GreenTouch™

# 2010–2011 Annual Report

# Contents

# Chairman's Letter


Dear GreenTouch Community:

As we conclude the first full year of operations for the GreenTouch Consortium, I am pleased to share with you our progress to date and goals for the future.

What started as the vision of a relatively small number of representatives from industry, government, and academia has now rapidly expanded to encompass more than 300 participants from 45 member organizations, with more joining literally every day. As I speak to audiences around the globe about energy sustainability and GreenTouch, people are amazed with what we are achieving, motivated by our ambitious goal, and challenged by the leadership GreenTouch has provided. GreenTouch now has members from 19 countries and is comprised of diverse constituencies: from global telecommunications industry leaders to regional research centers and premier academic institutions. Our members have created a community truly dedicated to reducing energy consumption and promoting environmental sustainability.

We, of course, also want to recognize and celebrate our accomplishments. GreenTouch has laid the groundwork to achieve its ambitious goal of increasing network energy efficiency by a factor of 1,000 by 2015. Key milestones include:

- Built a research portfolio around five major themes including Wireline Access, Wireless Access, Switching and Routing, Optical Networking, and Services and Applications.
- Hosted three global events to spread the news of GreenTouch and to recruit participants: the November 2010 Member Meeting and Open Forum in Amsterdam, the February 2011 News Briefing and Large Scale Antenna Demo in London, and the April 2011 Member Meeting and Open Forum in Korea. More than 300 people participated in these events.
- Established an active Executive Board and Operations Committee to oversee the organization.
- Initiated our public relations activities to promote the GreenTouch mission worldwide through ongoing announcements, global press coverage and speaking engagements.


The Committees and Working Groups of GreenTouch ensure strong momentum through regular meetings and active discussion. During the past year, the following seven projects were approved, with more in the development pipeline:

- *Core Optical Networking & Transmission Working Group (2):* SEASON and HALF MOON
- *Core Switching & Routing Working Group:* Single Chip Linecard
- *Mobile Communications Working Group (3):* Large Scale Antenna Systems, Beyond Cellular Green Generation, and Green Transmission Technologies
- *Wireline Access Networks Working Group (2):* Low Energy Access Architectures, Virtual Home Gateway and Quasi-passive CPE

Details about each of these projects are in this Annual Report.

On behalf of my colleagues on the Executive Board, I would like to thank everyone in the GreenTouch community for their support and participation during our first year. Without it, we would not have been able to achieve this year's success. Beyond that, I am truly excited to see us make continued progress in the coming year on improving environmental sustainability through the work of GreenTouch.

Cheers,
Gee Rittenhouse
Chairman
GreenTouch Consortium

# Operations Committee

**Chair:**
Thierry van Landegem
Alcatel-Lucent/ Bell Labs

**Co-Chair:**
Kevin Kemp, Freescale Semiconductor

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, Freescale, IMEC, Huawei, Fujitsu

## Focus Areas

The Operations Committee plays a key role in the day-to-day management of GreenTouch. Specifically, this Committee is responsible for financial management, infrastructure and logistics planning, and the oversight of its management partners.

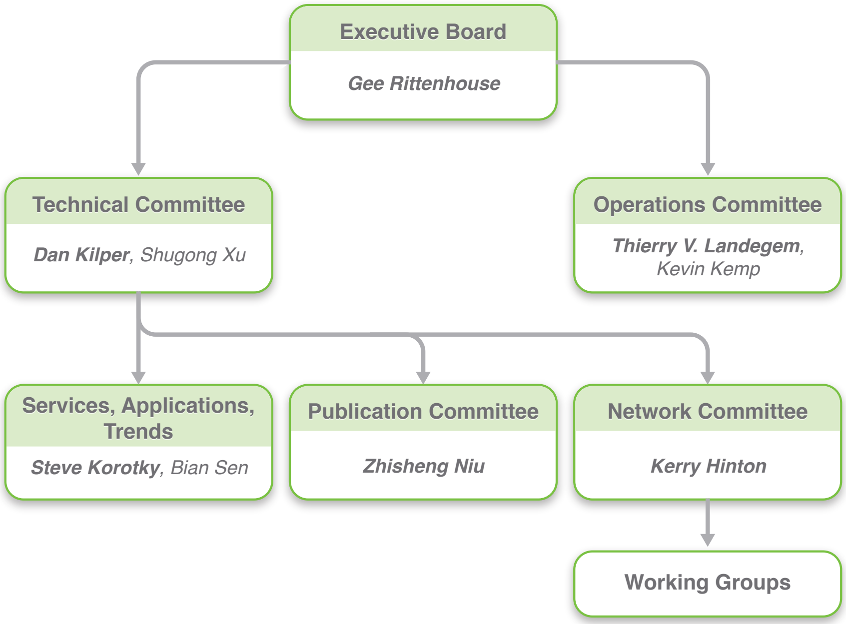
## Financial Management

Members of the Operations Committee play an integral role in the creation and approval of the annual budget. Throughout the year, they are also responsible for 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 (obtained via membership dues and sponsorship fees) and manages the new business development pipeline.

## Infrastructure and Logistics

The Operations Committee also played a key role in defining the Committee and Working Group structure of GreenTouch. Through the establishment of a Technical Committee and additional Committees and Working Groups as needed (see organizational chart below), a strong foundation has been laid for the initiation and development of GreenTouch projects. Through regular meetings, the Operations Committee stays apprised of key developments within the Committees and Working Groups and provides guidance on a number of issues, ranging from governance policies and procedures, to funding opportunities, member meeting planning and execution, to name a few.

*GreenTouch Organizational Chart*




## 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 third key role the Operations Committee plays is with respect to the oversight of these partner companies.

Virtual, Inc. is a full-service association management company, who handles a variety of management functions for GreenTouch, including:

1. Financial services, including maintenance of the cash budget and forecasts, processing of all vendor bills and expenses, and member invoicing and collections
2. Membership management services, including answering inquiries, processing new member applications, managing member database and providing monthly management reports
3. IT infrastructure and web services, including management of both the public and member-only site
4. Board and Committee support, including scheduling, attending, documenting and tracking action items for the Executive Board and all Committees,
5. Meeting & event management, including planning and executing bi-annual Member Meetings
6. Public relations and Marketing

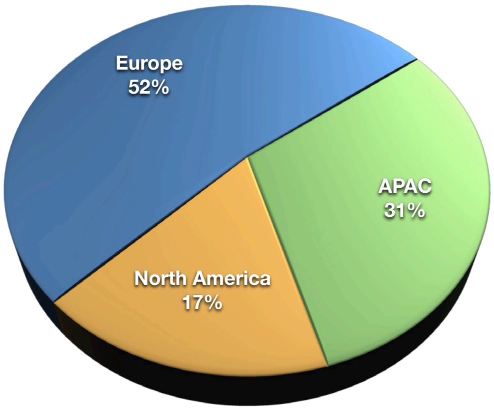
SGG is a Netherlands-based Trust Office who fulfills the following management functions for GreenTouch:

1. Maintain headquarters
2. Accounting functions, including preparation of quarterly and annual reports in accordance with Dutch GAAP, management of the bank account and arrangement of payments, and audit support
3. Corporate Legal services necessary to fulfill the obligations of the foundation in the Netherlands.

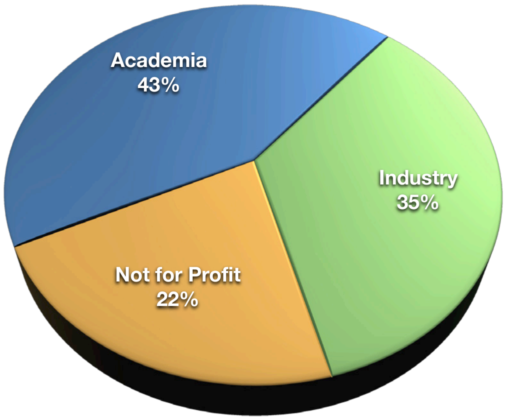
## Member Breakdown

As of June 30, 2011, GreenTouch has 48 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 Region*




*GreenTouch Members – By Organization Type*



# Technical Committee

**Chair:**
Dan Kilper
Alcatel-Lucent/Bell Labs

**Co-Chair:**
Shugong Xu, Huawei Technologies

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, ETRI, Fondazione Politecnico di Milano, Fjuitsu, Huawei Technologies, K U Leuven, The University of Melbourne, University of Maryland

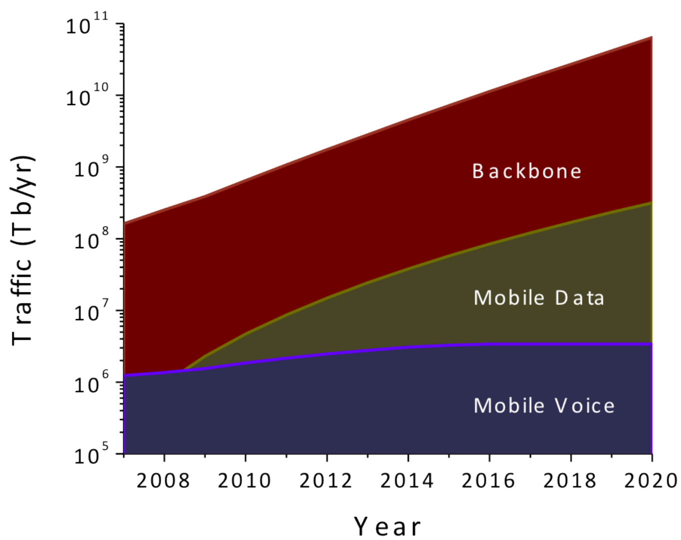
GreenTouch has embarked on an exciting new paradigm for global research cooperation, one that is as ambitious as it is important to the future of information and communication technology (ICT) networks. Recent studies point to a growing gap between network traffic volumes and network efficiency, leading to rising energy use in communication networks. At the same time, ICT is clearly one of our most valuable tools in combating climate change and realizing sustainable living—from smart phones to smart grids to smart cities. Historical technology scaling trends are encountering increasingly challenging obstacles from micro-electronics to fiber optics. Each of these factors points to the need for something different—a new approach that brings diverse research efforts together in a pre-competitive environment in order to effect the network transformations that will be needed in the years ahead. Setting the goal of a thousand-fold efficiency improvement points the compass of GreenTouch firmly in the direction of the major challenges ahead and forces consideration of all elements of the network.

The GreenTouch technical organization was established on May 7, 2010 and has enjoyed a first year of enthusiastic participation, enlightening discourse, and visionary research. When trying something new that is full of risk, one expects doubt and criticism. When we instead found strong enthusiasm and the broad recognition across the community of the benefits of GreenTouch, we realized, of course, that others have looked ahead and recognized the problems we all face—realized that an organization like GreenTouch is the right vehicle to address these challenges.

The technical committee had four main goals for its first year: build the project portfolio, achieve a first technology milestone, establish connections with other organizations, and develop the baseline architecture. Strong achievement was reached in each of these areas. Fifteen project proposals were introduced at the GreenTouch kick-off meeting in June, 2010. While several projects initiated work immediately following the meeting, others were refined within the working groups and a new ‘cluster project’ structure was created to enable several projects working on related aspects of a particular architecture or technology to join in a common effort. By May 2011, 12 projects had been active during the year, including four cluster projects, and one demonstration activity that was completed.

A large scale antenna system experiment was organized by a team from across industry and academia and achieved the first major milestone of the consortium. This successful technology demonstration illustrates many of the key principles and benefits of GreenTouch. This project revisited a technology well known for capacity enhancements in wireless systems: multiple input multiple output (MIMO) communication, by examining its potential for reduced power consumption. They showed that new algorithms optimized for low power operation could enable an air interface power reduction for constant performance that scales linearly with the number of antennas—as much as 16 times in the demonstration, with reductions of 100-1000 now considered feasible. Furthermore, the large power reductions involved here may enable an entirely new basestation architecture, going from large ~10 W power amplifiers used today to large arrays of mW or µW amplifiers—creating a fundamental redesign of the network infrastructure. This project was also an example of the consortium members leveraging their existing expertise and hardware to rapidly produce an important result.

*North American Internet traffic growth projections for total backbone traffic, and for mobile data and mobile voice services [see D. C. Kilper, et. al., J. Sel. Top. Quantum Electron. 17, 275, 2011].*




The scope of challenges facing all of ICT networks is beyond what GreenTouch can address alone, and the overall GreenTouch effort can be significantly enhanced by partnering with other organizations. This is particularly true of activities such as quantifying energy use in commercial networks and understanding metrics and models important to the problem. Cooperation was initiated with several research consortia including the Center for Integrated Access Networks (CIAN), the Intelligent Energy Aware Networks (INTERNET) consortium, and the Towards Real Energy Efficient Network Design (TREND) Network of Excellence. While GreenTouch activities are pre-standards, GreenTouch can help facilitate the eventual standards process by cooperating with


standards development groups and related organizations, as well as other pre-standards or roadmap organizations. This year, GreenTouch built relationships with the ITU-T, the Carbon Trust, and the International Technology Roadmap for Semiconductors (ITRS).

The GreenTouch roadmap is a key tool that is essential to the consortium's objectives and also an important asset that will facilitate research progress. The scope of the GreenTouch mission can only be made practical through the use of network models that bring together all of the diverse technologies, protocols, and architectures to quantify the resulting impact. Scientists and engineers working on different pieces of the puzzle can understand the importance of their research and direct their efforts to better purpose. In this way the consortium, through the roadmap, can coordinate diverse research efforts so that they can build to a larger, end-to-end, holistic network transformation. This comes about not only from the perspective afforded by the roadmap trends, but also because the roadmap includes an accounting of the major research challenges that need to be addressed and thus brings focus to the problems.  The last and critical role of the roadmap is to provide an accurate set of tools that can be used in network energy research. Information about energy use in networks can be hard to obtain, especially as many networks are proprietary, commercial facilities. Through the roadmap, GreenTouch strives to provide the research community with accurate information about networks and ICT network equipment, including reference architectures to serve as a common baseline platform.

