GreenTouch™

2012–2013 Annual Report

Contents

Chairman's Letter

Thierry Van Landegem
Chairman
Stichting GreenTouch

Dear Friends,

It is hard to believe we are now three years into the GreenTouch five-year initiative to increase network energy efficiency by a factor of 1000 compared to 2010 levels. What is not hard to believe, of course, is how much progress we've made thus far into our journey.

This 2012-2013 annual report highlights the important work of GreenTouch and the progress our members have made towards the mission of the consortium to date. The most notable achievement in the past year, of course, was the release of our Green Meter research study, a first-of-its kind analysis that provides the industry with a better understanding of energy efficiencies possible in network operations in 2020. The analysis indicated that net energy consumption in networks can be reduced significantly—up to 90 percent—by 2020. The study took into account new technologies, architectures and protocols, as well as the dramatic increases anticipated in communications traffic over the next decade.

This tremendous result is the climax of all the excellent work that GreenTouch members have performed in the last three years – and a critical reminder of the valuable work that lies ahead. After all, the Green Meter is the culmination of all the technologies, protocols, architectures and algorithms that have been worked on in the various working groups. That being said, as you read through this annual report you will learn more about the specific contributions from the various Committees, Working Groups and Project Teams.

Another key area to highlight in this year's annual report is project funding. Since last year's report, GreenTouch has committed 403,000k Euros to fund 5 new projects. This brings the total amount of funding provided by GreenTouch to its projects to 502,500k Euros distributed over a total of 7 projects. The following are the five projects which were approved for funding this year:

- IMEC/University of Ghent: Cascaded Bit Interleaving
- Heinrich Hertz Institute: Channel Model for Large-Scale Antenna Systems
- University of Paderborn: Comparing Energy-Efficient Assignment Methods of UE to BSs Based on Progressing Time
- INRIA: Interference Alignment for Transmission Power Reduction in Fully Loaded Small Cells and Heterogeneous Cells
- IMEC: Flexible Power Model of Future Base Stations

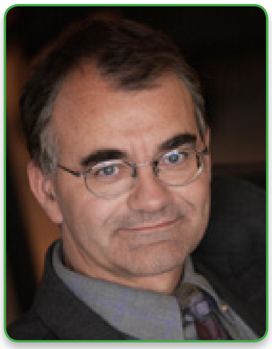
A final critical piece to highlight for this past operating years was the formation of a Services, Policies and Standards working group that is very much driven by our operator members. Through this group, GreenTouch is able to bring more value to its members as they start to seek commercial avenues to complement the consortium's ongoing research activities. It also ensures that our research is aligned with the work being discussed and advanced in other organizations.

We continue to have participation of over 50 member organizations from throughout the world representing the Information and Communications Technology (ICT) industry, academic and non-governmental research, all working together to meet the goals of the Consortium. It is due to the tireless efforts of the over 350 representatives from these member organizations that GreenTouch is able to drive our exciting initiatives that will demonstrate further results and milestones. On behalf of the Executive Board, I would like to thank everyone in the GreenTouch community for their support and participation. Without it, we would not have been able to achieve our many successes. The Green Meter is a clear progress report of our work – and the commitment of our members is a clear sign that more success is sure to come.

Sincerely,

Thierry Van Landegem
Chairman Stichting GreenTouch

GreenTouch Executive Board



Thierry Van Landegem
Bell Labs/Alcatel-Lucent,
Chairman

Dr. Laurent Herault
CEA-LETI

Dr. Chih-Lin I
China Mobile Communications
Corporation

Dr. Jongho Bang
Samsung Advanced Institute
of Technology

Dr. Rudy Lauwereins
IMEC International

Dr. Laurent Lefèvre
INRIA

Claude Monney
Swisscom Ltd.

Dr. Wen Tong
Huawei Technologies Co., Ltd.

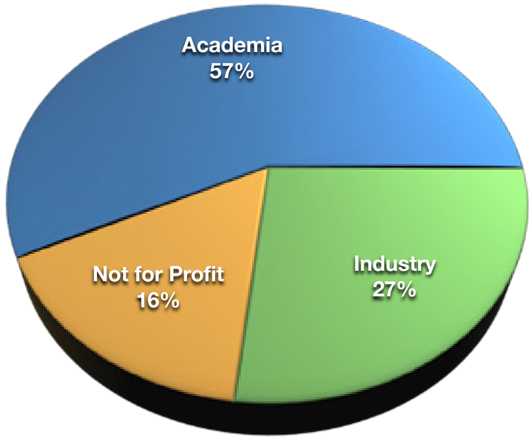
Dr. Rod Tucker
University of Melbourne

GreenTouch Members 2012-2013

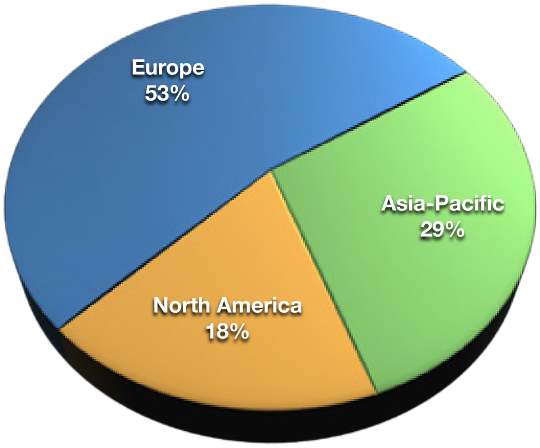
- AGH University
- Bell Labs / Alcatel-Lucent
- Athens Information Technology (AIT) Center for Research & Education
- California Institute of Technology (Caltech)
- CEA-LETI
- China Mobile Communications Corporation
- Chunghwa Telecom
- Columbia University
- Commscope/Andrew
- Dublin City University
- Electronics and Telecommunication Research Institute
- Energy Sciences Network/Lawrence Berkeley Labs
- Fondazione Politecnico di Milano
- France Telecom
- Fraunhofer-Gesellschaft
- Fujitsu Limited
- Huawei
- IMEC International
- iMinds
- Indian Institute of Science
- Indian Institute of Technology (IIT) Delhi
- INRIA
- Institute for Energy Efficiency, UCSB
- Karlsruhe Institute of Technology
- Katholieke Universiteit Leuven (K.U. Leuven)
- King Abdul Aziz for Science and Technology
- KT Corporation
- National & Kapodistrian University of Athens
- National Chiao Tung University, Intelligent Information Communications Research Center
- Nippon Telegraph and Telephone Corp (NTT)
- Politecnico di Torino
- Portugal Telecom
- Samsung (SAIT)
- South Korea Advanced Institute of Science and Technology (KAIST)
- Sungkyul University
- Swisscom (Switzerland) Ltd.
- The University of Manchester
- TNO
- TU Dresden
- Universitat Paderborn
- University College London
- University of Cambridge
- University of L'Aquila
- University of Leeds
- University of Maryland
- University of Melbourne
- University of Missouri-Kansas City
- University of Peloponnese
- University of Piraeus Research Center
- University of Rochester
- University of Surrey
- University of Toronto
- Utah State University
- Vodafone Group Services Limited
- ZTE Corporation

Member Breakdown

As of June 30, 2013, GreenTouch had 55 members, representing leaders in industry, academia and research. With broad representation from across the globe, the Consortium represents a wide range of constituents with varied expertise in the ICT sector.



GreenTouch Members - By Organization Type



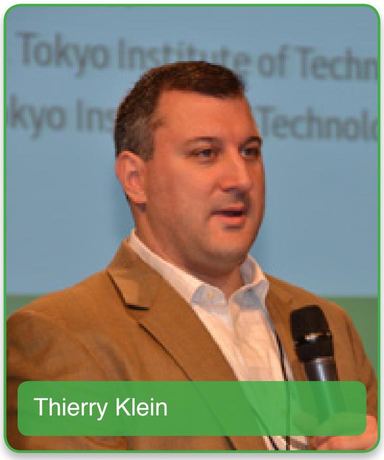
GreenTouch Members - By Region

Technical Committee

Leadership:

- Thierry Klein, Bell Labs / Alcatel-Lucent, Chair
- Shugong Xu, Huawei, Co-Chair

Chair's Summary / Key Accomplishments:



Thierry Klein

The Technical Committee is the main technical organization charged with coordinating and supporting the various technical working groups and projects in their efforts to achieve the GreenTouch objectives. The responsibilities of the Technical Committee include: 1) on the technical side: setting the overall strategic research directions and determining the architectures that achieve the GreenTouch goals; defining and updating service requirements, traffic characteristics, and traffic growth projections; reviewing new project proposals; driving and tracking progress toward final architectures; identifying key new results, and tracking progress toward key demonstrations, 2) on the organizational side: documenting and disseminating outcomes, results and progress of the consortium with the broader community and industry at large; organizing meetings and calls to stimulate discussion and progress towards the goals; participating in industry forums and events; and year-end reporting to the executive board.

By all accounts, GreenTouch had a very successful third year and made tremendous progress towards its goals of dramatic improvement in network energy efficiency. The Technical Committee, in cooperation with the Executive Board, led a comprehensive review of the strategic objectives of the GreenTouch consortium. This culminated in setting a course of action as the consortium enters a new phase more focused and targeted toward achieving the end goal of improving the network energy efficiency by a factor of 1000. This new phase requires more emphasis on execution and coordination to reach the technical objectives, while at the same time keeping the spirit and culture of disruptive innovation that is close to the hearts of all of our members.

At the beginning of the year, we implemented a reorganization of the Technical Committee that streamlined the organizational structure to facilitate sharing of ideas across projects and working groups and leverage commonalities in technologies. In particular, it was decided to combine the Core Routing and Switching, the Core Optical Networking and Transmission, and the Wireline Access working groups into the new Wired Core and Access Networks working group. In addition, the Services, Applications, and Trends sub-committee was reformed as the Services, Policies, and Standards working group in order to reflect the emphasis of GreenTouch in understanding the impact of its technologies on policies and standards for future networks. The present annual report is structured to reflect this new organizational structure, with an emphasis on the new accomplishments and results of the respective working groups and projects.

The Technical Committee has completed and released its first GreenTouch roadmap document outlining the main strategic research directions and providing an overview of the research project portfolio [1]. Three major research themes that have emerged within the consortium have been identified and find application in the different network platforms, including mobile and wireless networks, wireline access networks, and core optical and packet data networks. These include a multiplicity of small network elements and dynamic power management, service-aware heterogeneous networks, and low-power electronic and photonic devices.

Undoubtedly, the highlight of the year and the major activity within the Technical Committee is the Green Meter Research Study. This research study and the associated white paper [2], issued after three years of the five-year journey of the GreenTouch consortium, describe the outcome of a comprehensive research study to assess the overall impact and the overall energy efficiency benefits from the portfolio of technologies, architectures, components, devices, algorithms, and protocols being investigated, developed and considered by GreenTouch. It is in essence an interim assessment of the progress of the consortium toward its goal and an outlook for further opportunities for improving the energy efficiency in communications networks. This is a first-of-its-kind study due to its breadth and depth of technologies included, from the mobile networks to the fixed access networks and the core networks. The study does not just quantify the energy benefits of a single technology but rather focuses on the end-to-end network perspective and includes a full range of technologies. As a result, the research provides valuable insights into the overall impact as well as the relative impacts of these technologies being considered. It also explicitly includes traffic growth in the calculations of future network energy efficiencies and energy consumption.

The results of the Green Meter study were publically announced in a live webcast in May 2013 [3]. The study concluded that it is possible through the combination of technologies, architectures, components, algorithms, and protocols to reduce the net energy consumption in communications networks by up to 90% by 2020. This dramatic net energy reduction in mobile access, fixed access, and core networks, while taking into account the dramatic increase in traffic, is fueled by significant improvements in the energy efficiencies of the component networks (including a factor of 1043 for mobile networks, a factor of 449 for fixed access networks and a factor of 64 for core networks), which are summarized in Figure 1.

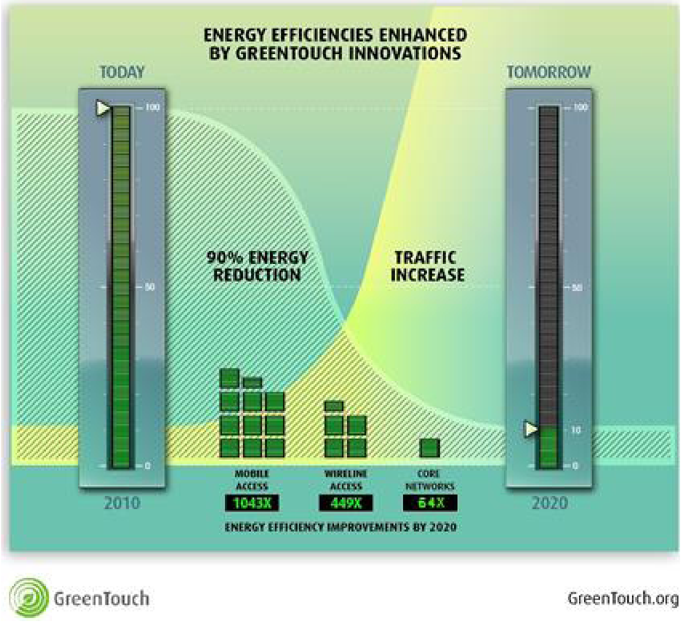


Figure 1: Energy efficiencies enhanced by GreenTouch innovations. GreenTouch Green Meter Research Study: "Reducing the Net Energy Consumption in Communications Networks by up to 90% by 2020"

This profound result demonstrates that we can support the predicted traffic growth in future networks while at the same time reducing the total energy consumption of the networks significantly. Deploying these technologies would have a significant economic impact (through reduced operational expenses) and environmental impact (through reduced energy consumption and carbon emissions) for operators and service providers, while at the same time providing value to consumers and businesses as well as revenue-generating opportunities through the delivered applications and services. In the process it also describes a roadmap and a portfolio of technologies for equipment vendors and service providers, and it quantifies the relative energy efficiency benefits of the individual technologies.

As expected, the Green Meter results have received a lot of attention in the industry through numerous reprints of the GreenTouch press release, articles, and reports in the technical and general press, links in blogs, and thousands of mentions on Twitter and other social media. We have also conducted over 30 interviews with technical reporters, journalists, and analysts to disseminate the GreenTouch results and the significant progress accomplished by the consortium. Overall the reactions have been extremely positive and supportive.

GreenTouch has also organized and participated in quite a large number of industry events, conferences, workshops, and trade shows to share its vision and results and encourage others to contribute to the mission of dramatic energy efficiency improvements. These opportunities include, among others, a tutorial on *Next Generation Optical Access Networks* at the European Conference on Optical Communications (ECOC 2012) in Amsterdam, the Netherlands, a keynote presentation on *Transforming ICT Networks for a Sustainable Future* at the Sustainable Internet and ICT for Sustainability Conference (SustainIT 2012) in Pisa, Italy, a session on *Green ICT and The Cost of Doing Nothing* at the Future Internet Assembly (FIA) in Dublin 2013, a panel discussion on *Collaborative Programs in Green Communications: Successful Cases and Key Remaining Research Challenges* at the International Conference on Communications (ICC 2013) in Budapest, Hungary, and a presentation on *GreenTouch Vision, Projects and Results* at the 2013 Eureka Celtic Event in Kayseri, Turkey.

GreenTouch has also organized several events bringing together leading experts from industry, academia, and policy organization (from GreenTouch as well as non-GreenTouch organizations) to discuss energy efficiency and to enable deeper collaborations. These events include a *Forum on Telecom and Energy* during the Photonics in Switching conference (PS 2012), a joint work with the European Network of Excellence TREND on energy efficiency, and a workshop on *Energy Efficiency in Action* during the EU Sustainable Energy Week (EU-SEW 2013) in Brussels. GreenTouch also continues its close collaboration with the Global E-Sustainability Initiative (GeSI) and has notably contributed its insights on network energy efficiency and its traffic growth projections to the update SMARTer 2020 report issued by GeSI in 2012 **[4]**.

GreenTouch had a very successful and productive year on the technical as well as the organizational side. Nevertheless, a lot of challenges remain in front of us, and GreenTouch is continuing its mission to address these challenges, to validate and demonstrate technologies, and to seek new ideas to further improve network energy efficiency. We are in the process of building a roadmap of milestones and project deliverables for the next couple of years and we are actively planning a set of future technology demonstrations. Through the publication of our strategic research direction and our Green Meter research results, we hope to stimulate further discussions, research, and focus within the industry on the topic of energy efficiency of future communications networks. This is further reinforced through GreenTouch funding for six new projects in the areas of mobile communications and wireline access networks.

