Pickavet (iMinds), Energy efficiency analysis of next-generation passive optical network (NG-PON) technologies in a major city network, International Conference on Transparent Optical Networks (ICTON 2013), Cartagena, Spain, June 2013.

[8] D. Hatzopoulos (UTH), I. Koutsopoulos (UTH), G. Koutitas (UTH), W. Van Heddeghem (iMinds), Dynamic Virtual Machine Allocation in Cloud Server Facility Systems with Renewable Energy Sources, ICC 2013, Budapest, Hungary, June 2013.

[9] S. Buzzi (CNIT), A. Zappone (TUD), Potential games for energy-efficient resource allocation in multipoint-to-multipoint CDMA wireless data networks, Physical Communication, Vol. 7, pp. 1 - 13, June 2013.

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Gateways, IEEE Conference of Networking, Sensing and Control (ICNSC), Paris, France, April 2013.

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[13] E. Le Rouzic (Orange), E. Bonetto (PoliTO), L. Chiaraviglio (INRIA), F. Giroire (INRIA), F. Idzikowski (TUB), F. Jiménez (TID), C. Lange (DT), J. Montalvo (TID), F. Musumeci (CNIT), I. Tahiri (INRIA), A. Valenti (FUB), W. Van Heddeghem (iMinds), Y. Ye (HWDU), A. Bianco (PoliTO), A. Pattavina (CNIT), TREND towards more energy-efficient optical networks, Optical Network Design and Modelling, Invited, Brest, France, April 2013.

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8. List of Acronyms

CPE	Customer Premises Equipment
EINS	Network of Excellence in Internet Science
EPIC	European Photonics Industry Consortium
FTTH	Fiber To The Home
ICT	Information and communication technologies
IEA	International Energy Agency
IP	Internet Protocol
IRA	Integrated Research Activity
NGPON	Next Generation Passive Optical Network
OASE	Optical Access Seamless Evolution
OLT	Optical Line Terminal
STRONGEST	Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport
TCP	Transport Control Protocol
TD	Technical Domain
TDM	Time Division Multiplexing
WP	Work Package