Most of the work is still ahead of us. We've taken important first steps over the past year to build a solid foundation for GreenTouch. Activities are accelerating as we continue to gain momentum. The energy and expertise of our members is our greatest asset. If this first year is any indicator, it will carry us far.

**Why 1000x?**

- Traffic will grow by 1000x within 20 years
- All parts of the network will matter
- All technologies we use in the network will matter
- It makes you question all aspects of the network
- It requires a highly scalable network
- You can't solve it with growth alone
- You can't solve it with power reductions alone
- The goal should fit the problem

## About the Technical Committee

The GreenTouch Technical Committee is the executive body for the technical organization, which has the responsibility for identifying and tracking consortium projects, including planning demonstrators, managing publications, results, and progress toward goals, the overall coordination of technical committees and reporting to the Executive Board. The primary functions of the technical organization, which are overseen by the Technical Committee, are listed below in terms of technical and organizational objectives.

**Technical Functions**

- Determine the architectures that achieve the GT goals
  - Define target requirements
  - Evaluate technical accomplishments
  - Determine parameter sets for architecture models
- Define and update service requirements
  - Determine network models for each service
  - Determine traffic trends for each service
- Track alternative metrics

**Organizational Functions**

- Document & disseminate consortium projects and outcomes
- Negotiate and assign (if GT funded) new tasks & projects
- Drive & track progress toward final architectures
- Identify & track progress toward key demonstrators
- Document gaps in effort
- Organize meetings and calls to stimulate progress toward goals
- Year-end report to the Executive Board

# Technical Goals

The Technical Committee is tasked with organizing the technical organization to execute the mission of GreenTouch by providing the architectures, specifications and roadmap to achieve a factor of 1000 energy efficiency improvement in ICT networks. In early 2010, the GreenTouch founders group defined the details behind this goal. In particular, they agreed to take a network model based approach that uses a reference model to represent the state of the art with respect to the energy efficiency of ICT networks in 2010. The GreenTouch efficiency improvements will be measured against this reference model. Furthermore, traffic and service models would be developed to represent a potential set of service requirements and traffic load for a 2020 scenario. The GreenTouch innovations would be evaluated using this 2020 scenario in order to determine the efficiency gains. The year 2020 was chosen in order to encourage a long range view, and since current models expect 30x total traffic growth for the decade, the energy per bit efficiency metric requires both an increase in capacity and a reduction in total power consumption in order to reach the goal. By achieving the efficiency goals using these model scenarios, the GreenTouch innovations will demonstrate the direction in which future commercial networks can evolve in order to achieve scalable growth and commensurate efficiency gains.

**Greentouch Mission:**

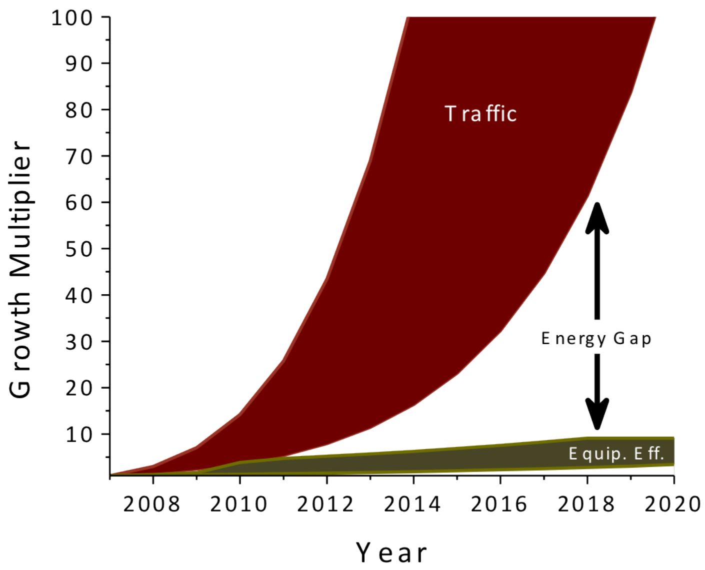
By 2015, our goal is to deliver the architecture, specifications and roadmap — and demonstrate key components — needed to increase ICT network energy efficiency by a factor of 1000 from current levels.

Gauge impact of innovations on:

- Alternative metrics (e.g. carbon footprint, network power, embedded energy)
- Adjacent technologies (e.g. data centers, handsets)

Measure, model and predict energy consumption in ICT networks (including equipment, traffic, and deployment trends)

The scope of communication networks that will be included in these models is given by the scope of activities in the four initial working groups within the Network Committee and was chosen to represent mature technology communication networks that comprise the Internet. Furthermore, the impact of the GreenTouch innovations on adjacent technologies or networks would be evaluated to confirm that the GreenTouch solutions do not shift the energy load to other out of scope areas such as data centers, personal computers, or handsets. Alternative metrics such as the carbon footprint and total network power will also be examined to again avoid negative impacts for these other metrics and to determine potential benefits from an overall green networks perspective. In order to ensure that the GreenTouch results are relevant and to provide accurate information to the research activities, the consortium also has the goal to measure, model, and predict energy consumption in commercial ICT networks.




*Projected growth relative to 2007 for traffic (including range from backbone to mobile data) and equipment efficiencies (including range from core transport to mobile networks). Traffic is growing faster than the equipment energy efficiency can be improved [see D. C. Kilper, et. al., J. Sel. Top. Quantum Electron. 17, 275, 2011].*

### Sustainable Network Growth

Energy consumption in ICT networks is increasing as a result of network growth, especially with the explosion of mobile data traffic. Network growth is outpacing equipment efficiency improvements, which is slowing as limits to historical capacity and scaling laws loom. This trend could adversely effect the Internet and the broad energy efficiency benefits that ICT networks and associated smart technologies enable.

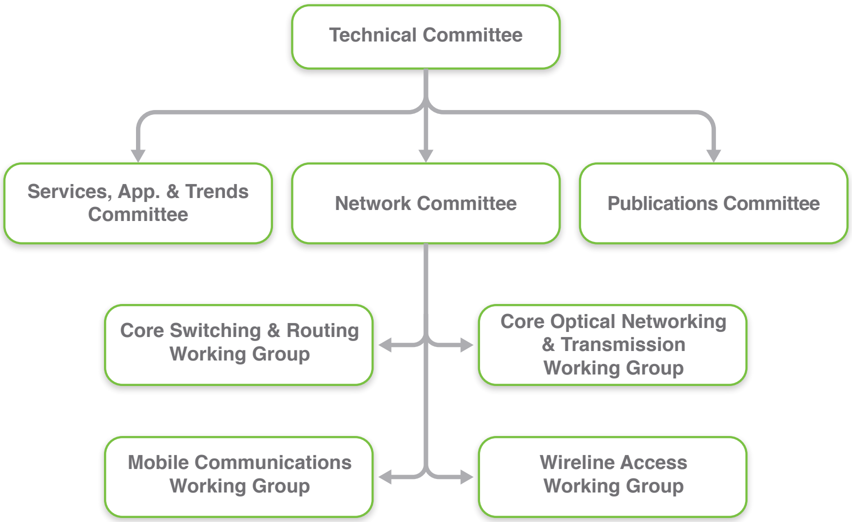
### Social Responsibility

Given the urgent need to meet the global challenge of reducing greenhouse gas emissions and increasing reliance on renewable energy, every industry must play its part and ICT, at the forefront of technology, can be a leader.

The GreenTouch mission and related objectives identified above are motivated by the desire to achieve sustainable network growth and to responsibly address the energy and climate challenges facing society. Information and communication technology networks are important tools to help facilitate sustainable living. Realizing this potential requires a communication infrastructure that is itself sustainable. Given the recorded trends of near-exponential or exponential network growth in users, traffic, hosts, and other network parameters, similar scale improvements in network energy efficiency are required.

As part of this endeavor, the GreenTouch Consortium strives to provide open and global participation, a venue for cooperation and demonstrations among research organizations, and a forum for the exchange of information on energy trends, challenges, and research on communication networks. The consortium is a bottom up research organization that is structured to enable the participating research groups and individuals to best address the technical challenges facing GreenTouch. Details of the organizational structure are described below.

## Technical Organization




The Technical Committee is an executive group responsible for the leadership of the technical organization within GreenTouch. At the start of the year, the technical organization included two sub-committees under the Technical Committee: the Network Committee and the Services, Applications, & Trends (SAT) Committee. The Network Committee has primary responsibility for executing research programs directed toward achieving the main GreenTouch technical energy efficiency goal. The SAT Committee on the other hand focuses on the overall parameters that factor into the technical goals including the traffic and service definitions, alternative metrics, and network trends and measurements. While the SAT Committee has not yet formed working groups, it includes several special study groups. The Network Committee includes four working groups organized around the different network technology areas of expertise and equipment. The Working Groups are organized vertically: providing top to bottom expertise, from algorithms and protocols down to chips and lasers. The projects and study groups, however, cut across the working groups to provide an end to end perspective and bring focus to areas between working groups that might develop into separate working groups. Each technical project has a primary committee or working group in which it is introduced, but becomes part of all of the working groups

in which they have impact. The Publication Committee was kicked off during our Seoul all member's meeting and promises to be busy during our second year.

## Cooperating Organizations & Related Activities

### ACCORDANCE

- EU Consortium
- A converged copper-optical-radio OFDMA-based access network with high capacity and flexibility (Liaison partner: AIT)

### CIAN

- US Consortium
- Keren Bergman (Columbia Univ.) is a member of CIAN and facilitates cooperation with GreenTouch through the SEASON project.

### INTERNET

- UK Consortium
- GreenTouch Core Switching & Routing Working Group members Jaafar Elmirghani (Univ. of Leeds) and Richard Penty (Cambridge Univ.) are members of the INTERNET consortium and facilitate cooperation with GreenTouch through the OPERA project.

### ITRS

- International Technology Roadmap for Semiconductors
- GreenTouch Technical Committee chair Dan Kilper (Bell Labs, ALU) is participating on the Assembly and Packaging technical working group as a liaison between the ITRS and GreenTouch.

### ITU-T

- JCA on ICT & Climate Change
- GreenTouch Executive Board member Claude Monney (Swisscom) is participating in this Joint Action Committee to share information between GreenTouch and ITU-T.

### TUCAN

- PIANO PLUS Consortium
- The project targets the development of a low cost tunable transceiver technology that will be capable of meeting access network cost targets whilst maintaining high performance and reducing power requirements (Liaison partner: University of Cambridge)

### TREND

- EU Network of Excellence
- GreenTouch Executive Board member Rodney Tucker (IBES, Univ. of Melbourne) is representing GreenTouch on the TREND Advisory Board; TREND members are active within GreenTouch

## New Organizational Initiatives

With the completion of the GreenTouch publication procedures, a new committee, the Publication Committee, was formed in order to help to execute these procedures and to promote and disseminate technical publications within the consortium. This committee held its first meeting at the Seoul all members meeting. One key mechanism that was introduced during this year is the special study group. These groups are intended to address special topics of interest that require focus or that might develop into a working group. The formation of seven special study groups was begun during the year; within the Network Committee these include: network modeling group, OFDM group, and the energy-efficient electronics group. The SAT Committee took steps to develop working groups through the formation of the following special study groups: Macro Traffic Group, Network Operator Survey Group, Application Taxonomy Group, and Mobile Traffic Group.

## Services, Applications and Trends Committee

GreenTouch works to identify technological and architectural solutions for future communication networks that can provide a substantial improvement in energy efficiency. The process of researching, developing, and designing solutions for this goal requires us to anticipate needs of future communication networks – including their applications, traffic, services, and metrics by which they will be judged. The primary role of the Services, Applications and Trends Committee (SAT) is to provide guidance on these requirements with input to the Network Committee and its Working Groups. In particular, SAT will:

- Identify, characterize, and disseminate the requirements of past, present, and anticipated applications in dimensions of bandwidth, latency, storage, and their time- and spatial-dependence.
- Collect and disseminate data on historical trends and current network traffic.
- Collect, formulate, and disseminate formulations, projections, and forecasts of future network traffic.
- Consider, define, and disseminate alternative metrics to judge network energy performance, such as carbon footprint, power per user, life-cycle resources, and cost.

Keywords: services, applications, application requirements, application taxonomy, bandwidth requirements, latency requirements, traffic, access traffic, mobile traffic, data traffic, video traffic, backbone traffic, traffic trends, traffic growth, traffic per subscriber, subscriber growth, traffic forecasts, traffic projections, traffic statistics, traffic profiles, traffic models, packet statistics, flow duration, traffic load variation, spatial traffic variation, temporal traffic variation, diurnal traffic cycles, peak traffic load, average traffic load, network performance metrics, constrained resources, energy consumption, energy efficiency, carbon footprint, life-cycle analyses, cost

## Network Committee

The Network Committee oversees all GreenTouch activities related to the physical infrastructure of information and communications technology (ICT) networks. In addition to its oversight function, the Network Committee comprises four working groups, one in each of four key technology areas:

- Mobile Communications
- Wireline Access
- Core Optical Networking and Transmission
- Core Switching and Routing

The Mobile Communications Working Group focuses on the functions and technologies needed in the access network to provide wireless communication services to mobile and stationary users, while the Wireline Access Working group focuses on functions and technologies needed to provide wireline broadband communication services to residential users. The Core Optical Networking and Transmission Working Group addresses the metro and long-haul segments of transport networks, including components in high-capacity telecommunications networks that provide the wavelength-related (Layer 1) operations such as optical networking, grooming and restoration at the wavelength level, and for wavelength-based services provisioning. The Core Switching and Routing Working Group considers components, technologies, systems, algorithms and protocols at the data link layer (Layer 2), the network layer (Layer 3) and the transport layer (Layer 4) in the traditional OSI network protocol stack.