In summary, GreenTouch is well on its way to accomplish its very ambitious mission and has further solidified its thought leadership in the industry.

References

[1] "GreenTouch Roadmap: Strategic Research Areas and Project Portfolio," Sept. 2012
http://www.greentouch.org/uploads/documents/GreenTouch%20Strategic%20Research%20Areas%20and%20Project%20Portfolio.pdf

[2] "GreenTouch Green Meter Research Study: Reducing the Net Energy Consumption in Communications Network by up to 90% by 2020," GreenTouch White Paper, June 2013
http://www.greentouch.org/uploads/documents/GreenTouch_Green_Meter_Research_Study_26_June_2013.pdf

[3] GreenTouch Green Meter Announcement, May 2013
http://www.greentouch.org/index.php?page=green-meter-research

[4] GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future
http://gesi.org/assets/js/lib/tinymce/jscripts/tiny_mce/plugins/ajaxfilemanager/uploaded/SMARTer%202020%20-%20The%20Role%20of%20ICT%20in%20Driving%20a%20Sustainable%20Future%20-%20December%202012._2.pdf

Mobile Communications Working Group

Leadership:

- Ulrich Barth, Bell Labs / Alcatel-Lucent, Chair
- Azeddine Gati, Orange, Co-Chair

Chair's Summary / Key Accomplishments:

Ulrich Barth

The Mobile Communications Working Group (MC) contributes research to improve the energy savings of the wireless access network. These savings will accrue with innovations in architecture, access nodes, and deployment of the mobile communication network for future generations. Examples of promising areas for research include air interface technologies, radio resource management, Multiple-Input-Multiple-Output antenna systems and other antenna technologies, relays and cooperative transmission, power amplifier technologies, base station architectures, baseband processing, backhaul technologies, network topologies, deployment strategies, and operation and management concepts.

Mobile Communications is focused on new highly energy efficient air interfaces, tradeoffs between energy efficiency and mobile system design criteria such as spectrum efficiency or service delay, power models of wireless access points, dynamic coverage and capacity management, and deployment and management strategies for energy efficient mobile systems.

Participants from mobile vendors, mobile operators, device manufacturers, and academia collaborate in the Mobile Communications Working Group. The work of the Mobile Communications Working Group is organized in three umbrella projects, the Green Transmission Technologies (GTT) project, the Large Scale Antenna Systems (LSAS) project, the Beyond Cellular Green Generation (BCG2) project, and one architecture sub-group that integrates the results from the umbrella projects and defines the GreenTouch mobile architecture.

Based on the "wireless box," i.e. the principal methodology for computing the energy efficiency of nationwide mobile networks that was developed in 2012, the architecture group specified all parameters and simulation assumptions as well as the reference scenarios for the performance evaluation of solutions and technologies provided by the umbrella projects [1].

Based on these specifications, the Mobile Communications Working Group performed research studies to determine the energy consumption of mobile networks for the Green Meter study. The results show that energy efficiency strongly changes with the load of the system and that the overall energy consumption is mainly driven by the consumption in rural and suburban areas. Assuming an overall 89-fold increase in mobile traffic between 2010 and 2020, together with a representative traffic variation over time and geographical area, a reduction of the total energy consumption by a factor of 11.5 was predicted by the computer simulations [2].

The reasoning for the 11.5-times reduction in energy consumption can be summarized by the following observations.

- The LTE system in the 2010 reference scenario provides a capacity which is by far above the demand from the year 2010. Then, the power consumption is only weakly dependent on load, but dominated by the base station offset power.
- The base stations in 2020 implement improvements in hardware and hardware management, which result in a 2.3-fold less power per base station even at the higher load of 2020.
- Small cells were deployed in a heterogeneous network environment as an overlay to macro base stations. In particular the deployment of small cells in dense urban environments provided a 10% overall energy saving.
- Special energy management technologies such as micro sleep modes contribute further 20% savings.
- A nearly four times less energy consumption is achieved by operator network sharing to avoid redundant coverage by four networks. When all traffic is served by a single physical infrastructure, the number of base stations, especially in coverage-limited areas, is significantly reduced.

Further energy-saving technologies resulting from the three umbrella projects are currently being integrated in the mobile architecture to further improve the energy efficiency.

References:

[1] "Reference scenarios," GreenTouch Mobile Working Group Architecture Doc2, March 2013. Internal document of GreenTouch Mobile Working Group

[2] O. Blume, A. Ambrosy, M. Wilhelm, and U. Barth, "Energy Efficiency of LTE Networks under Traffic Loads of 2020," in the Workshop on Energy Efficient Wireless Networks at the 10th International Symposium on Wireless Communication Systems (ISWCS 2013), August 27, 2013, Ilmenau, Germany

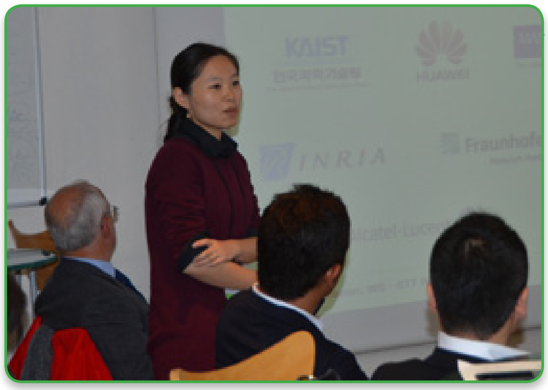
Green Transmission Technologies (GTT)

Type of Project: GreenTouch

Working Group Affiliation: Mobile Communications

Project Participants: Huawei (project lead), INRIA, Orange Labs, University of Melbourne, Fraunhofer HHI, Chunghwa Telecom, NCTU, Samsung, KAIST, CMCC, University of Manchester, Bell Labs / Alcatel-Lucent, University of Maryland

Project Mission:



This project mainly focuses on improving network energy efficiency via physical layer transmission scheme design and MAC layer radio resource management design. It can be seen as the optimization engine at these lower layers for the overall energy efficient network design. Figure 2 shows the way GTT works. There are different dimensions of resources (degree of freedom) that can be utilized to maximize network energy efficiency. Innovations are inspired by the groundbreaking work of Shannon's information theory. In particular, fundamental tradeoffs between spectrum efficiency (SE) and energy efficiency (EE) have been identified and explored for energy efficiency oriented design and optimization. Similarly the bandwidth and power tradeoff and the transmission delay and power tradeoff are also investigated. The physical layer transmission schemes are jointly designed with the energy adaptation strategies. This approach provides the MAC layer with a higher degree of freedom (e.g., cooperative transmission takes cooperative nodes as another dimension), and enables a wider range for adaptation in existing dimensions (e.g., low SNR receiver works for low power transmission scenarios).

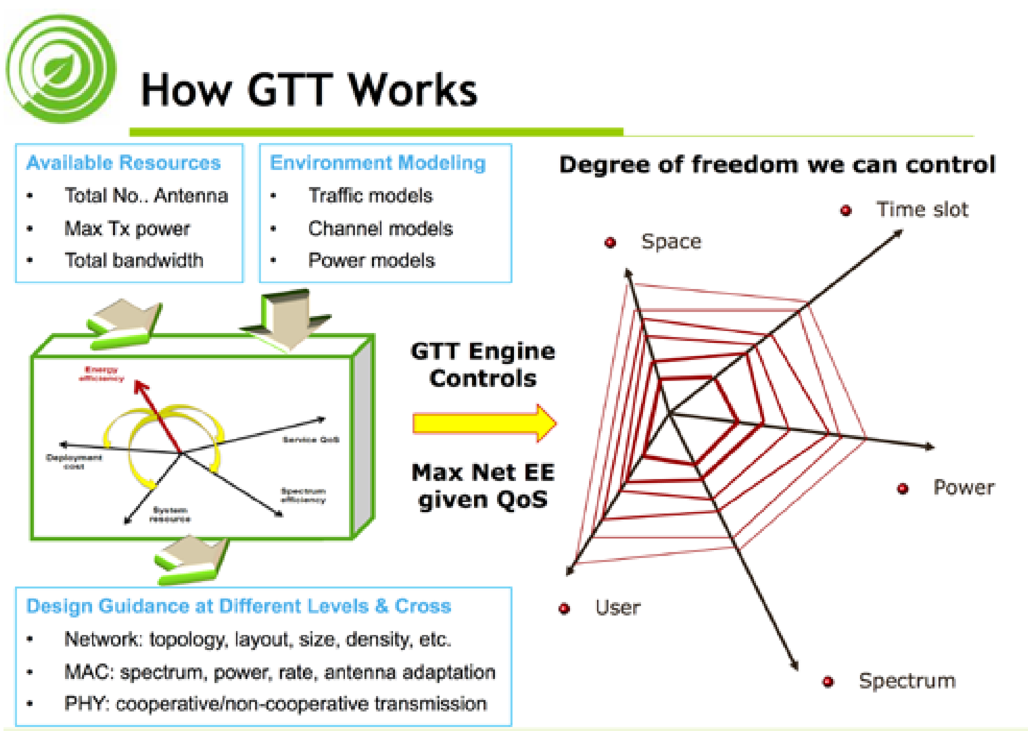


Figure 2. How GTT works

Accomplishments:

- Given the understandings gained from the previous phase of the project, we now have extended the SE-EE tradeoff research from single cell setup to more complicated scenarios, such as non-cooperative/cooperative multi-cell setups, and heterogeneous networks. We have shown that network EE can be improved to a much greater degree by the same level of bandwidth expansion in interference-limited multi-cell scenarios, compared with that in the single cell situation. However, the absolute value of EE is greatly reduced in the interference-limited case, compared with the noise-limited case. This finding suggested that there are two basic ways to improve network EE in the interference-limited case: 1) if there is a sufficiently large amount of spectrum available, it is suggested that users expand their bandwidth to keep the transmit power as low as possible , which requires advanced receiver designs to cope with the carrier, phase and time synchronization in a very low SNR situation; 2) when the amount of available spectrum is not large enough for substantial bandwidth expansion, there are a lot more parameters to optimize and configure, which brings research topics such as Interference alignment, optimal power, and bandwidth allocation into the overall design strategy. Both directions are currently being investigated in our research project.
- For the cross MAC and PHY layer network EE optimization, we have identified the most promising ideas from all proposed research topics and have summarized them as ”6 Smarts,” as shown in Figure 3. To maximize the freedom for resource utilization, we have assumed a CRAN-based architecture, in which multiple transmission nodes, also known as transmission points (TPs), are connected with fiber back to a centralized baseband pool. Global intelligence is exploited to jointly optimize the temporal and spatial duty-cycles (activation/deactivation) of each TP, taking into consideration the temporal and spatial variations. Extensions toward two tiers of heterogeneous TP networks, ultra-dense collaborative TP systems, or even multi-RAT TP scenarios, are under investigation now.
- A big challenge for the GTT project is to combine the technologies developed by different partners. Important progress has been made toward integrated GTT technologies. In particular, we have found the framework and methodology with the potential to put the pieces together. We have proposed the framework of a “GTT Toolbox” and have defined its components and interfaces that would link all the potential technologies together. Inspired by the “geometry” table-based method used in the reference scenario EE simulations, we propose to use an SINR Improvement and Geometry MApping (SIGMA) methodology to decouple the network level simulator from the PHY and MAC level simulator.
- As a result, each project partner is expected to focus more on the PHY and MAC layer performance of their respective technologies, and contribute corresponding SINR improvements and geometry tables as input to the overall network level simulator.

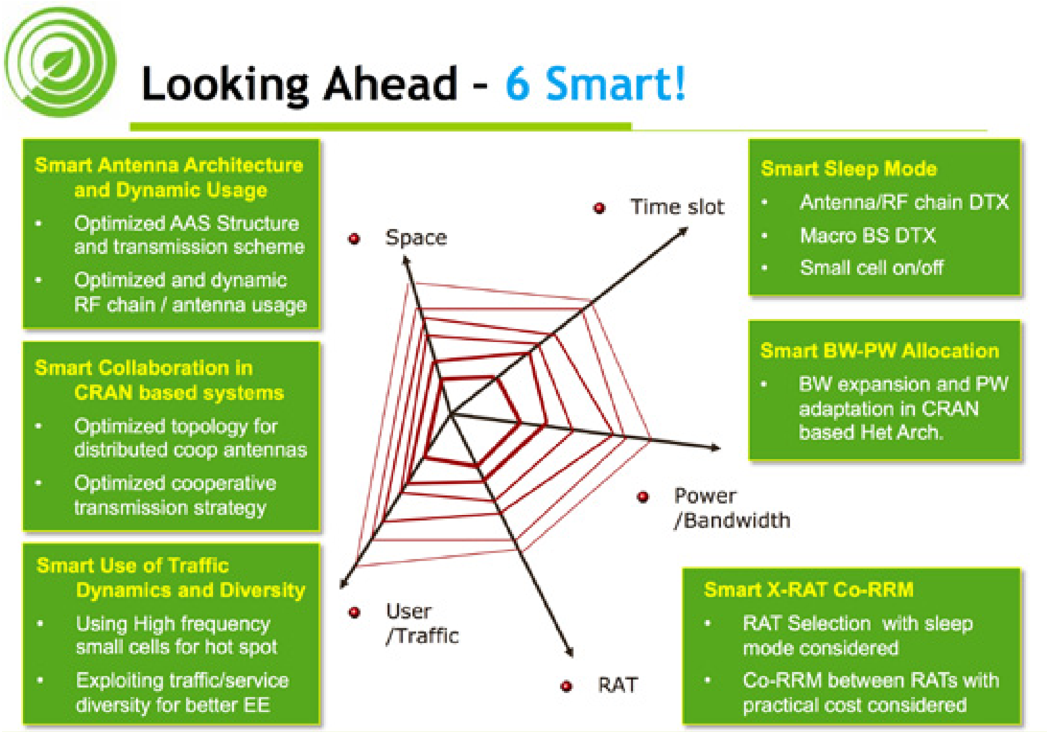


Figure 3. Six smart optimization ideas for maximizing network EE

Beyond Cellular Green Generation (BCG^2)

Type: Cooperative

Working Group Affiliation: Mobile Communications

Project Participants: Fondazione Politecnico di Milano (project lead), Bell Labs / Alcatel-Lucent, Huawei, Samsung, Orange, China Mobile, IMEC, TNO, INRIA, Technical University of Dresden, University of Paderborn, Politecnico di Torino, University of Piraeus, The University of Melbourne, University of Missouri-Kansas City

Project Mission:

In this project we address the improvement of energy efficiency in mobile access networks from a system architecture perspective, and we focus on the use of network management strategies to manage traffic and communication resources in order to reduce energy consumption.

We propose to go beyond the traditional cellular architecture of wireless access networks, through a complete separation of the signaling infrastructure that is used to request communication services and the data infrastructure that is used to provide these services (see Figure 4). The signaling network is in charge of providing continuous full coverage so that communication services can be requested at any time by users located in any point of the service area. In contrast, resources of the data network are activated on demand based on an intelligent selection of the best access device that will meet quality of service requirements at the minimum energy cost. Wireless technologies used by the data network can in general be heterogeneous and operating in different spectrum portions, and selection of the resources to be activated to serve a user request can take into account the specific capabilities of the user terminal (usually supporting a set of technology standards).

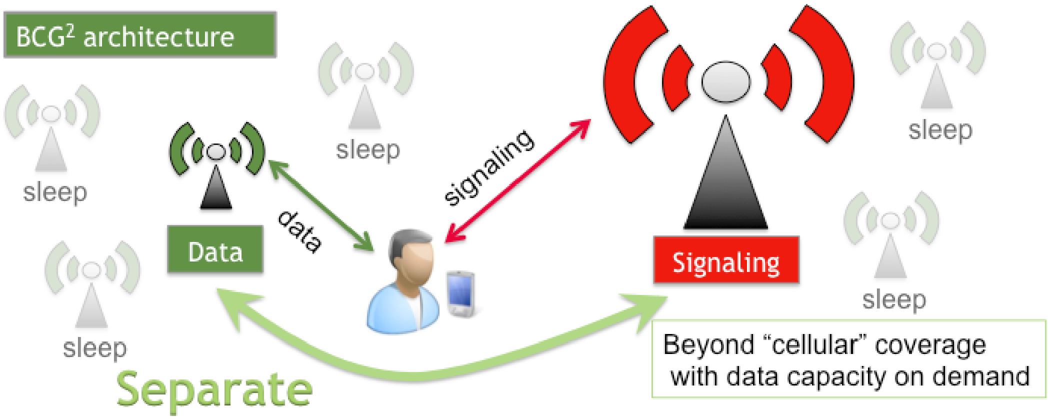


Figure 4: The main concept of BCG^2

Accomplishments:

An overview of the achievements of the project so far is presented in Figure 5. The main achievements include:

- Definition of the general system architecture: the high level architecture of the system has been designed with the separation of functions between signaling base stations and data base stations.

Example procedures for the management of the signaling functions (such as network access and mobility management) have been provided.

- Definition of the energy efficiency gains with simple analytical models: simplified analytical models for estimating potential gains achievable with the BCG architecture have been defined. The models are based on simplified assumptions on traffic distribution and cell layout and make use of stochastic process analysis and queuing theory.
- Advanced models for energy efficiency estimation: some advanced models for performance evaluation of the system based on the data/signaling splitting have been also designed. The models provide some more insight into the system's key characteristics, such as cell coverage overlap and interference distribution, and make use of stochastic geometry, integral geometry, and information theory.
- Definition of the general on/off strategies for the base stations: general strategies for the activation and deactivation of data base stations have been defined. The strategies consider the association of users to cells that are triggered by access requests (activation of data bearers).
- Analysis of signaling traffic: a preliminary analysis of the characteristics of signaling traffic has been carried out in order to estimate traffic volumes and classify different traffic types.
- Design options for the data and signaling separation: an analysis of possible strategies for distributing signaling functions among the elements of the network has been done.
- Models for advanced network scenarios and layouts (relay nodes, green energy sources, etc.): some possible advanced network scenarios and layouts have been analyzed. These are different from the main scenarios considered in the project and add some new features (such as the use of relay nodes, the association of green energy sources to base stations, base station cooperation, etc.) that can further improve the energy performance of cellular systems.

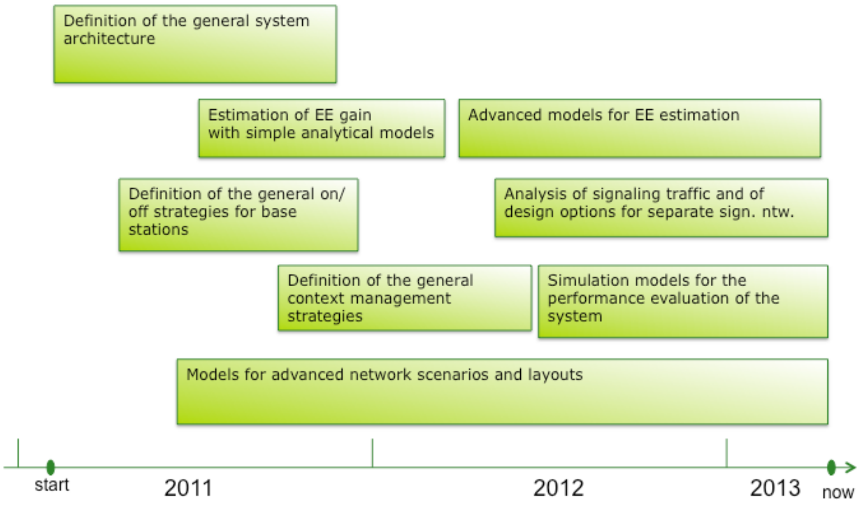


Figure 5: Overview of BCG² achievements

Large-Scale Antenna Systems (LSAS)

Type: GreenTouch (Funded)

Working Group Affiliation: Mobile Communications Working Group

Project Participants: Bell Labs / Alcatel-Lucent (project lead), Fraunhofer HHI, Huawei, IMEC, Samsung

Project Mission:

The Large-Scale Antenna Systems (LSAS) project seeks to improve wireless energy efficiency through a combination of radiated power reduction and increased throughput, exploiting the fact that bits/Joule = (bits/second)/(Joules/second). The distinguishing feature of LSAS is that unprecedented numbers of service antennas communicate with a much smaller number of autonomous terminals over the same time/frequency resources. Knowledge of the channels between the service antennas and the terminals – derived from up-link pilots and TDD reciprocity – enables the creation of focused information-bearing beams on the down-link, and the selective reception of simultaneous up-link transmissions from the terminals. Extra service-antennas (with a proportionate increase in total radiating area) always improve both radiated energy efficiency and spectral efficiency. Under all conceivable propagation conditions, doubling the number of service antennas permits the total down-link radiated power to be reduced by a factor-of-two with no degradation in performance.

LSAS constitutes a game-changing technology: quantitatively because of its potentially huge radiated energy efficiency and spectral efficiency compared with 4G, and qualitatively because it alters the nature of wireless communications. Under LSAS all complexity resides in the base station, only cheap single antenna terminals are required, expensive ultra-precise 40-Watt transmitters and receivers are replaced by hundreds or thousands of cheap, milliwatt devices, diversity becomes a non-issue, scheduling and resource-allocation are easier for LSAS than for LTE, a large excess of service antennas over terminals makes the simplest sort of multiplexing signal processing competitive, and the system functions seamlessly irrespective of the nature of the propagation.

Accomplishments:

Simulations and total energy efficiency

We have performed comprehensive simulations of multi-cellular access deployments of LSAS, fully accounting for LSAS phenomenology (i.e., the overhead of CSI acquisition, CSI errors, inter-cell interference, near-far effects, power control, the imperfections of multiplexing pre-coding, and pilot contamination). The output of the simulations comprises estimates of throughput (bits/second) and total energy efficiency (bits/Joule) for which three sources of power consumption are accounted for: (i) RF generation (25% efficiency assumed), (ii) LSAS-critical computing, and (iii) a per-antenna internal power consumption that covers analog electronics and A/D and D/A converters. The per-antenna power consumption is treated parametrically. Figure 6 is an example of such a simulation. The per-antenna internal power consumption ranges from 32 mW to 4096 mW. At 1024 mW per antenna, 64 antennas, and a dense urban and suburban deployment the relative energy efficiency gain is about 100 fold.

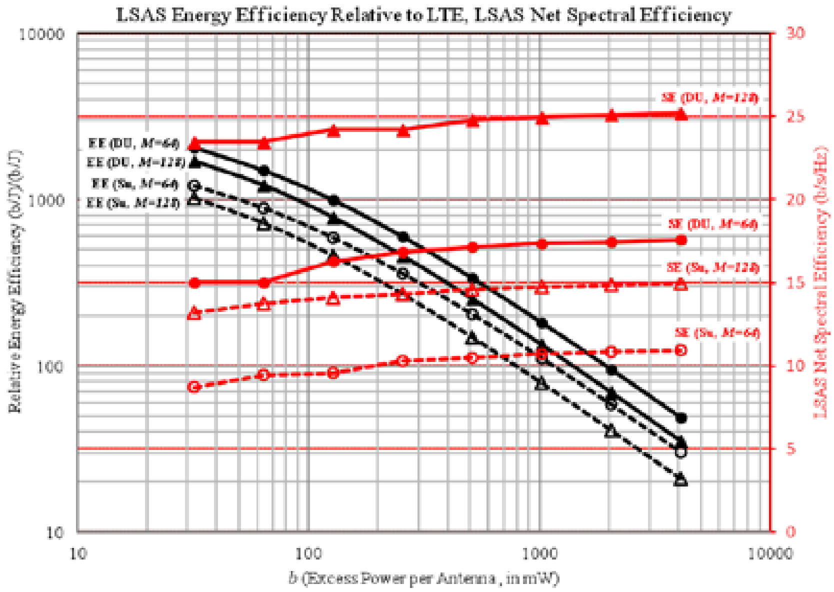


Figure 6. Multi-cell LSAS access: M=64 and M=128 antennas, dense-urban (DU) and suburban (SU) deployments; black curves are total energy efficiency (EE) relative to LTE (assumed 13.3 Kb/J) and red curves are net spectral efficiency (SE - b/s/Hz), both versus the assumed excess per-antenna power consumption

Realistic power modeling

Progress was made on reconciling the “bottom-up” power model so far used in LSAS with existing “top-down” models. Work began on obtaining realistic estimates of excess per-antenna power consumption.

Small power amplifiers and peak-to-average power reduction

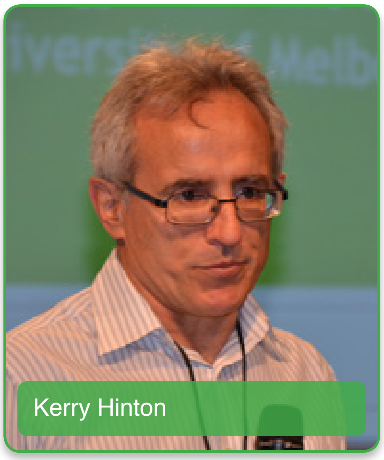
Additional research was performed concerning small power amplifiers (one required by each antenna), and peak-to-average power reduction methods.

Wired Core and Access Networks Working Group (WCAN)

Leadership:

- Kerry Hinton, CEET (University of Melbourne), Chair
- Jaafar Elmirghani, University of Leeds, Co-Chair

Chair's Summary / Key Accomplishments:


Kerry Hinton

Apart from overseeing the progress in the various projects in the Wired Core and Access Networks (WCAN) working group, the primary focus of WCAN's activity during the 2012-13 year has been the development of the technology roadmap presented in GreenTouch's Green Meter research study and reflected in the associated white paper.

The development of a technology roadmap and estimations of the contributions of those technologies to GreenTouch's goal of 1000-fold improvement in network energy efficiency required a substantial amount of collaborative work amongst the WCAN members. WCAN's contribution to the roadmap and Green Meter covered both wireline access (with a focus on Passive Optical Networks and related technologies) and wireline core networks.

To develop the roadmap of technologies for these two network areas, WCAN created two focus groups. One group focused on Access networks and the other group on the Core network.

The Access network group undertook a detailed analysis of the various components in a passive optical access network and developed a timeline for technology and architectural improvements that, over the period 2010 to 2020, will provide for a 449-times improvement in energy efficiency. The technologies and timelines for these improvements, described in the Green Meter white paper, include the innovative use of sleep modes, equipment re-design, and modifying the access network architecture. Cumulatively these innovations will enable a reduction of power per user from approximately 7 Watts (2010) to less than 0.14 Watts (2020).

The Core network group had to address two issues as part of developing the core network roadmap. The first was how to translate total network traffic per month projections into link-by-link capacities over a 24-hour (diurnal) period. The second issue was mapping out the technology, protocols, and architecture roadmap to 2020.

Understanding the diurnal traffic cycle for each link in the network is a key component of estimating possible improvements in network energy efficiency. In current networks all equipment is operating 24 hours a day irrespective of the traffic load in the links to which they are connected. Therefore, a significant contribution to improving network energy efficiency is ascertaining how much equipment can be put into a low-power mode during times of reduced traffic demand. This is a non-trivial problem because large networks span multiple time zones and different services display different diurnal cycles. This means the process of determining what equipment can be placed into a low-power mode during low traffic times requires a sophisticated optimization technique.

The second issue that the Core network group had to address was forecasting the technologies and architectures that can be developed (both within and outside of GreenTouch) for use in the optimization process. This required a substantial amount of collaborative work across the WCAN membership to review and develop new technologies that will be available in 2020 to reduce network energy consumption.

These technologies include improvements in router technologies to reduce power consumption and deployment of multiple-line-rate equipment that can adjust its data rate (and hence minimize its power consumption) according to the diurnal variations in capacity demand. With advanced technologies such as these plus new energy efficient architectures, GreenTouch forecasts an energy efficiency improvement of the core network between 2010 and 2020 by a factor of 64.

This improvement is significantly less than that mapped out for Mobile Communications and Wireline Access because core networks are already relatively energy efficient.

As an integral part of developing the wireline contribution to the GreenTouch Green Meter, the WCAN Working Group has road-mapped a series of innovations that, collectively, provide significant improvements in network energy efficiency. These innovations, which range across technologies, architectures, and protocols, are described in detail in the project reports in this document.

In the coming year, the WCAN Working Group will continue to refine the Green Meter technology roadmap as well as develop the innovations and technologies required for GreenTouch to attain its network energy efficiency improvement goal of a factor of 1000 by 2020.

OPtimum End-to-end Resource Allocation (OPERA)

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: University of Leeds (project lead), University of Cambridge, Politecnico di Milano

Jaafar Elmirghani

Project Mission:

Energy saving in communication networks is proposed through optimum end-to-end resource allocation. Currently, networks are typically three to five times over-provisioned to maintain quality of service (QoS). This leads to increased energy consumption, which can be reduced (while maintaining QoS) through the optimization of resource allocation in a real-time fashion following demand, making use of dynamic bandwidth allocation, for example. Furthermore, protection resources are typically powered on all year round, but only used two to three times a year. Wake-up on-demand algorithms can lead to energy saving here. This project investigates the optimum allocation of these resources in a network in a dynamic fashion to reduce the network's power consumption. It also examines the optimum allocation of other resources, for example processing, storage, switching, and routing.

Accomplishments:

Joint optimization of distributed energy efficient resources, including network, processing, and storage resources

We introduced a framework for designing energy efficient cloud computing services over IP/WDM core networks [1], [2]. We investigated network-related factors, including centralization versus distribution of clouds and the impact of demand, content popularity, and access frequency on the clouds' placement, and cloud capability factors, including the number of servers, switches, and routers, amount of storage required in each cloud and optimum use of renewable energy [2]-[4]. We optimized three cloud services. First, we developed a mixed integer linear programming (MILP) model to optimize cloud content delivery services. Our results indicate that replicating content into multiple clouds based on content popularity yields up to 43% total saving in power consumption compared to power un-aware centralized content delivery. Based on the model insights, we developed an energy-efficient cloud content delivery heuristic with comparable power efficiency. Second, we extended the content delivery model to optimize Storage as a Service applications. The results show that migrating content according to its access frequency yields up to 48% network power savings compared to serving content from a single central location. Third, we optimized the placement of Virtual Machines (VMs) in different core network nodes to minimize the network and cloud energy consumption. Our results show that slicing the VMs into smaller VMs and placing them in proximity to their users saves 27.5% of the total power compared to a single virtualized cloud scenario. We also developed a heuristic for real time VM placement that achieves comparable power savings.

Energy-efficient virtual network embedding in IP over WDM networks

Currently, a considerable amount of energy is wasted in IP over WDM networks due to over-provisioning of resources. We introduced an energy-efficient virtual network embedding (EE-VNE) methodology, optimized using an MILP model, as a means of resource consolidation to bring about energy savings in IP/WDM networks; see Figure 7 The performance of our energy-efficient VNE architecture was compared to a “bandwidth cost” (CostVNE) architecture whose goal is to minimize the use of available bandwidth only. Our architecture achieves an average 20% energy saving compared to CostVNE with a maximum of 60%. For real-time implementation, we developed a heuristic, Energy Optimized VNE (EOVNE) that can achieve 19.6% and 60% average and maximum energy savings, respectively, compared to the CostVNE architecture.