The Network Committee receives advice from the Services, Applications and Trends Committee and coordinates interactions between the Working Groups. The Network Committee also coordinates the road-mapping activities undertaken by the Working Groups and reports to the Technical Committee.

The focus statements for each of the Network Committee working groups are given below.

## Core Switching & Routing Working Group

The Core Switching and Routing Working Group considers components, technologies, systems, algorithms and protocols at the data link layer (L2), the network layer (L3) and the transport layer (L4) in the traditional OSI network protocol stack. The working group also investigates interactions with lower and higher layers and research efficiencies that can be obtained from cross-layer optimizations. Areas of interest may include:

- Network equipment architectures including switches and routers.
- Low energy technologies including electronics and photonics.
- Power measurements.
- Energy and traffic monitoring.
- Rate adaptation and dynamic reconfiguration of network equipment.
- Network topologies and architectures.
- Tradeoff between optical and electronic data transport.
- Joint optical – IP network design.
- New switching modes: optical label, burst, packet and flow switching.
- Packet versus circuit-switched architectures.
- Packet and frame aggregation.
- Energy efficient and simplified routing.

- Addressing.
- Traffic engineering.
- Bandwidth allocation and traffic grooming.
- Energy-aware over-provisioning of network resources.
- Efficient network protection and restoration.
- Network management, operation and control.
- Quality of service support.
- Network-wide dynamic reconfiguration and control of network elements.
- Separation of control and data planes.
- Stability and robustness of networks.
- Protocols and algorithms.
- Efficient multi-casting.
- Efficient and energy-optimal content distribution.
- Integration of application and transport layers.
- Modeling and simulations of networks.
- Prototyping of key technology enablers.

All GreenTouch experts interested in any of these technology areas are invited to participate in the Core Switching and Routing WG.

Keywords/Topics: low energy components, architectures, protocols and algorithms, energy and traffic monitoring, network topologies, joint optimal IP and optical network design, traffic engineering, network management, energy-efficient routing, quality of service, energy-aware content distribution

## Core Optical Networking and Transmission Working Group

The Core Optical Networking and Transmission Working Group addresses the metro and long-haul segments of a transport network. “Optical” denotes the technologies and components in high-capacity telecommunications networks that provide the functionality of routing, grooming and restoration at the wavelength level, and for wavelength-based services provisioning. Wavelength-related (Layer 1) operations covered by this working group may include:

- Optical transport/transmission systems.
- Optical network elements and sub-systems.
- Optical circuit switching and wavelength switching.
- Survivability, reliability, and security of optical networks.
- Interfacing of the wavelength transport/switching elements to the control plane.
- Optical communication components and devices.
- Coding and forward error correction in optical systems.
- Architecture of fiber, free-space, and hybrid optical networks.
- Transparency and all-optical networks.
- Signaling and information models for optical network control and management.
- Architectures, protocols, and algorithms for dynamic optical networks.
- Operations support systems for optical networks.
- Modeling and simulation of optical networks.
- Advanced optoelectronic circuits and optical signal processing.
- Quantum optical communication.
- Novel core transmission/communication technologies.

Topics addressed by this working group include disruptive technologies that improve the energy efficiency of the equipment of the optical layer. The working group also explores techniques to achieve energy use optimization originating from the optical layer, which reduce the energy per bit of the overall network through proper optical network design.

All GreenTouch experts interested in any of these technology areas are invited to participate in the Core Optical Networking and Transmission Working Group.

Keywords/Topics: advanced transmission technologies, novel photonic components, photonic versus electronic processing, hybrid photonics/


electronics platform optimization, energy efficient/aware optical network design and planning, energy constrained wavelength routing and resource allocation, energy-efficient/aware control plane for dynamic circuit switched optical networks

## Mobile Communications Working Group

The Mobile Communications Working Group addresses all functions and nodes needed in the access network to provide wireless communication services to mobile and stationary users. It includes all types of access points, from public macro cellular base stations to residential femto base stations and WLAN access points. Backhaul provisioning for these access points is covered by this working group as well as the mobility related functions in mobile gateways. Areas of interest may include:

- Air interface technologies.
- Radio Resource management.
- Multiple-Input-Multiple-Output Antenna Systems.
- Antenna technologies.
- Relays and Cooperative Transmission.
- Power amplifier technologies.
- Base Station architectures.
- Baseband processing.

- Backhaul technologies.
- Network topologies.
- Deployment strategies.
- Operation and Management concepts.

Examples of topics of interest to the Mobile Communications Working Group are new highly energy efficient air interfaces, tradeoffs between energy efficiency and mobile system design criteria like spectrum efficiency or service delay, power models of wireless access points, dynamic coverage and capacity management, deployment and management strategies for energy efficient mobile systems.

All GreenTouch experts interested in any of these technology areas are invited to participate in the Mobile Communications Working Group.

Keywords/Topics: advanced air interface technologies, dynamic coverage and capacity management, MIMO, power models, power amplifier efficiency, heterogeneous networks

## Wireline Access Working Group

The Wireline Access Working Group addresses the energy efficiency of all functions between the customer premises equipment (CPE) and edge node needed to provide broadband communication services to residential users. Topics of interest may include:

- Fiber access, including point-to-point and point-to-multipoint topologies.
- Copper access solutions.
- Access network architectures and protocols between CPE and edge node, including possible node consolidation of access and edge nodes enabled by long-reach access technologies.
- Functions in the CPE and a more energy efficient relocation of those functions in other parts of the network (e.g. virtual home gateway).
- Functions in the access and edge nodes that are specific for the access network.
- Backhauling via the wireline access network to small cells for wireless.
- Optical and electronic components or subsystems required for energy efficient access networks.

The following topics are not in the scope of this working group:

- Fixed radio access and mobile access solutions (covered by the Mobile Working Group).
- Satellite access.
- Generic switching and routing functions (covered by the Core Switching and Routing Working Group). The Wireline Access Working Group will reuse energy saving concepts developed by CS&R if applicable to an access node.

- CPE for enterprise, because they involve technologies that are closer to CS&R and different from CPE for residential users.
- Home network solutions (not in scope of the GreenTouch mission).

The objective of this working group is to achieve improvements in the energy efficiency of wireline access networks. Our research focuses on the physical layer and connectivity, but may also address application awareness if this saves energy consumed by the access network.

All GreenTouch experts interested in any of these technology areas are invited to participate in the Wireline Access Working Group.

Keywords/Topics: optical access, access node, CPE, wireline access, virtual home gateway

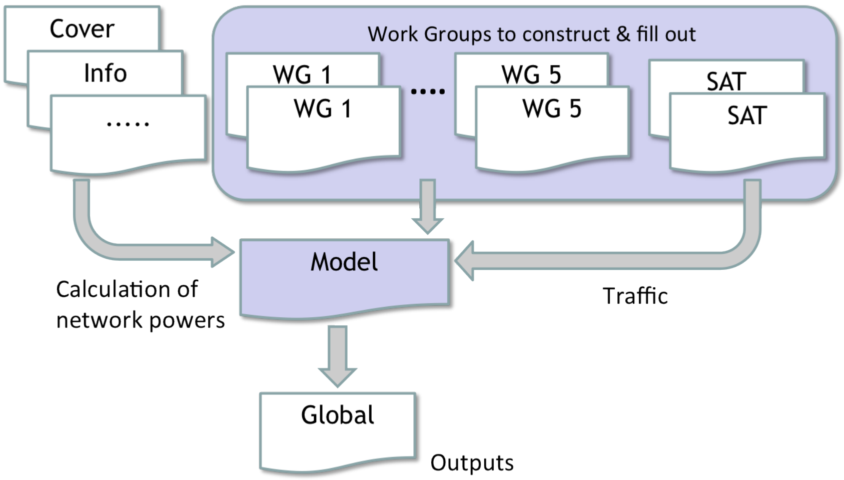
# Committee Highlights

## The GreenTouch Roadmap

A major activity of the Technical Committee has been the development of the research roadmap. This roadmap includes the baseline architecture, representative of networks in 2010 and including a business as usual extension of the current trends to 2020. This forms the reference against which progress in the consortium is measured. Also included in the roadmap is the impact of the different architectures developed within GreenTouch and their expected efficiency benefits using the 2020 service models. A roadmap document describing these architectures is under development. Furthermore, a spreadsheet will go along with the roadmap document. This spreadsheet will include the major technology trends and models used by the consortium. The Network Committee working groups will also provide a table of the major research challenges that must be addressed in order to realize the GreenTouch goals.

*Roadmap Spreadsheet Organization*

*Technology trend sheets from the WGs and SAT committee feed into the models, which then provide overall network efficiency trends.*



## Project Portfolio

**Core Optical Networks & Transmission**

- Highly Adaptive Layer for Meshed On-Off Networks (HALF-MOON)
- Service Energy Aware Sustainable Optical Networks (SEASON)*

**Core Switching & Routing**

- Optimum End to End Resource Allocation (OPERA)
- Router Power Measurements (REPTILE)
- Silicon Photonic Interconnects & Single Chip Linecard
- Zero Buffer Router Architectures (ZeBRA)

**Mobile Communications**

- Beyond Cellular Green Generation ($BCG^2$)*
- Green Transmission Technologies (GTT)*
- Large Scale Antenna Systems (LSAS)*
- Massive MIMO Demonstration

**Wireline Access**

- Low Power Access Architectures
- Virtual Home Gateway

*indicates a cluster project made up of multiple sub-projects addressing the focus area described by the project. More details on each of these projects can be found in the respective working group activities described below.

The complete project portfolio for the year is shown above, by respective primary working group. Twelve projects were active this year, including the Massive MIMO demonstration project that was completed in February of 2011, the results of which were rolled into the Large Scale Antenna Systems project. Four projects are 'cluster' projects consisting of multiple projects addressing different aspects of a particular topic or architectural paradigm. Including extensions to the cluster projects, which are additions to the initial set of sub-projects in the cluster, 14 projects were active this year.

## Where is GreenTouch with Respect to Its Goals?

A full account of progress against the GreenTouch goals will be provided in the first edition of the GreenTouch roadmap. During this first year, projects were organized and kicked off. While the results are not in yet, we can understand much from the project portfolio. Within the Mobile Communications Working Group two different architectural paradigms are studied: large scale antenna systems and beyond cellular green generation ($BCG^2$). The large scale antenna systems project aims for more than 100 fold air interface efficiency gains and

demonstrated a proof-of-concept system with 16x efficiency gains. Attention is now focused on aggressively studying new basestation architectures to realize commensurate overall gains. The BCG[2] project is targeting efficiency gains between 500x-1500x depending on the urban or dense urban scenarios under consideration. The Green Transmission Technologies project seeks to further enhance these different approaches through fundamental considerations of energy in wireless systems. The Wireline Access Working Group has identified a series of technology steps within their project plans with the potential to achieve 3000 fold efficiency enhancements. Within the Core Switching and Routing Working Group, technologies with the potential for 40x overall efficiency improvement have been identified. For Core Optical Networking and Transmission, two dynamic network projects are underway, one of which includes a new clean-slate service optimized architecture with the potential for greater than ten-fold efficiency improvement. Other transmission hardware related projects are in preparation. This current collection of projects includes a scope of activities that promise to achieve the GreenTouch goals. However, there are still many details to be analyzed, assumptions to be proven and results to be reported. In some cases, additional activities must be defined around components needed for the larger project efforts. Progress will be monitored through the technical organization and roadmap. New methods and approaches will continuously be pursued, as the best result in the end would be a collection of architecture and technology alternatives, any of which could provide the desired result.

## Research Gaps

Details of the research gaps, i.e. specific areas not yet covered in the GreenTouch portfolio or the activities of other cooperating organizations, will be developed from the targets identified in the GreenTouch roadmap. Working from a strawman set of targets, the working groups have been refining these targets as part of the roadmap activity. Based on these early developments, each working group and committee is developing a list of research activities that are not part of the GreenTouch activities and that may be important for the GreenTouch objectives. The current high level organizational gaps are listed below.

### Overall Research Gaps

- Activity primarily considering energy efficient electronics
- Enterprise and data center networks
- Projects on cooling and thermal management
- Activity primarily considering fundamental communication theory
- Working group or study group on network management, protocols, and control planes.

## Technical Events

In addition to the all-members meetings in London, Amsterdam, and Seoul, the Technical Committee organized several special events during the year. These included workshops and panel sessions at major international conferences as well as special public forums during the consortium's all-members meetings. GreenTouch members were active on the organizing committees of a wide range of energy-focused technical meetings and workshops worldwide. Details of the full set of GreenTouch related activities are described in the respective committee and working group sections. Events organized by the GreenTouch consortium Technical Committee are detailed below.

### ECOC GreenTouch Workshop

- GreenTouch working group and committee chairs presented details of the GreenTouch consortium and their respective group activities. A panel session followed including GreenTouch members and other leading experts on optical network energy topics.

**OFC/NFOEC GreenTouch Panel Session**

- This event included presentations and discussion on energy issues in the core and access networks. Ioannis Tomkos, AIT, Core Optical Networking and Transmission Working Group chair, presided over the session, which included two GreenTouch panelists: Frank Effenberger, Huawei, Wireline Access Networks Working Group co-chair, and Kerry Hinton, Univ. of Melbourne, as well as one invited external panelist, Gary Epps, Cisco. Attendees lined the theatre walls and the crowd extended out into the exhibit hall.

**November All Members Meeting Open Forum**

- GreenTouch members and other leading experts gave presentations during four sessions covering: 'Rethinking Mobile Networks', 'Beyond Networks','Understanding Energy & Technology', and 'Holistic Innovation vs Commercial Challenges'.

**GreenTouch Announcement Anniversary Event**

- The GreenTouch Consortium presented its first technology demonstration at this event and described the first set of GreenTouch projects to the public. The large scale antenna system demo included a robust mobile link operating with 16 times lower air interface power than an equivalent single antenna system.