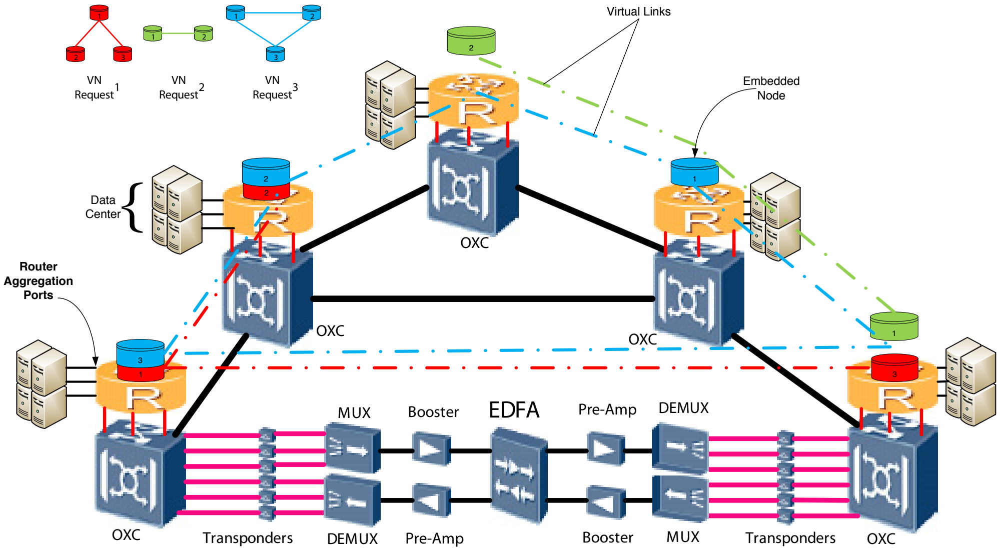


Figure 7. Virtual Network Embedding in IP over WDM core networks

Energy-efficient BitTorrent content distribution in optical networks

We investigated the energy consumption of BitTorrent, the most popular Peer-to-Peer (P2P) application, and compared it to Client/Server (C/S) systems [5], [6]. We developed an MILP model to minimize the energy consumption of BitTorrent over IP/WDM networks while maintaining its performance. The results indicate that the original BitTorrent protocol, based on random peer selection, has energy consumption comparable to the C/S system. The results also reveal that in order to achieve lower energy consumption, the energy-efficient BitTorrent model converges to locality in peers selection, resulting in 30% and 36% energy consumption savings compared to the C/S system under the bypass and non-bypass IP/WDM routing approaches, respectively. For real-time implementation, a simple heuristic was developed based on the model insights. Comparable energy savings were achieved with the heuristic with a penalty of 13% reduction in the average download rate. Further, we extended our model and heuristic to study the impact of leechers’ behavior on BitTorrent energy consumption [7]. We also compared the energy consumption of VoD service using CDN, P2P and a promising hybrid CDN-P2P architecture over IP/WDM core networks. The results show that the hybrid CDN-P2P saves 61% of the total energy consumption compared to the CDN-only architecture. Finally, we carried out an experimental evaluation of the original and energy-efficient BitTorrent heuristics and a demonstration for the GreenTouch members at the Stuttgart members meeting in November 2012. Our experimental results show about 40% saving in energy consumption for the energy efficient BitTorrent, compared to the original version in non-bypass IP/WDM networks, and good agreement is obtained with the MILP theoretical predictions.

Energy-efficient content caching

The increasing popularity of media-rich Internet content and the associated growth in energy consumption have highlighted the need for energy-efficient content distribution schemes. We have investigated the energy savings introduced by caching content in IP over WDM networks [8], [9]. We developed an MILP model to minimize the energy consumption of cache-based services over an IP over WDM network by optimizing the cache sizes of the network nodes at different times of the day. A Constraint-Based Genetic Algorithm (CBGA) was developed to validate the optimum cache sizes obtained from the MILP model and a simulation based on lightpath bypass validates the energy consumption of routing traffic demands. We considered different popularity distributions including the Zipf, Pareto, and Bimodal content popularity distributions to exemplify different types of IPTV services. Our results reveal that deploying the optimum variable cache sizes at the nodes reduces the overall network energy consumption by up to 42%, 68%, and 72% under the Zipf, Pareto, and Bimodal distributions for content popularity, respectively. We further studied the impact of regular cache updates on power efficiency. The results show that removing the 10 most popular objects (for example the top 10 most popular movies in a YouTube type video library) from caches increases the network power consumption by up to 20%.

Reduced power consumption through mixed line rates and flexible spectrum utilization in optical OFDM

Orthogonal Frequency Division Multiplexing (OFDM) has been studied as an enabling technique for elastic optical networks to support heterogeneous traffic demands. We have investigated the energy efficiency of rate- and modulation-adaptive optical OFDM-based networks [10], [11]. An MILP model was developed to minimize the total energy consumption of optical OFDM networks. We introduced two optimization schemes: power-minimized and spectrum-minimized optical OFDM-based networks. The results show that while similar energy consumption savings of up to 31% are achieved by the two schemes compared to conventional IP over WDM networks (see Figure 8), the spectrum-minimized optical OFDM is 51% more efficient in utilizing the spectrum, compared to the power-minimized optical OFDM.

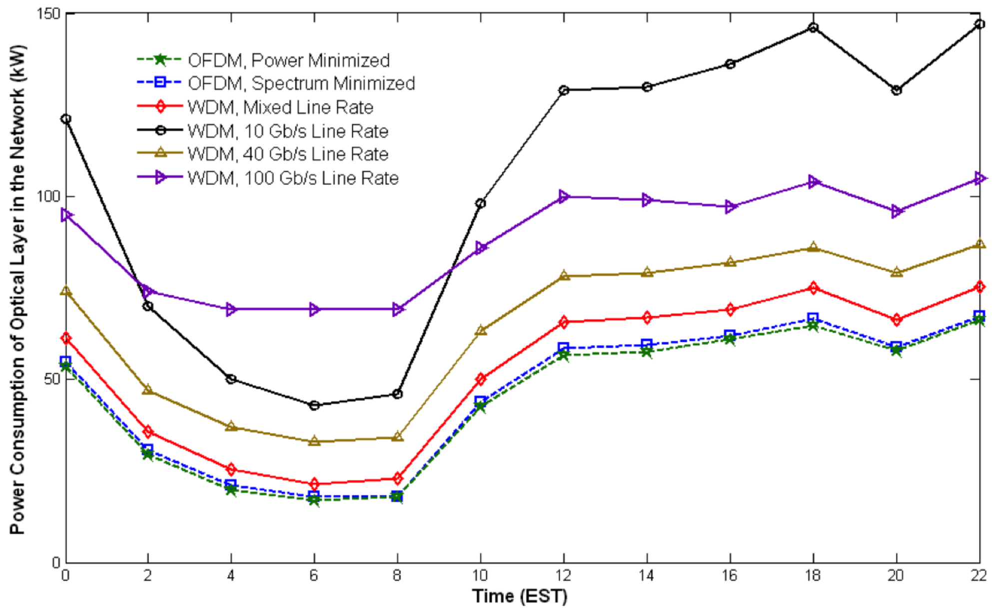


Figure 8. Power consumption of the optical layer with discrete line rates, mixed line rates, and using optical OFDM

Energy-efficient resilient optical transport network architecture

The ever-increasing Internet traffic demand introduces new challenges for telecommunications carriers. Telecom networks will have to be upgraded to cope with the new capacity requirements while at the same time providing the expected end-to-end quality of service, expressed as network resilience. The impact of new optical solutions as regards capital investment (CAPEX) and energy consumption (OPEX) becomes a key issue [12]. New mechanisms and technologies to improve the energy efficiency of backbone networks have been investigated, considering both adoption of low-power sleep-mode of unused network devices and adoption of innovative flexible-grid orthogonal-frequency-division-multiplexing (OFDM) replacing the classical ITU-T fixed grid operations of WDM systems. On one hand, different protection schemes have been considered, either dedicated or shared, for the upcoming core networks. On the other hand, the hourly traffic fluctuations have been taken into account to properly identify the actual capacity needs of the different network sections. It has been demonstrated that significant savings (20%-30%) of energy consumptions can be achieved with each of these new approaches for designing and managing optical core networks [13], [14].

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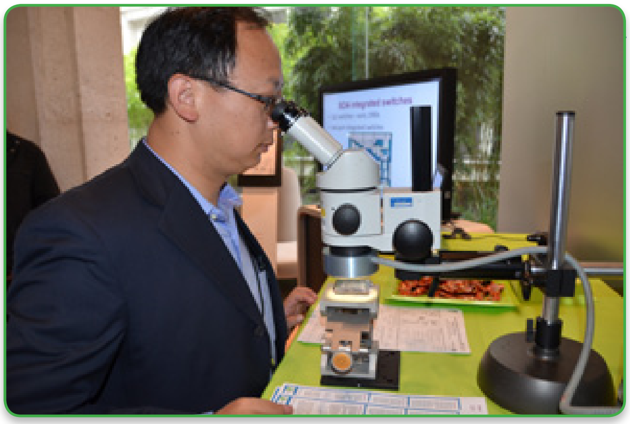
SwiTching And tRansmission (STAR)

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: University of Cambridge (project lead), University of Leeds, Bell Labs / Alcatel-Lucent

Project Mission:



We plan to study the optimization of the physical topology of IP over WDM networks with the objective of minimizing the total power consumption of the network. Given the large disparity between the power consumption of the IP and that of the optical layers, we plan to introduce power saving through architectures that employ transmission and switching more than IP routing, leveraging recent progress in low-power large photonic switch architectures.

While current architectures provide optical bypass through the use of ROADMs, these are largely static circuit configurations. Here we will examine architectures and technologies to allow more rapid reconfiguration of bandwidth to greater reduce the packet load on the routers.

We will design new large photonic switch architectures, possibly based on quantum dot semiconductor optical amplifiers as gating elements, and plan to optimize the network architecture, making use of these new switch architectures, and to introduce on-chip (photonic switch) power monitoring to inform higher layer decisions.

Accomplishments:

Optimum topology design with symmetric and asymmetric traffic

We developed a mixed integer linear programming (MILP) model to optimize the physical topology of IP over WDM networks with the objective of minimizing the total network power consumption. We considered the NSFNET topology and compared its energy consumption with the energy consumption of optimized physical topologies under different IP over WDM approaches and nodal degree constraints. Simulation results show that the full mesh and star topologies result in significant power savings of 95% and 92%, respectively.

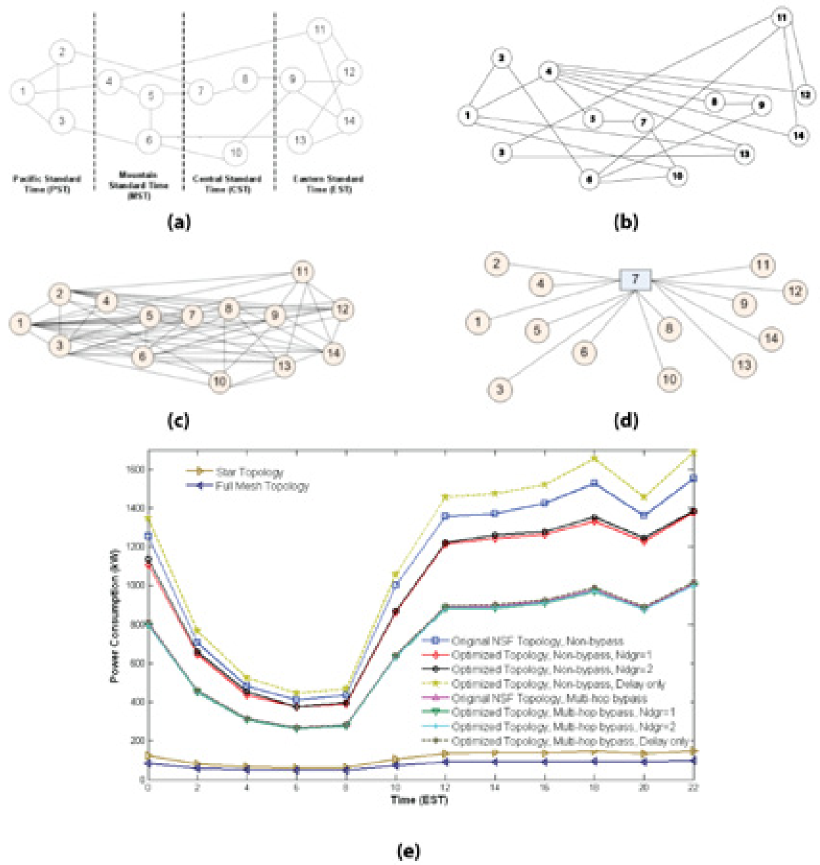


Figure 9. Energy-efficient physical network topologies: (a) original NSFNET; (b) optimized topology with 21 links as in (a) and symmetric traffic; (c) optimized topology with symmetric traffic and no constraint on number of links (full mesh); (d) asymmetric traffic optimized topology; (e) Results

Energy efficient network topologies under network coding

We proposed the use of network coding to improve the energy efficiency of non-bypass IP over WDM networks, where IP routers are used at intermediate nodes. The results show that network coding is an effective approach, combining energy efficiency and cost reduction with a simple routing approach. Savings up to 23% and 20% are achieved through the use of network coding in the USNET and NSFNET topologies, respectively; see Figure 10.

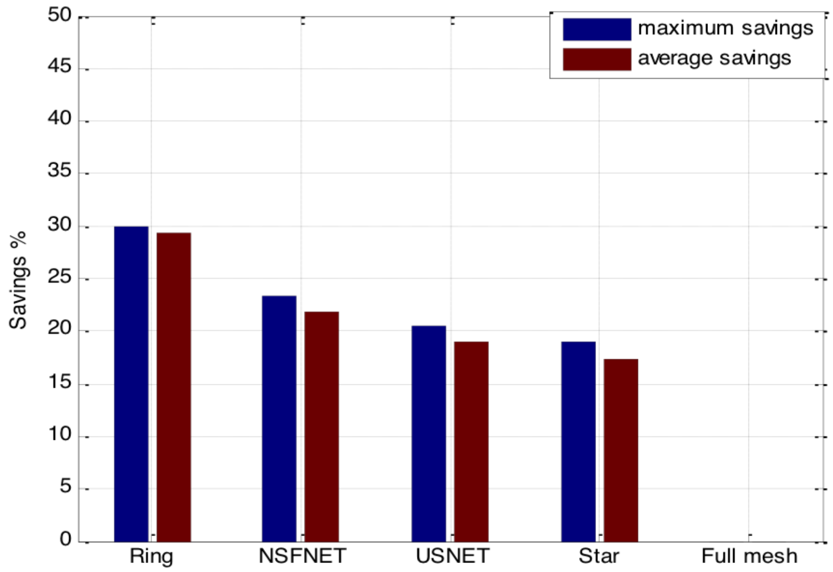


Figure 10. The power savings obtained through network coding in different topologies

Active-passive 4x4 switches tested in 16x16 Clos architecture configuration

A 4x4 active-passive semiconductor optical amplifier (SOA)-based switch incorporating switching SOA, output booster SOAs, and monitor photodiodes has been fabricated and tested. The active-passive integration allows reduced operating power at 4.2W for the full 16x16 switch (26pJ/bit), compared to 16W for the previously reported fully active 16x16 switch (100pJ/bit), a reduction of 74%.

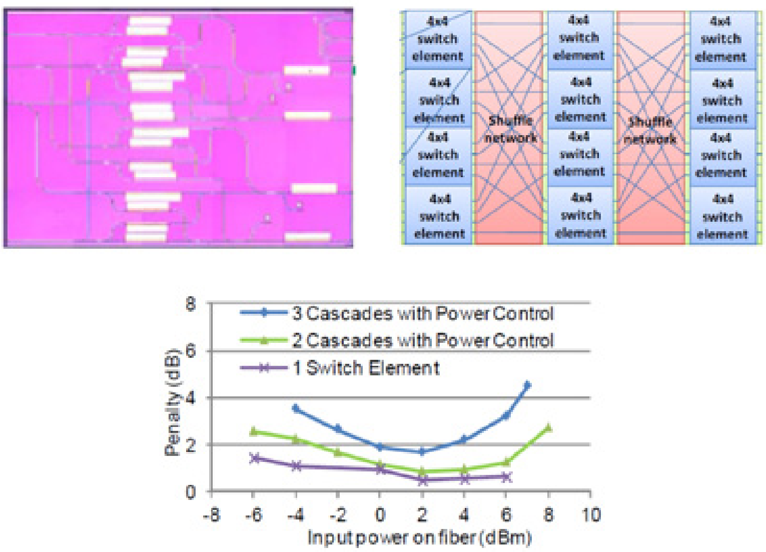


Figure 11. Fabricated 4x4 switch, 16x16 Clos architecture, and emulated 16x16 operation

Design, fabrication, and test of active-passive integrated hybrid MZI-SOA switch

A novel 2x2 hybrid MZI-SOA switch element has been designed and fabricated. The MZI aims to provide low-energy switching, whilst the SOA aims to improve crosstalk. Overall, the switch element performs very well, with an input power dynamic range (IPDR) of >16dB (for a penalty <0.5dB or <16dB).. The extremely low penalty and non-resonant switching element mean that it is possible to operate the switch with multiple wavelengths per port. Channels operating with 10 wavelengths at 10Gb/s each have been switched error-free in our lab experiments. Extrapolating this result to the 16x16 port device (via simulation), a 1.6Tb/s throughput switch, with an energy consumption of 0.8pJ/bit, is feasible. Once demonstrated, this will be a 125x reduction in per-bit operating power for the switch.

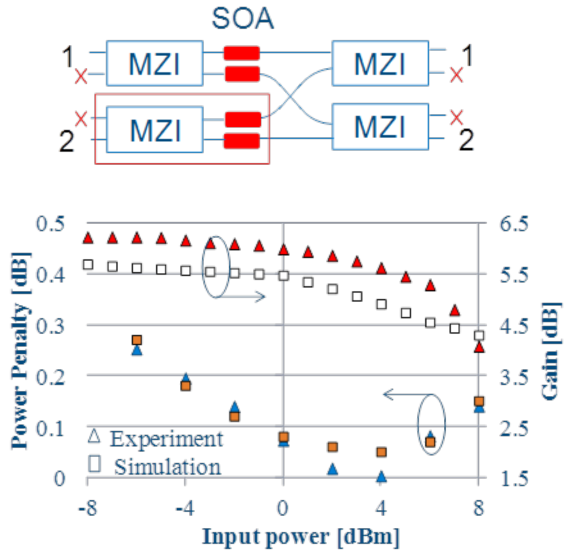


Figure 12. Dilated hybrid 2x2 MZI-SOA functional element with penalty results (experiment and simulation) for 10Gb/s / port operation

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Single Chip Router with Photonic Integration (SCORPION)

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: Bell Labs / Alcatel-Lucent

Project Mission:

The goal of SCORPION is to understand power consumption of routers and their scaling. We incorporate results from investigating prospective new technologies into this understanding. Interconnect technologies, both optical and electrical, are critical to the future of router scaling. We also consider alternative router or networking architectures and their effects on hardware and hence power requirements.

Within GreenTouch this project seeks to set the direction and targets for the technologies required to implement these new approaches to router architecture and hardware. We are currently pursuing the photonic integration and hybrid integration goals required to implement these goals.

Accomplishments:

In this year's report we will consider two areas that have significance for the scaling and energy consumption of routers. These are software defined networking and interconnect technology. Regarding power consumption and scalability:

- We see software defined networking having a net positive benefit on router power consumption..
- We see optical interconnects being necessary for all interconnections beyond the board level in 2020 core routers.

Software defined networking

Software defined networking (SDN) is taking hold in the networking community. This has both positive and negative impacts on the power consumption of routers. Some versions of SDN reduce switching complexity of intermediate nodes, allowing them to be implemented as lower power layer 2 switches, which typically consume 50% of the power of layer 3 routers. This will require more intelligent distribution of the SDN packet processing system. However, SDN also can push towards a more flexible routing architecture, allowing more and varied routing protocols. This potentially increases the complexity and power consumption of packet processing in the system.

Interconnect technologies

Optical interconnect technologies have continued to become more attractive, with practical limits for electrical technologies being around 100Gb/s for a 1m interconnect distance [1]. Thus, electrical interconnect at or beyond 25Gb/s shows significant challenges for link distances beyond the board level. By 2020 we estimate interconnect rate requirements to be 50-100Gb/s per link assuming a constant link number, thus electrical interconnects will be at or beyond practical limits for rack level interconnects. With optical interconnects being critical to future scaling, the maximum line rates are an important parameter. Vertical cavity surface emitting laser (VCSEL) based systems continue to show scaling of data rates, with 25Gb/s in commercial prototypes and beyond 50Gb/s in labs [2], [3]. These can address interconnects in the up-to-100m range, though the use of multiple fibers for parallelism is a constraint on scalability.

The emerging area of silicon photonics represents a path to increasing the data rate per fiber and increasing reach beyond the 100m range. We continue to work on the integration of silicon photonic devices with CMOS electronics [4], [5] including integration with laser sources [6] and CMOS Electronics.

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Router Power Monitoring (REPTILE)

Type: Contributed

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: Centre for Energy-Efficient Telecommunications, University of Melbourne (project lead)

Project Mission:

At its heart, the Internet is an incredibly complicated array of interconnected computers. The Internet uses an extensive network of switches, routers, and transmission systems to direct traffic between these computers. Although most of the energy consumed in running the Internet is in the last link to the customer (wired access and wireless access networks), the power consumption in the core network occurs in a limited number of very large power-hungry switches and routers. The power consumption of these machines is already posing a significant challenge to manufacturers and service providers.

This project developed a new methodology for constructing accurate, quantitative power models based on vendor-agnostic measurements on commercially available routers and switches. This methodology provides key information on energy consumption relating to various internal operations performed by them. This information has not previously been available via external measurements.

The project has provided data that has been used to develop detailed power consumption mathematical models for network equipment. These models can be used in the GreenTouch reference architecture model and other network models that may be developed by GreenTouch.

Accomplishments:

Developed a vendor-agnostic router/ switch power consumption model that can be applied to any packet traffic profile

This technique is based on a set of simple, pre-defined measurements that can provide values for three key aspects of router operation: idle operation power, energy per packet for header processing, and energy per byte for storage and forwarding. The analysis is based upon an understanding of the relationship between router power consumption, packet size, and router load. An example of this is shown in Figure 1 below. The model was validated on an Alcatel-Lucent router (pictured in Figure 14), and it predicted the power consumption of the router for arbitrary traffic with an error of less than 0.2%.

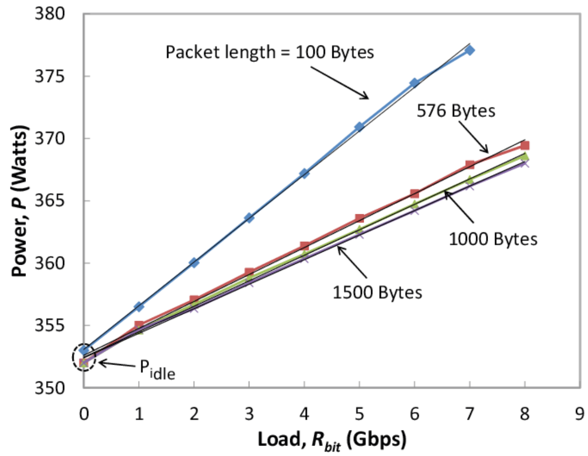

Figure 13. Dependence of router power consumption (y-axis) on load (x-axis), packet size (indicated for each trace), and idle power (y-intercept). Analyzing these relationships provides a model of power consumption for arbitrary traffic profiles

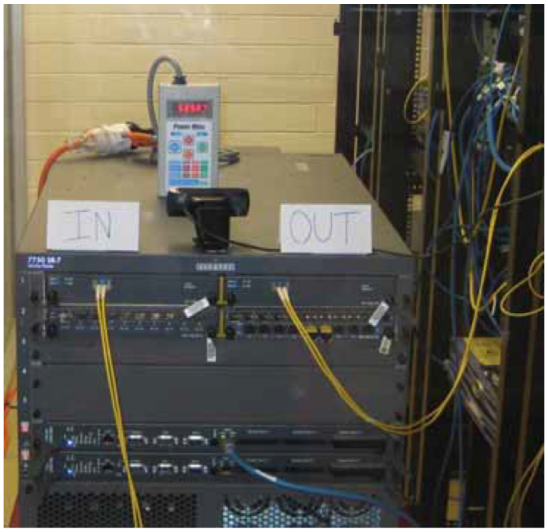

Figure 14. Experimental setup to validate the router power consumption model

May 2013 demonstration of the Universal Router Energy Model in the Australian Broadband Applications Laboratory (ABAL), at the University of Melbourne

In this demonstration, we showed how the results from the measurement method described above can be used in the model to assess the energy consumption arising from carrying traffic across different paths through a network. The demonstration illustrated how the ability to model the power consumption of components in the different data paths will provide service providers an opportunity to choose the most energy efficient path for data.

Understanding how traffic packet size can affect energy efficiency in a network

The model also provides an understanding of how traffic packet size can affect energy efficiency in a network. Defining "packet energy efficiency" as the ratio of energy consumed to pass the customer data through a router to the total energy required to pass an entire packet though the router (i.e., customer payload and the packet headers), Figure 15 below shows that traffic types that use short packets can be significantly less energy-efficient than those using longer packets. Packet energy efficiency can be less than 50% for services that use short packets. This means that the majority of router power is spent processing overheads rather than passing the customer payload through the machine.

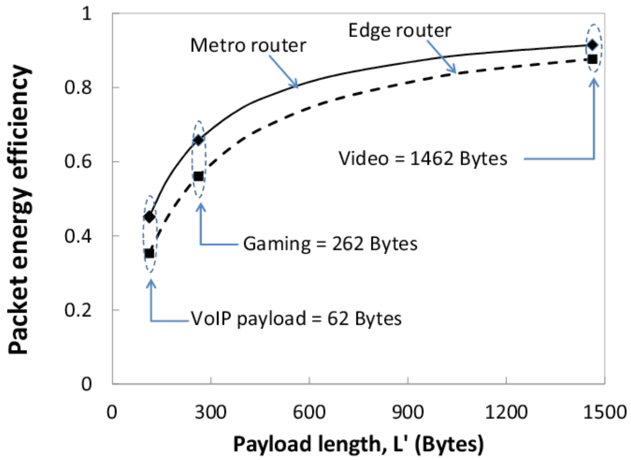

Figure 15. Packet energy efficiency vs. payload length

This result provides a warning that significant growth in services that use small packets (VoIP, Machine-to-Machine) may come at the cost of reduced packet energy efficiency.

Providing a technique for estimating the incremental power incurred by additional traffic

The router power model has been extended to provide a technique for estimating the incremental power incurred when additional traffic is added to an existing network. This traffic may arise from a new service being introduced or growth in popularity of existing services. Viewing the plot in Figure 16 below, the consequence of increasing the traffic in a network by amount ΔC will cause an increase in power consumption ΔP.

To estimate the size of ΔP for a given traffic increase, we need to account for the deployment of new or upgraded equipment that may be required. The addition of new equipment means we must include the idle power that equipment consumes as well as their incremental power. The red line in the figure below shows these contributions. To calculate ΔP the router power model is used to estimate the average of these contributions (shown by the green dashed line) for the given capacity increase accounting for any changes of equipment deployed in the network.

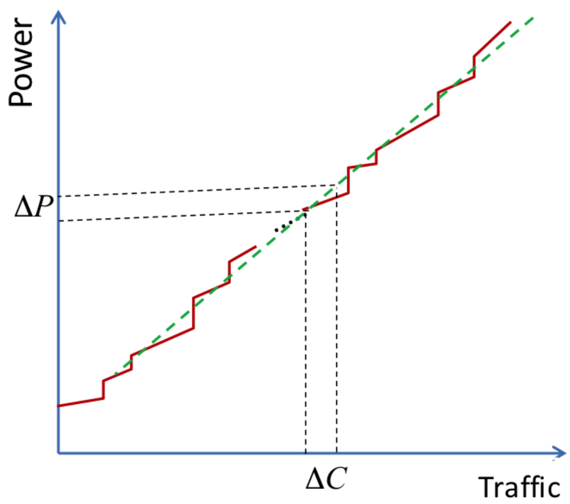

Figure 16. Increases in power resulting from increases in traffic

The total network power is dependent upon the equipment deployed and the traffic load on that equipment. Figure 16 depicts the fact that, as the traffic through the network increases, the power consumption will display steps representing the introduction of new equipment. Between these steps, the power consumption of the deployed equipment will increase linearly as it processes more traffic. An estimate (the red line) of the incremental power (ΔP) caused by the introduction of traffic from a new service (ΔC) is based upon averaging these increments (the green line).

Highly Adaptive Layer for Flexible Meshed On-off Optical Networks (HALF-MOON)

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: Bell Labs / Alcatel-Lucent (project lead), Politecnico di Milano, Universitat Politècnica de Catalunya (non-member Collaborator)

Project Mission:

Today optical networks are dimensioned and managed statically: the number of devices to deploy is evaluated beforehand, considering forecasts of the peak traffic exchanged between all network nodes. These devices, once set up, remain always on, even if the transported traffic fluctuates during the network's lifetime. Various traffic analyses in core optical networks have shown that some of the fluctuations are predictable (e.g., daily, weekly). Because of the quasi-static system management (all elements are powered on to sustain peak traffic), devices cannot tackle the traffic dynamics, and therefore current optical networks waste a significant amount of energy, proportional to the difference between the peak and the average transported traffic.

The HALF-MOON project aims to investigate how to implement power management of optoelectronic devices in optical networks and estimate how network performance (in terms of network reliability, connection setup …) is affected by this new operational mode.

Within HALF-MOON the adaptation of the power used for a given traffic amount is investigated along two directions, which can act separately and jointly:

Adaptive spectral-efficiency: Adaptation of data-rate and modulation format in the optical layer to minimize energy consumption according to both capacity demand and physical impairments

Device power management: Introduction of different power states relative to a device/system and management of transition between these states.

Accomplishments:

- Estimation of the energy consumption for 40Gb/s, 100GGb/s, 400Gb/s and 1Tb/s devices
- Realization of an MILP formulation for computing the energy consumption for 1:1 protected networks where the energy savings are realized by powering on-off optoelectronic devices (transponders) and/or in-line amplifiers (also known as link on-off)
- Realization of an MILP formulation for computing the energy consumption of an IP/MPLS over DWDM multi-layer optical networks, which is survivable against any single link failure scenario using IP/MPLS protection switching. We target the design of survivable multi-layer optical networks over Single Line Rate (SLR), Mixed Line Rate (MLR) or Elastic DWDM optical layer minimizing the CAPEX. As shown in Figure 17, in the Elastic scenario the daily power consumption of the optical layer reduces by 34% compared to SLR, while MLR can only do it by 13%.. Indeed, TXPs in MLR are dimensioned to the maximum capacity required in any failure scenario, remaining underutilized most of the time. Conversely, elastic TXPs can lower their data rate in non-failure conditions saving power. This reduction leads to an overall network power consumption reduction (IP and optical layers) of 9%, against 5% for MLR. Hence, showing MLR and Elastic similar CAPEX (their cost is i.e., 1995 a.u. vs. 1983 a.u. respectively), Elastic technologies become more interesting, as they yield superior OPEX reduction in terms of lower power consumption.

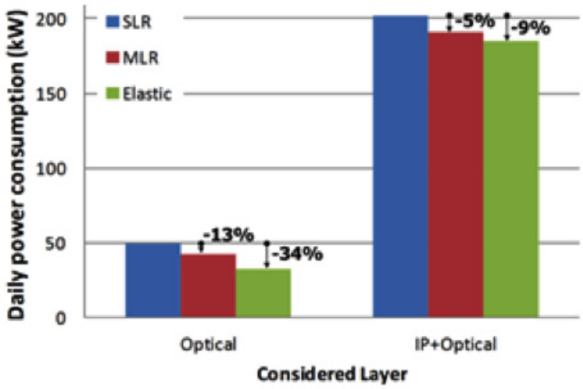

Figure 17: Daily power consumption (in kW)

- Comparison of elastic optical networks and power-managed ones (sleep-mode). Such strategies can be applied either separately or jointly, according to the functionalities implemented into the OE-devices and the protocol enhancements introduced into the control plane. Unprotected networks with daily traffic variations are taken into account. Results for a European-like network are summarized in Figure18.

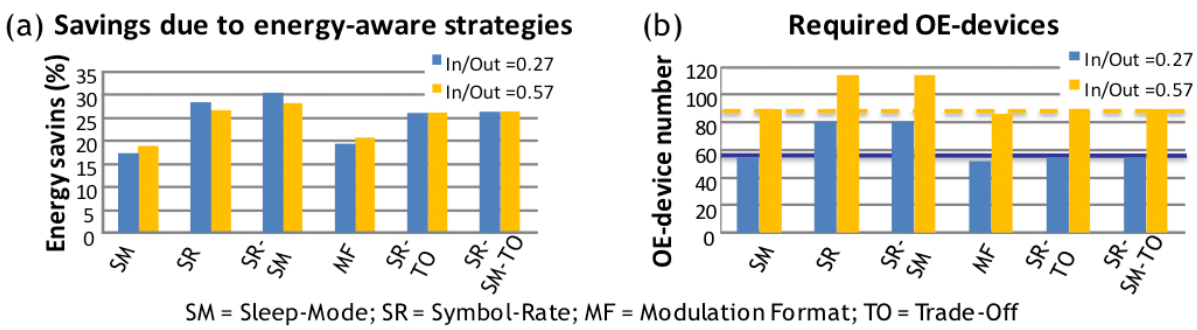

Figure 18: Comparison of the different energy-aware strategies for In/Out traffic equal to 0.27 and 0.57. (a) Energy savings with respect to the static network management. (b) Number of required OE-devices (transponders and regenerators). Continuous and dashed lines stand for the OE-devices used by the static network when In/Out traffic is 0.27 and 0.57, respectively.