**April All Members Meeting Open Forum**

- This public forum featured a presentation on the GreenTouch Large-Scale Antenna System, and included two sessions of presentations delivered by industry experts on various topics related to energy-efficient network technologies, eco-sustainability and climate change.

# Services, Applications, & Trends Committee

**Chair:**
Steve Korotky
Alcatel-Lucent/ Bell Labs

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, AT&T Services, Broadcom, China Mobile Communications, Chunghwa Telecom, ETRI, Fondazione Politecnico di Milano, Fujitsu, KT, Nippon Telegraph and Telephone, University of Melbourne, Tsinghua University, University of Delaware

The Services, Applications and Trends Committee (SAT) seeks to improve energy efficiency of the baseline network architecture – particularly affected by macro traffic trends, network characteristics and traffic details, and the taxonomy of feature requirements in applications.

During its first year, SAT has been focused on formulating recommendations for input to the Baseline Architecture, specifically in the areas of macro traffic trends, network characteristics and traffic details, and a taxonomy of applications based upon key feature requirements. The activities have included critical reviews of traffic and architecture documents and whitepapers, and the formulation and approval of recommendations on the baseline architecture document, traffic, a network operator questionnaire, and draft application taxonomy. Three study groups were formed to address each topic area. SAT will socialize these recommendations with the Network Committee and its Working Groups, and with the general GT membership before refining and executing the recommendations.

SAT may also create another study group to address the need for more detailed traffic data, such as traffic statistics on a variety of time-scales, expressed by the Networking Committee's Working Groups.

## Activities

- Macro Traffic Study Group
- Network Operator Survey Study Group
- Application Taxonomy Study Group
- Mobile Traffic Study Group

## Events

- "GreenTouch Services, Applications and Trends Committee: Overview," S. K. Korotky, GT Workshop, ECOC 2010 (Torino), 2010.

# Network Committee

**Chair:**
Rod Tucker
University of Melbourne

**Co-Chair:** Man-Fai Wong, Orange

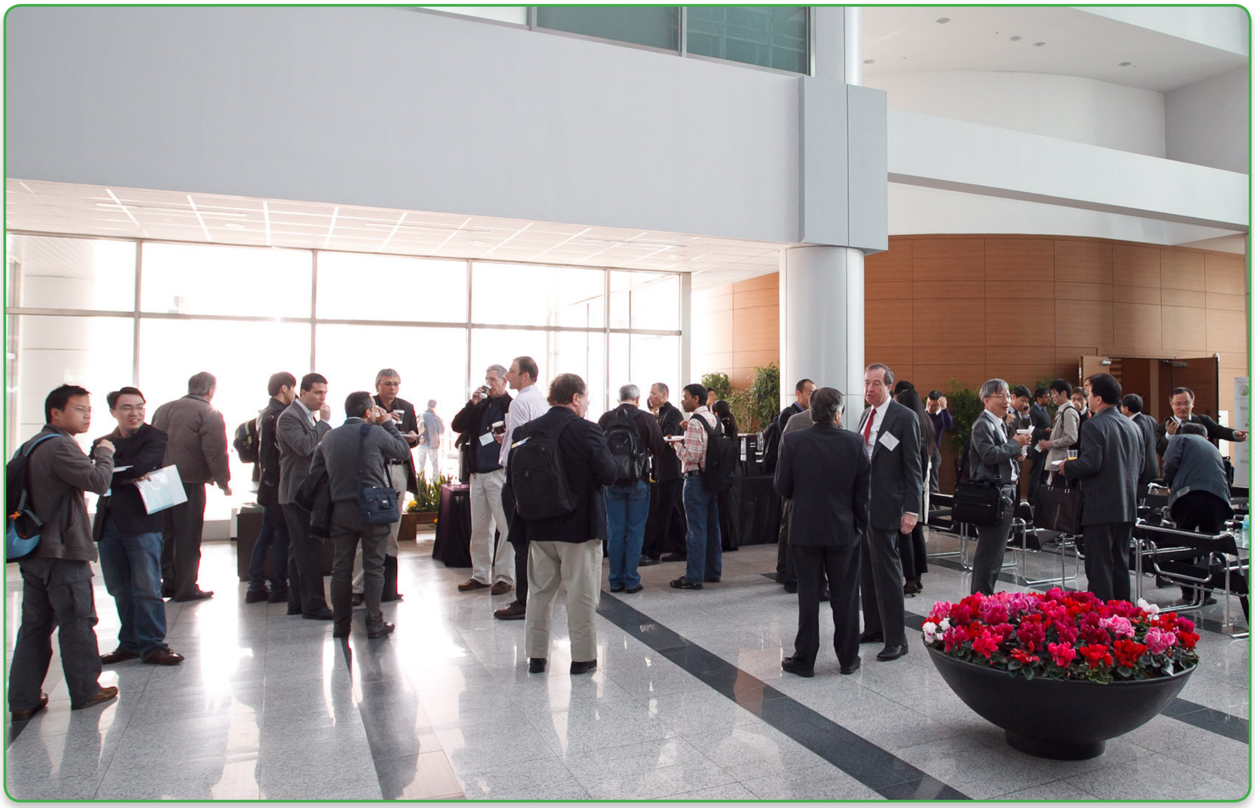
**Participating Organizations:**
University of Melbourne. Alcatel-Lucent/Bell Labs, INRIA, Athens Information Technology (AIT), Orange

The Network Committee oversees all GreenTouch activities related to the physical infrastructure of the network. This work is carried out in its four Working Groups. The Committee receives advice from the Services, Applications and Trends Committee and coordinates interactions between the Working Groups. The Network Committee also coordinates the road-mapping activities undertaken by the Working Groups and reports to the Technical Committee.

During the first year, research by the Working Groups lead to improvements in energy efficiency across the network.  Details of this work are described elsewhere in this report.

In the access network, the Mobile Communications Working Group has focused on new highly energy efficient air interfaces; tradeoffs between energy efficiency and mobile system design criteria; power models of wireless access points; dynamic coverage and capacity management; and deployment and management strategies for energy efficient mobile systems. The Wireline Access Working Group has identified the access solution with the lowest possible energy consumption for a scenario with a PON-based fiber infrastructure. It also defined the architectural options, advantages in terms of energy efficiencies, and challenges to achieving high energy gains. Specific include a Large Scale multiple-input multiple-output (MIMO) wireless demonstration, investigations of low –energy wireless systems that break away from conventional cellular methods, low energy point-to-point access systems, energy efficient protocols for fiber-to-the-premises systems and coolerless tunable sources for WDM access.

The Core Switching and Routing Working Group initiated four projects last year, including an ambitious program to integrate all packet processing functionalities onto a single chip, thereby greatly reducing energy consumption in interconnects; a project to dynamically manage and control resources in the network at different timescales in response to time-varying traffic demands;  optimization of a photonic switch; and a measurement-focused project aimed at gaining a better understanding



of the router power consumption and its relationship to traffic.  Among its activities, the Core Optical Networking and Transmission Working Group have studied the overall efficiency of core optical network components comprising the transport plane and have accounted for all link and node level components in calculating total energy efficiency. It also evaluated the energy footprint of different routing approaches, including a comprehensive inventory of the power-consumption specifications of transponders, transceivers, etc.  Two of its projects detailed in this report are “Highly Adaptive Layer for Meshed On-off Optical Networks (HALF-MOON) and “Service Energy Aware Sustainable Optical Networks” (SEASON).

# Core Optical Networking and Transmission Working Group

**Chair:**
Ioannis Tomkos
Athens Information Technology (AIT) Center for Research and Education

**Co-Chair:** Jean-Christophe Antona, Alcatel-Lucent/Bell Labs

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, Athens Information Technology (AIT) Center for Research and Education, Broadcom, Chunghwa Telecom, Columbia University, Dublin City University, Electronics and Telecommunication Research Institute, Fondazione Politecnico di Milano, France Telecom, Fujitsu, Huawei Technologies, IBBT, INRIA, Karlsruhe Institute of Technology, KT, National ICT Australia, Nippon Telegraph and Telephone, University of Melbourne, University of Leeds, University of Toronto

The Core Optical Networking and Transmission Working Group (CONT) studies the energy efficiency of metro and long-haul segments of a transport network in Layer 1 operations and components (wavelength level). CONT covers technologies that achieve energy-use optimization originating from the optical layer, which reduce the energy per bit of the overall network through proper optical network design. CONT plans to achieve up to a 50-times improvement in energy efficiency by 2020.

The members of the CONT WG initiated studies to estimate the overall efficiency of core optical network components comprising the transport plane. "Energy Efficiency Calculation for the Transport Layer in a Core Optical Network" accounts for all link and node level components in calculating total energy efficiency. "Power Consumption in Core Optical Networks: A Routing-based Approach" evaluates the energy footprint of different routing approaches. In devising common assumptions for these studies, CONT prepared a database with power-consumption data for all relevant WDM components. It includes a comprehensive inventory of the power-consumption specifications of transponders, transceivers, muxponders, regenerators, amplifiers, WDM terminals, ROADMs, OXCs, and others. The data were collected from manufacturer data sheets. The associated Report on Baseline Power Consumption elaborates on the reference power consumption figures. It proposes a model to determine power consumption and energy efficiency of a long haul network that exploits these network device reference consumption values.

CONT also launched two projects. The first, "Highly Adaptive Layer For Meshed On-off Optical Networks (HALF-MOON), aims to investigate the impact of new transmission technologies such as elastic data-rate devices; the introduction of new device characteristics, such as complete or partial switch-off of optoelectronic devices; and new protocols for reducing the global amount of energy required by the optical network to transport a determined amount of data (following temporal evolution).

"Service Energy Aware Sustainable Optical Networks" (SEASON) is a project for designing a clean-slate network for maximum energy efficiency through awareness of service requirements. SEASON aims to determine a set of architectural trade-offs, algorithms, and rules for designing future energy efficient networks; and create basic technologies for tools to enable future energy efficient networks.

CONT also created a demo project on the energy efficiency of flexible transponders, tentatively called "Energy Efficient High Capacity OFDM Signal Transmission" (EFICOST). Over the coming year, it will demonstrate network efficiency achieved by the Optical OFDM architecture; a related discussion group was also opened to GT members. Another proposed study is for control plane and algorithms supporting bit-rate/bandwidth flexible elastic optical networking. The goal is to develop GMPLS protocol extensions incorporating routing and spectrum allocation algorithms, which can control an elastic optical network.

**Projects**

- SEASON
- HALF-MOON

**Recommendations**

- Alcatel-Lucent Bell Labs France defined an IP/WDM network architecture for mono-rate, multi-rates and elastic interfaces, the goal of which is the evaluation of the energy efficiency related to the optoelectronic interface technologies as a function of the daily traffic fluctuation (with Politecnico di Milano).

**Reports**

- WDM Power Database
- Draft Report on Baseline Power Consumption

**Activities**

- Optical OFDM Study Group

**Events**

- GreenTouch Open Workshop in ECOC 2011
- GreenTouch Panel Session: "When will the energy crunch hit optical networks?"

# Service Energy Aware Sustainable Optical Networks (SEASON)

## Partners

- Alcatel-Lucent Bell Labs
- Columbia University
- University of New South Wales
- University of Toronto

## Project Extensions:

- Zero Buffer Router Architectures (ZeBRA)

## Cognizant Committee(s) and/or Working Groups(s)

- Core Optical Networking & Transmission
- Core Switching & Routing

## Description

SEASON is a clean-slate core network design project focused on a few basic design principles. It provides an underlying dynamic wavelength capability as a basis to build other projects. The main idea for SEASON is saving lots of energy by optimizing the end-to-end network for key high bandwidth services. SEASON also targets energy savings in the physical layer through dynamic wavelength capabilities. As a starting point, SEASON examines the use of an “Application Center,” which serves as the demarcation point between an access network and a core network. Application 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.

## Primary Activities

- Inventing new algorithms, protocols, and architectures based upon an “Application Center” network. These enable energy efficient, dynamic, service aware wavelength switching across a long-haul mesh network with distributed and robust signaling and control – including end to end FEC.
- Demonstrating optical transport with optimized, flow oriented service communication models (beyond IP) to reduce switching energy in the Application Centers.

Different categories of services will be identified based upon basic traits such as bandwidth, latency, security, quality of service, and storage. Within the SEASON framework, the energy cost attributed to these traits will be evaluated with the associated architectural trade-offs. Energy dependent design criteria, such as switching time and number of wavelengths, will be used to drive the experimental studies of wavelength switching. Also, new physical layer control algorithms will be studied to achieve key energy targets, together with energy efficient transmission and wavelength management hardware. To facilitate the dynamic physical layer, new energy aware protocols will enable robust and distributed control within a minimal set of network layers.

# Highly Adaptive Layer for Meshed On-Off Optical Networks (HALF-MOON)

## Partners

- Alcatel-Lucent Bell Labs
- Politecnico di Milano
- Universitat Politècnica de Catalunya

## Cognizant Committee(s) and/or Working Groups(s)

- Core Optical Networking & Transmission

## Description

HALF-MOON is about optimizing optical network energy efficiency. Today's networks must account for the peak traffic required between all nodes. Once the optical connections are set up, periodic or un-forecasted traffic evolutions are managed by the upper layers (i.e., L1 that is OTN, or L2 and L3, that is SDH and IP). As a consequence, many optical resources are lit without being completely filled, which reduces energy efficiency of optical networks. To improve the optical network's energy spectral efficiency, HALF-MOON aims to investigate the impact of 1) new transmission technologies, such as elastic data-rate devices; 2) the introduction of new device characteristics, such as complete or partial switch-off of optoelectronic devices; and 3) implementing new protocols to reduce the global amount of energy required by the optical network to transport a determined amount of data (following temporal evolution).