Up to 30% of average energy savings during the day can be achieved by performing symbol-rate adaptation combined with sleep-mode management (SR-SM) of OE-devices. Unfortunately, this approach results in a 48% extra cost. So, we proposed a new strategy where the amount of initial available resources is limited to the amount obtained by designing the network with fixed rate 100Gb/s transponders. In this case we still obtain a significant 26% of energy saving at no additional cost in the number of OE-devices. Note that a quasi-optimal saving is obtained by using only the symbol-rate adaptation (SR-TO), as the joint operation of symbol-rate adaptation with the sleep-mode does not provide significantly higher gains (lower than 0.5%).

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Content Distribution and Clouds for Service Delivery (CROCODILE)

Type: Contributed

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: Centre for Energy-Efficient Telecommunications, University of Melbourne

Project Mission:

Previously, cloud and content services were typically sourced from a centralized data center, but increasingly content is distributed from localized regional cache servers, which thus form a content distribution network (CDN). A CDN may span a very large geographical region (even up to international scale) and may service many thousands of users scattered throughout that region. The data centers used by a CDN may likewise be widely spread.

The energy consumption of a CDN or cloud service or application is a function of all of its components, including all of its computing resources, storage, and network transport. The expectation is that there will be significant growth in accessing cloud and CDN services from mobile devices (iPhone, iPad, tablets, etc.). Mobile access to the Internet is the least efficient access network technology. These trends will affect the energy consumption of future cloud and CDN services.

This project will utilize theoretical and experimental techniques to construct energy consumption models of the various types of cloud-based services and content distribution networks, such as architectures with centralized servers and various levels of localized servers for popular content, with a major focus on developing tools for optimizing the energy consumption of these services and networks.

Accomplishments:

Development of energy consumption models

Energy consumption models have been developed for interactive cloud services: Google, Microsoft 365 (interactive document composition and editing). This research has shown that cloud services are not always more energy-efficient than local document composition and editing. This identified a key contributor to the energy inefficiency of interactive cloud services. As shown in the graph in Figure 19, there is a 1000x overhead for every byte entered by the user for the data exchanged between the user and the cloud. It is unclear why this overhead is so large.

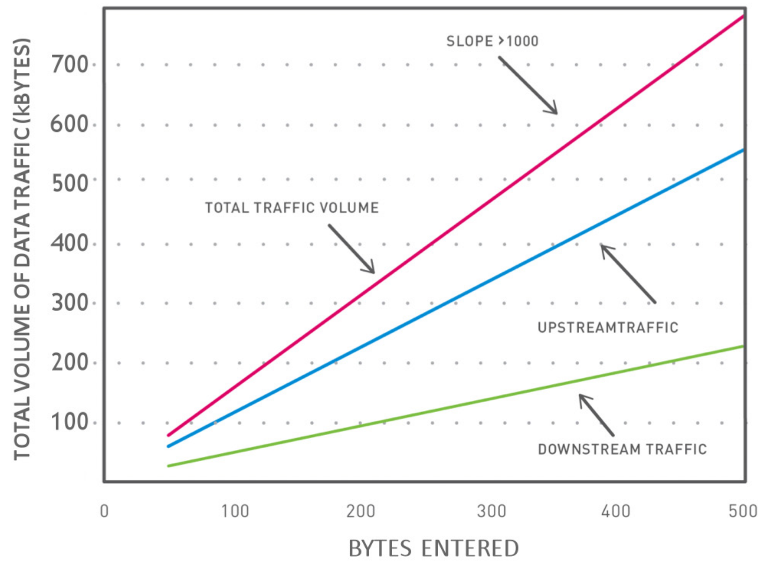

Figure 19. Bytes exchanged with the data center (y-axis) plotted against bytes entered by the user for an interactive cloud service

Energy consumption model for a CDN service

A very popular service provided by Facebook is the distribution of pictures by Facebook users. The CDN required to support this service is globally distributed, involving many decentralized data storage locations as depicted below. Localized data storage is used because it can provide low latency better than centralized storage. Results show that distribution of pictures can (as distinct from storage in the data centers) contribute significantly to the overall energy consumption of a photo distribution service.

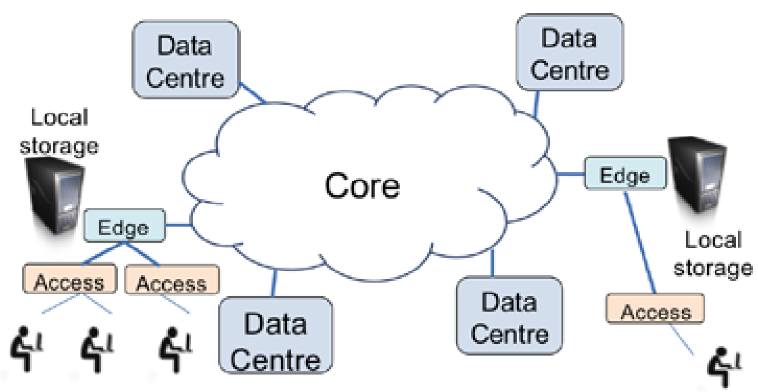

Figure 20. CDN required to support distribution of pictures by Facebook users

Storage locations for a decentralized Content Delivery Network will involve data centers located at geographically diverse sites. Despite this, the energy consumption of transport may still be a significant component of overall service energy consumption.

Energy consumption model for wireless access to cloud services

Results show that, based on current forecasts for the number and traffic of users who will access cloud services via wireless in 2015, the data centers will account for approximately 10% of annual energy consumption of these services. The majority of the energy used (approximately 90%) will be consumed in the transport of data between the wireless users and the cloud data centers. See Figure 21 below.

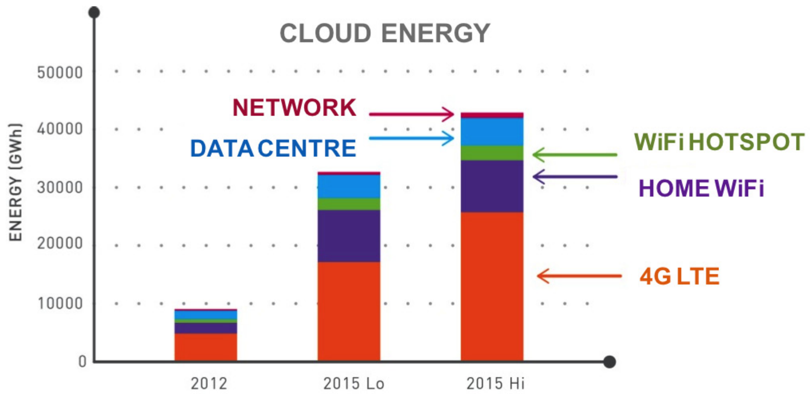

Figure 21. Forecast annual energy consumption of wireless access to cloud services for 2015 based on current industry trends

It is important to note that this model relates only to the use of wireless access for cloud services and only allows comparison between the different components of such a service. This model does not relate to total data center energy usage nor does it relate to total mobile access energy usage.

These results show that, for wireless access to cloud services, efforts for improving energy efficiency should focus on the wireless access network.

These results were presented as part of an invited talk at an industry-wide summit on “How Green is the Internet?” organized by Google in June 2013.

Service Energy Aware Sustainable Optical Networks (SEASON)

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Core Networks

Project Participants: Bell Labs / Alcatel-Lucent (project lead), CEET (Univ. of Melbourne), Columbia University, University of Toronto

Project Mission:

SEASON is a clean-slate core network design project focused on maximizing energy efficiency by optimizing the end-to-end network for key high-bandwidth services. At the physical layer, it provides an underlying dynamic wavelength capability for energy-efficient support of bandwidth-demanding multimedia services. At the service layer, media content is dynamically allocated (for storage, processing, and distribution) according to resource efficiencies and service requirements. SEASON examines the use of distributed "Micro Data Centers" serving as demarcation points between access and core network. Micro data centers accomplish two goals: (1) they are the main service delivery and management location, and (2) they serve as the nodes for a dedicated dynamic wavelength backbone network.

Accomplishments:

Main activities during this year focused on analyzing the optimal allocation of content in a distributed micro data center network and the design of efficient distributed online algorithms for making dynamic caching decisions in response to changing user demands and content popularity. In addition, the use of network coding and its interaction with in-network caching schemes was investigated for improving the energy efficiency of content distribution under the increasingly asynchronous and time-shifted demand for media content. Highlights of results from the third year are provided below:

Dynamic in-network caching for efficient content delivery

- We showed that unlike best practice caching algorithms such as LRU and LFU, energy-optimized solutions only cache content objects in those network locations where request rates and transport energy costs are high enough to balance additional storage energy costs.
- We developed a fully distributed, energy-aware, online solution (EE-OND) that dynamically and jointly adjusts the caching configuration (replication and replacement of content objects) and the routing paths (cache selection and request routing) through the adaptive learning of object popularity and fetching costs. EE-OND provides effective cache cooperation with negligible constant-time computational complexity and constant-size communication overhead, takes into account the heterogeneity and dynamics of user demands and network resources, and adapts to changing network conditions minimizing overall energy use. Simulation results show a 2X overall network efficiency gain with respect to both LRU and LFU in networks of up to 80 cache-enabled nodes with a homogeneous transport-storage efficiency ratio $\eta=10$ (Figure 22). Our findings were published at the 2013 IEEE INFOCOM [1]. Ongoing work includes considering larger networks with increased heterogeneity, where larger gains are expected.

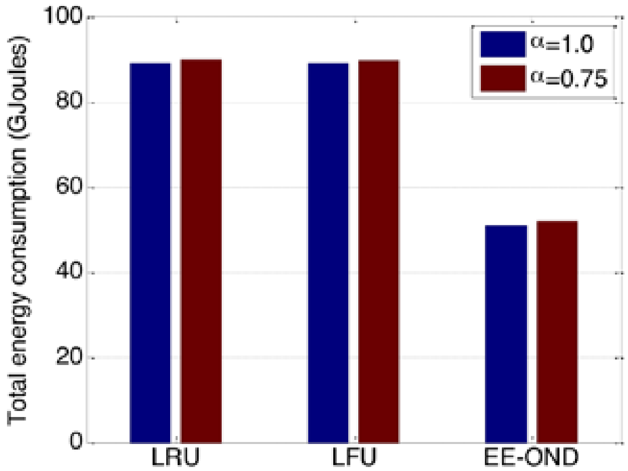

Figure 22. [1] The total energy consumption during a 10-hour content delivery session over the 3967 Rocketfuel 79-node network for LRU, LFU, and EE-OND solutions Network-coded caching-aided multicast

- We showed that the combined use of network coding and in-network caching can further increase overall energy efficiency by creating multicasting opportunities even in the presence of distinct object requests along shared network resources.
- For the single bottleneck network scenario, we designed a simple randomized popularity-based caching policy in which nodes randomly cache packets/chunks of content objects according to their popularity. We showed that, while for skewed popularity distributions (high Zipf parameter) the proposed caching policy approaches traditional schemes that entirely cache the most popular objects (e.g., LFU), for low Zipf parameter (more uniform popularity), it allows efficiency gains of up to the number of distinct object requests at the expense of increased complexity index coding based transmission schemes that exploit coded multicasting to simultaneously serve requests for distinct objects of similar popularity. Simulation results show up to 6X transport efficiency gains with respect to LFU in a 20-node single bottleneck network (Figure 23). Our findings have been published at the 2013 IEEE ICC [2]. Ongoing work includes considering larger networks with increased heterogeneity.

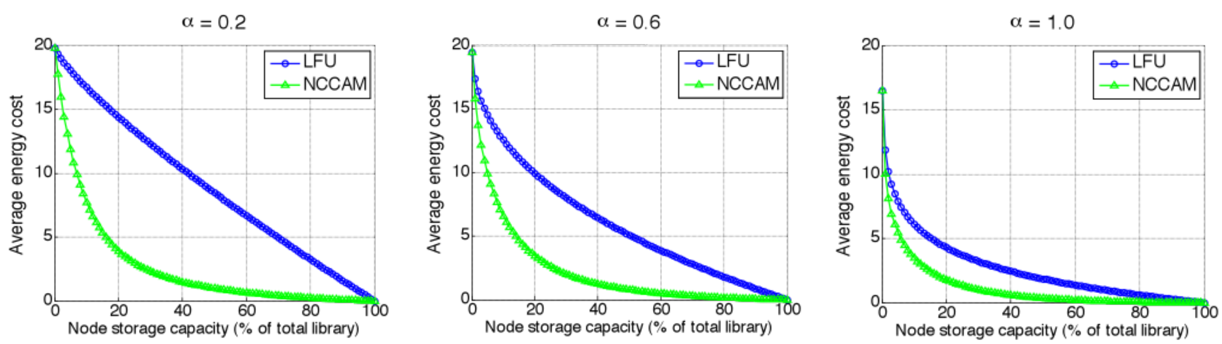

Figure 23. Normalized transport average energy cost vs node storage capacity for the delivery of content requests coming from 20 cache-enabled nodes in a single bottleneck network. The content library consists of 1000 content objects requested according to a Zipf popularity distribution with parameter α = 0.2, 0.6, and 1.0. LFU caches entirely the most popular objects, while our proposed network-coded caching-aided multicast (NCCAM) scheme uses random caching proportional to object popularity and index coding transmission. Up to 6X energy efficiency gains are achieved by exploiting caching-aided coded multicasting under low Zipf parameter.

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Bit-Interleaved Passive Optical Network Technology (Bi-PON)

Type: GreenTouch (Funded)

Working Group Affiliation: Wired Core & Access Networks – Fixed Access Networks

Project Participants: Alcatel-Lucent (project lead), IMEC University of Ghent, Orange Labs, Stanford University

Project Mission:

The goal is to define the most energy-efficient protocol for a time division multiplexed (TDM) passive optical network (PON) and experimentally demonstrate the efficiency gains compared to standard protocols.

Accomplishments:

- After the successful demonstration of bit-interleaving (Bi)-PON in 2012, which showed more than an order of magnitude efficiency improvement for the protocol processing compared to a standard PON, we reported the results in various conferences and a journal paper [1]-[6].

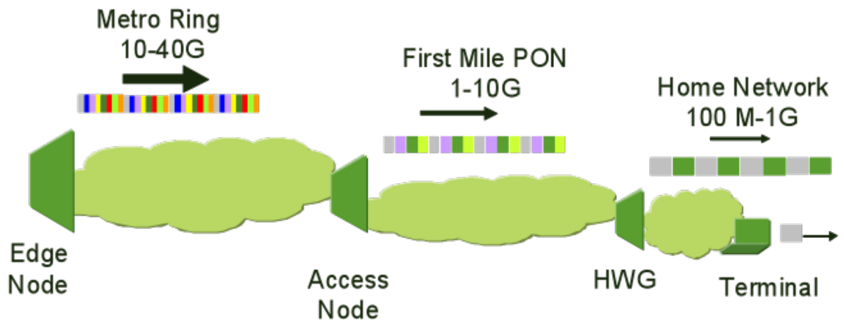

Figure 24: Cascaded bit-interleaving access architecture

- We extended the concept to cascaded network segments that span across metro, first-mile access, and home networks, as illustrated in Figure 24. The bits for each end-terminal are sorted by a hierarchical scheduler at the Edge node, so that an intermediate node (also called repeater node) can select relevant bits for its subsequent lower rate segment using a simple decimator. The repeater can transparently pass the relevant bits onto the subsequent segment in an interleaved fashion at a lower rate without the need of processing and reshuffling the received data. Hence, power consumption in electronic processing at the repeater node can significantly be reduced. This so-called cascaded bit interleaving (CBI) can be used in a quasi-passive home gateway [7], for example, or in a converged metro access network (cf. 24).
- We defined the protocol for CBI and prototyped the functionality of the repeater in field programmable gate array (FPGA). This activity will continue in a dedicated new GreenTouch project. "CBI," which aims at proofing the concept and evaluating the efficiency gains of CBI by 2015.

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Low Energy Access Architecture

Type: GreenTouch

Working Group Affiliation: Wired Core & Access Networks – Fixed Access Networks

Project Participants: Alcatel-Lucent (project lead), AIT, Cambridge University, CEET, iMinds, NTT, Orange Labs, SwissCom

Project Mission:

The goal is to compare the average power consumption of different optical access architectures (e.g., point-to-point, passive optical networks, and converged, long reach metro-access network) in order to identify the most energy-efficient access solution. This includes the analysis of different multiplexing and modulations schemes, as well as different approaches for efficiency improvements, such as sleep mode and protocol innovation.