## First Results

We proposed a protocol enhancement to manage the power state of optoelectronic interfaces in automatically reconfigurable optical networks. In the GMPLS signalling protocol (i.e. RSVP-TE) a bit, A, is committed to administratively set up or down a specific Label Switched Path. We proposed to enhance this utility to enable a dynamic power management by defining a set of actions for reception of RSVP-TE Path/Resv messages. To do that, we associate three "power" states to each OE device: up, idle and down. We proposed to extend the signaling protocol by introducing a new bit "S" so that when A=0, S discriminates whether the OE devices are up or idle, as shown in Fig. 2.

*Figure 1: Three proposed power states relative to an optoelectronic device and their transitions*

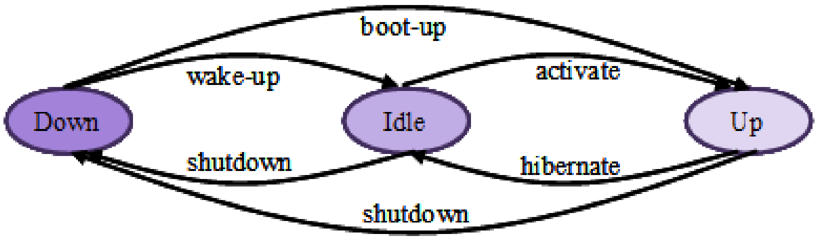



*Figure 2: Protocol description of the different states relative to an OE device*

| Proposed power management | A | S |
|---|---|---|
| Up state | 0 | 0 |
| Idle state | 0 | 1 |
| Down state | 1 | 0 |
| Damaged | 1 | 1 |

The energy savings from using idle and down states in dynamic reconfigurable optical networks was experimentally evaluated in the GMPLS-enabled CARISMA test-bed at UPC in Barcelona. For this evaluation, a Pan-European network composed of 16 nodes and 23 links was configured with each link carrying 10 bidirectional wavelengths. To accommodate incoming traffic, each node was equipped with 20 add/drop transponders and 10 regenerators. No dispersion management was configured in the test-bed so the transparent reach of 100Gb/s signals was set to 1200 km. For the traffic characteristics, uniformly distributed connection requests arrived on the network following a Poisson process, with average holding time equal to three hours. The maximum offered load was 80 Erlang.

In this test, all OE (335 add/drop transponders and 160 regenerators) were powered on for a total 184kW power consumption. The test showed that with our proposed dynamic control of the "power" state, the number of powered-up devices can be greatly reduced. At 80 Erlang, the powered OEO devices were, on average, 154 transponders and 48 regenerators, for a global energy consumption of 74kW. The ratio of unused but powered OEs was 60% for networks operating with current protocols (only on state), and 14% when the proposed extension was implemented (idle states). The capability of controlling the OE power state enables energy savings of 60%.

We also proposed a generic architecture of 100Gb/s transponders and regenerators with Polarization-Multiplexed QPSK modulation and then we estimated the power consumption derived from the data sheets of typical components required in the implementation.

# Core Switching and Routing Working Group

**Chair:**
Thierry Klein
Alcatel-Lucent/Bell Labs

**Co-Chair:** Achille Pattavina, Fondazione Politecnico di Milano

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, Athens Information Technology (AIT) Center for Research & Education, Broadcom, Chunghwa Telecom, Columbia University, Dublin City University, ETRI, Fondazione Politecnico di Milano, Freescale Semiconductor, Fujitsu, Huawei Technologies, IBBT, INRIA, Karlsruhe Institute of Technology, Samsung Advanced Institute of Technology (SAIT), Seoul National University, University of Melbourne, University of Cambridge, University of Leeds, University of New South Wales, University of Toronto

The Core Switching and Routing Working Group (CSR) investigates, proposes, designs, evaluates and validates components, technologies, systems, architectures, algorithms and protocols for improving the energy efficiency of routers, switches and packet data networks. CSR focuses on the data link layer (L2), the network layer (L3) and the transport layer (L4). It also examines interactions with lower and higher layers and energy efficiencies that can be obtained from cross-layer optimizations.

During the past year, CSR initiated four projects. “Silicon Photonic Interconnects and Single Chip Linecard” will integrate all packet processing functionalities onto a single chip. The goal is to reduce the number of on-off chip transitions and thereby reduce the power consumption of the chip interconnects.

Another project, “Optimal End to End Resource Allocation” (OPERA), aims to dynamically manage and control resources in the network at different timescales in response to time-varying traffic demands.

The “Zero Buffer Router Architectures” project (ZeBRA) is investigating the feasibility of bufferless or near-zero buffer networks.

Finally, the “Router Power Measurements” (REPTILE) project will help CSR researchers gain a better understanding of the router power consumption and its relationship to the traffic load.

Projects

- "Silicon Photonic Interconnects and Single Chip Linecard"
- "Optimal End to End Resource Allocation" (OPERA)
- "Zero Buffer Router Architectures" (ZeBRA)
- "Router Power Measurements" (REPTILE)

# Optimum End-to-end Resource Allocation (OPERA)

## Partners

- University of Leeds
- University of Cambridge
- Politecnico di Milano
- University of New South Wales
- Athens Information Technology (AIT)

## Cognizant Committee(s) and/or Working Groups(s)

- Core Switching and Routing

## Description

Power saving in communication networks is proposed through optimum end-to-end resource allocation. Currently, networks are about three to five times over-provisioned to maintain quality of service (QoS). This leads to increased power consumption, which can be reduced (while maintaining QoS) by optimizing the resource allocation in real time based on demand. A good technique is using dynamic bandwidth allocation. Note that protection resources are typically powered on at all times, but are used just two to three times a year. Wake up on demand algorithms can lead to energy saving. Buffers consume a large proportion of the power in a node. Buffering can be reduced through coordinated scheduling at the edge of the network. This project will investigate the optimum allocation of these resources in a network in a dynamic fashion to reduce the network's power consumption (see Fig. 1).

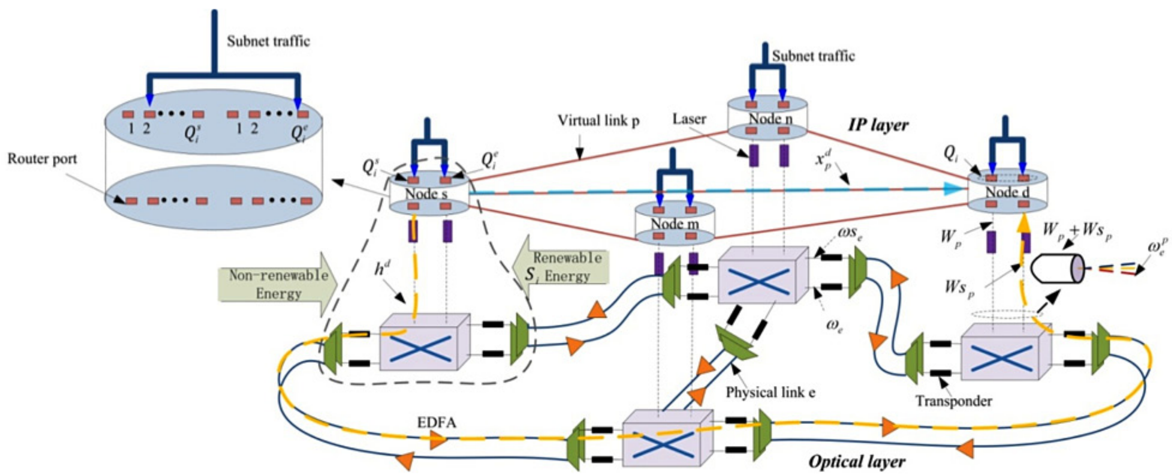



*Fig. 1 The proposed OPERA network architecture*

## Primary Activities

OPERA will be conducted in three research activities, each led by one of the partners.

**Research Activity #1: Optimum architectures, routing protocols and resource allocation strategies (Lead Leeds, Milano, Cambridge)**

This activity will decompose the network's optimum resource allocation into three interlinked time frames. On the longest time frame, use of static mixed integer linear programming (MILP) will determine the optimum resources in the network for a given traffic profile and QoS requirements. On a slightly shorter time scale, this activity will develop traffic engineering algorithms to optimise energy savings and resource allocation. Finally, in the shortest of time scales, this activity will develop optimum routing algorithms and heuristics for energy savings. One novel feature of this research is its "all time scales end-to-end" approach to optimize resource allocation for energy saving in networks.

**Research Activity #2: Protection and restoration resource allocation and energy saving (Lead Milano, Leeds, Cambridge)**

Telecom network failures usually occur with accidentally cut fiber. These occur at a rate of about 4.39 cuts/year/1,000 sheath-miles, which equates to about one cut per day in a large operator network made up of 100,000 miles of fiber cables. In a network like this, protection resources are powered all year but used just one day in the year. Significant power savings may be attained if the protection routes are powered down. This activity will introduce dynamic control protocols to switch off (or put into low power mode for fast re-activation) shared and dedicated protection paths until a failure is detected. The activity will use peer-to-peer (and centralized) signaling to activate the protection paths when a failure is detected; and when extra capacity is needed. An "all time scale end-to-end" approach will be adopted for the optimum allocation of protection resources and paths that meet the required Quality of Resilience (QoR) and QoS – and minimize the power consumption.

**Research Activity #3: Buffer allocation and management (Lead University of New South Wales, Cambridge, Leeds, Milano, AIT)**

This activity will develop new techniques to reduce the energy consumption of core network routers, primarily focusing on memory storage (i.e. buffering) operations. Today's routers have gigabytes of packet buffers, which are idle much of the time and put to use only during transient periods of high loads. This activity will 1) characterize the energy consumed by always-on buffers in today's routers; 2) characterize the usage of storage elements at each level of the buffer hierarchy (on-chip and off-chip cache/main-memory); and 3) investigate the feasibility of dynamically turning memory elements on/off to reduce energy consumption without affecting traffic loss/throughput performance. The research will also consider other operations in a router. For example, parts of the router (e.g. hardware acceleration engines or processors) will be reconfigured or switched off based on the packet processing requirements. We will use a NetFPGA platform as an evaluation/validation platform.

## Router Power Measurements (REPTILE)

### Partners

- University of Melbourne (via the Centre for Energy Efficient Telecommunications, CEET)

### Cognizant Committee(s) and/or Working Groups(s)

- Core Switching and Routing

## Description

The "Router Power Measurements" (REPTILE) project will provide a detailed power profile of a range of network equipment such as IP-routers, Ethernet switches, SDH/SONET cross connects, and OTN cross connects. The project will develop power measuring hardware and software to provide overall power consumption data, and sub-system power consumption data based on measurements of real equipment. Examples of "sub-systems" include: forwarding engine, control plane, buffers, switching fabric, O/E and E/O ports.

## Primary Activities

REPTILE will develop techniques and equipment to measure the relationship between the overall power consumed by network equipment and its traffic load. We will acquire and/or develop equipment to generate different traffic conditions within a network, and atypical traffic conditions required to construct an extensive power model of the network equipment. The research includes developing techniques and equipment to measure the power consumption of network equipment at the sub-system level, including the following stages:

- Determine the relationship between network equipment sub-system function and the location of specific hardware (i.e. electronic chips) in the equipment rack.
- Develop thermal sensors that can be placed on specific chips within a rack of network equipment.
- Calibrate the sensors to monitor output data related to chip power consumption.
- Network these sensors to a centralized data collection unit.
- Coordinate time stamping/identification of the data to equipment throughput/traffic load.
- Develop software to collect and tabulate the power consumption and throughput/traffic load data.

REPTILE will also test its techniques on laboratory and deployed network equipment. Our team will develop and test detailed mathematical models for power consumption of network equipment under a diverse range of network configurations and loads.

Expected Energy Efficiency Benefits: The project will provide data for developing detailed power consumption mathematical models for network equipment. The data also will be used in power consumption models for network architectures and other network models that may be developed within CEET and/or GreenTouch.

# Silicon Photonic Interconnects and Single Chip Line Card

## Partners

- Alcatel-Lucent Bell Labs

## Cognizant Committee(s) and/or Working Groups(s)

- Core Switching and Routing

## Description

The transmission of data between chips in a router dominates its power consumption. Since interconnect power scales only at around 10% per year, this means that router power consumption will grow about 30% per year based on an annual traffic growth rate of 40%. Line cards are currently power density limited, so the number of line cards also will increase at 30% per year – greatly boosting the footprint and global interconnect distances between line cards.

A router line card is composed of multiple chips required for complex packet processing. It also needs large buffers, which further increases power requirements for data interconnects. Packet processing capability is specified for minimum length packets at maximum line rates, whereas actual packet rates are more than 10 times less.

## Primary Activities

This project examines the architectures and technologies required to implement a single-chip line card. We will explore the feasibility of using on-chip buffers to reduce the need to drive off-chip memory lines, and to provide additional processing capability for hiding the latency of DRAM chips. The project covers architectures that allow packet processing to match average load while accommodating localized bursts of short packets. We believe this will enable all the functions of a line card to be realized on a single chip.

Today’s global architecture consists of electrical interconnects from the originating chip to optical transceivers at the edge of a board, then to an optical interconnect, and finally an electrical interconnect from the edge of board to the destination chip. The power consumption of these links is dominated by the two electrical connections. We will address lowering the power consumption with photonic technologies that can be integrated with the electronic chips. The object is creating low power global interconnects. We will also explore integrating client side transponders into the single chip line card by using the same technology innovation.