Accomplishments:

- We updated a study of the power consumption of different multiplexing technologies on passive optical networks (PON), including time division multiplexing (TDM), wavelength division multiplexing (WDM), time and wavelength division multiplexing (TWDM), and orthogonal wavelength division multiplexing (OFDM). We also compared it with point-to-point access. We reported the results for access networks with 10 Gbit/s aggregated bandwidth shared by all subscriber connected to the same PON in [1]. Given the recent importance of next generation capable PON (NG-PON2) in full service access network (FSAN), we also evaluated different technologies for 40 Gbit/s aggregated bandwidth [2], [3].
- Additionally, we evaluated approaches that can improve the energy efficiency of the different optical access technologies. Cyclic sleep mode is an effective method to reduce the power consumption compatible with existing standards [4]. In a TDM-PON, cyclic sleep mode applies to the ONU. We optimized the sleep cycle parameters so that the user experience is not affected by the sleep states [5]. The OLT is always on, because it is shared by multiple ONUs, but its power consumption per subscriber is already low. In an Ethernet PTP system, cyclic sleep mode can be applied to both the OLT port and ONU port [6]. As convincingly demonstrated in the Bi-PON project in 2012, it is possible to achieve additional gains by stepping away from the standards and designing a system with a new energy efficient TDM protocol for PON (see Bi-PON project section in this document).
- TWDM-PON is the most energy efficient NG-PON2 technology that will be commercially viable by 2015. It offers an interesting capability to scale the power consumption of the OLT as a function of the required total capacity by lighting up an appropriate number of wavelength pairs accessible by all ONUs connected to the shared medium. In the longer term, Bit-Interleaving may be an energy-efficient alternative for 40 Gbit/s capable TDM-PON [2], [3].

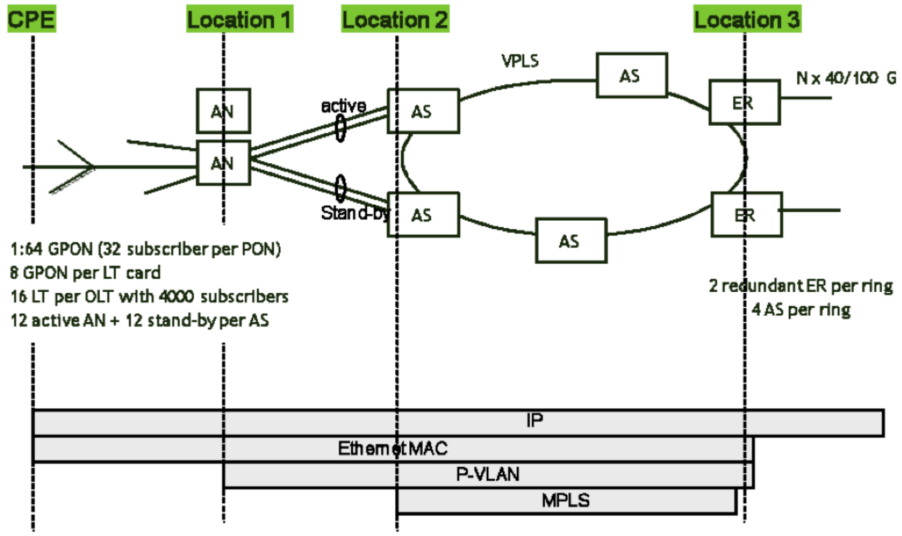

Figure 25: Metro-access aggregation network with access node (AN), aggregation switch (AS), and edge router (ER)

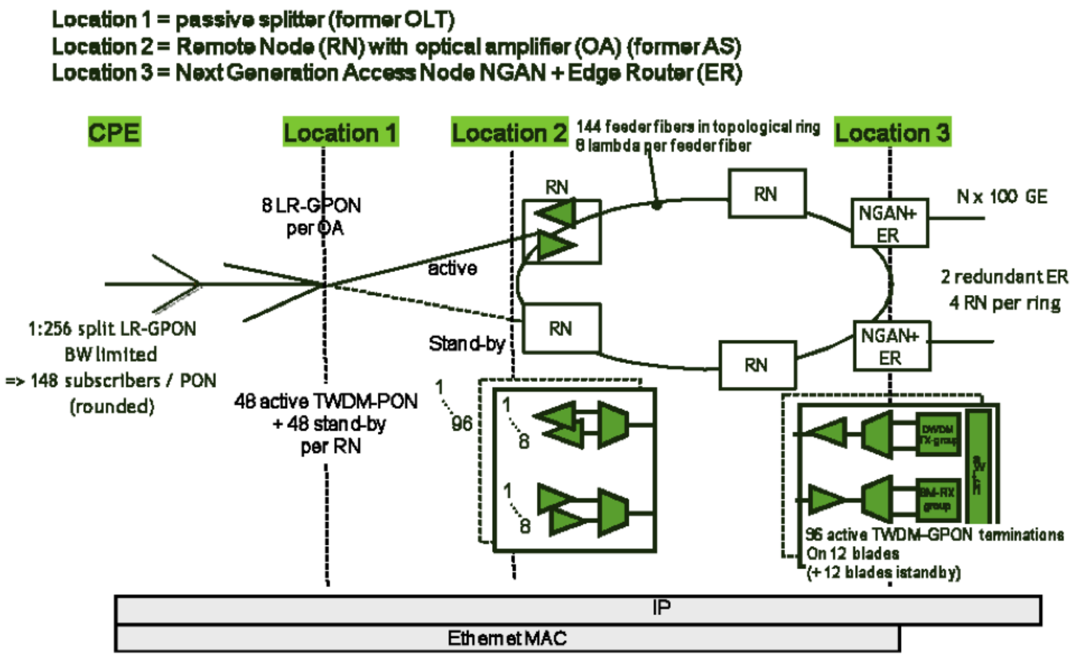

Figure 26: Converged metro-access network with long reach PON

- We evaluated the power consumption of a metro-aggregation network, which includes the access node, aggregation switch, and edge router (cf. Figure 25). Our analysis shows that about a 2x efficiency improvement can be achieved by the introduction of long reach access architectures that bypass the access node and aggregation switch (cf. Figure 26).
- We updated the study of the total power consumption in an access network and the efficiency gains that can be obtained in each subsystem by applying improvements as studied in the wireline access activities of GreenTouch. Thanks to a combination of different improvements and considering Moore's law for general power evolution in semiconductors by 2020, it is possible to reduce the average power consumption per subscriber of a wireline access and aggregation network by more than 50x.

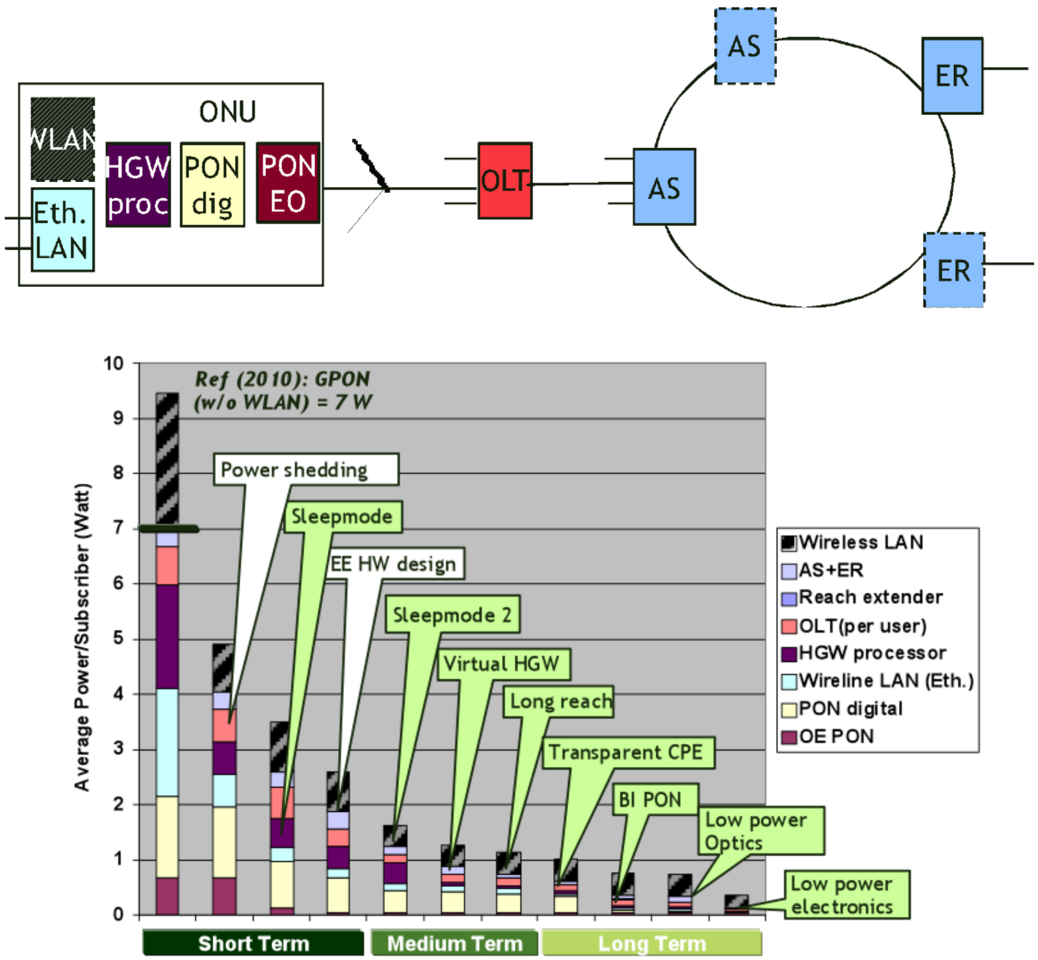

Figure 27: Evolution of average power consumption per subscriber (with reference architecture)

- In order to calculate the energy efficiency shown in Figure 28, we integrated the total energy consumption per subscriber over a year and divided it by the traffic over that same period. Considering a traffic growth of 8.5x per subscriber (i.e., a single family unit) in a mature market between 2010 and 2020, this results in an improvement of the energy efficiency per transferred bit by 449x. We also performed an extensive sensitivity analysis of the different gain parameters and showed that more than 1000x efficiency improvement is possible in the best case. These results were input to the Green Meter research study in the consortium. Results were presented in [7], [8], [9].

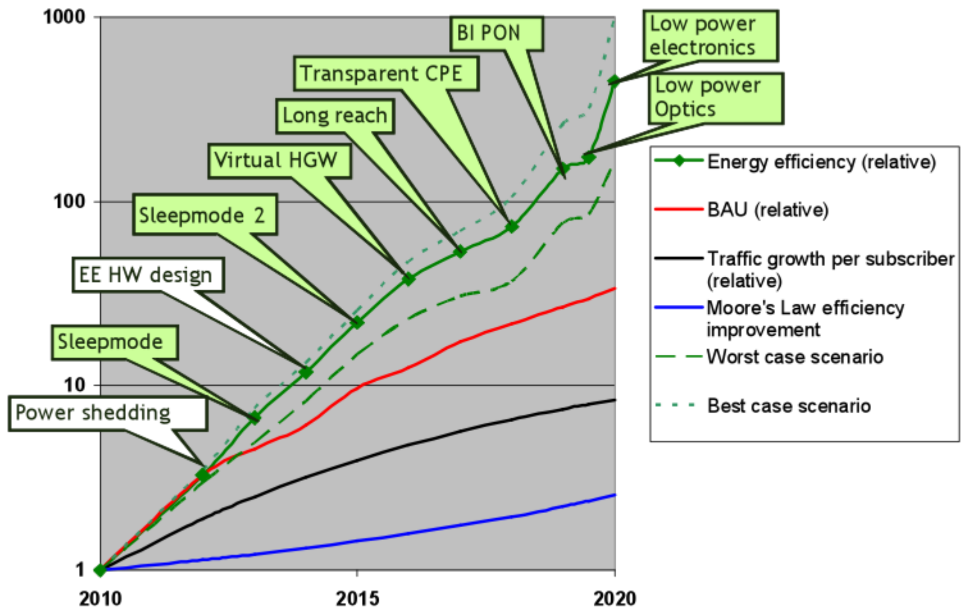

Figure 28: Evolution of energy efficiency in wireline access network with worst case and best case sensitivity analysis

- In a more detailed study on point-to-point fiber access networks, we have shown that the power consumption of the transceivers can be reduced by more than an order of magnitude through (1) optimization of the transmitter and receiver settings for a low-loss optical link and slow subscriber rate; (2) use of low threshold current VCSELs; and (3) energy efficient CMOS drivers, which are possible thanks to the slow subscriber rate in point-to-point access links [10], [11].
- We provided a first estimate of low power optical backhaul solutions for small cells to the mobile communications working group.

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virtual Home Gateway (vHGW)

Type of Project: GreenTouch (Funded)

Working Group Affiliation: Wired Core & Access Networks – Fixed Access Networks

Project Participants: INRIA (project lead)

Project Mission:

The customer premises equipment (CPE), which provides the interworking functions between the access network and the home network, consumes more than 80% of the total power in a wireline access network. The present project aims at a drastic reduction in power consumption by means of a passive or quasi-passive CPE. Such approach requires that typical home gateway functions, such as routing, security, and home network management, are moved to a virtual home gateway (vHGW) server in the network.

Accomplishments:

- In our first prototype, virtual home gateways of the subscribers were put in LXC containers on a unique GNU/Linux server. The container approach is more scalable than separating subscribers by virtual machines. We demonstrated a sharing factor of 500 to 1000 virtual home gateways on one server, which consumes about 150 W, or 150 to 300 mW per subscriber. Comparing this power consumption with the power of about 2 W for the processor in a thick client home gateway, we achieved an efficiency gain of 5-10x. The prototype was integrated with the Bi-PON and demonstrated at TIA 2012 in Dallas.
- In the second prototype, we first evaluated another container technology, called OpenVz, still based on a Linux kernel. The advantages are twofold: Live migration and Live backup. The very first experimental results show that we obtained the same performance as with the first prototype based on LXC.
- Then we proposed a new architecture: a Clustered vHGWs data center architecture to yield optimal energy conservation through virtual machine migration among physical nodes based on the current subscriber's service access state, while ensuring that the service level agreements for the respective subscribers are respected. Thus, optimized energy utilization of the data center is assured without compromising the availability of service connectivity and QoS preferences of respective subscribers.
- Another accomplishment was the dissemination of our project results, such as through displays in the GreenTouch booth at the TIA event in June 2012 (see Figure 30).

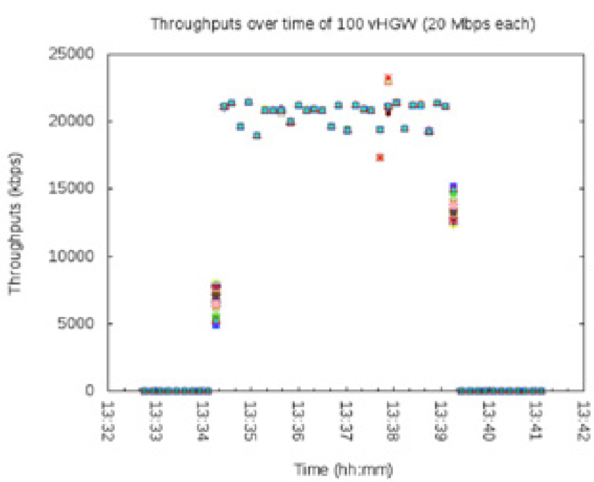

Figure 29. Fairness for 100 VHGW deployed on one physical server

Figure 30. vHGW project in the GreenTouch Booth -- TIA Demo June 2012

References:

[1] Jean-Patrick Gelas, Laurent Lefevre, Teferi Assefa, and Mulugeta Libsie. "Virtualizing Home Gateways for Large Scale Energy Reduction in Wireline Networks," Electronic Goes Green 2012 (EGG), Berlin, Germany, September 2012

[2] P. Vetter, L. Lefevre, L. Gasca, K. Kanonakis, L. Kazovsky, A. Lee, C. Monney, X. Qiu, F. Saliou, and A. Wonfor. "Research Roadmap for Green Wireline Access," Workshop on Green Communications and Networking during IEEE ICC'12, Ottawa, Canada, June 2012. IEEE

[3] Website: http://www.ens-lyon.fr/LIP/RESO/vhgw/

Services, Policies, and Standards Working Group

Leadership:

- BianSen, China Mobile, Chair
- Gilbert Buty, Bell Labs / Alcatel-Lucent, Co-Chair

Chair's Summary / Key Accomplishments:

Standardization is one of the key elements for research results to be turned into commercial products. In order to be really effective, standardization actions should be defined from and supported by a well-defined standardization strategy and planning. These – strategy and planning – are necessary to define a path of standardization-related actions and objectives. Without any standardization strategy, the standardization actions are in general unsuccessful or lead to suboptimal results.