# Zero Buffer Router Architectures (ZeBRA)

## Partners

- University of New South Wales
- Alcatel-Lucent Bell Labs

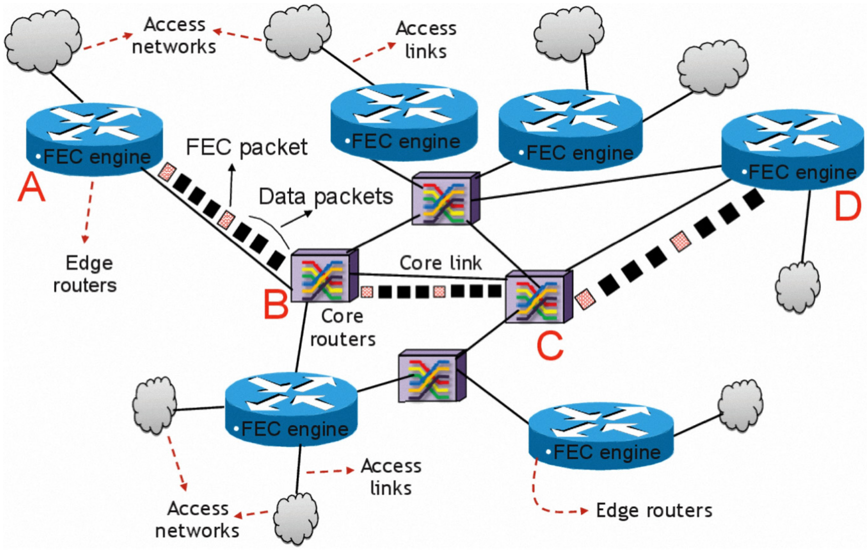
## Cognizant Committee(s) and/or Working Groups(s)

- Core Switching and Routing

## Description

Project ZeBRA will develop novel techniques, architectures and algorithms to manage congestion for services utilizing packet, flow, or circuit capabilities appropriate to core networks with zero (or near-zero) buffers. It is inspired by the fact that the energy-efficiency of core routers can be significantly improved if the packet buffer size is small enough to fit on-chip – or be eliminated.

## Primary Activities




**Research Activity #1. Providing low-energy congestion recovery using packet-level forward error correction (FEC).**

In this approach, losses for packets, frames, or bundles in the core network are recovered in edge routers by using FEC coding at the packet, frame or bundle level. For example, the adjacent figure shows all traffic flowing from edge router A to edge router D along path A-B-C-D is protected by FEC codes, which can be used by edge router D to reconstruct the data lost in the near-zero buffer core network.

**Research Activity #2. Providing low-energy congestion prevention using traffic conditioning at edge routers.**

It is widely known that bursty traffic necessitates larger buffers to minimize loss. Consequently, traffic conditioning can be performed at the edge routers to reduce traffic burstiness prior to injection into the near-zero buffer core network. We envisage a traffic-pacing mechanism that releases packets, frames or bundles at a variable rate, dynamically adjusting to the service characteristics such as loss and delay required by the flow. We propose to quantify the impact of traffic conditioning on the energy and service performance.

Expected Energy Efficiency Benefits: The above techniques will yield substantial energy benefits, as they (a) allow network equipment to be built and operated with near-zero buffering capability, and (b) leverage service characteristics to reduce energy footprint of individual flows.

# Mobile Communications Working Group

**Chair:**
Ulrich Barth
Alcatel-Lucent/ Bell Labs

**Co-Chair:** Jong-Ho Bang, Samsung and Emilio Calvanese Strinati, CEA-LETI

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, CEA-LETI, China Mobile Communications, Chunghwa Telecom, Draka Communications, Dublin City University, Electronics and Telecommunication Research Institute, Fondazione Politecnico di Milano, France Telecom, Freescale Semiconductor, Fujitsu, Huawei Technologies, IBBT, IMEC International, INRIA, K.U. Leuven, KT, Samsung Advanced Institute of Technology (SAIT), Seoul National University, Swisscom, TNO, University of Melbourne, Tsinghua University, TU Dresden, University of Cambridge

The Mobile Communications Working Group (MC) contributes research to improve 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.

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

During its first year of work, MC began four large collaborative research projects with participation from mobile vendors, mobile operators, device manufacturers, and academia.

Our first project was “Large Scale MIMO Demo.” It showcased a proof of concept for reducing the total transmitted power over air by a factor of two each time the number of antennas was doubled. The demonstrator had 16 antennas, which enabled a power reduction of 16 times. The public presentation also showed that GreenTouch could build a common interest group of research partners that collaboratively achieved an ambitious research target in a short timeframe.

The "Large Scale Antenna Systems" project builds upon the demo project by addressing key research problems required to practically make large scale antenna systems with up to a few hundred antennas.

Another project, "Green Transmission Technologies," focuses on the energy efficient design of transmission schemes, radio resource management strategies, and signal processing algorithms based on the fundamental tradeoffs in wireless communications.

The "Beyond Cellular Green Generation" project aims to surmount limitations of traditional cellular architectures for dynamic energy management. Its principal idea is separating the signaling network from the data network and provides energy efficient dynamic capacity provisioning.  MC also established an architecture and metrics subgroup. It addresses general network energy efficiency metrics suitable for various wireless architectures, and will create a roadmap for saving energy in the future wireless access network. MC defined a framework for the calculation of energy saving factors to be used by all projects in the working group.

**Projects**

- Beyond Cellular Green Generation ($BCG^2$)
- Green Transmission Technologies (GTT)
- Massive MIMO- Large Scale Antenna Systems (LSAS)

**Events**

- Massive MIMO demonstration at GreenTouch Announcement Anniversary event

# Beyond Cellular Green Generation ($BCG^2$)

## Partners

- Fondazione Politecnico di Milano
- Alcatel-Lucent Bell Labs
- Huawei
- Samsung
- INRIA
- TNO

## Cognizant Committee(s) and/or Working Groups(s)

- Mobile Communications

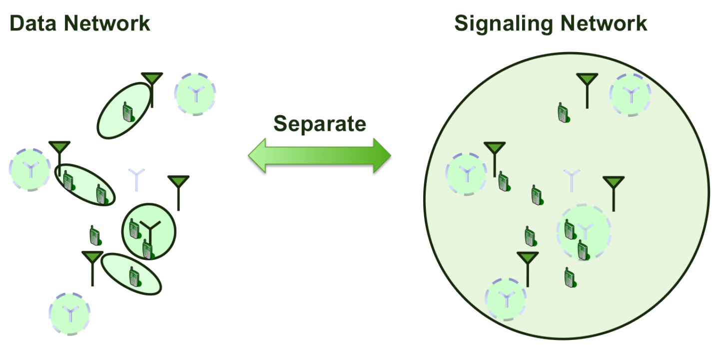
## Description

Access technology for mobile networks is responsible for more than 80% of their energy consumption. Access also is the most critical part of the network for capacity planning, which usually accounts for peak traffic conditions. A common approach for reducing energy consumption considers the dynamic management of network access devices in order to switch some of them off during low traffic.

In particular, the cellular architecture used for wireless access networks severely limits energy management strategies for reducing energy consumption. The roadblock is a presumption that full cellular coverage of a service area requires user terminals to access to the network at any time and in any point of the area. To guarantee full coverage, many access devices cannot be turned off – even if there are no active users in the cell. This will become more problematic with new micro cellular layouts because all base stations are essential for full coverage.

Beyond Cellular Green Generation (BCG²) proposes to overcome these limits by going beyond traditional cellular architecture with a complete separation of signaling and data networks. The signaling network will provide continuous and full coverage with highly efficient macro base stations, which enable communication services at any time and at any point of the service area. Portions of the data network will be activated on demand in order to minimize energy cost. Several heterogeneous data networks can be used and managed by the same signaling infrastructure.

*Figure1. Examining tradeoffs of splitting the data and signaling network.*



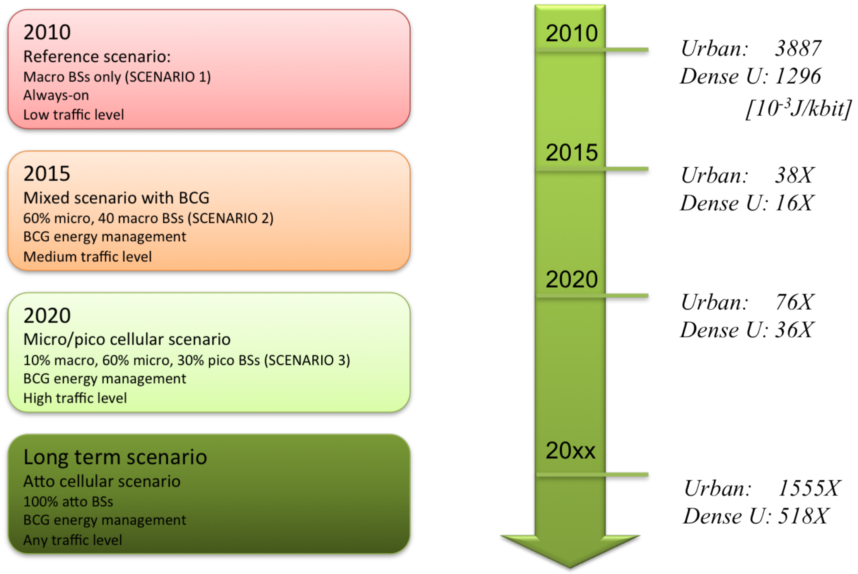

## Primary Activities

There are four technical challenges for this project: 1) performing the quantitative analysis of advantages for the BCG² architecture; 2) designing context-detection mechanisms for the signaling network able to determine user position, terminal capabilities, service and energy costs, etc.; 3) designing resource selection algorithms to identify the most suitable access point for serving traffic requests and activating the radio resources; and 4) defining the signaling network architecture and functionalities and the design of the interaction mechanisms between the signaling network and heterogeneous data networks.

## Initial Results

The project started with a preliminary evaluation of energy performance improvements by the new system architecture. Team members defined some reference scenarios and models to leverage results available from a European project called EARTH. The team also defined two mathematical models for estimating the gain achievable in the energy efficiency. The figure below shows a potential timeline noting achievable gains for different network layouts and traffic levels.

*Fig.2. Potential timeline for different network layouts and traffic levels*




# Green Transmission Technologies (GTT)

## Partners

- Huawei
- Alcatel-Lucent Bell Labs
- CEA-LETI
- INRIA
- University of Maryland

## Cognizant Committee(s) and/or Working Groups(s)

- Mobile Communications

## Description

The Green Transmission Technologies (GTT) project focuses on the energy efficient design of transmission schemes, radio resource management strategies, and signal processing algorithms based on the fundamental tradeoffs in wireless communications.

The improvement of energy efficiency and the reduction of energy consumption are usually associated with cost in other operational metrics. This means the energy efficiency of the system will have tradeoffs. The key issue is when and how to trade off what, while maintaining satisfactory network service. Shannon's groundbreaking work on reliable communication over noisy channels showed that higher bandwidth leads to lower transmitted power for the same data rate. It also suggests the benefit of transmitting a packet over a longer period of time to save transmitter energy. Inspired by Shannon's theory, GTT will investigate ways to improve the system energy efficiency based on tradeoffs between spectrum efficiency (SE) and energy efficiency (EE), and service delay (DL) and power (PW) consumption (see Fig. 1).

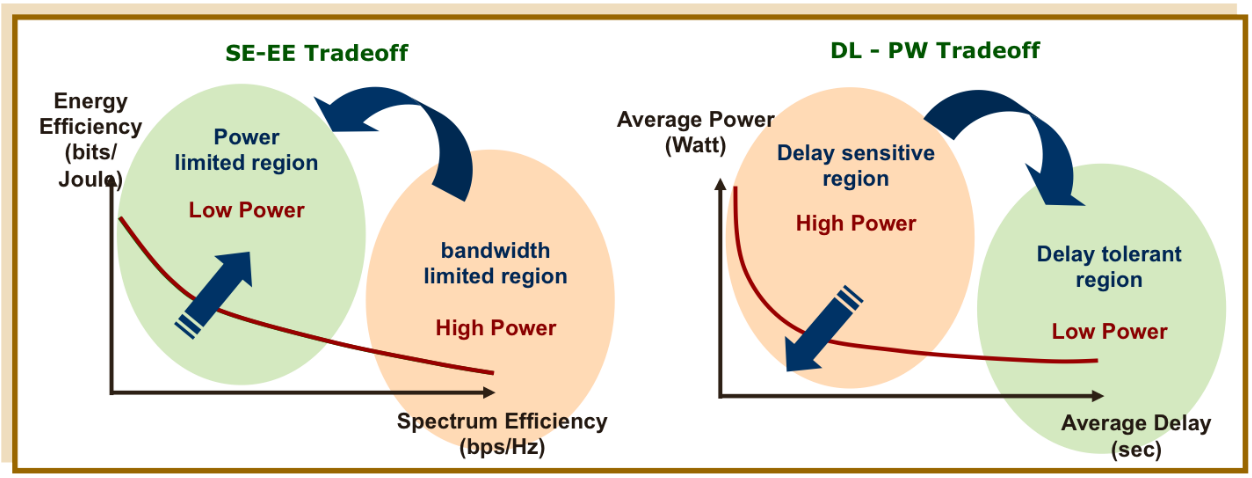



*Figure 1. Tradeoffs considered by the GTT project*

Tradeoffs in real systems are far more complicated than the point-to-point Gaussian channel. One reason pertains to the processing power consumption in both the base band (BB) unit and the radio frequency (RF) unit, which makes the actual tradeoff curves counter intuitive. The literature provides no data for tradeoffs in multi-user multi-cell scenarios. For service DL-PW tradeoffs, their characterization needs a complex combination of information theory and queuing theory; for SE-EE tradeoffs, when the bandwidth is very high or the transmission rate is very low, new signal processing algorithms may be needed in these new operation regions. This project will attempt to describe these tradeoffs with more precision, resulting in more energy efficient PHY/MAC/Network design (see Fig. 2).