Moreover, the standardization strategy has to consider multiple aspects, including the maturity of the standardization ecosystem, the position of the technology proposed for a standard in the standardization life-cycle, the objectives of the research projects, possible open issues, and the research project maturity.

Finally, dealing with the dynamics of both standardization and research environments requires this strategy to be reassessed on a regular basis. As a consequence, this process is characterized by iterative cycles of defining/refining the strategy and adapting actions and expected achievements in standardization bodies.

To cope with these requirements, the Services, Policies and Standards (SPS) Working Group was established in mid-2012 and is based on three pillars of activity:

- The identification of application and network requirements for long-term technology solutions, particularly those affected by macro traffic trends, network characteristics and traffic details, and the taxonomy of feature requirements in applications
- The provision of an appropriate platform to understand and influence standards central to realizing the GreenTouch innovations and architectures and the potentialities for standardization for projects developed under GT
- The provision of un-biased, pre-competitive information, guidance, and other resources that further the GreenTouch mission in the policy arenas

During this reporting period, SPS has identified the GreenTouch projects presenting short, medium, or long-term opportunities in the standardization domains. These include four projects from the Wired Core and Access Networks Working Group, three projects from the Mobile Working Group, and one project from the SPS Working Group; a preliminary process has been triggered for those projects with high standardization demands.

As far as the SPS projects are concerned, this first-year activity has led to:

- An update the Macro Traffic Projections 2010-2020, including tables of traffic volumes projected to 2020 based on historical trends and near-term forecasts (2010-2015)
- An update of the application taxonomy document based on the characterization and abstraction of the properties of present and possible future applications, defined by typical ranges of key parameters that describe the application requirements, such as bandwidth and latency requirements
- The launch of the Energy Metrics for Users (EMU) project, which formulates energy metrics to permit users to include energy consumption in forming product purchase decisions.

Energy Metrics for Users

Type: GreenTouch

Working Group Affiliation: Services, Policies, and Standards Working Group

Project Participants: CEET (project lead), Bell Labs / Alcatel-Lucent, China Mobile

Project Mission:

Due to growing consumer awareness and concerns about Internet sustainability, we need to develop a systematic reporting framework to assess and report the energy consumption of Internet services and the effectiveness of green strategies. As a consequence, the project aims to design energy assessment methodologies to better evaluate the environmental impact of telecommunications services. This could help in defining a Green Rating system that differentiates "green" services offered by service providers and network operators. This project will provide the foundational models, tools, and understanding to facilitate the development of a globally accepted reporting framework for energy efficiency of telecommunications networks and services.

Accomplishments:

Methodologies for assessing the use-phase power consumption and greenhouse gas emissions of telecommunications network services

We developed a set of models for assessing the use-phase power consumption and carbon dioxide emissions of telecom network services to help telecom providers gain a better understanding of the GHG emissions associated with the energy required for their networks and services [1]. Measuring the power consumption and traffic in a telecom network is a challenging task due to limited network equipment monitoring capability for some network equipment (e.g., legacy network equipment) and the complexity of how services are delivered within networks. Therefore, the models proposed in [1] utilize different granularities of available network information ranging from network platform level to equipment class level and individual equipment unit level. The accuracy of the energy assessment models has been validated using real network datasets from the California Research and Education Network (CalREN). We found that as the granularity of the network measurement information decreases, the corresponding models have the potential to produce large assessment errors depending on several factors: (i) network size, (ii) total amount of network service traffic, and (iii) the number of network equipment units used to process the service.

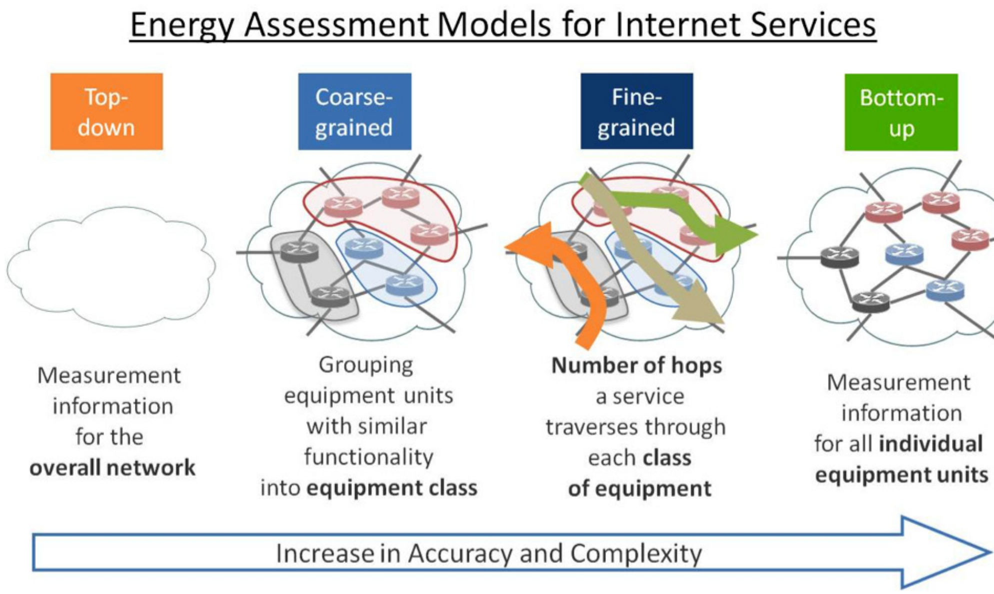

Figure 31. Energy assessment models for Internet services

References:

[1] Chien A. Chan, André F. Gygax, Elaine Wong, Christopher A. Leckie, Ampalavanapillai Nirmalathas, and Daniel C. Kilper, "Methodologies for Assessing the Use-Phase Power Consumption and Greenhouse Gas Emissions of Telecommunications Network Services," Environmental Science & Technology, vol. 47, no. 1, pp. 485-492, 2013

Operations Committee

Leadership:

- Elle Baese, Huawei, Chair
- John Ciacciarelli, Bell Labs / Alcatel-Lucent, Co-Chair

Participating Organizations:

- Bell Labs / Alcatel-Lucent, CEA-LETI, Fujitsu, Huawei, Fondazione Politecnico di Milano and Samsung Advanced Institute of Technology

Focus Areas

Elle Baese

The Operations Committee plays a key role in the day-to-day management of GreenTouch. It is responsible for financial management, infrastructure and logistics planning, and the oversight of its management partners. The Operations Committee also has Sub-committees to provide additional support in the areas of Funded Projects and Marketing Communications.

Financial Management

Members of the Operations Committee play an integral role in the creation and approval of the annual budget, approving budgeted expenses, providing structure for the processing of unplanned consortium expenses, and reviewing the planned vs. actual budgets on a monthly basis. The Operations Committee, in conjunction with the Executive Board, also monitors consortium revenue and manages the new business development pipeline.

Infrastructure and Logistics

The Operations Committee also provides ongoing support in the Committee and Working Group structure of GreenTouch. Through regular meetings, the Operations Committee stays apprised of key developments within the Committees and Working Groups and provides related guidance such as governance policies and procedures, funding opportunities, and member meeting planning and execution.

Oversight of Management Partners

To assist in the day-to-day management of the Consortium, GreenTouch has engaged the services of two management partners: Virtual, Inc. and SGG Management B.V. The Operations Committee oversees engagement of these partner companies. Virtual, Inc. is a full-service association management company that handles a variety of management functions for GreenTouch, including: Financial services, membership management services, IT infrastructure and web services, Board and Committee support, and meeting and event management.

SGG is a Netherlands-based Trust Office who fulfills the following management functions for GreenTouch: Maintain headquarters, accounting functions, and corporate legal services necessary to fulfill the obligations of the foundation in the Netherlands.

Funded Projects Subcommittee

Leadership: Didier Bourse, Alcatel-Lucent

Chair's Summary / Key (New) Accomplishments:

Reaching the factor of 1000-fold increase in energy efficiency is clearly one of the ICT grand challenges for the decade, and it requires a significant effort and budget. The momentum developed by the GreenTouch consortium could be amplified by the possible prioritization and funding of research grants and funded cooperations in different regions, through the funding support of different agencies. The dedicated GreenTouch Funded Projects subcommittee was set-up in June 2011 to support this worldwide development. The GreenTouch roadmap, reference architecture, and research challenges can be major contributors to the EU, US and APAC scientific research roadmaps, identifying the key challenges to be potentially tackled in different cooperation instruments as well as by legal bodies (policy, regulatory, and standardization). This approach is captured in Figure 32 below.

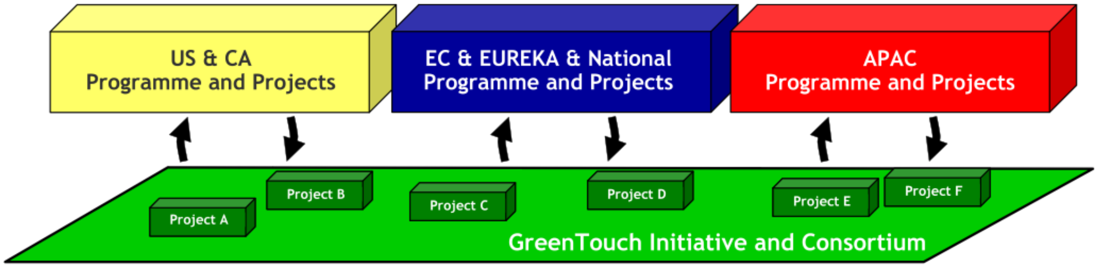

Figure 32: GreenTouch Initiative and Funded Programs

The subcommittee shares with GreenTouch members a list of various funding calls for proposals that relate to GreenTouch project areas (including EU EC, EU EUREKA, EU COST, EU Member States, US DARPA, US NSF, US DoE, CA NSERC, CN MOST) and mobilizes GreenTouch members around important funding opportunities. For example, one of the calls-for-proposals was the European Commission ICT Call 11 on Future Networks (FP7-ICT-2013-11), for which several GreenTouch projects' members contributed in April 2013 to proposals related to Green ICT. GreenTouch was also engaged in specific Energy Efficiency issues of two EC FET Flagships proposals submitted in October 2012 (FuturICT and Guardian Angels). At the national level, proposals were also submitted to the French National Research Agency (ANR) call for proposals in February 2013. Finally, Green ICT and Energy Efficiency research challenges are also discussed in the context of the forthcoming EC Horizon2020 (H2020) program under current definition (FP7 follow-up program in the period 2014-2020).

Members from the subcommittee also raise awareness of the work of GreenTouch among external funding parties. For example, GreenTouch was highly visible during the Dublin Future Internet Assembly (FIA 2013) event organized on 08-10.05.13 in Ireland, through an opening plenary presentation in the technology stream and during the Green ICT-GreenTouch parallel session "Green ICT: What would be the cost of doing nothing?" GreenTouch was also represented in the "Sustainability" plenary session of the EC E1 Unit (Network Technologies) Future Networks and Mobile Summit (FuNeMS 2012) organized on 04-06.07.12 in Berlin, and GreenTouch updates were presented during the two latest EC E1 Unit Concertation meetings organized on 11.10.12 and 28.02.13 in Brussels. One dedicated workshop between GreenTouch and the EC FP7 TREND project was organized on 19.04.13 in Turino, collocated with the INFOCOM 2013 conference. Concerning EU EUREKA, GreenTouch was presented in the context of the EUREKA CELTIC-Plus 2013 event on 06-07.03.13 in Kayseri.

The subcommittee organizes regular phone conferences and participation is open to all GreenTouch members.

Marketing & Communications Subcommittee

Leadership: Kay Seo, Bell Labs / Alcatel-Lucent


Kay Seo

Chair's Summary / Key (New) Accomplishments:

This year has seen the biggest media push by the Marketing & Communications Subcommittee (MCSC) to date, with a big impact on promoting the consortium's external presence.

As part of the Operations Committee, the MCSC is responsible for managing internal and external communications and marketing activities. Its goals are to:

- Establish a clear identity for the consortium's unique positioning as Green Thought Leadership and a values-based program.
- Generate excitement among GreenTouch members, boost momentum, and make it an exciting activity to contribute to.
- Establish an effective communication plan to improve internal communication and member engagement.
- Enhance a proactive media relations program, utilizing a variety of media sources to maximize awareness, create excitement, and enhance the consortium's image to support our goals, objectives, and programs.
- Develop positive and collaborative relationships with target audiences.
- Reinforce a coherent image so as to establish "One Clear Voice" throughout all communication channels by creating key messages, talking points, and value propositions.

Positioning GreenTouch and ICT's Role in Sustainability

Increasing awareness, creating excitement, and enhancing the GreenTouch image

This year has seen many remarkable activities that helped promote the consortium's external presence, marking a significant milestone in its five-year mission. In particular, we unveiled the GreenTouch Green Meter, which shows progress toward the consortium's very ambitious goals. The Green Meter quantifies the improvement in energy efficiencies for the technologies developed for mobile access, wireless, and core network architectures, and it also shows the potential reduction in energy consumption and costs possible in the different network architectures. We shared the findings of the consortium's research via live webcast during the members meeting in Shanghai in May, highlighting the announcement of the Green Touch Green Meter.

The reaction from this announcement was extraordinary in its coverage and in the level of positive acceptance of the research results. The press release received more than 3,000 views and was reposted more than 200 times during the week of the announcement, including reposts in the *Wall Street Journal,* CBS *MarketWatch*, and on many other major media and trade outlets. There were 32 unique articles generated, and more than 20 reposts of unique articles in top outlets appeared, including three contributed articles. Hundreds of tweets resulted from the news release, press briefings, and media coverage.

Following the successful announcement of the GreenTouch Green Meter, the consortium continued to emphasize our presence in the EU area, where the "green" efforts are most prominent globally. In June 2013, we had a successful workshop during the EU Sustainable Energy Week in Brussels, with distinguished guests in the energy efficiency area from the European Parliament, Boston Consulting

Group, Microsoft, Orange, Alcatel-Lucent, etc., which created very lively discussions and stamped our presence in the EU.

GreenTouch has been invited to and has been represented in an increasing number of global organizations on sustainability initiatives, such as the World Economic Forum, Fortune Brainstorm GREEN event, Global Green Growth Forum, and Telecommunications Industry Association, just to name a few. Notably, GreenTouch has been playing an increasingly significant and active role with the World Economic Forum's Global Agenda Council on Governance for Sustainability. Considered as an industry best practice initiative, GreenTouch is now actively helping the Council with its Green Lights project, which is an initiative to showcase scalable and replicable examples of ideas and multi-stakeholder cooperative efforts that can support and complement government and international efforts on sustainable development.

Additionally, many GreenTouch leaders and members have participated in various interviews, conferences, and technology forums, helping promote GreenTouch and its mission.

Engaging Members and Non-members

Increasing the level of activities and interactions among members and non-members

Since its full refresh a year ago, the GreenTouch website has been the primary vehicle to share information on the key activities of the consortium and its individual members. This website continues to focus on dynamic and engaging content, sharing case studies, videos, research results, interviews, and speaking engagements.

The GreenTouch Episode 1 video has been introduced, which summarizes the consortium's mission, work, and the dedication of our members. Along with the Green Meter announcement, the launch of the video was received very positively, and it is the consortium's intention to continue with the GreenTouch story.

The focus on social media continues. With an increasing number of Twitter followers and the introduction of the GreenTouch Linkedin group, we are expanding these avenues further.

To promote even tighter community, the consortium continues to publish bi-monthly Members Newsletters with robust content and updates. Additionally, the Chairman actively communicates through the Chairman's Blog, summarizing key initiatives, issues, and events to which he wants to call attention.

With increased recognition of GreenTouch in the industry, key industry associations and conferences are initiating co-marketing collaboration, such as the Broadband World Forum, Telecommunications Industry Association, Informa, IEEE, etc.