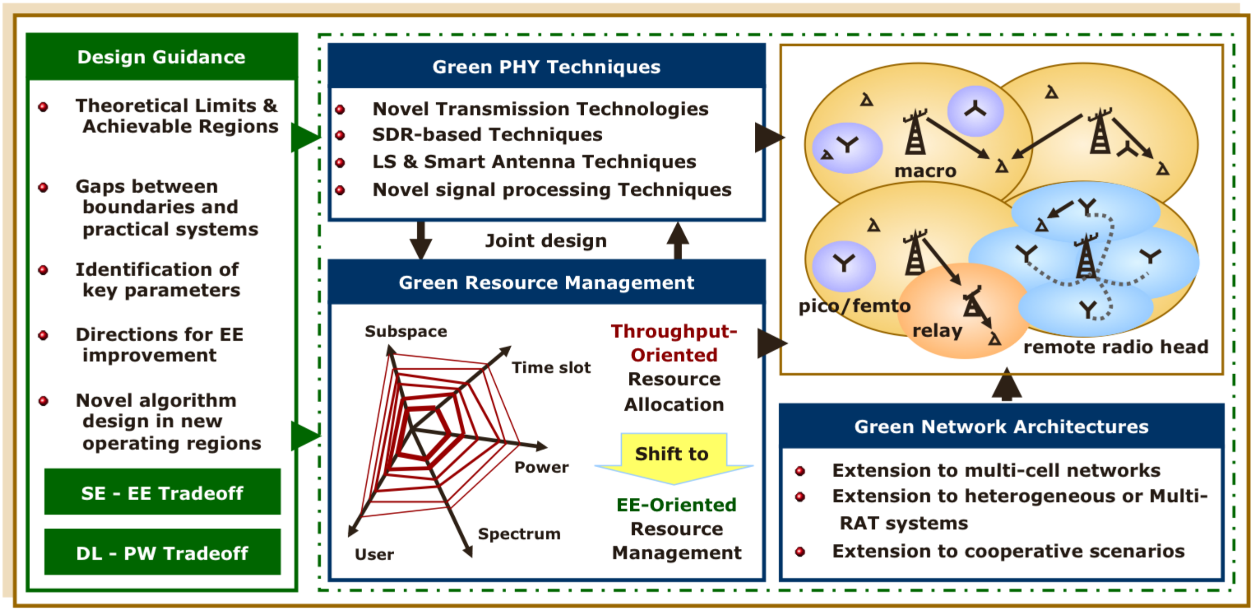



*Figure 2. GTT project's value (green box) is a more energy efficient PHY/MAC/ Network design*

## Primary Activities

The GTT project begins with a survey of current work on the SE-EE/ DL-PW tradeoff analysis and the corresponding scheme design. This information will help characterize tradeoffs in single systems from Shannon's formula and existing technologies. It also enables the creation of a framework to quantify the tradeoffs, taking into account the transmitted power and the power consumption in BB and RF units. With this foundation, team members will devise transmission schemes, resource management strategies, and baseband processing algorithms to realize power savings promised by SE-EE/DL-PW tradeoffs. Simulations will demonstrate the behavior of tradeoff curves in different system settings, and the energy saving gains under different novel designs. Multi-user multi-system scenarios will result from these activities. GTT also will study the impact of low-SNR impairments on basic physical-layer functions such as carrier recovery, synchronization, channel estimation, etc. – along with developing practical algorithms for implementation.

# Massive MIMO – Large-Scale Antenna Systems (LSAS)

## Partners

- Alcatel-Lucent Bell Labs
- Fondazione Politecnico di Milano
- Huawei
- IMEC

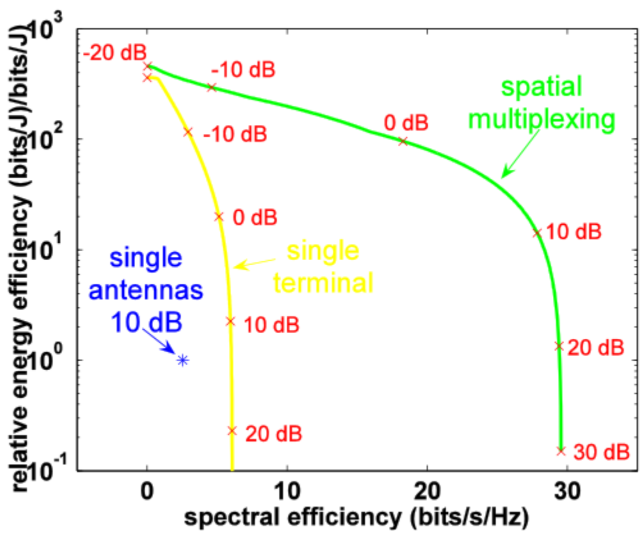
## Cognizant Committee(s) and/or Working Groups(s)

- Mobile Communications

## Description

The Mobile Communications Working Group's first project was "Large Scale MIMO Demo." The experiment entailed reverse-link transmission for a single-antenna "terminal" to a receive-only antenna array comprising between one and sixteen active elements, each element in turn comprising four co-phased patch antennas. The array performed maximum-ratio combining based on channel estimates derived from reverse-link pilots. The experiment demonstrated that, for every doubling of the number of antennas, the radiated power of the terminal could be reduced by a factor of two without degrading the quality of the processed signal. It also showed this procedure is fully adaptive to the propagation environment. The principle of TDD reciprocity permits the conclusion that similar improvements in radiated power efficiency can be realized in forward-link data transmission. This project, Large-Scale Antenna Systems (LSAS), seeks to improve wireless energy efficiency through a combination of radiated power reduction and increased throughput (spectral efficiency). Fig. 1 shows what could theoretically be done with one hundred antennas using LSAS (green and yellow curves) versus what could be done with a single antenna operated conventionally (blue asterisk).

*Figure 1. Spectral efficiency with LSAS versus a single conventional antenna*




## Primary Activities

The LSAS project was designed to address both problems that concern reduction to practice (signal processing algorithms; acquisition at low radiated power levels; quantization effects) as well as fundamental problems (how to deploy hundreds or thousands of antennas; how to reduce internal power consumption commensurate with reducing radiated power). The project includes three tasks: Architecture and Deployment, Algorithms and Simulation, and Energy Modeling and Control.

**Architecture and Deployment**

Typical macro-cell cannot accommodate hundreds of antennas. LSAS considers new deployment scenarios and their architectures classified as Massively Co-located Antennas, Spatially Distributed Antennas, or a hybrid solution.

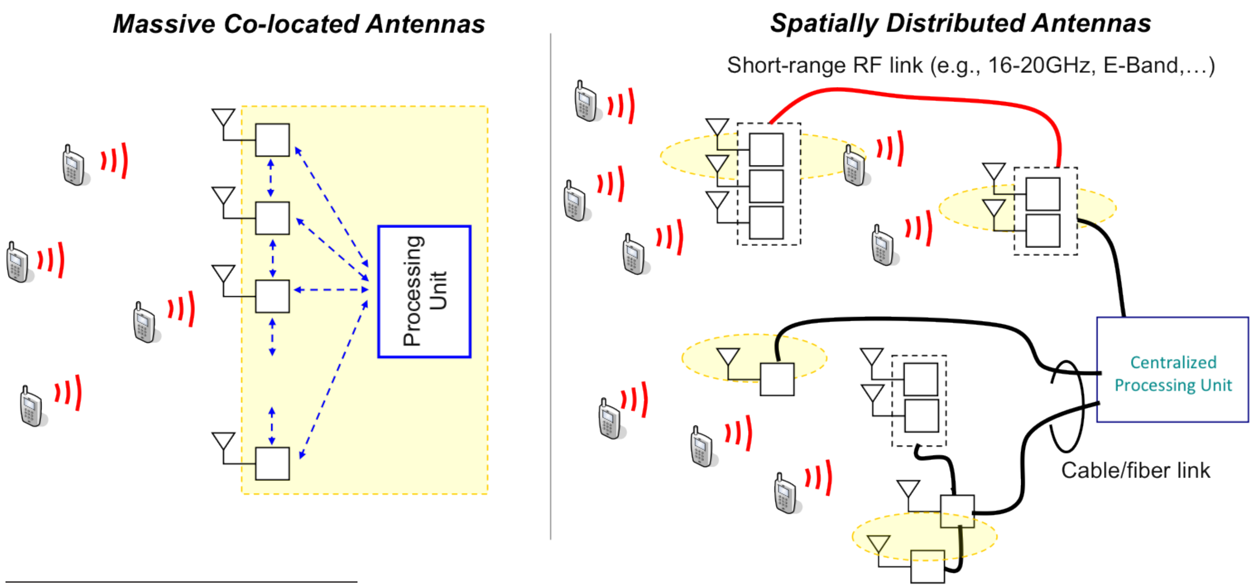



*Figure 2. Massive co-located antennas versus spatially distributed antennas*

Co-located antennas reduce the energy expenditure and overall inter-cell interference. A distributed solution exploits the multi-cell processing paradigm for interference mitigation by progressively breaking the concept of a cellular system when the antennas' density increases. To enable centralized processing, each antenna must be remotely deployed to extend coverage while preserving the benefits of a co-located antenna system. Hardware and software partitioning between central and remote antenna units plays a crucial role in reducing radiated and processing energy expenditure. Femtocell paradigm framed into the distributed antennas architecture has two inherent advantages:

- Energy expenditure reduction for home equipment (2-3 times each DSL line) and for the delivered information bit; interference mitigation is achieved by coordinating clusters of antennas.
- Radio coverage extension with meaningful reduction of the radiated power by a conventional deployment of large cells.

Backhauling is part of all cooperative MIMO schemes that involve massive antennas deployments.


### Algorithms and Simulation

A test bed end-to-end system-level simulation is required to evaluate system performance, develop practical signal processing algorithms, and assess their performance. LSAS employs simulation studies on:

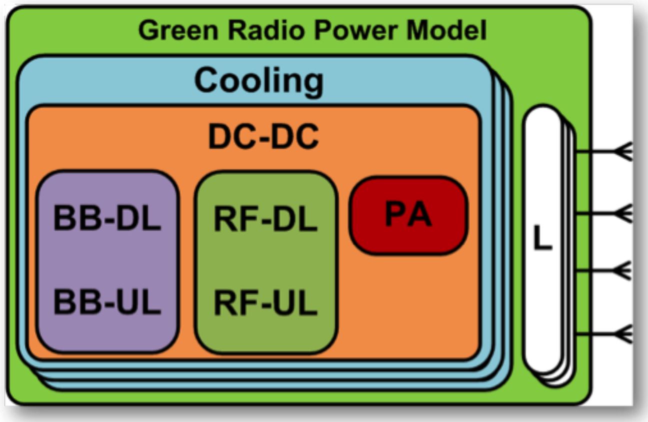
- Channel estimation: As LSAS implements large number of antennas, the accumulation of errors from channel estimation at each antenna may greatly impair the SNR of the MRC output signals. We simulated and studied the effect of the phase estimation error and magnitude estimation error. This simulation showed the estimation error in each antenna is independent, all the errors are added up incoherently, and the maximum ratio combining (MRC) is quite robust to the channel estimation errors.
- A/D resolution: A large number of antennas requires a larger number of A/D converters. The resolution determines both the power consumption of the A/D converter and the SNR of the output signals. We determined the minimum number of bits required by a target transmission rate is 90% of the rate achieved by perfect A/D converter. Since the A/D noise at each converter is independent, they are added up incoherently at the MRC. Therefore, for larger number of antennas, MRC does not require very high resolution.

### Power Modeling and Control

This task will develop power models to enable accurate assessments of power consumption for various deployments, architectures, and approaches to signal processing.

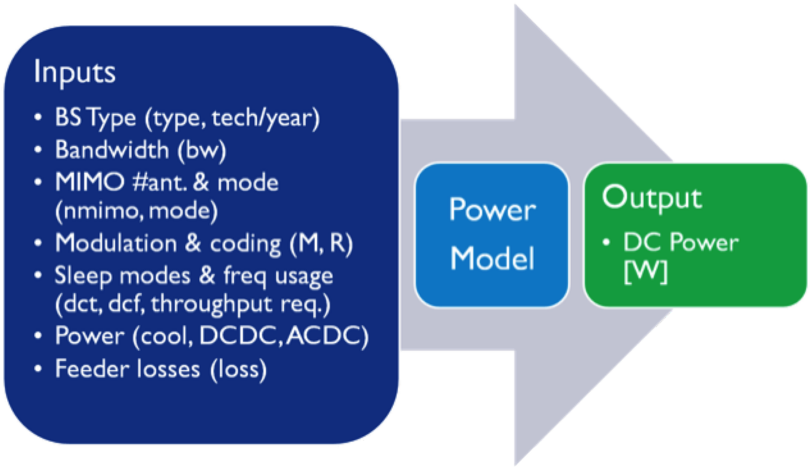
The power modeling activity is crucial to ensure LSAS considers the gain in total output power, and the increased digital and analog signal processing needed to support more antennas. This project builds on a high-level base station architecture inspired by the LTE standard, which also supports various types of base stations and combines detailed power models for their components.

*Figure 3. Power modeling for a base station architecture*




The model will scale to many input parameters, including the number of antennas and other parameters described in the following figure.

*Figure 4. Input parameters for power modeling a base station architecture*




Depending on the selected parameter set, the different power contributors will scale in some way – constant power for some, linear for others, possibly quadratic or cubic for some functional blocks in multiple-antenna processing. This enables achieving total required power with multiple configurations.

# Wireline Access Working Group

**Chair:**
Laurent Lefevre
INRIA

**Co-Chair:** Frank Effenberger, Huawei

**Participating Organizations:**
Alcatel-Lucent/Bell Labs, Athens Information Technology (AIT) Center for Research & Education, Broadcom, Chunghwa Telecom, Draka Communications, Dublin City University, ETRI, Fondazione Politecnico di Milano, France Telecom, Fujitsu, Huawei Technologies, IBBT, IMEC International, INRIA, K.U. Leuven, National ICT Australia, Nippon Telegraph and Telephone, Swisscom, University of Melbourne, University of Cambridge

The Wireline Access Working Group (WA) addresses energy efficiencies in the wired network infrastructure. During its first year, WA initiated two projects toward this objective.

For the project "Low Energy Access Architectures," WA sought to identify the access solution with the lowest possible energy consumption for a scenario with a PON-based fiber infrastructure. It also included the option of a "greenfield" scenario with no existing infrastructure. WA defined the architectural options, advantages in terms of energy efficiencies, and challenges to achieving high energy gains. A database was developed with power consumption values for required optical and electrical components; these are used to estimate the total power consumption of different architectural options. Several WA partners started more detailed research on specific architectures (e.g. low energy point-to-point access, energy efficient protocols for TDM PON) and components (e.g. coolerless tuneable sources for WDM access).

The Virtual Home Gateway and Quasi-Passive CPE project aims to lower energy consumption for the connectivity between the access network and terminals in the home. The project is rethinking distribution of CPE functionality in the home and access architecture in terms of energy efficiency. The CPE is the most power-hungry element in wireline networks. WA's goal is to achieve a (quasi)-passive CPE. To do this, a virtual home gateway will move typical home gateway functions, such as routing, firewall, and home network management, to a server in the network. Energy efficiency will result from the sharing of processing resources on a server instead of the underutilized resources of individual subscribers – and from a drastic reduction of power consumption by interfaces on the WAN and LAN side of the CPE. WA described concepts and research challenges in a working document.

## Projects

- Low Energy Access Architectures
- Virtual Home Gateway and Quasi-Pasive CPE

## Events

- ECOC 2010: GreenTouch sesion – presentation of Wireline access research challenges by Peter Vetter, Bell Labs
- OFC 2011: GreenTouch Panel Session – presentation "Broadband Access and the Power Crunch" by Frank Effenberger, Huawei

## Recommendations

The working group recommended new research areas that can lower the energy consumption of a wireline access. Recommendations included estimates of potential gains and provided a roadmap on when concepts can be expected to be commercially available.

Figure 2 illustrates how the research concepts have an impact on different parts of the access network and CPE. It also projects when the energy saving technology may be commercially available. The white labels indicate state-of-the-art concepts that are already covered by standardization or other research consortia; hence they do not require further efforts by GreenTouch. The green labels indicate new concepts that are envisaged by GreenTouch. The standard GPON and XGPON are used as a baseline, for which significant savings can be achieved by applying sleep modes.

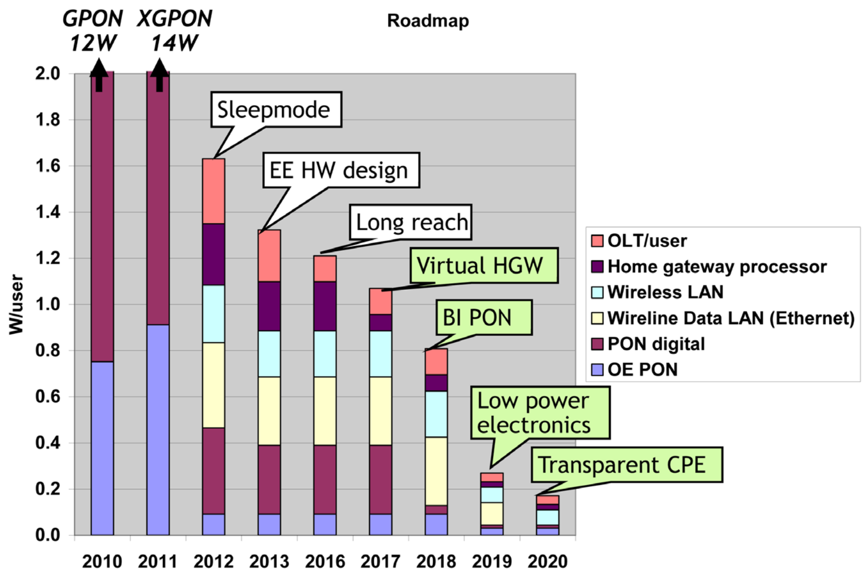



*Figure 2: Roadmap of energy saving concepts for optical access and the estimated reduction of the power consumption per user*

# Low Energy Access Architectures

## Partners

- Alcatel-Lucent Bell Labs
- CEET Melbourne University
- Univ. of Cambridge
- AIT (Athens Information Technology)
- SwissComm
- Orange Labs

## Cognizant Committee(s) and/or Working Groups(s)

- Wireline Access

## Description

Our research on low energy access solutions began at the network architecture level. Development of existing access networks has mainly been influenced by cost, performance, support of existing applications, and migration from legacy infrastructures. This project takes a clean-slate approach on a different angle: to define an access network architecture optimized for energy efficiency. We detailed results in an internal working document, which will be the basis for a public report during GreenTouch's second year.

## Primary Activities

The Low Energy Access Architectures under study in this project entail four areas of promise. These are illustrated in Figure 1 and described below.

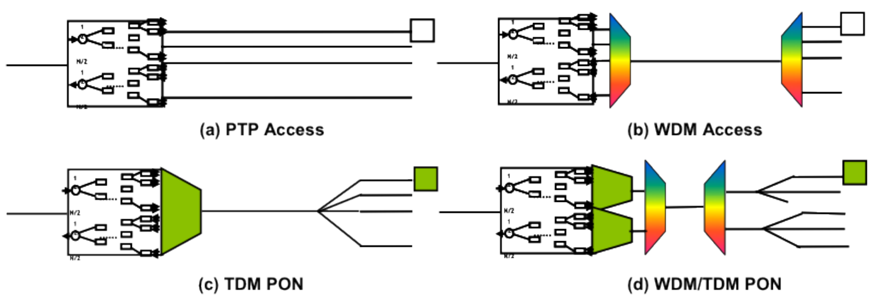



*Figure 1: Comparison of low energy access architectures*

### 1) Point-to-point fiber

Fig. 1(a) shows an access network requiring the least amount of energy to transfer a bit of information. It is a point-to-point (PTP) connection between a single switching stage and each user. Optical fiber should be used as the lowest loss medium, for this enables the least amount of energy (i.e. minimum number of photons) to be transmitted while achieving the required bit error rate. The access node operates as a binary tree of switches implemented in the CMOS technology. A combination of sleep modes and rate adaptation per line is applied to a PTP fiber network in order to make its energy consumption proportional to the payload.

The major drawback of this architecture is the high fiber count required in the feeder sections and central office. So we also address other architectural options for low power, described below.

**2) WDM Access**

Wavelength division multiplexing (WDM), shown in Figure 1(b), is an effective technique for sharing the common fiber while maintaining the advantages of a point-to-point architecture. The major challenge is in achieving a high density of channels without a power consumption penalty. For practical deployment purposes, tunable lasers are required. Note that a conventional WDM source integrates a power-hungry thermo-electric cooler to stabilize the wavelength, which reduces the overall achievable power savings. Research of new, un-cooled tunable lasers represents a direction of promise for GreenTouch.

**3) New Energy Efficient protocol for TDM PON**

Time division multiplexing (TDM) passive optical network (PON), shown in Figure 1(c), limits the number of fibers in the feeder and reduces the number of fiber termination ports in the central office. This is therefore the lowest power solution for existing equipment in the network. TDM is the most widely used multiplexing PON protocol today (e.g. GPON), but the current frame format is not designed for power efficiency. Power consumption will rise in the next generation of PON running at 10Gbit/s and higher, since the power consumption increases almost proportionally to the bit rate. The recent standards include very efficient sleep mode techniques, which exploit the fact that high bandwidth on the shared link is not required all the time. GreenTouch is addressing new energy efficient protocols that can reduce the power of the electronics even further by another order of magnitude. Preliminary results show that protocol optimizations can reduce the power of digital electronics for downstream 10GPON from today's 3W, to less than 300mW. Further significant reduction in average power consumption is possible by combining new protocols with sleep modes on a timescale of tens of ms.

**4) Other architectures**

The stacked TDM/WDM PON of Figure 1(d) combines the advantages of TDM and WDM PON architectures. OFDMA PON is known to consume a large amount of power in the electronic processing, but promises interesting advantages, such as dispersion immunity for NGPON with higher rates and longer reach. GreenTouch is addressing energy efficient solutions for such OFDMA PON systems.

# Virtual Home Gateway and Quasi-passive CPE

## Partners

- INRIA
- SwissComm
- Draka
- Orange Labs
- Alcatel-Lucent Bell Labs

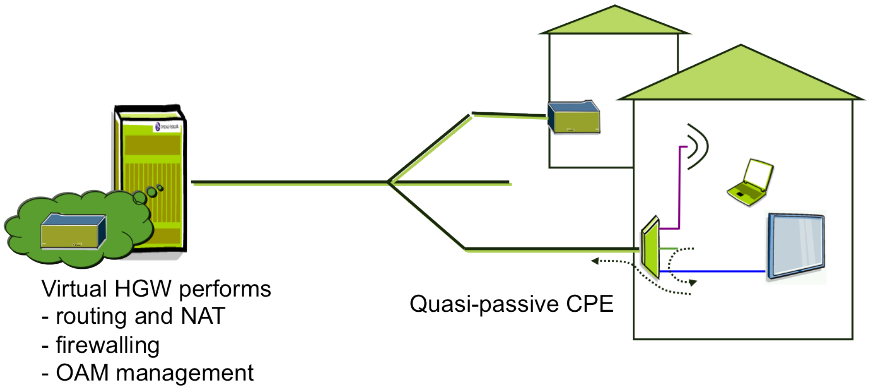
## Cognizant Committee(s) and/or Working Groups(s)

- Wireline Access

## Description

The customer premises equipment (CPE) provides the interworking functions between the access network and the home network. Currently, CPE in wireline networks consumes about an order of magnitude more power per user than any other network element. Whereas the industry is adopting energy saving mechanisms like sleep modes, power shedding, and energy efficient hardware design, it is possible to achieve even lower energy consumption for the connectivity between the access network and terminals in the home by rethinking the distribution of CPE functionality in the home and access architecture with energy efficiency in mind.

*Figure 2: Reducing the energy by a quasi-passive CPE and moving functionality to a virtual home gateway*




GreenTouch research is investigating the concept of "transparent CPE", which moves most of the current CPE functionality to a virtual home gateway in the network, as shown in Figure 2. This enables a further power reduction by simplifying the CPE's WAN and LAN interfaces, and by sharing processing resources on a server instead of powering underutilized resources of individual subscribers.

Options for transparent CPE are investigated, where the term "transparent" refers to protocol, format or optical transparency, which may involve some form of regeneration. The ultimate objective is to have


a completely passive optical CPE that consumes zero power. We expect easy-to-install single mode fiber with a small bending radius will be cost-effective for in-house wiring before the end of the decade. If regeneration to another medium is used, we speak of a quasi-passive CPE.

A passive cut-through will likely be applied for high bandwidth connectivity to wired home devices, such as a computer or television. Consumers will continue using wireless home networks for flexibility and mobility. A future research challenge for GreenTouch is to find the most energy efficient solution in support of a wireless home network in combination with a transparent CPE.

In an architecture with quasi-passive CPE, several of the home gateway functions, such as routing, security, and home network management, must move to a virtual home gateway in the network. A virtual home gateway can also serve as a point of presence to provide service continuity while the CPE is in a sleep state. Virtual home gateways provide additional flexibility to deploy new home service management capabilities (e.g., based on OSGi) on legacy CPE that do not have the required processing resources. An important question in GreenTouch is to identify if a different virtual HGW is required and what the functional requirements are in order to achieve minimal power consumption.

# Other Technical Activities

Other events or presentations that involved GreenTouch technical organization members are listed below. Also included are selected external publications by GreenTouch technical organization members on topics of interest in GreenTouch or that involve background material for the consortium activities.

## Other Events

- D. C. Kilper, "Network Energy Use: Challenges Today and Looking Forward" Microphotonics Center Fall Meeting 2010, MIT, Boston.
- Panel: How the IT and Telecom Industries are changing to embody principles of sustainability, Annual Meeting of the International Bar Association 2010, Vancouver.
- Keynote: S. Xu, "Recent Progress on Green Wireless Research" INFOCOM 2011 Workshop on Green Communications and Networking (GCN), Shanghai.
- Panel: Sustainable computing and networking, INFOCOM 2011, Shanghai.
- D. C. Kilper, "GreenTouch Consortium: Building the Roadmap", ON*VECTOR 2011, San Diego.
- Panel: Business Opportunities and the Low Carbon Economy in the Information Age, TIA 2011, Dallas.
- D. C. Kilper, "Tutorial: energy efficient netoworks" OFC/NFOEC 2011, Los Angeles.

## Selected External Publications By GreenTouch Members


- M. Andrews, A. Fernandez, L Zhang, W. Zhao, "Routing and Scheduling for Energy and Delay Minimization in the Powerdown Model", IEEE Infocom 2010 Miniconference, March 2010
- M. Andrews, A. Fernandez, L Zhang, W. Zhao, "Routing for Energy Minimization in the Speed Scaling Model", Infocom 2010, March 2010
- M. Andrews, S. Antonakopoulos, L Zhang, "Energy-aware Scheduling Protocols for Network Stability", IEEE Infocom 2011, April 2011
- M. Andrews, S. Antonakopoulos, L Zhang, "Minimum-Cost Network Design with (Dis)economies of Scale", IEEE Symposium on Foundations of Computer Science (FOCS), October 2010
- S. Antonakopoulos, S. Fortune, L Zhang, "Power-aware Routing with Rate Adaptive Networking Elements", The 3rd International Workshop on Green Communication, December 2010
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- J. Baliga, R. W. A. Ayre, K. Hinton, R. S. Tucker, "Green Cloud Computing: Balancing Energy in Processing, Storage, and Transport" Proc. IEEE 99, 149, 2011.
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- Panagiotis Zakynthinos, Athens Information Technology (AIT) Center for Research & Education, *, †, §
- Haibin Zhang, TNO, ‡
- Shunqing Zhang, Huawei Technologies Co., Ltd., ‡

## Legend

Core Optical Networking & Transmission Working Group (*)
Core Swiching & Routing Working Group (†)
Mobile Communications Working Group(‡)
Wireline Access Working Group (§)
Services, Applications & Trends Committee (**)
Network Committee (††)
Technical Committee (‡‡)
Operations Committee (§§)
Executive Board (¶)